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CONTENTS

SECTION
PHYSICAL GEOGRAPHY

**TRACING THE TORRENTIAL FLOODS:
INSIGHTS FROM 110 YEARS OF RECORDS *(Keynote presentation)***
Ana M. Petrović 3

**MONITORING ROCK GLACIER DYNAMICS
IN THE HOHE TAUERN MOUNTAINS: INSIGHT
INTO RECENT ALPINE PERMAFROST CHANGES**
Harald Zandler, Andreas Kellerer-Pirklbauer, Wolfgang Sulzer 11

**LOCATION OF EARLY MEDIEVAL HILLFORTS IN THE
POLISH CARPATHIANS – PHYSIOGEOGRAPHIC ANALYSIS**
Cyryl Konstantinovski Puntos, Tomasz Kalicki 25

**METALLURGICAL MACRO- AND MICROARTEFACTS IN FAN
SEDIMENTS AS RESULT OF FLUVIAL PROCESS CHANGES
– CASE STUDY FROM SIELPIA RESERVOIR (S POLAND)**
Paweł Przepióra, Tomasz Kalicki, Monika Żelezik 33

**RESULTS OF GEOARCHAEOLOGICAL STUDY OF ARCHAEOLOGICAL
SITE AT BUKOWA GÓRA (SILESIAN UPLAND, POLAND) – MEGALITH,
EARLY MEDIEVAL STONE-EARTH BARROWS, MEDIEVAL MINES**
Tomasz Kalicki, Dariusz Rozmus, Jacek Kościuk, Bartłomiej Ćmielewski,
Paweł Przepióra, Monika Żelezik, Izabela Biegalska, Wojciech Nadziałek 39

**TREE UPROOTING IN THE SUCHEDNIÓW AREA
(KIELCE UPLAND) AFTER THE SEVERE STORM
OF 23 JUNE 2025 – EVENT ANALYSIS**
Wojciech Nadziałek, Tomasz Kalicki 49

**INTEGRATING HYDROMORPHOLOGICAL DATA INTO
THE ASSESSMENT OF RIVER ECOSYSTEM SERVICES**
Ján Babej, Jiří Jakubínský, Žaneta Straňáková,
Ana M. Petrović, Tomáš Galia, Veronika Kalníková,
Valentina Nikolova, Martin Pavel, Stanislav Ruman, Jiří Schneider 59

**INTERACTION MAN-ENVIRONMENT CHANGES
TRIGGERED BY CLIMATE FLUCTUATION IN THE
ROMAN PERIOD: CASE STUDY FROM SOUTHERN POLAND**
Halina Dobrzańska, Tomasz Kalicki 73

**GENERATIONS OF PALAEOMEANDERS IN THE VALLEYS
OF THE CZARNA NIDA AND BIAŁA NIDA VS. THE GENERATION
OF PALAEOMEANDERS OF THE UPPER VISTULA RIVER**
Izabela Biegalska, Tomasz Kalicki 83

ENVIRONMENTAL INFLUENCES ON STEĆCI NECROPOLISES IN BOSNIA AND HERZEGOVINA: A SPATIAL ANALYSES
Milka Grmuša, Jelena Golijanin, Sanda Šušnjar, Mariana Lukić Tanović, Rade Ivanović 91

TRANSFORMATION OF THE ANTI-TANK DITCH DURING THE LAST 80 YEARS – CASE STUDY FROM THE BIAŁA NIDA BASIN (S POLAND)
Jakub M. Niebylski, Paweł Przepióra, Tomasz Kalicki 103

SECTION
SOCIO-ECONOMIC GEOGRAPHY

THEORETICAL FOUNDATIONS OF THE BALKAN HEARTLAND: THE GEOGRAPHICAL PIVOT OF THE BALKANS
Dimitrije Teodosić 113

FOREST POTENTIAL AS A POLITICAL AND GEOGRAPHICAL CATEGORY OF THE REPUBLIC OF SRPSKA IN THE FUNCTION OF GEOPOLITICAL VALORIZATION OF TERRITORY
Igor Zekanović, Vanja Mirjana Vujić 123

THE DEVELOPMENT OF URBAN-RURAL RELATIONSHIP AT THE EXAMPLE OF THE CITY OF GRAZ/AUSTRIA
Wolfgang Fischer, Maximilian Flor, Christian Außerlechner 137

GEOGRAPHIES OF KNOWLEDGE AND ASYMMETRICAL EPISTEMIC ORDERS
Mirek Dymitrow, Valentin Mihaylov, Rene Brauer 157

TOURIST LENGTH OF STAY: CHALLENGES FOR OHRID (NORTH MACEDONIA)
Biljana Petrevska 169

PAST AND FUTURE TRENDS IN NORTH MACEDONIA'S WORKING-AGE POPULATION
Hristina Ninevska, Marija Ljakoska, Petar Vasić 177

WINE GEOGRAPHICAL INDICATIONS: COMPARATIVE ANALYSIS OF CROATIAN AND MACEDONIAN LEGISLATIONS
Rebeka Mesarić Žabčić, Goce Naumovski 199

TRANSFORMATION OF RELIEF AND WATER NETWORK IN THE KOLLOSI REGION (SOUTHERN CYPRUS) IN THE MIDDLE AGES – A HISTORICAL AND GEOGRAPHICAL ANALYSIS
Tomasz Kalicki, Jani Konstantinovski Puntos, Cyryl Konstantinovski Puntos 211

LOCAL AGRITOURISM BUSINESS CONCEPTS AS A PLACE-SENSITIVE STRATEGY TO EMPOWER RURAL COMMUNITIES IN ALBANIA
Andreas Koch 219

IS FERTILITY IN BOSNIA AND HERZEGOVINA NOW DECLINING FASTER THAN IN THE REST OF THE EX-YUGOSLAV AREA?
Petar Vasić, Radoslav Ćorović, Miodrag Pantović 233

REFINING THE LOCATION OF THE BATTLE OF MOHÁCS FOUGHT 500 YEARS AGO AT THE GATEWAY OF THE BALKANS (USING GEOGRAPHICAL METHODS)
Péter Gyenizse, Norbert Pap, Dénes Lóczy, Gábor Varga, Máté Kitanics 249

MEASURING THE SPATIAL CONCENTRATION OF HIGHLY EDUCATED POPULATION: THE EXAMPLE OF THE REPUBLIC OF CROATIA
Zdenko Braičić, Jelena Lončar..... 261

TOURIST SATISFACTION AND KEY FACTORS OF ATTRACTIVENESS OF SUMMER DESTINATIONS: A CASE STUDY OF PIERIA, NORTHERN GREECE
Andrijana Strgulc, Anđelina Marić Stanković 275

OLDER PEOPLE'S PERSPECTIVES ON RESIDENTIAL CARE: INSIGHTS FROM THE CITY OF ZAGREB
Sanja Klempić Bogadi, Sonja Podgorelec, Dubravka Spevec 287

WHERE MEMORIES TAKE SHAPE: THE ROLE OF SOUVENIRS IN CREATING UNFORGETTABLE TOURIST EXPERIENCES
Maja Nešić, Marina Vesić..... 299

ENVIRONMENTAL CHALLENGES AND REPRODUCTIVE DECISIONS: A QUALITATIVE STUDY BASED ON FOCUS GROUPS
Natalija Mirić 313

VULNERABILITY OF CULTURAL HERITAGE TO ANTHROPOGENIC IMPACTS: A CASE STUDY OF THE STEĆCI NECROPOLIS IN THE CITY OF EAST SARAJEVO
Milka Grmuša, Mariana Lukić Tanović,
Jelena Golijanin, Sanda Šušnjar, Mitar Krsmanović..... 319

TRENDS IN TOURISM EMPLOYMENT IN SERBIA – HIGHLIGHTING THE GENDER DIMENSION
Jelena Stojilković Gnjatović, Marija Belij Radin..... 331

FROM DIVERSITY TO HOMOGENIZATION - THE RISE AND DECLINE OF ETHNIC FRACTIONALIZATION IN SERBIA
Nevena Trnavčević, Damjan Bakić..... 343

CERTIFIED BUT UNSEEN: GUEST AWARENESS OF SUSTAINABILITY INITIATIVES IN EUROPEAN HOTEL REVIEWS
István Egresi..... 355

SECTION
CARTOGRAPHY, GIS & SPATIAL PLANNING

LAND SUITABILITY CLASSIFICATION FOR SUSTAINABLE AGRICULTURAL PRODUCTION AND CLIMATE CHANGE ADAPTATION IN SLOVENIA
Lovro Sinkovič, Janez Bergant, Klara Čevka 375

IDENTIFICATION OF POTENTIAL GEOHAZARD AREAS IN WESTERN MACEDONIA BASED ON SEISMIC DATA
Katerina Drogreshka Jasmina Najdovska, Dragana Chernih, Svemir Gorin, Ivan Radevski, Blagoja Markoski, Irena Stojkovska, Ljubcho Jovanov, Monika Andreeska, Ivana Molorovikj Arse Kuzmanoski, Erblina Zaqiri Sinani 381

INTERDIURNAL THERMAL ANALYSES OF INNER COURTYARDS BY MEANS OF AIRBORNE REMOTE SENSING
Wolfgang Sulzer, Daniela Hirlaender, Benjamin Signitzer 391

INTEGRATING GEOGRAPHIC INFORMATION SYSTEMS AND ARTIFICIAL INTELLIGENCE FOR INTELLIGENT ENVIRONMENTAL MONITORING AND NATURAL RESOURCE MANAGEMENT
Aleksandar Petrovski, Rexhep Mustafovski, Marko Radovanović 405

QUANTIFYING LAND COVER CHANGE IN ZADAR (2017–2025) USING PLANET SCOPE IMAGERY
Rina Milošević 415

SYNERGY OF AR AND GIS DATASETS TO IMPROVE SPATIAL REASONING AND NAVIGATION INTELLIGENCE
Dušica Jovanović, Marko Savković, Sanja Stojković 425

SECTION
TEACHING & EDUCATIONAL GEOGRAPHY

PRIOR KNOWLEDGE AND MISCONCEPTIONS ABOUT THE PHYSICAL-GEOGRAPHICAL CHARACTERISTICS OF ASIA AMONG PRIMARY SCHOOL PUPILS
Anita Todorova, Blagoja Markoski, Olgica Dimitrovska, Nikola Dimitrov 437

SOCIOECONOMIC IMAGE OF ASIA FROM THE STUDENTS' PERSPECTIVE: RESULTS FROM THE FOUR-TIER DIAGNOSTIC PRE-TEST
Anita Todorova, Marija Ljakoska 449

SECTION
PHYSICAL GEOGRAPHY

HYDROLOGICAL ANALYSIS OF THE HIGH WATERS OF THE KUTINSKA RIVER, SERBIA
Milena Ristić, Mrđan Đokić, Nataša Martić Bursać, Ljiljana Stričević **461**

SECTION
PHYSICAL GEOGRAPHY

TRACING THE TORRENTIAL FLOODS: INSIGHTS FROM 110 YEARS OF RECORDS

(Keynote Presentation)

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ABSTRACT

Torrential floods rank as Serbia's most destructive and frequent natural hazards, inflicting profound social, economic, and environmental impact. This study delivers a comprehensive analysis of torrential flood phenomenon, covering the period 1915–2024, integrating historical records with contemporary data from multiple sources. A total of 2287 flood events have been documented, claiming over 197 lives. The findings highlight a distinct seasonal trend, with floods peaking in late spring (May–June), primarily driven by intense convective storms. The highest number of events was recorded in tributaries belonging of the Zapadna Morava, Južna Morava, and Kolubara river basins. A breakthrough of this research is the development of Serbia's first inventory of torrential floods, offering unprecedented insights into their spatial and temporal dynamics. This inventory can be integrated into a multi-user national hazard database, with future applications extending to European-scale flood risk assessments. By enhancing hazard preparedness and risk mitigation strategies, this study paves the way for data-driven policies and climate resilience planning—crucial in an era of escalating extreme weather events.

Keywords: torrential floods, frequency, spatial and temporal patterns, Serbia

INTRODUCTION

As far as water resources in Serbia are concerned, there are two main problems related to hydrological extremes: suffering from floods and a lack of water. This duality is particularly evident in torrential floods, a rapid-onset hydrological phenomenon characterized by a sudden peak discharge, high suspended and bed-load sediment transport, and a concentration of destructive energy within small- to medium-sized catchments [1]. The most devastating torrential flood events since 2000 occurred in April and May 2014, resulting in over 50 fatalities and heavily affecting communities in western and central Serbia. Torrential floods remain the dominant hydrological hazards in the country, arising from the complex interplay of extreme precipitation, catchment morphology, geological conditions, and land-use practices. A significant proportion of annual sediment yield is transported during these short-lived flood events, making them powerful geomorphological agents shaping river channels [2].

The catchment slope, relief energy, and basin shape exert dominant control over runoff response [3]. Steep slopes and compact, fan-shaped basins produce short concentration times and high maximal discharges. Geological structure and soil texture significantly

influence infiltration capacity, while shallow, poorly permeable soils promote rapid surface runoff. Vegetation cover plays a crucial mitigating role; forested catchments generally exhibit lower peak discharges and reduced sediment yield compared to deforested or agriculturally exploited areas. Conversely, anthropogenic activities such as deforestation and urbanization often amplify natural flood processes. On the other hand, torrential floods carry substantial destructive potential and may leave long-term socio-economic consequences increasingly threatening human lives, activities, and assets.

Given the limited availability of hydrological measurements in small mountainous and sub-mountainous catchments, torrential flood analysis in Serbia largely relies on indirect and parameter-based methods. One of the most commonly applied approaches combines the Soil Conservation Service Curve Number (SCS-CN) method for effective rainfall estimation with the Synthetic Unit Hydrograph (SCS-UH) for runoff transformation. Catchment morphometric parameters such as area, slope, drainage density, relief energy, basin shape, and stream network characteristics are derived from topographic maps and digital elevation models within a GIS environment. Land-use and soil data are incorporated to estimate infiltration capacity and surface runoff potential. Hydraulic reconstruction of peak discharge is performed using high-water marks, channel geometry, and Manning's equation. Spatial susceptibility to torrential floods is further assessed using GIS-based indices, particularly the Flash Flood Potential Index (FFPI), which integrates morphometric, geological, soil, and land-cover parameters [4, 5]. These complementary methods allow cross-validation of results and provide a robust foundation for flood assessment in data-scarce environments.

Rainfall–runoff modelling can be employed for the relatively small number of watersheds with available hydrological monitoring data. The selected hydrological model should be physically based, spatially distributed, and suitable with respect to data requirements. Such hydrological software simulates runoff at the slope-channel scale, calculating processes of infiltration, evapotranspiration, base flow, overland flow, and flow through the river network. The input data consist of hourly rainfall records and watershed characteristics, while the output includes simulated discharge values, which are subsequently compared with observed data. In terms of the spatial discretization of the watershed, the grid, channel, and river bank are linked, so that computations at the watershed level at a defined hourly time step and through the whole simulation period are enabled. The developed watershed model can be continuously updated and applied for forecasting future flood events when rainfall forecasts are available.

Climate variability, including the increase in short-duration extreme precipitation events, further amplifies the frequency and magnitude of torrential floods. Simultaneously, land-use changes such as deforestation, agricultural intensification, and urban expansion have significantly modified runoff generation mechanisms.

In Serbia, torrential floods predominantly occur south of the Sava and Danube rivers, where high relief energy, erosion-prone geology, and land-use pressures, in combination with extreme convective precipitation, favour rapid hydrological response. Previous studies [6] indicate the existence of more than 12,000 torrential streams, affecting the majority of the national territory. Despite their frequent occurrence and severe socio-economic impact, systematic documentation of torrential flood events has historically been neglected.

This paper aims to provide an integrated overview of torrential flood occurrence in Serbia by presenting insights from the *Inventory of Torrential Floods in Serbia* covering the period from 1915. This inventory represents the most comprehensive dataset of torrential

flood events in Serbia to date. It was compiled by the author of this paper and was extensively presented in 2021 in the book [7] for the period by 2019. The Inventory update and revision are conducted every five years. This contribution is intended to support future research and practical flood risk management, extending insights into the torrential flood phenomenon. Understanding the mechanisms, temporal and spatial distribution of torrential floods is therefore essential for effective risk assessment and management. Results contribute to improved hazard communication, risk assessment, and sustainable watershed management under changing climatic and socio-economic conditions.

METHODS AND MATERIALS

The primary data source for this paper is the Inventory of torrential floods in Serbia, a unique and systematically compiled database of historical and recent torrential flood events. The inventory covers a period exceeding more than one century and includes information on event date, geographical location, affected catchments and settlements, triggering mechanisms, hydrological characteristics, and their aftermath—material damage, human losses, and casualties. The inventory marked a major step toward systematic archival and contemporary documentation and analysis of this phenomenon.
From a conceptual perspective, the development of the inventory followed structured data management principles, also inspired by international approaches to hazards documentation. The process included defining minimum data requirements, collecting data from diverse sources, verifying, systematizing, and categorizing records, and conducting analytical evaluation. The inventory is compiled from scientific literature, hydro-meteorological yearbooks and reports, newspaper archives, and official emergency records and reports. Each event has a geographical location and is classified by date, river basin, and documented consequences. Events were aggregated at the basin level to allow comparative analysis among major river systems.
The inventory aims to serve as a multi-purpose database adaptable to different user groups, including hydro-meteorological services, water management authorities, emergency sectors, insurers, and researchers.

RESULTS AND DISCUSSION

The updated inventory records 160 recent torrential flood events for the period 2020–2024 and 5 newly identified records for the earlier period. Altogether, the database documents 2,287 torrential flood events across Serbia with over 197 fatalities. Historical records extend as far back as 1915, although earlier documentary evidence— such as 13th-century chronicles) also describes catastrophic torrential flood events.



Figure 1. Aftermath of torrential floods in Arandjelovac, June 1969 (from the newspaper archive)

The inventory focuses on catchments south of the Sava and Danube rivers, including tributaries that belong to the Black Sea Basin (tributaries of the Drina, Kolubara, Zapadna Morava, Južna Morava, Velika Morava, Mlava, Pek, and Timok rivers), the Adriatic Basin (tributaries of the White Drim), and the Aegean Basin (tributaries of the Lepenac, Dragovištica, and Pčinja rivers). The highest numbers of events and fatalities were recorded in the Zapadna Morava, Južna Morava, and Kolubara river basins (Figure 2).

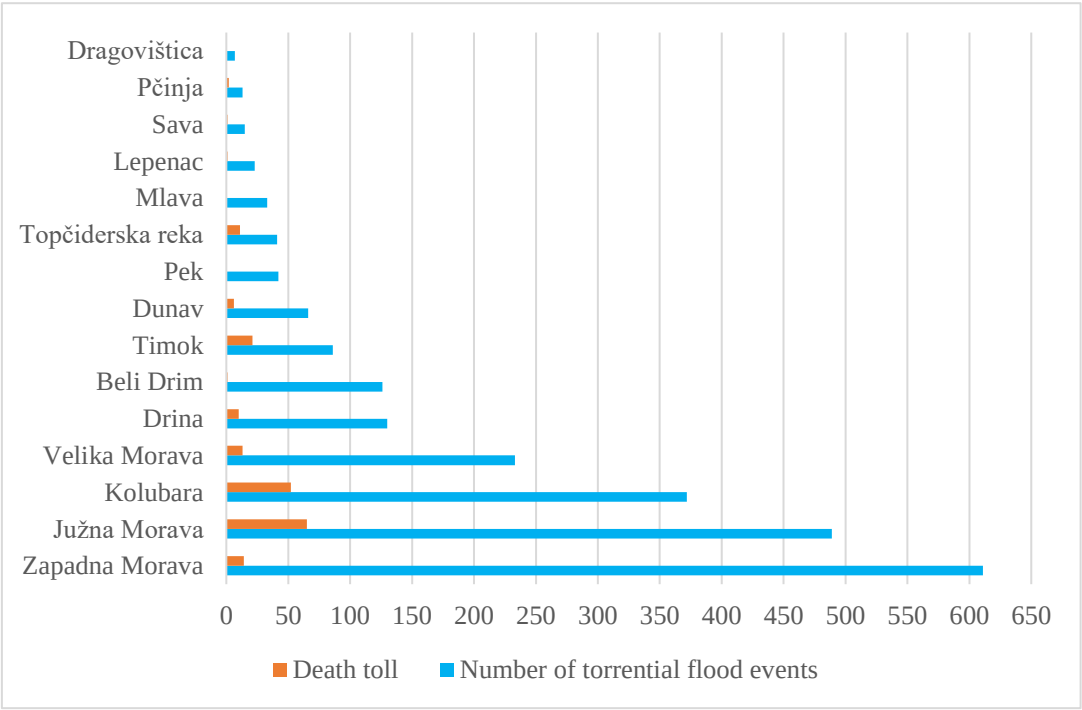


Figure 2. Torrential flood events per river basin

Temporal variability was analyzed using annual and decadal frequencies. Long-term trends were assessed by comparing early and late parts of the study period, while monthly distributions were examined to identify seasonal patterns of occurrence. Particular attention was paid to years with exceptionally high event counts. The average annual number of events increased considerably over time, reflecting not only improved documentation but also a rise in extreme rainfall episodes and heightened flood vulnerability due to urbanization in flood-prone areas.

Figure 3 reveals a clear upward trend in torrential flood occurrence across Serbia. A non-parametric Mann–Kendall (MK) test confirms the presence of a statistically significant upward trend in the annual time series covering the period of 110 years. Temporal analysis indicates a marked increase in the number of events after the 1950s. The period 2005–2014 recorded the highest decadal frequency of events and death toll; however, elevated flood occurrence was also recorded for the decades 2015–2024 and 1975–1984.

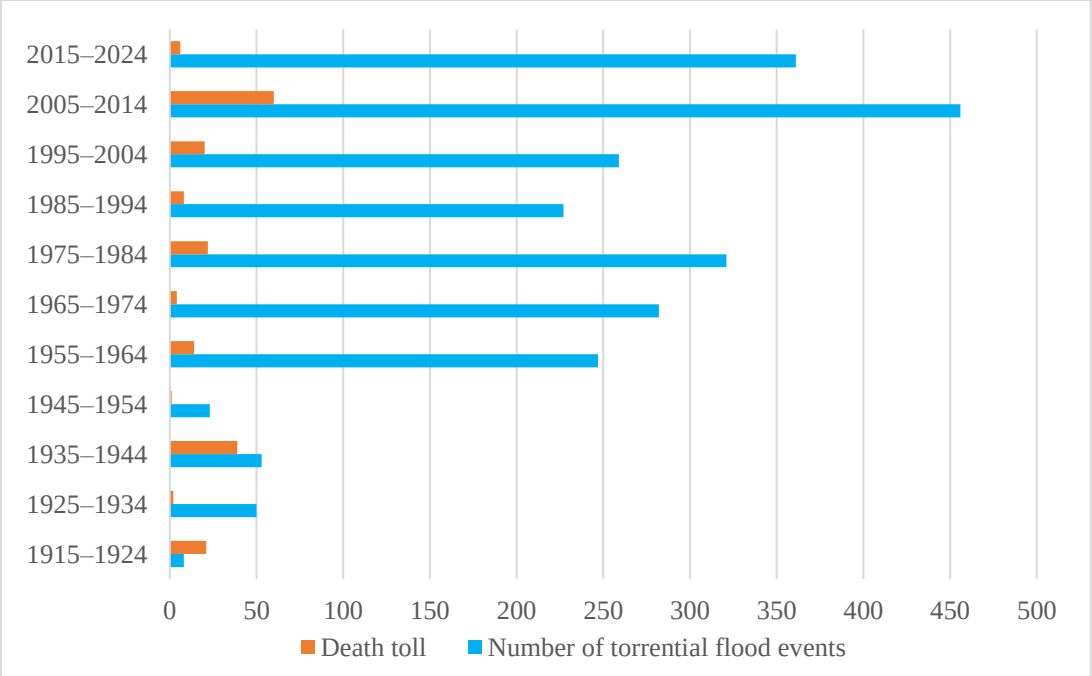


Figure 3. Decadal distribution of recorded torrential flood events

Over the past five years, the most impactful torrential floods occurred in the following watersheds:

- on 22 June 2020 in *the Ljubovi đa river* (watershed area A=158 km^2, Drina river basin), reconstructed as a 100-year return period flood with the specific maximal discharge, q_{max} (1%) of 1.09 m^{3}s^{-1}km^{-2} [8], *Skrapež* (A=166 km^2, q_{max}=1.27 m^{3}s^{-1}km^{-2}, Zapadna Morava river basin), *Lopatnica* (A=116 km^2, q_{max}=1.14 m^{3}s^{-1}km^{-2}, Zapadna Morava river basin), *Ribnica* (A=102 km^2, q_{max}=1.75 m^{3}s^{-1}km^{-2}, Zapadna Morava river basin), *Lučka* (A=94 km^2, q_{max}=1.39 m^{3}s^{-1}km^{-2}, Zapadna Morava river basin);
- on 12 June 2022 in the *Ribnica* (A=108 km^2, q_{max}=1.66 m^{3}s^{-1}km^{-2}, Kolubara river basin), and *Kamenica* (A=201 km^2, q_{max}=1.33 m^{3}s^{-1}km^{-2}, Zapadna Morava river basin);
- on 19 January 2023 in the *Toplica* (A=180 km^2, q_{max}=1.14 m^{3}s^{-1}km^{-2}, Južna Morava river basin); and

- on 15 June 2023 in the *Lopatnica* (A=116 km^2, q_{max}=2.03 m^{3}s^{-1}km^{-2}, Zapadna Morava river basin) [9].

All listed floods exhibited exceptionally high specific maximum discharges (the ratio of peak discharge to watershed area), exceeding 1 m³s⁻¹km⁻², indicating their extreme severity.

Temporally, floods with a rapid onset exhibit strong seasonal concentration in late spring and early summer, coinciding with convective rainfall episodes combined with antecedent soil moisture conditions. Rapid snowmelt, when coupled with intense rainfall, represents a compound hydro-meteorological driver of torrential flood generation in late winter.

Table 1 highlights a pronounced peak in May and June, corresponding to maximum rainfall intensity and convective storm activity, while secondary peaks occur in March and April. May and June torrential floods represent 41.6% of all recorded events and account for the majority of fatalities, claiming as many as 130 lives during the observed timeframe.

Table 1. The frequency of recorded torrential floods per month in Serbia

Period	**Relative frequency**
January–February	Moderate
March–April	High
May–June	*Very high*
July–August	Moderate
September–October	Low to moderate
November–December	Low

In examining the temporal variability of the torrential flood phenomenon, it is crucial to trace changes in runoff indicators while accounting for alterations in land use and vegetation cover over the decades. In this context, research [10] shows that runoff and soil erosion decreased over the past three decades in watersheds located in the border areas of south-eastern and eastern Serbia, largely due to depopulation and decreased human pressure. By contrast, an almost opposite trend was observed in the south-western and western regions of the country.

Furthermore, given that torrential floods represent a two-phase flow, the analysis of sediment characteristics as key indicators of torrential flow events in ungauged watersheds should be further encouraged. Deposited materials exhibit complex behavior governed by geological, geomorphological, and hydrological interactions, with parameters such as grain size distribution, shape, and orientation providing valuable insights into flow type, transport dynamics, and energy. In addition, integrating hydrological methods with modern geospatial and photogrammetric techniques offers a robust interdisciplinary approach for investigating watershed responses to both environmental and anthropogenic pressures.

Overall, the insights from the inventory confirm that torrential floods are a persistent and increasing hazard in Serbia. The observed increase in event frequency can be attributed to a combination of climatic variability and anthropogenic factors. Intensification of short-duration rainfall events plays a key role, consistent with broader regional climate trends in Southeast Europe. Land-use changes, including agricultural expansion and deforestation on steep slopes in the upper parts of the river basin, and urbanization in the

lower parts, have significantly altered runoff conditions and amplified the flood processes in many watersheds. Inadequate maintenance of torrent control structures and insufficient integration of flood hazard information into spatial planning further exacerbate vulnerability. The inventory results call for work on several key priorities: expansion of automatic rainfall and discharge monitoring in mountainous regions, implementation of integrated watershed management combining technical measures (check dams, channel regulation), biological measures (afforestation, erosion control), land-use planning, and sustainable forestry [11]. For mitigating consequences, improved early warning systems based on real-time rainfall thresholds, enhanced public awareness and education, and community-based risk reduction are needed. Effective mitigation of torrential floods requires an integrated approach that unites a deep understanding of natural hydrological processes with comprehensive socio-economic planning. All in all, the inventory provides the first unified historical database of torrential floods in Serbia, a foundation for spatio-temporal hazard assessment, a platform for risk communication, and a basis for integration into European databases (e.g., EM-DAT, ESWD). It follows the "3W" principle: what happened, when, and where.

The spatial concentration of recorded events within the Morava river system highlights the need for basin-scale approaches to flood risk management. The findings support previous studies that emphasize integrated watershed management, combining structural measures with nature-based solutions and land-use regulation [12].

With respect to data limitations, several challenges remain: incomplete historical records, particularly during the early decades, variability in the quality and content of reports, lack of continuous rainfall intensity data, and sparse hydrological monitoring in small basins. Despite these constraints, in a number of historical records, cross-verification across multiple sources enhanced the reliability.

CONCLUSIONS

Torrential floods represent a persistent and spatially concentrated natural hazard in Serbia. This paper presents a synthesis of key findings derived from the inventory of torrential floods in Serbia. Future research in this field should require improving monitoring networks, incorporating high-resolution data, and further developing multi-purpose databases. Sustainable watershed management, combining technical measures with biological and land-use planning approaches, is essential for mitigating the impacts of future torrential floods. The interaction between climatic extremes and human-induced landscape changes is central to understanding future flood risk in Serbia.

The study emphasizes the importance of systematic data collection and integrated watershed management as key elements for reducing torrential flood risk in Serbia. The comprehensive inventory provides a valuable foundation for understanding long-term trends and spatial patterns. A total of 2,287 torrential flood events were analyzed to identify spatial distribution, temporal trends, seasonal patterns, and material damage data can be employed for the assessment of impacts on the local population and infrastructure. The inventory of torrential floods in Serbia provides an essential scientific and practical tool for hazard analysis, policy formulation, and international data harmonization.

In an era of climatic uncertainty and accelerating land-use change, systematic documentation of past events is not merely archival—it is strategic. Understanding where, when, and why torrential floods occur is fundamental to anticipating their future behavior and reducing societal vulnerability.

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MONITORING ROCK GLACIER DYNAMICS IN THE HOHE TAUERN MOUNTAINS: INSIGHT INTO RECENT ALPINE PERMAFROST CHANGES

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ABSTRACT

Changes in mountain permafrost are of major scientific and societal interest due to associated potential risks to mountain communities. Rock glaciers, which are slowly creeping debris-ice landforms typical of mountainous permafrost regions, are key indicators of permafrost dynamics. Their movement serves as a critical parameter for the Essential Climate Variable (ECV) permafrost. This study investigates the movement of two rock glaciers in the Hohe Tauern Mountain Range, Austria: Tschadinhorn rock glacier (TRG) and Leibnitzkopf rock glacier (LRG), during 2023–2024 and compares derived movement rates to previous rock glacier velocity studies of these sites, as well as to ground and air temperature records. For rock glacier velocity quantification, we used unoccupied aerial vehicles (UAVs) with real-time-kinematic capabilities to create geodatasets of high spatial resolution and accuracy for both years. Rock glacier movement patterns were calculated using orthoimages, aligned to an existing geodetic network, using a state-of-the-art image correlation algorithm (GeoCosiCorr3D).

Results show that TRG exhibited the highest published, photogrammetrically derived mean RGV to date, 3.8 m/year in 2023–2024, exceeding previous maxima of interpolated point measurements reported for 2014–2015 and photogrammetric data from 2015–2016. At LRG, the maximum velocity reached 6.2 m/year, surpassing the previously published maximum of 5.8 m/year, but with a spatial shift in the location of peak movement. Spatial patterns at LRG indicate deceleration within central sectors and acceleration at the frontal zone, whereas TRG shows a more uniform acceleration. The climate context supports these trends: long-term, regional station data registered an all-time annual temperature record in 2024, consistent with a positive temperature-RGV relationship. However, local ground and air temperature observations since 2018 reveal site-specific responses with no clear trends, but a tendency of higher movement rates in warmer years at TRG and no simple, uniform linkage at LRG, suggesting modulation by internal kinematics and spatial heterogeneities.

Our findings provide robust, spatially resolved velocity evaluations for two representative alpine rock glaciers in the Alps and demonstrate recent acceleration consistent with long-term ongoing warming. The results underscore the need for sustained, multi-sensor monitoring to disentangle climatic forcing from internal deformation processes, thereby improving process understanding and risk assessment in high-mountain permafrost environments.

Keywords: Permafrost, rock glacier velocity, UAV, climate change, Alps

INTRODUCTION

Global warming has profound impacts on mountain environments, driving widespread permafrost degradation and, as a direct consequence, increasing alpine geohazards [1]. Rock glaciers (RGs), widely distributed permafrost landforms in high-mountain systems, serve as key geo-indicators for the state of alpine permafrost and for past, present and projected climate change [2–4]. Monitoring RGs is therefore essential for understanding ongoing transformations in high mountain environments. A central parameter for evaluating permafrost conditions in RGs is their deformation and displacement, which has led to the recognition of rock glacier velocity (RGV) as an Essential Climate Variable (ECV) for permafrost[2,5]. Recent studies have documented an acceleration in RG movement driven by climatic forcing [2,4]. Therefore, continued research and sustained monitoring of RGV are critical for detecting, attributing, and predicting the effects of environmental change in alpine settings.

Due to its importance, surface velocities of RGs have been measured since the last century using both ground-based and remote sensing approaches. Ground-based methods, such as Differential Global Navigation Satellite System (DGNSS) surveys, provide precise point-based displacement measurements, while remote sensing techniques, including satellite imagery and Unoccupied Aerial Vehicle (UAV) photogrammetry paired with various surface velocity algorithms [6], enable spatially comprehensive assessments of surface deformations [7]. UAV-based approaches, in particular, offer high-resolution mapping of surface displacements, facilitating the analysis of spatial variability across the landform, and supporting standardized, multi-temporal comparisons.

To provide new insights into recent alpine permafrost dynamics, this study investigates the movement patterns of the two rock glaciers Tschadinhorn (TRG) and Leibnitzkopf (LRG) using UAV surveys. These two RGs are well suited for examining changes in permafrost behavior as their historical flow velocities have been intensively studied [8–10], they are located in close proximity to each other (~7 km) and are subject to similar regional topoclimatic and geological settings, and both are highly active. By comparing our UAV-derived velocity fields to existing remote sensing studies and regional climate data, we aim to interpret observed dynamics to assess regional similarities and differences.

STUDY AREA

Both RGs are located in the Schober Mountains, Hohe Tauern Mountain Range, in the political district of Lienz, Eastern Tirol, Austria (Figure 1). Elevations of the lower limit of these landforms are around 2640 m.a.s.l. for TRG and 2500 m.a.s.l for LRG. Geologically, both RGs are formed by metamorphic rock types, TRG by amphibolite and LRG by mica schist [4]. Detailed descriptions of both rock glaciers and their morphology can be found in the literature [8–10].

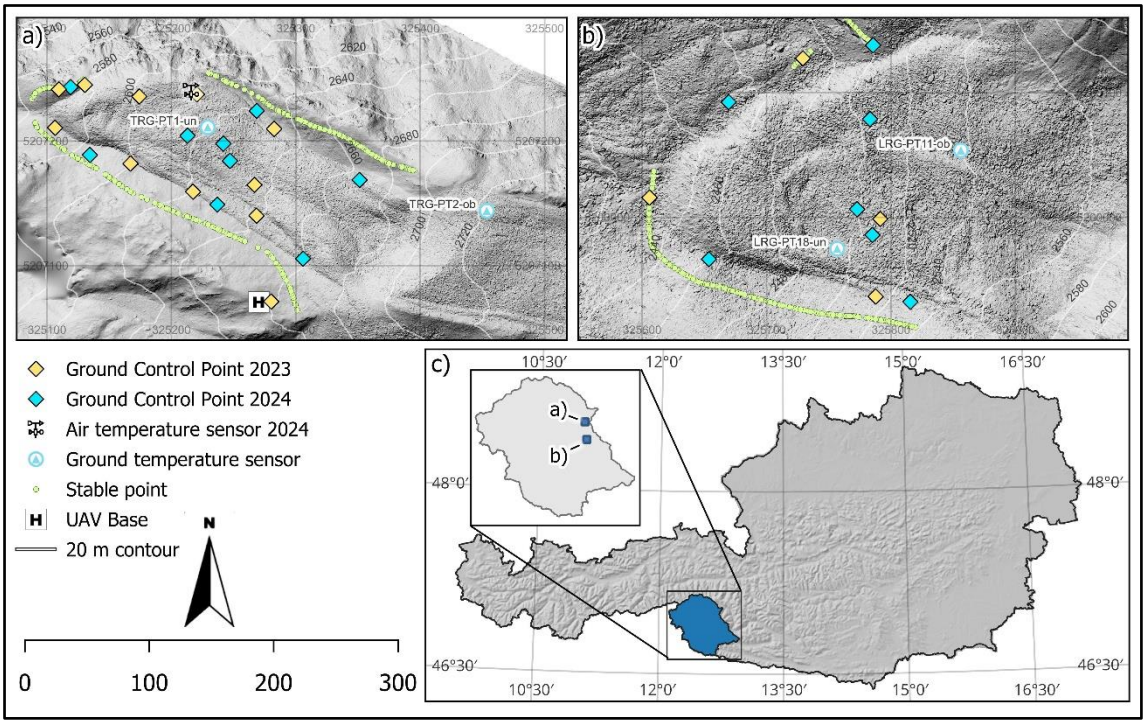


Figure 1: Overview of the studied rock glaciers TRG (a) and LRG (b) in 2024. Both rock glaciers are located in the political district of Lienz, Eastern Tirol, Austria, which is shown as blue polygon in (c). Coordinate reference system is 25833 (a, b) and 3416 (c). The UAV Base at the Leibnitzkopf research area is located approximately 200 m to the west outside of the map and was not covered by the UAV imagery. DEM data source for (c): [11]

DATA AND METHODS

We performed image acquisitions in August 2023 and 2024 at both sites using the UAV DJI Matrice 300 RTK, equipped with the photogrammetric camera DJI Zenmuse P1 with a focal length of 35 mm (Table 1). We used coordinates of an existing geodetic network, established by Viktor Kaufmann [8,10], and set up base stations at coordinates of respective fixed points for real-time-kinematic (RTK) corrections for terrestrial and UAV based DGNSS measurements. To assure high-accuracy, all images were recorded in RTK mode and post processed (Post-Processing Kinematic – PPK) using the local base station corrections and UAV DGNSS logs from the flights using the software Emlid Studio 1.9 [12]. This allowed for recording cm-accurate UAV images across all our research areas.

Table 1: Overview of UAV survey flight parameters at the two studied RGs

Location	Date [YYYY.MM.DD]	Ground sampling distance [m]	Number of images [n]	Ground control points [n]
TRG	2023.08.24	0.015	399	10
TRG	2024.08.29	0.015	601	7
LRG	2023.08.25	0.015	465	4
LRG	2024.08.30	0.015	587	7

Terrestrial DGNSS measurements of Ground Control Points (GCPs), colored targets that were placed previous to the flight, were performed using a base-rover configuration with

an Emlid Reach RS2 and an Emlid Reach RS3 DGNSS [13]. Each target was measured three times to reduce measurement uncertainties with a ten second averaging interval each, and afterwards summarized to one mean coordinate for each GCP. Respective measurements served for checking the accuracy of the photogrammetric products and were not used in the processing or bundle block adjustment. Due to changing weather conditions and therefore, temporal resources, as well as unstable and difficult terrain, the number of GCPs varied between the different surveys (Table 1).
Photogrammetric processing, including image alignment, bundle adjustment, creation of point clouds, digital surface models and orthoimages, was performed using a standard Structure-from-Motion (SfM) approach in Agisoft Metashape 2.2 [14]. Afterwards, we resampled the resulting, coregistered orthoimages to achieve an exact match of the different time periods and to derive the desired resolution for computing surface displacement and velocity. In this study, we aim to derive horizontal (2D) surface displacement, as this variable is comparable to existing research at both sites. Various algorithms for the calculation of surface displacement exist [6]. For regular displacements, intensity tracking methods using cross-correlation are considered as a suitable approach [7]. The approach uses rectangular sliding windows to correlate sections of base- with areas of target images, representing different acquisition times, and derives displacement from the shift of highest-correlating windows. We applied the python based geoCosiCorr3D algorithm [15,16], an improvement of the methodology of Leprince et al. [17], which uses a normalized cross-correlation method of fast fourier-transformed, multi-scale sliding windows, as it showed good performance in comparison to other approaches in situations of horizontal deformations [18,19]. For the algorithm, several parameters have to be defined. The most important parameter is the window size, as it sets the area for the correlation window, but also depends on the maximum expected displacement. Existing studies recommend a window size that is about two times the displacement to be measured [17]. Therefore, the window size in pixels depends on the resolution of the input rasters and the maximally expected displacement. We selected two different parameterizations: a) parameters similar to existing research for both sites, which used an input raster resolution of 0.2 m, a window size of 31 pixels and an output grid spacing of 5 m [9,10], whereby we increased the window size to 64 pixels to match recommendations for the applied frequency algorithm [17] and b) a higher resolution version using 0.03 m input rasters, a window size of 512 and an output grid spacing of 0.06 m (Table 2).

Table 2. Overview of parametrization for velocity computations at both studied RGs.

Location	Input resolution [m]	Output grid spacing [m]	Window size [pixels]	Abbreviation
TRG	0.2	5.00	64	TH_020m_64
TRG	0.03	0.06	512	TH_003m_512
LRG	0.2	5.00	64	LK_020m_64
LRG	0.03	0.06	512	LK_003m_512

Both parameterizations were calculated with the red band only as this approach showed good performance at velocity computations in high-mountain settings and lower atmospheric scattering effects are expected [20].
To evaluate the velocity computations and the detection threshold for displacements, we mapped areas outside of the RG that represent potentially stable terrain with an expected

displacement of zero, as this approach is frequently used in permafrost research and easily comparable [21]. Therefore, we mapped polylines in (potentially) stable terrain, and calculated 200 random points along the lines with a minimum distance of 1 m around each RG (Figure 1). Computed velocities from the different approaches were subsequently extracted and used to calculate the level of detection (LoD) in m/year according to Fey and Krainer [7] as:

$$LoD = (\mu + 2 * \sigma)$$

Thereby, μ represents the mean displacement on stable points in m/year and σ is the standard deviation of displacements at stable points in m/year.
Comparison to existing results is conducted by using areal averages of clearly defined Areas Of Interest (AOI), as outlined in Kaufmann et al. 2018 [8] in case of TRG, or the maximum displacement in addition to newly mapped AOIs around geodetic survey points used in Kaufmann et al. [10], due to the unavailability of existing reference areas.
Own air and ground temperature measurements were conducted between 2018 and 2024 using miniature temperature dataloggers. The dataloggers used are products from GeoPrecision, whereby each data logger is equipped with a PT1000 temperature sensor and records hourly temperature values. The loggers have an accuracy of ±0.05 °C, a range of −40 to +100 °C and a calibration drift <0.01 °C yr−1. From these measurements, mean annual ground surface temperature (MAGST) and mean annual air temperature (MAAT) values have been calculated based on monthly averages from September to August of the following year. A snow cover day was considered as such when the weekly standard deviation of the mean daily ground surface temperature was ≤0.25 °C [22]. For long term climate data, we used the homogenized HISTALP dataset [23] for air temperature at the station Sonnblick (SON), as it is a high-mountain weather station (3105 m a.s.l.) and has a distance of less than 25 km to the studied RGs. We did not use the whole time series available, which starts in 1887, but used data from 1950 onwards, as the onset of published RGV analysis was 1954 at both sites [9,10]. We used Locally Weighted Scatterplot Smooth (LOWESS) to visualize smoothed non-linear trends, a widely used and comparable method [24], with a data fraction for smoothing of 25 years following recommendations in existing climate research [25]. For linear trends, we used Sen's slope together with Mann–Kendall significance testing for the trend direction, because Sen's slope is more robust compared to parametric methods and as Mann–Kendall is considered suitable for climatological datasets [26,27]. We did not calculate trends for our own climate measurements due to the short available time period.

RESULTS AND DISCUSSION

Photogrammetric processing of the UAV images resulted in independently assessed horizontal errors between 0.02 m to 0.04 m (Table 3). No clear pattern was visible regarding the X or Y domain of horizontal errors, but elevation errors (Z) were slightly higher than horizontal errors. Accumulation of errors for two periods would amount to 0.06 m at TRG and 0.05 m at LRG.

Table 3. Error measures of the UAV campaigns using independent GCPs

Region-Year	n	X [m]	Y [m]	Z [m]	XY [m]
TRG2023	10	0.020	0.011	0.042	0.022
TRG-2024	7	0.035	0.021	0.026	0.040
LRG-2023	4	0.019	0.010	0.032	0.021
LRG-2024	7	0.013	0.026	0.048	0.029

Results of the period 2023-2024 showed a mean RGV of 3.80 m/year (3.79 m/year) for the lower (higher) resolution parameterization at TRG and of 3.54 m/year (3.66 m/year) for the lower (higher) resolution parameterization at LRG (Table 4).

Table 4. Overview of mean RGV and LoD values with different parameterizations. All LoDs were calculated using 200 points

Parameterization	Mean RGV [m/year]	LoD [m/year]	Maximum displacement [m/year]
TRG_020m_64	3.80	0.029	4.66
TRG_003m_512	3.79	0.032	4.70
LRG_020m_64	3.54	0.069	6.19
LRG_003m_512	3.66	0.065	7.08

LoD values ranged from 0.03 m/year to 0.07 m/year, which is below 1% to 2% of the mean RGV. Maximum velocity values were at 4.66 m/year (4.70 m/year) at TRG and at 6.19 m/year (7.08 m/year) for the lower (higher) resolution parameterization at the LRG. TRG shows a zone with lower displacements in the southeast above a slope break, and a faster zone in the northwest including the tongue-shaped front, whereby lower velocities occur at the tongue of the RG and higher velocities in the middle of the southeastern part of this zone (Figure 2). The two parameterizations showed largely identical results. Maximum displacements were found in close proximity to maxima of existing studies. Decorrelations were visible at the slope break zone but not within the averaging area of the RG.

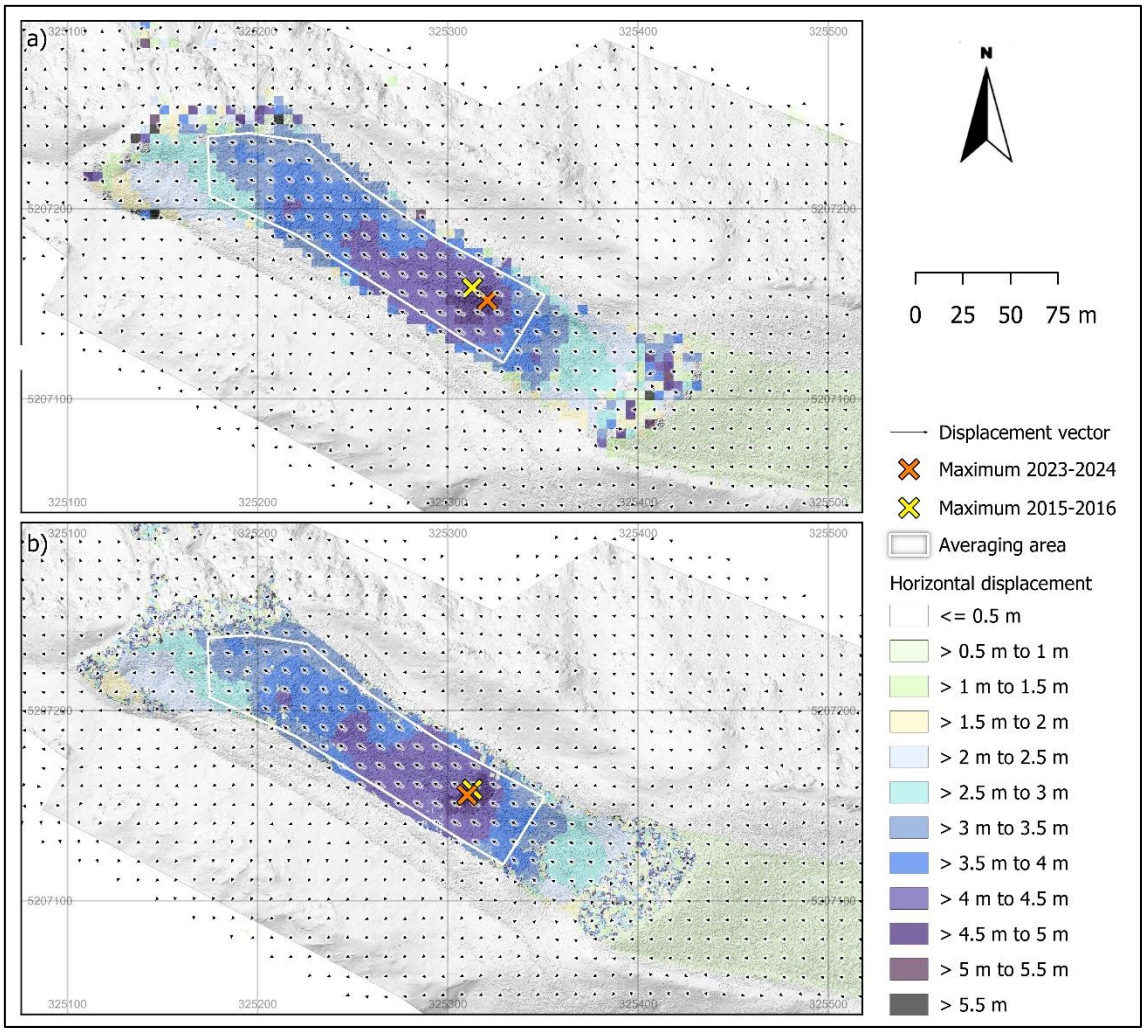


Figure 2. Derived displacements between 2023 and 2024 at the TRG with the parameterizations TRG_020m_64 (a) and TRG_003m_512 (b). Orange crosses mark the location of the maximum displacement of this study (4.66 m/year for TRG_020m_64 and 4.70 m/year for TRG_003m_512) compared to yellow crosses, indicating the approximate location of the maximum displacement (3.56 m/year) in 2015-2016 published in [8,9]. Displacement vectors are at map scale. White border shows the AOI for calculating mean RGV.

LRG showed high displacements of more than 4.5 m over a large area in the southwestern part and low velocities along a broad border zone in the northeast (Figure 3). Location of maximum values 2023-2024 were at different locations compared to previously published positions and were located at the southwestern end of the tongue. The different parametrizations largely showed similar results with some differences along the western tongue. A notable difference was decorrelation in the higher resolution parameterization north of the maximum value published in Kaufmann et al. [10].

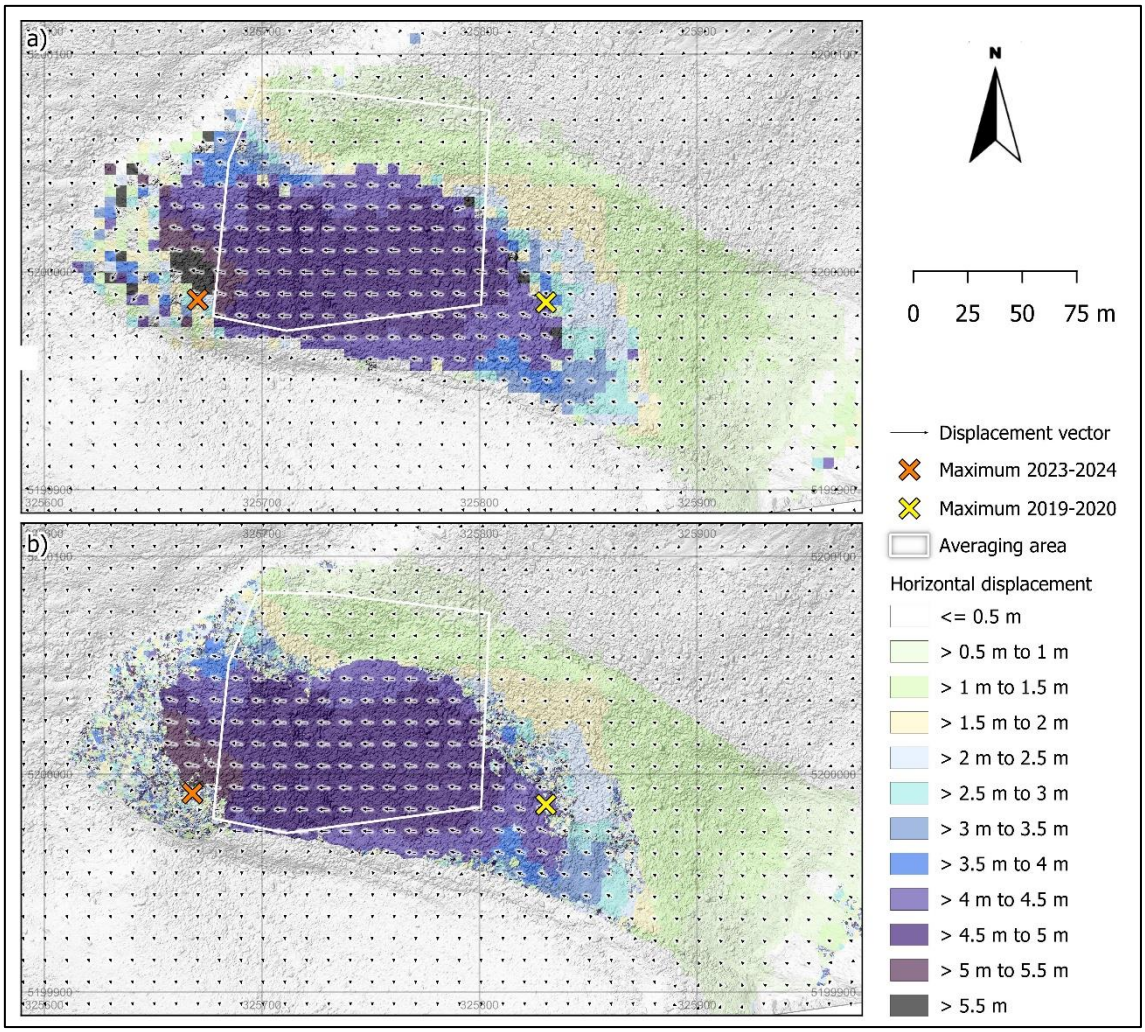


Figure 2. Derived displacements between 2023 and 2024 at the LRG with the parameterizations LRG_020m_64 (a) and LRG_003m_512 (b). Orange crosses mark the location of the maximum displacement of this study (6.2 m/year for LRG_020m_64 and 7.1 m/year for LRG_003m_512) compared to yellow crosses, indicating the approximate location of the maximum displacement (5.76 m/year) in 2019-2020 published in [10]. Displacement vectors are at map scale. White border shows the AOI for calculating mean RGV, which was mapped around geodetic survey points 2019 shown in Kaufmann et al. [10].

Long term climate data analysis shows an accelerating trend of increasing yearly temperatures with maximum mean values measured in 2024 (Figure 4). The 2023-2024 period of this study represents the warmest two-year period of the whole times series. On site weather stations show a similar pattern for MAGST and MAAT during 2018-2014 at TRG (Figure 5). Snow cover duration at TRG was the longest in 2023-2024 at the lower sensor and showed an intermediate duration at the upper sensor. The upper MAGST sensor values were among the highest at LRG, whereas the lower sensor showed the third lowest temperatures. Generally, both sites at LRG showed lower or similar temperatures compared to the 2019-2020 period. Snow cover duration was very low at both sensors at LRG compared to the whole time series and lower than the 2019-2020 values.

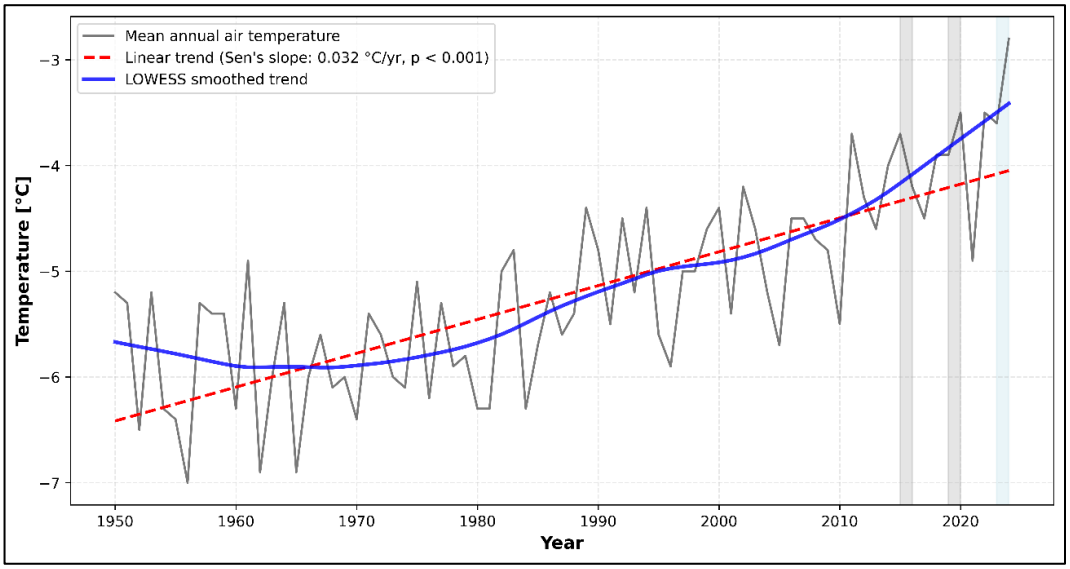


Figure 4. Mean annual temperatures and trends 1950-2024 at Sonnblick (3105 m a.s.l.). Grey bars indicate periods of published maximum values of existing photogrammetric research in 2015-2016 [8,9] at Tschadinhorn rock glacier and 2019-2020 at Leibnitzkopf rock glacier [10], and light blue bar indicates the period of the presented study. Data source: HISTALP 2026 [23]

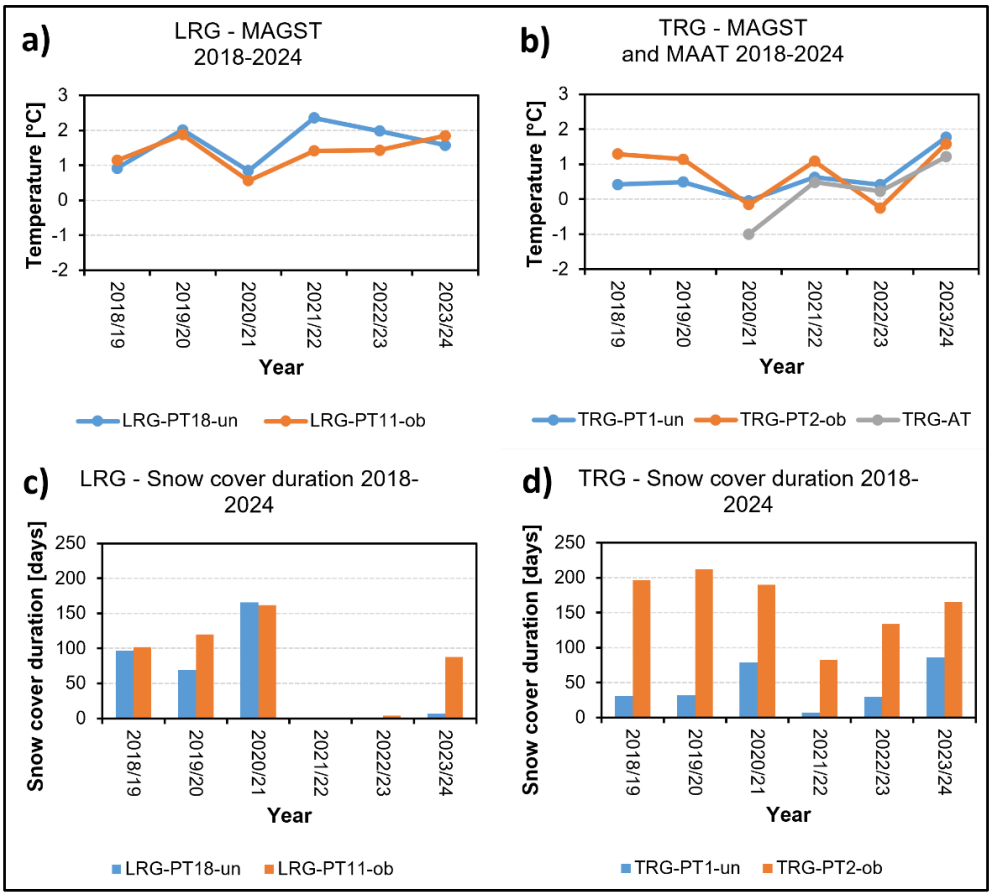


Figure 5. Temperature-derived parameters at the two rock glacier sites for the period 2018-2024: Mean annual ground surface temperatures (MAGST) and mean annual air temperatures (MAAT) for the LRG (a) and TRG (b) sites. Snow cover conditions were derived from the ground temperature data for the LRG (c) and TRG (d) sites. For location of sites refer to Figure 1

DISCUSSION

Our results indicate an increase of mean RGV at TRG compared to previously published values. The 2023-2024 mean was 3.80 m/year, exceeding the mean within the AOI reported for 2015-2016 (2.91 m/year) based on UAV photogrammetry [9], and for 2014-2015 (3.28 m/year), which represents the maximum mean displacement 1954-2017 but was derived with terrestrial RTK-GNSS scaled to the AOI [9]. At the same site, the maximum 2023-2024 value (4.66 m/year) also exceeded the 2015-2016 maximum (3.56 m/year) [9], highlighting a clear acceleration at TRG.

At LRG, velocities were more variable. The maximum 2023 2024 velocity was 6.19 m/year (7.08 m/year for the LRG_003m_512 parameterization), higher than the 5.76 m/year reported by Kaufman et al. [10] for 2019-2020. However, the sector where the 2019 2020 maximum occurred exhibited substantially lower values in 2023 2024 (4.4 m/year to 4.8 m/year). In general, the main body of LRG was characterized by lower velocities (<5 m/year), whereas the this zone contained extensive areas exceeding 5 m/year in 2019 2020 [10]. In contrast, our 2023 2024 data show markedly higher velocities in the frontal zone, indicating a contemporaneous acceleration at the front and deceleration in the central sections.

The accuracy assessment and LoD indicate robust velocity computation over all sites and for all UAV campaigns. Values between 0.03 and 0.07 are at the lower end compared to previously published results on high-resolution RG velocities [7], although direct comparisons have to be interpreted with caution due to different settings and study designs. However, comparing LoD and errors of photogrammetric processing in the cm range to annual displacements at the m-scale support robustly computed velocity rates.

The general acceleration observed at TRG in 2023 2024, representing the highest published, photogrammetrically derived RGVs at this site, coincided with the highest air and ground temperatures recorded by sensors installed directly on the RG. At Sonnblick station (~21 km away from TRG), the annual all-time temperature record (in terms of MAAT) since 1887 was reported for 2024, emphasizing the broader regional warming signal. These findings support the established link between increased RGVs and elevated permafrost temperatures [2,4], and suggest a continuation of rising displacement rates consistent with the parallel warming trend and record temperatures at TRG. Additionally, an above-average snowpack during winter 2023 2024 may have contributed to higher velocities through enhanced insulation from winter cold and/or increased water input following melt [2]. It is noteworthy that unpublished point-based RTK-GNSS observations at both sites indicate that the temporal peak in RGV may have occurred during 2020–2021, followed by a decline [28,29]. Nevertheless, the 2023 2024 RGVs at both TRG and LRG rank among the highest when compared to published photogrammetric datasets.

Compared to TRG, LRG presents a more complex coupling between climate and kinematics in this study. While Sonnblick station data show record-breaking mean annual temperatures, local MAGST and snow cover at LRG were not exceptional in 2023 2024 relative to conditions between 2018 and 2024. Furthermore, spatially heterogeneous velocity patterns persist, with acceleration concentrated at the frontal zone and deceleration evident in central parts. This pattern likely reflects not only climatic and hydrological influences but also intrinsic kinematic evolution described by Kaufmann et al. [10], with acceleration of the central zone since 2009 that has propagated westward and is now showing in increased frontal velocities, contributing to the maxima observed

in our study. Consequently, although significant climate-RGV correlations were reported for LRG [10], the relationship appears non-linear and mediated by internal RG dynamics. Longer, spatially resolved kinematic time series combined with comprehensive local climate monitoring will be necessary to disentangle these interactions.

Overall, our findings highlight ongoing changes in permafrost dynamics under accelerating warming in high mountain environments. The strong acceleration at TRG aligns with regional records of air temperature and local ground warming, while LRG illustrates how internal deformation patterns can modulate, delay, or redistribute the climatic signal across a RG. These results emphasize the need for multi-sensor, multi-scale monitoring to capture both climatic forcing and internal kinematic processes that govern RGV variability.

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LOCATION OF EARLY MEDIEVAL HILLFORTS IN THE POLISH CARPATHIANS – PHYSIOGEOGRAPHIC ANALYSIS

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ABSTRACT

The study area is located in southern Poland, in the Carpathians between Cieszyn in the west and Przemyśl in the east. Complex physiogeographic and geoarchaeological analyses are helpful, including: analysis of the Digital Elevation Model and derived maps based on EU-DEM, geological characteristics of the immediate vicinity of the central part of the hillfort (maidan) based on geological map (1:50 000) – litostratigraphy and tectonics of the surrounding area, relief and morphogenetic processes, a description of the mesoclimates of individual landscape elements around individual hillfort components based on hillfort plans (Marszałek 1993). The main methods include geoinformatics and geomorphological studies. The first of these was developed using modern ArcGIS Pro and QGiS software. Precise information from the National Geoportal (hillshading map) was also implemented.
There are approximately 44 archaeologically confirmed the Early Medieval strongholds in the Polish Carpathians, often with difficult-to-determine chronological order. There are mostly small, single-rampart structures, commonly found in forests within relatively low mountains and foothills. The strongholds' basement is usually hard and compact. They often occur near brown, lessive soils. Detailed field research will be carried out on selected strongholds in the future.

Keywords: Hillforts, Carpathians, Poland, Middle Ages, Geoarchaeology

INTRODUCTION

Hillforts in the Polish Carpathians remain an underappreciated research topic among both domestic and international researchers. Over the past decade or so, there has been very little archaeological work in this area, which may be due to the lack of excavations and reliance on surface surveys. This significantly hampers the precise chronology of hillforts. Furthermore, almost all sites lack environmental context, revealing a clear research gap.
A hillfort is the remnant of a former hillfort, a possible settlement, most often defensive, surrounded by a rampart. In the territories of present-day Poland, Germany, the Czech Republic, and Slovakia, they were a characteristic feature of the lowland, upland, and mountain landscapes. In the south, Slavic settlements were less numerous, perhaps due to different geographic and cultural conditions. In this article, the Early Middle Ages is defined as the period from the beginning of hillfort construction in the mid-8th century until the 13th century [1], when the first proto-towns began to emerge. The Polish

Carpathians have long been a borderland, forcing the local population to adapt to geopolitical and cultural conditions. Two types of the Early Medieval hillfort remains exist today. The first is a hillfort covered in dense forest, e.g., Tyrawa Solna (Fig. 1), and the second is a site developed by a later castle, e.g., Manasterzec [2].



Figure 1. The hillfort in Tyrawa Solna on Diabla Góra (Devil's Hill) above the San River. An example of a hillfort on top of a forested hill (type: watershed IIIb). Photo by Cyryl Konstantinovski Puntos

AIM AND METHODS

The main research goal was to create a comprehensive environmental database for the locations of 44 Early Medieval hillforts [3] in the Polish Carpathians, from Cieszyn to Przemyśl (Fig. 2), as well as to collect data characterizing the hillforts themselves—the number of ramparts and their surface area. This allowed, on the one hand, for an analysis of the "human-environment" relationship and the reconstruction of the realities and causes of the emergence of early Slavic hillforts in these locations. On the other hand, for the development of a hillfort typology based on their location.

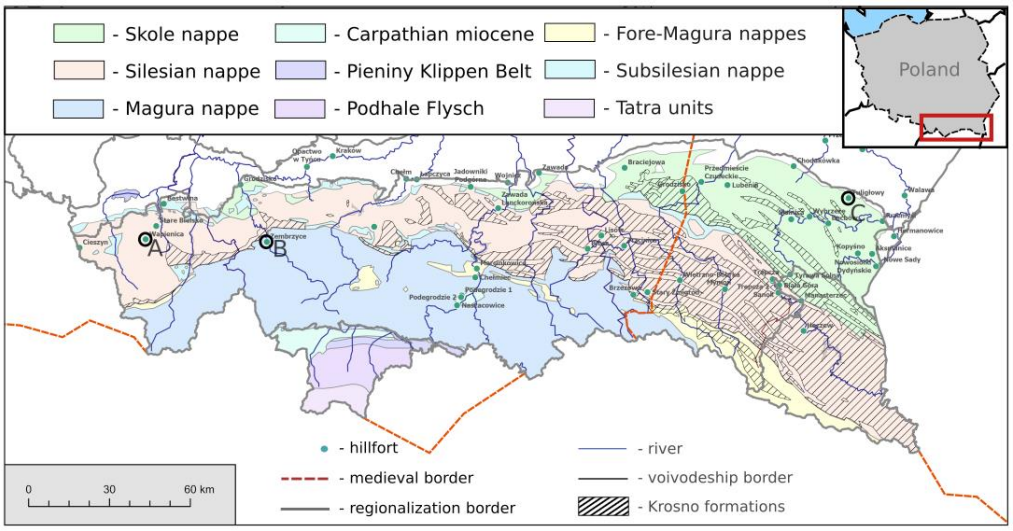


Figure 2. Area of the study. Carpathian hillforts [8, 9] on the background of the tectonic map [18]. Hillforts (see Fig. 4): A – Wapienica, B – Zembrzyce, C – Tuligłowy.

The developed database for hillforts consists of over twenty elements. Various literature and cartographic data were used to characterize them (Table 1).

Table 1. Schematic diagram of the table structure developed for this research.

Name of the component	Classes or types	Sources and data
Regionalization	16 regions where are hillforts	[4]
Tectonics	3 main nappes and others	[13]
Stratigraphy and litology	Interpretation of geological map. Various classes	[13]
Quaternary deposits	Interpretation of geological map. Various classes	[13]
Relative height	m	[14]
Absolute height	m a.s.l	[14]
Relief typology	3 classes	[6]
Landforms	7 classes	[8], [11], [14]
Aspect	0-360 degrees	[14]
Climate vertical zone	2 classes	[14]
Mesoclimate	3 classes	[7], [9]
River order	3 classes (II., III., IV.)	[15]
Basin	Various names of the rivers	[15]
Soils	5 main types and 1 combination	[13], [17]
Vegetation vertical zone	2 classes	[14]
Potential vegetation	Various classes of vegetation	[5]
Area of hillfort	8 classes	[10], [1], [12]
Rampart's count	3 classes	[10], [12]
Typology	7 classes	Author's typology
Chronology	8th/9th-13th c. Various combination	[10], [1]
Preservation	3 classes (good, medium, bad)	[12]
Landslides	2 classes (Yes, No)	[13]
Comments	-	-

Geoinformatics methods (arcgis pro and qgis) were used to process the data and analyze it. This involved working with raster data (digital elevation model) [11, 13] and vector data (including vectorization of the location points of the hillforts on the map). Some maps were calibrated (relief map, tectonic map) and then compared with a point layer of the locations of the early medieval hillforts. Obtained archaeological data regarding the chronology of hillforts and their morphometry were used. In many cases, data (such as geological data from the map 1:50,000 or soil science data) were implemented directly from the maps and saved in a spreadsheet. Some information was generated directly in the gis environment. Individual maps of each hillfort were also created using available rasters. Contour and slope maps were also created based on eu-dem. A preliminary field survey was conducted on selected hillforts, primarily in the eastern part of the carpathians.

RESULTS

The distribution of hillforts in the Polish Carpathians is uneven, with more occurring in the eastern part than in the western part (Fig. 2). The Dunajec River Valley, along which

a distinct, linear concentration of hillforts is a distinct boundary between these two regions.
Carpathian hillforts were predominantly small, single-rampart structures (55%), located within predominantly low mountains [5, 10] (32%) and foothills (66%). This means that the majority, as many as 45% of hillforts, are located within the Silesian nappe, 32% within the Skole nappe, and only 7% within the Magura nappe. The basement is Mesozoic and Cenozoic flysch [13], which favors landslides. The Quaternary cover are most often composed of weathered rock, but 4 hillforts (9%) were built on loess.
The Dynów Foothills (approximately 11% of all hillforts in the Polish Carpathians) [4] contain the largest number of hillforts with three (or more) lines of defensive ramparts. In the Silesian Beskid, there is one hillfort with a single rampart, in the Wyspowy (Island) Beskid, one hillfort with a single rampart, and in the Low Beskid, there are two hillforts: one with a single rampart and one with three or more lines of defensive ramparts.
The hillforts occur between 200 and 688 meters a.s.l. They are located on various relief forms, 7 of them on the Tertiary, “foothill peneplain” with a relative elevation of approximately 150-200 meters above the valley floor. Approximately 20% of the hillforts are located within terraces, near their edge [8]. Climatically, the hillforts are located in a favorable, warm, and temperate location near relatively wide rivers [15]. 95% of the hillforts are located in the "moderately warm vertical climate zone" (average annual temperature from +6 to +8°C), and only 2 in the”moderately cool vertical climate zone” [16]. More than half of the hillforts (25 sites) are located within mesoclimate II (slopes and lower ridges; so-called "warm zone on slopes" with optimal mesoclimatic conditions) [4, 7], 14 hillforts are within mesoclimate Ic (valley sides, dryer and warmer at night), and 5 on terraces within mesoclimate Ib (central and lower parts of slopes).
Collectively exists 66% of the hillforts, which are located near valleys of II. river order, with a particular concentration in the Dunajec Valley. This is followed by 23% in IV. and 11% of the III. river order.
Hillforts often occur near areas with brown and lessive soils. The proximity of Cambisols (52%) and Retisols (34%) is the largest, according to the American classification WRB (The World Reference Base) [17].
On the potential vegetation map, most hillforts are located in forest habitats typical of oak-hornbeam, alder, and beech forests [5]. Currently, these areas are forested, but the species composition has been changed and created as a result of forest management in recent centuries.
Most hillforts have an area of less than 4 hectares (80%). More than half of the hillforts have only one line of defensive ramparts. Hillforts were constructed differently on hilltops (a defensive rampart surrounding the hilltop, usually at a single elevation) and on slopes and hillsides (the rampart can be built according to the relief, at varying heights). A typology based on the location of hillforts indicates that the majority of hillforts can be classified in the watershed (39%) and slope (36%) categories (Table 2, Fig. 3).
Hillforts are most often poorly preserved due to multidirectional anthropogenic impact. Their transformation or destruction by landslide processes, which are very common in the Polish Flysch Carpathians, is relatively rare. Approximately 23% of all hillforts are subject to landslide processes.

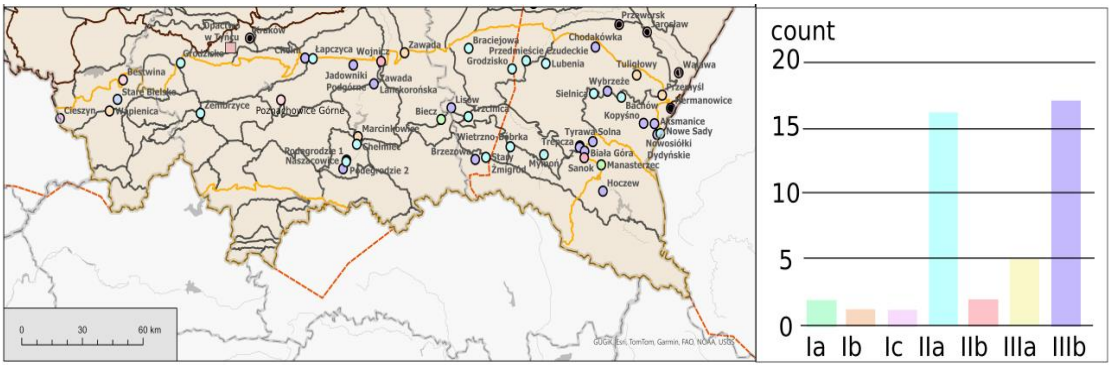


Figure 3. The typology of Polish Carpathians hillforts. Regionalisation (physicogeographical mesoregions-black line; physicogeographical subprovinces – orange line): [4], Medieval border of countries (red line) [1], Locations of hillforts [3]. Basemap Geography socio-economic: Esri

Table 2. Hillforts typology

Types of hillforts	Characteristics	Count	Sample
Ia	Flat	2	Wojnicz
Ib	Flat – slope	1	Stare Bielsko
Ic	Flat- watershed	1	Cieszyn
IIa	Slope	16	Braciejowa
IIb	Slope - watershed	2	Biecz
IIIa	Watershed – slope	5	Zawada
IIIb	Watershed	17	Wybrzeże

Three cases were selected for future detailed research. The site in Zembrzyce (type: slope IIa), where a hillfort was built in a side valley (III. river order) suspended above the Skawa valley (II. river order) on the Pleistocene alluvial fan (Fig. 4). For comparison, the hillfort was also compared with the site in Tuligłowy on Borusz Hill and its slope part (watershed-slope IIIa), located north of the Pleistocene valley near the Węgierka valley (IV. river order) and occupying the culmination of Wapienica Hill (type: watershed IIIb) above the Wapienica valley (III. river order), on hypsometric and slope maps.

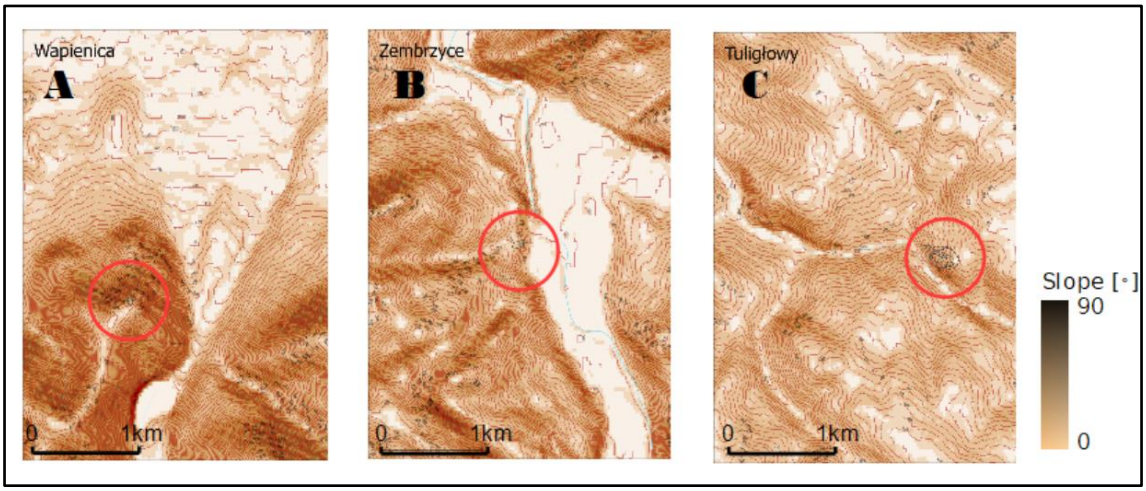


Figure 4. Examples of hillforts in the Polish Carpathians. Based on [12], [14], [15]. Hillforts are marked with a red circle on the map

CONCLUSION

A database of environmental data for the locations of 44 hillforts in the Polish Flysch Carpathians can serve as a starting point for geographical, archaeological, and historical analyses.

This preliminary analysis allows us to hypothesize that geopolitical and strategic factors played a significant role in the location of the hillforts. Their small size, coupled with their greater number in the eastern part, suggests that their primary role was to protect the borderland from potential enemies. These are not primarily large refuges, such as Naszacowice near Nowy Sącz, but rather small watchtowers, such as Hoczew near Lesko. These small hillforts were constructed around the main hillfort in Przemyśl or Sanok. They also protected major trade routes, such as the Dunajec Valley, along which they are clearly concentrated.

The significantly smaller number of hillforts built on the Magura nappe may be a result of their location within the low mountains and foothills that formed on the flysch of the Silesian and Skole nappes. This conclusion is also supported by the geological structure of the Polish Outer Carpathians. In the eastern part, where the hillforts are most numerous, the Magura nappe occurs only in a very limited area and in the interior of the Beskidy Mountains.

The selection of sites for hillfort construction was largely determined by specific, favorable geomorphological conditions. Relatively "flat" areas were often chosen, such as Tertiary peneplain – the “foothill level”, which facilitated development. At the same time, these flatlands sloped downward on steep slopes formed during the Quaternary phases of erosion. This also applies to younger forms, such as the Pleistocene terraces and alluvial fans in side valleys, such as Zembrzyce (Fig. 4), suspended as a result of the early Pleniglacial and Holocene deep erosion in second-order valleys.

It appears that the location of hillforts was also related to knowledge of mesoclimatic conditions – the frequency of inversions, particularly in winter. This was all the more significant because they were built during the cooling period of the Late Antique Little Ice Age. A suitable temperature and climate were crucial for the population at that time, and hillforts were often temporary or permanent habitats for local communities.

The land around hillforts was certainly cleared to obtain timber for the construction of palisades and box ramparts, and for military reasons – to increase the field of observation and prevent undetected enemy approach.

In most cases, the specific location provides favorable viewing and defensive conditions. Only some of them were located in locations that do not fit this pattern, which may be related to their different function. Further, detailed analysis of the developed database should answer questions about the purpose and function of the Early Medieval hillforts in the Polish Outer Carpathians. Further detailed research, including paleogeographic and geoarchaeological fieldwork at selected sites, is planned for the future.

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METALLURGICAL MACRO- AND MICROARTEFACTS IN FAN SEDIMENTS AS RESULT OF FLUVIAL PROCESS CHANGES – CASE STUDY FROM SIELPIA RESERVOIR (S POLAND)

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ABSTRACT

The Sielpia Reservoir is located on Czarna Konecka River in the N part of Świętorzyskie Voivodeship (Central Poland), about 30 km NW from Kielce. In the Middle Ages, there was a significant development of metallurgical industry in Old-Polish Industrial District (OPID). The Sielpia Reservoir is in place where one of historical industrial pond operated. Suddenly other reservoir drainages and disastrous flows in the middle section of the Czarna Konecka River led to intensified incision and bank erosion of the river and intensive accumulation of material in the Sielpia Reservoir. In the Czarna Konecka estuary into the Sielpia Reservoir an inland delta (high-energy subequenus fan) was deposited. These fan and inland delta were formed during many flash floods caused by failures of the dams of former industrial ponds located upstream of the reservoir.
A geological profiles in inland delta were made, and samples were taken for grain size analysis, macro-, microslags and iron spherules content by Magnetic Spherule Separation (MSS) method. The analyses have shown the occurrence of slags and iron spherules in fan sediments. Slags are mainly accumulated quite shallowly creating later characteristic aeolian pavement. Mainly delta fan is built by sandy sediments at terraces cut by the river, in which both slags and spherules do not occur. A small amount of them in the inland delta sediments confirm their redeposition from the upper section of Czarna Konecka River during flood events.

Keywords: Makro- and microslags, iron microspherules, historical metallurgy remains, redeposition, Old-Polish Industrial District

INTRODUCTION

In the Middle Ages in Holy Cross Mts. Region was a significant development of metallurgical industry in Old-Polish Industrial District (OPID) [1]. The Sielpia Reservoir is placed in one of the many old industrial ponds where historical forges were operating before. Research from other rivers in this region [2] and Europe [3],[4] indicates many traces of metallurgical activity preserved in the alluvial deposits. So far, the occurrence of microspherules in lacustrine sediments has been recognized in the Suchedniów Reservoir (Kamionka Valley)[2] and in the discussed reservoir in Sielpia Wielka (Czarna Konecka Valley), however, the spatial distribution of microartefacts in the sediments has not been studied so far. Contemporary sediments have been intensively transported and

accumulated from the upper sections of river, which in last years has formed a distinct high-energy subaquenus fan and later inland delta in the reservoir bottom [5]. Since the construction of the new reservoir at this location in 1960, it has been dredged several times due to intensive transport and accumulation of the alluvia from upstream. This led to a reduction in the reservoir capacity by up to 5 ha [6]. This reservoir is an excellent place to identify the contemporary redeposition of metallurgical microartefacts from many former forge sites located upstream in the river.

STUDY AREA

The Sielpia Reservoir is located in Holy Cross Mts. (Kielce Upland, Poland) about 30 km NW from Kielce. In many rivers of this region, like Czarna Konecka or Kamienna a former industrial ponds ware operated in the historical times [1]. On Czarna Konecka River, there were many ponds built as the part of the water wheel-powered hydrotechnical infrastructure of forges and other ironworks [1]. Sielpia Reservior is in place of one of these industrial ponds creating characteristic anthropogenic small-scale water retention system (ASWRS) on the river [1],[7]. Most of them were later destroyed or their functions were changed during economic transformations in the OPID region [1],[7]. In the river estuary into the Sielpia Reservoir an inland delta (high-energy subequenus fan) was deposited. This form located in the SE of the reservoir is the main object of the current research. The studied form was completely destroyed during the revitalization works on the reservoir finished in 2023.

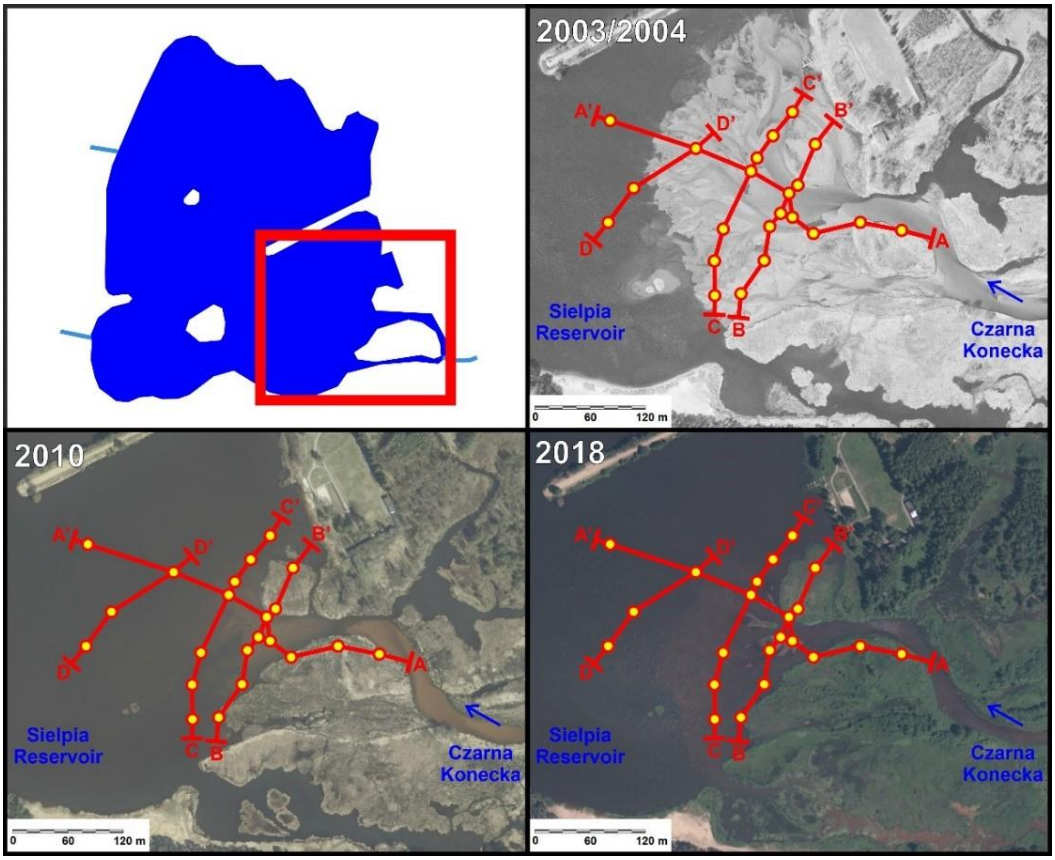


Figure 1. Location of profiles/drillings (yellow points) and cross-sections (red lines) in western part of Sielpia Reservoir in archival photos 2003/2004, 2010 and 2018 [8]

METHODOLOGY

Aim of the study is to recognize microartefacts of historical metallurgical activity on the river in the redeposited alluvia of inland delta. For this purpose, the types of macro-, microslags and microspherules were differentiated in selected grain fractions including the processes leading to their accumulation from upper section of the river.
Geological profiles and drilling were made in 2019-2020 during the hydrotechnical works on the Sielpia Reservoir that was carried out. Fieldwork was mainly concentrated in the SE part of the reservoir in the inland delta (subaqueous fan) area. Drillings and profiles were made throughout the entire form area to identify spatial lithological and sedimentological changes of the delta. The samples collected from it were subjected to grain size analyzing, macro- and microslags distribution measurement (quantitative method given in percentage) and the Magnetic Spherule Separation (microspherules per 10 grams of material) laboratory methods [9]. Also field inspection with photographic documentation of the study site was made. The research materials were supplemented with archival documentation and previous results of research conducted at this study site [2],[5],[6],[7]. Detailed analyses were carried out again for 22 geological profiles (215 samples), which will enable precise spatial recognition of the lithological structure of the studied form and the distribution of microartefacts of historical metallurgy at Czarna Konecka River.

RESULTS

Grain size analyses showed that delta (high-energy subaqueous fan) is built mainly of sand and gravel sediments with a darker layer of finer deposits admixture with visible detritus inserts. Grain size analysis amble to make a lithological reconstruction of the delta. Earlier, preliminary analyses allowed for the preparation of a less detailed longitude section considering the distribution of slags and microspherules in the sediments [2].

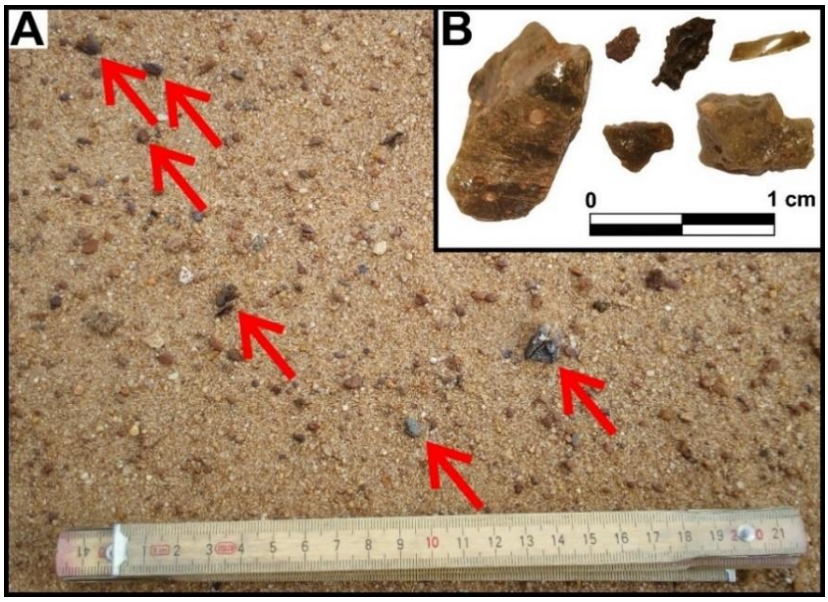


Figure 2. A – Aeolian (deflation) pavement made of slag formed on the surface of Sielpia inland delta (Photo P. Przepióra 2019),
B – Macro- and microslags separated from sediments (Photo P. Przepióra 2024)

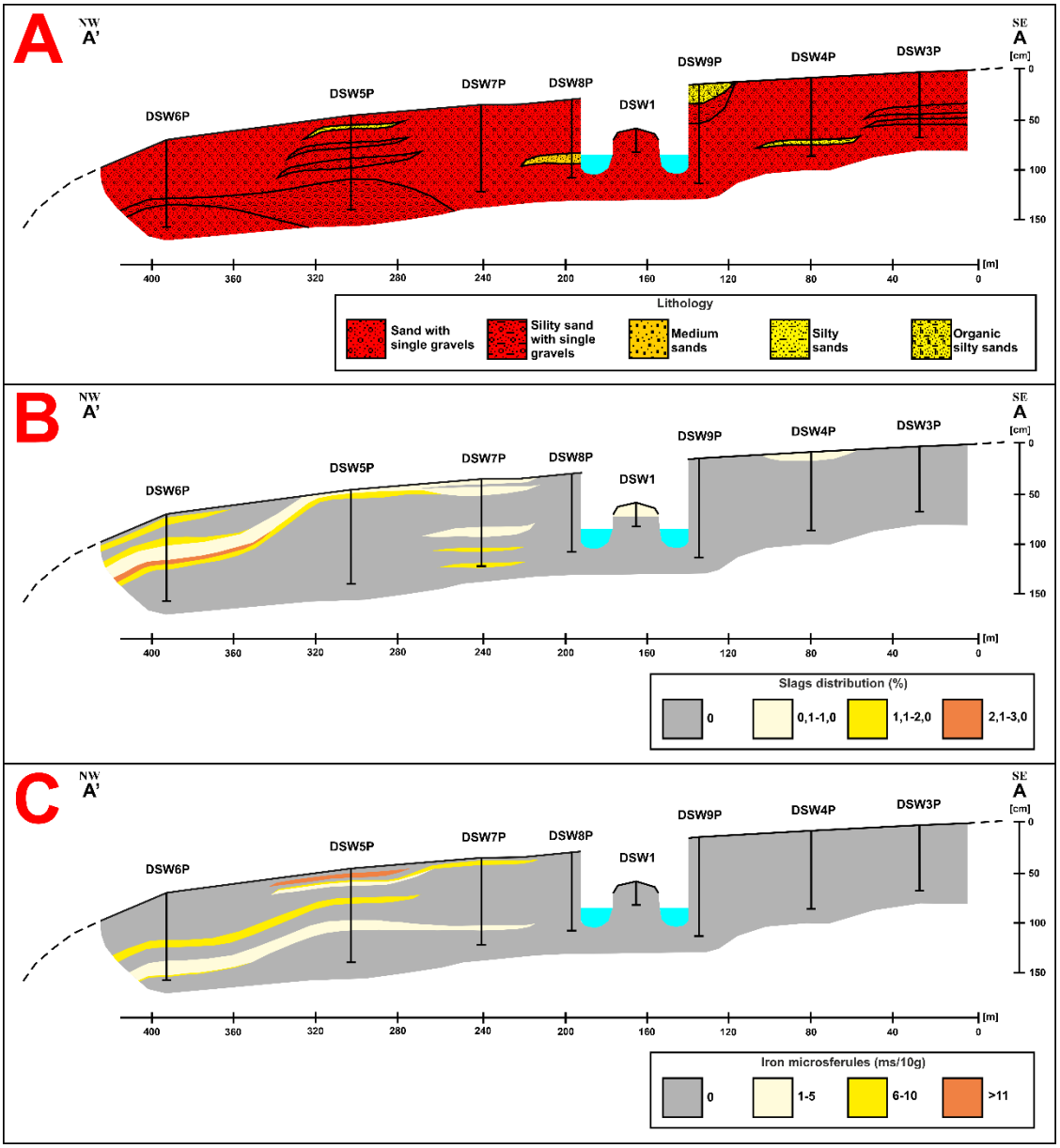


Figure 3. Selected A-A' cross-section of Sielpia inland delta [2], [6] (supplemented and changed): A – lithological data; B – distribution of macro- and microslags in fan sediments; C – distribution of iron microsferules in fan sediments.

These results confirmed the possibility of measuring not only macro- and microslags, but also iron microspherules redeposited from the upper section of the river. Cross-sections made based on geological profiles indicated the distribution of individual metallurgical artefacts in the delta sediments. Macro- and microslags are mostly found in the surface and mostly shallow sediments at the head of the delta. They occur mainly in sandy and gravelly material that create visible aeolian (deflation) pavement on the surface after drying of the reservoir in 2019 (Fig. 2). Iron microspherules, however, usually occur only in the finer fraction of sediments, often where no macro- or microslags have been detected. The artefacts detected in the sediments form distinct layers in the frontal part of the studied form (Fig. 3). The percentage of macro- and microslags does not exceed 10% in the analyzed samples, but most often their number is trace, as reflected by values below

1%. In the case of iron microspherules, the situation is analogous to slags, and their number is relatively small (from a few to a dozen pieces per 10 grams of sieved sample), however, possible measurement errors caused by the small weight of the available samples should be considered.

DISCUSSION

In the Middle Ages, there was a significant development of metallurgical industry in OPID. Many ironworks and forges were built along most of the rivers of the area [1]. This led to the construction of ASWRS with small industrial ponds [1],[7]. At the beginning of the 20th c. many of those ponds were drained with the collapse of the metallurgical and water mills activity. Later, the abandoned dams of former industrial ponds were destroyed and led to a flash floods in the river [10]. In the Czarna Konecka River this flash flood led to intensified incision and bank erosion and intensive accumulation of material in the Sielpia Reservoir forming a high-energy subequenus fan [5]. A macro-, microslags, and microspherules have been detected in the delta sediments of the Sierpia Reservoir, which are traces of historical metallurgical activity in the river. These occur in relatively young subequenus fan and later delta sediments that existed in the reservoir until 2019, confirming long-term intensive redeposition processes on the river. Small number of these artefacts in the sediments is probably caused by its redeposition (flushed out), but also by the fact that during the flash flood the river cut the Pleistocene sandy terraces [7], in which these artefacts did not occur. New analyses have shown the occurrence of slags and iron spherules mainly at the delta front. Slags are mainly accumulated quite shallowly, and their greatest concentration occurs directly at the head of the analyzed form. The constantly supply of more slags by the river is confirmed by occurring of them in the bar in the channel cutting the delta (Fig. 3). The occurrence of iron spherules occurs only at the delta front, and they are found deeper at the head of the delta. A small amount of both slags and spherules in the sediments of the inland delta confirms their redeposition from the upper section of Czarna Konecka River during floods [7]. However, there is a clear fundamental difference in the sediments in which macro- and microslags and microspherules are accumulated. Slags are predominantly found in coarse sediments carried by stronger water currents, for example during flash floods, forming distinct sand-gravel layers. Microspherules, on the other hand, occur mostly in a sediment with finer fraction admixture, indicating that they accumulate mostly under low-energy flow conditions. These results show a relationship between types of redeposited sediments with metallurgical artefacts that occur in them.

CONCLUSIONS

Iron spherules detected in the delta sediments of Sielpia Reservoir can relate to mainly their redeposition from upstream of the river. The macro- and microslags preserved in the delta's sediments were flushed out from the upper section of Czarna Konecka, where many forges operated with similar industrial ponds (ASWRS) These reservoirs were abandoned and destroyed led to create flash floods. The formed layer of iron spherules may indicate the accumulation of these sediments during one of such catastrophic events on the river during 21st c. The results of MSS and slags separation show a relationship between the types of redeposited sediments in which metallurgical artefacts occur. Most of the slags are accumulated in coarse alluvium when microspherules only in sediments

with admixture of finer fraction. This is caused, i.a., by the size of the particles carried in different water flow strengths.

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RESULTS OF GEOARCHAEOLOGICAL STUDY OF ARCHAEOLOGICAL SITE AT BUKOWA GÓRA (SILESIAN UPLAND, POLAND) – MEGALITH, EARLY MEDIEVAL STONE-EARTH BARROWS, MEDIEVAL MINES

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ABSTRACT

Multicultural archaeological site at hill Bukowa Góra (365.5 m a.s.l.) is located at Dąbrowa Górnicza–Ujejsce on an isolated hill with steep slopes, part of the Middle Triassic Step on Silesian Upland, southern Poland. Geological, geomorphological, sedimentological, geophysical, geochemical archaeoastronomy research, archaeological excavation, radiocarbon and luminescence datings were done. Three areas can be distinguished within the site. The lowest-lying area contains preserved traces of Early Medieval mining (pinga, warpie, adits) of zinc and lead ore with a silver admixture from ore-bearing dolomites. The second area, located on the plateau, is an extensive barrow cemetery, clearly visible in the LiDAR image and in the field. There are Early Middle Ages (8th-12th centuries AD) stone-earth barrow. The third area with stone structures of megaliths is located on the culmination of the hill, which is surrounded by a stone circle with a radius of 53–56 m. The age of the megalithic structures is unknown and controversial, both in light of the artifacts found and luminescence dating.

Keywords: geoarchaeology, megalith, Early Medieval, mining, barrow cemetery, Bukowa Góra, southern Poland

INTRODUCTION

The differences in megalith density across Europe are astonishing and incomprehensible. Over 10,000 megaliths have been recorded in Denmark and northern Germany, approximately 550 in Sweden, 53 in the Netherlands (Drenthe province), and only 17 in Poland [1]. In the monumental publication Megaliths of the World [2], Poland appears marginally (four times). According to one of many scientific theories, debated for decades, the megalithic tradition spread across Europe along the coasts [3]. Chronological

stratification is taken into account, as well as a kind of recycling of stone blocks [3]. However, very old archaeological sites (Göbekli Tepe and others), dating back several thousand years, with structures that can be broadly defined as megalithic, appear in Turkey far from the coast.
Probably due to the insufficient state of research, we observe a significantly smaller number of archaeological sites in Poland associated with megalithic traditions e.g. tombs from Wietrzychowice, Sarnów, Gaj Stolarski (Kujawy mounds), Polish pyramids etc. [4], [5], [6], [7].

STUDY AREA

The study area is located in the Silesian Upland on the border with the Kraków-Częstochowa Upland. The cuesta of Middle Triassic Step is composed of Lower and Middle Triassic limestones, marls, and dolomites, dipping isoclinally 3-8° NE and locally overlain by Mesozoic rocks. Its relief is dominated by hills, hummocks, and plateaus with undulating or flat surfaces (Fig. 1). From the Dąbrowa Basin (from the W, N, and NE), it forms a strongly fragmented by active (Czarna and Biała Przemsza rivers) and dead gorges and "stepped" structural front with a relative height of 40-130 m, on the foreground of which rise the “witness hill” (erosional remnants) e.g. Bukowa Góra. The NW-SE-oriented Ząbkowice Garb (Hump), eastward of Czarna Przemsza gorge, is approximately 6 km wide. In the central part, fragments of the Palaeogene peneplain (384-370 m a.s.l.) have been preserved, but these have been eroded into rounded spurs and intervalley hills, lowered in the northern part to an altitude of 365-340 m a.s.l. The slopes of the hills, with the exception of Bukowa Góra (365.5 m a.s.l.), are generally slight. On the plateau surfaces and steep denudation slopes of the Garb, there are mostly only rubble-clay weathered covers, while the erosion depressions are filled with the Quaternary sands, in which karst sinkholes are reproduced (around Trzebiesławice). Poor drainage results in numerous marshes and wetlands in the valleys, for example in the Trzebyczka Valley southward of Bukowa Góra [8], [9].

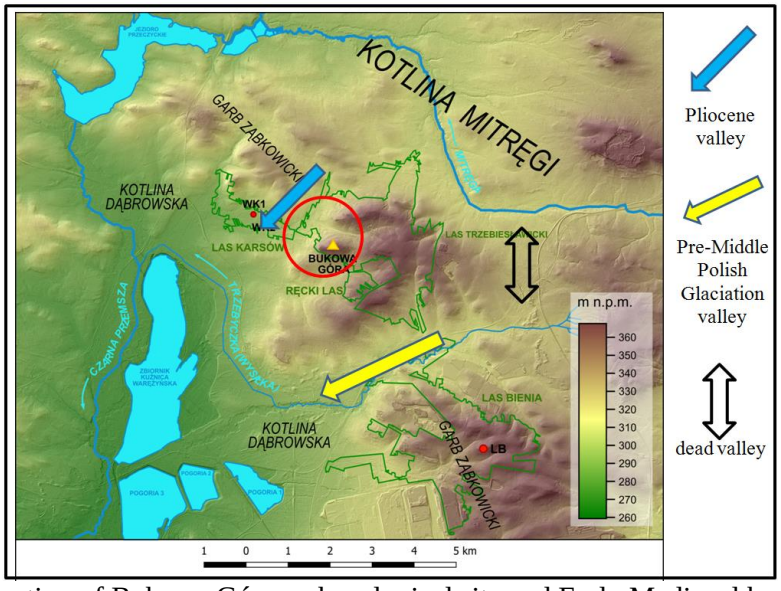


Figure 1. Location of Bukowa Góra archaeological site and Early Medieval barrow fields at Wojkowice Kościelne/Karsów (WK1, 2) and Las Bienia (LB) on DEM of Ząbkowice Garb (Hump) and Dąbrowa Basin [10, supplemented]

RESULTS

Multicultural archaeological site no. 18 at Bukowa Góra (365.5 m a.s.l.) is located in Dąbrowa Górnicza–Ujejsce on an isolated hill with steep slopes, part of the Middle Triassic Step. It was originally identified as associated with Early Medieval, Medieval, and modern ore mining. Three areas can be distinguished within the site (Fig. 2).

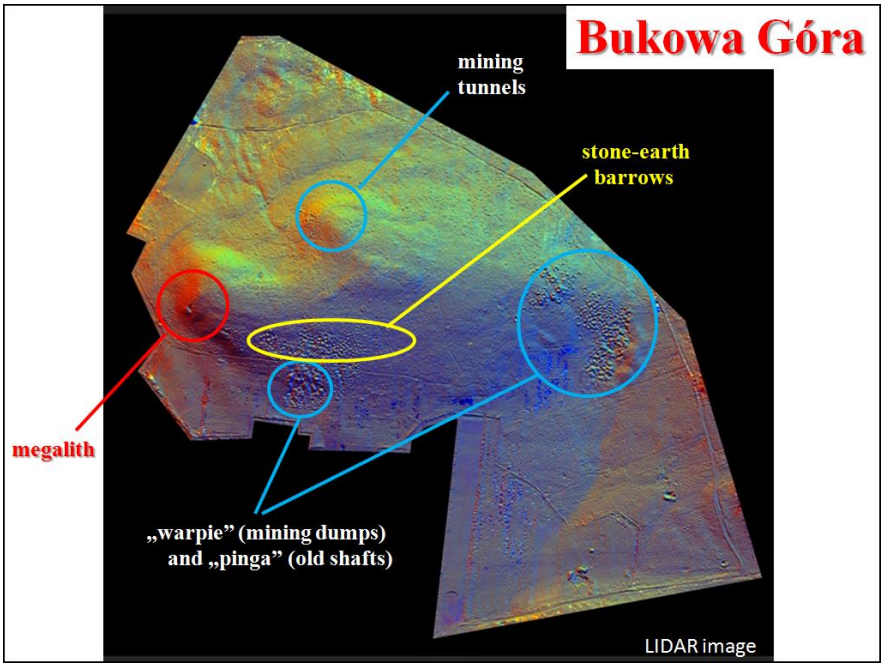


Figure 2. LiDAR image of Bukowa Góra site

The lowest-lying area contains preserved traces of mining (pinga, warpie, adits) of zinc and lead ore with a silver admixture from ore-bearing dolomites (Fig. 3). Mining pits surround the hill, and the beginnings of mining date back to the 11th–12th centuries, as evidenced by artifacts discovered in the area, including Early Medieval lead weights [11, 12]. Mining work was not carried out on the top of the hill because the Diplopora dolomite there does not contain metal ores.



Figure 3. Small „warpie" (mining dumps) and „pinga" (old shafts) (photo T. Kalicki)

The second area, located on the plateau, is an extensive barrow cemetery, clearly visible in the LiDAR image and in the field [13, 14] (Fig. 4).

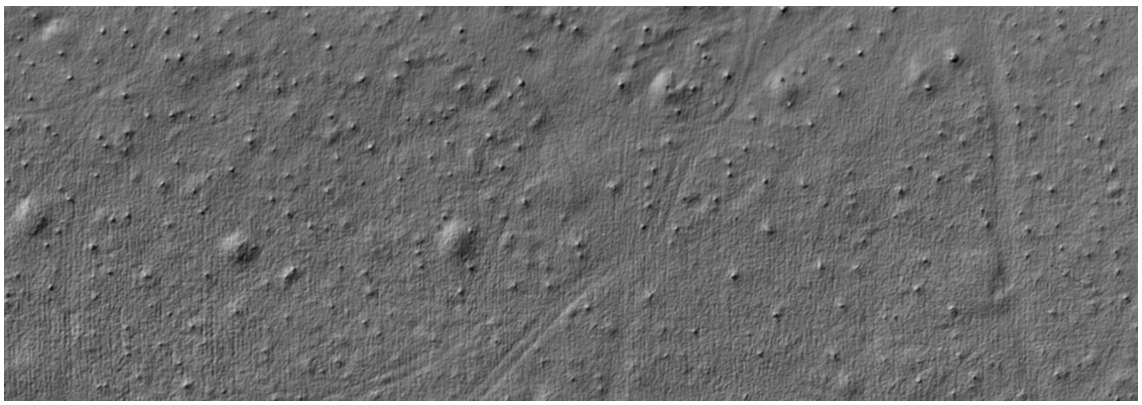


Figure 4. A barrow cemetery in a LiDAR image

Rock-earth barrows, circular mounds, are topped with stone steles often oriented N–S (Fig. 5). There are also graves covered with large stone slabs, many of which are topped with triangular steles [14]. An increase of phosphorus content have been found in the soil [15].



Figure 5. Rock-earth barrow (upper) with stone stele oriented N-S at the top (lower, photo T. Kalicki)

Detailed research covered a barrow (approximately 70% of the surface) with three vertical stele – object 2/2020. It is a stone box covered with earth. The bottom of the grave was half-filled with reddish clay (Fig. 6). A limestone stele, broken into three pieces and inverted, was discovered here. It likely originally stood upright and was topped with a face (Fig. 7). The limestone from which it was made does not occur naturally on the hill, so it must have been intentionally made, transported to the summit, and placed in the stone box anthropogenically.



Figure 6. Object 2/2022. The interior of a stone box with a light and reddish bottom (photo D. Rozmus)



Figure 7. The top of a broken limestone stele ("man head") from a stone box in object 2/2022 (photo D. Rozmus)

Radiocarbon dates from the barrows date to the Early Middle Ages (8th-12th centuries AD), although one of the dates falls on the second century AD [16], while the TL dating of 11.5±1.7 ka (KIE-989) indicates that they were built on Late Glacial weathering cover.

The third area with stone structures is located on the culmination of the hill, which is surrounded by a circle with a radius of 53–56 m (Fig. 8) formed by large boulders placed vertically on the slope (Fig. 9).

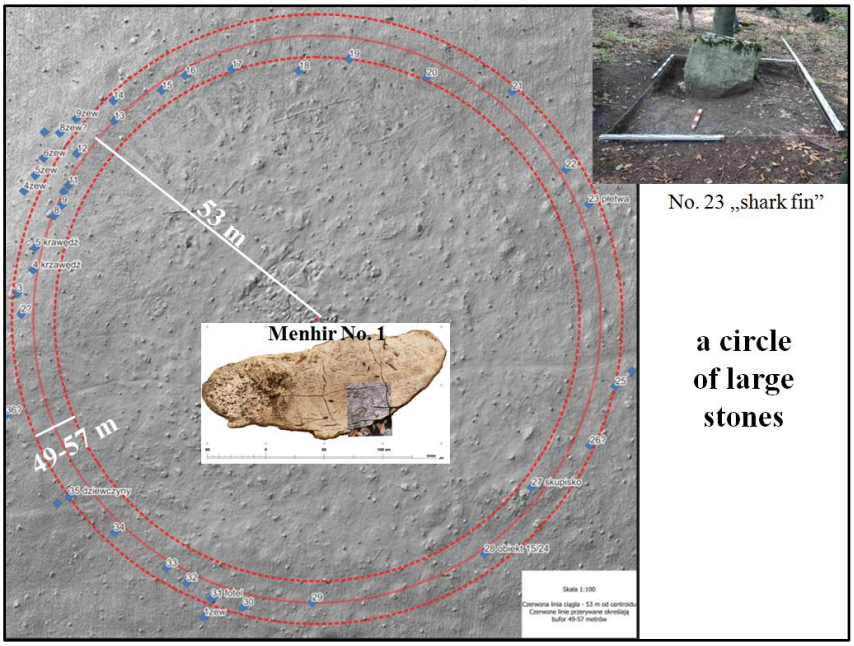


Figure 8. Stone circle around the summit of the Bukowa Góra with numbering of stone blocks



Figure 9. Vertically placed stones (No. 5 and 8) on the slope forming a circle around the summit of the Bukowa Góra: you can see the support of the triangular rock (above the arrow on right photo)

Steles, both overturned and standing, as well as worked blocks and rock structures on the summit occur. These are mostly Diplopora dolomites, but there are also large fragments of limestone that must have been transported here [13], [14], [17], [18], [19]. The results of archaeoastronomical studies (M. Rodziewicz, M. Nuckowski et al.) indicate an intentional arrangement and orientation of the steles (Fig. 10).

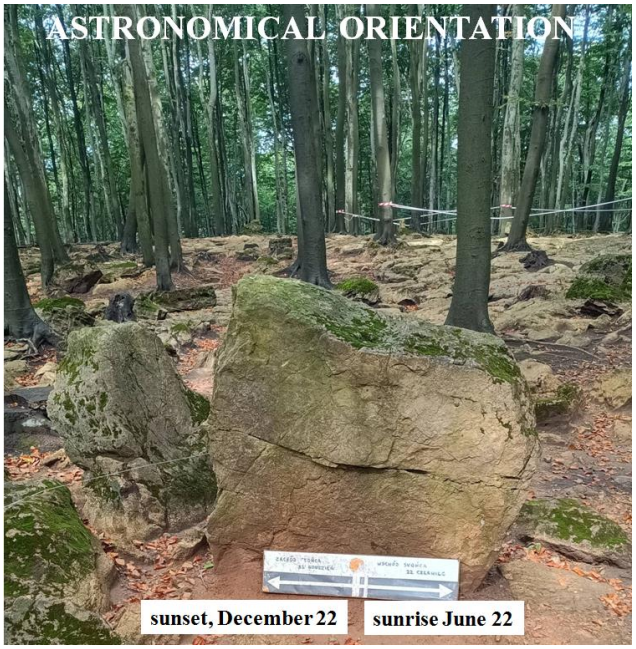


Figure 10. Stele with astronomical orientation (photo T. Kalicki)

The steles and rock blocks on the summit of Bukowa Góra were anthropogenically placed. This is evidenced by structures excavated in more than a dozen surveys beneath the Diplopore dolomite blocks, including traces of postholes, foundation pits (sometimes multi-stage) for embedding the steles and blocks, and sandy bedding (Fig. 11) between the blocks and the weathered rock [13], [14], [17], [18], [19].

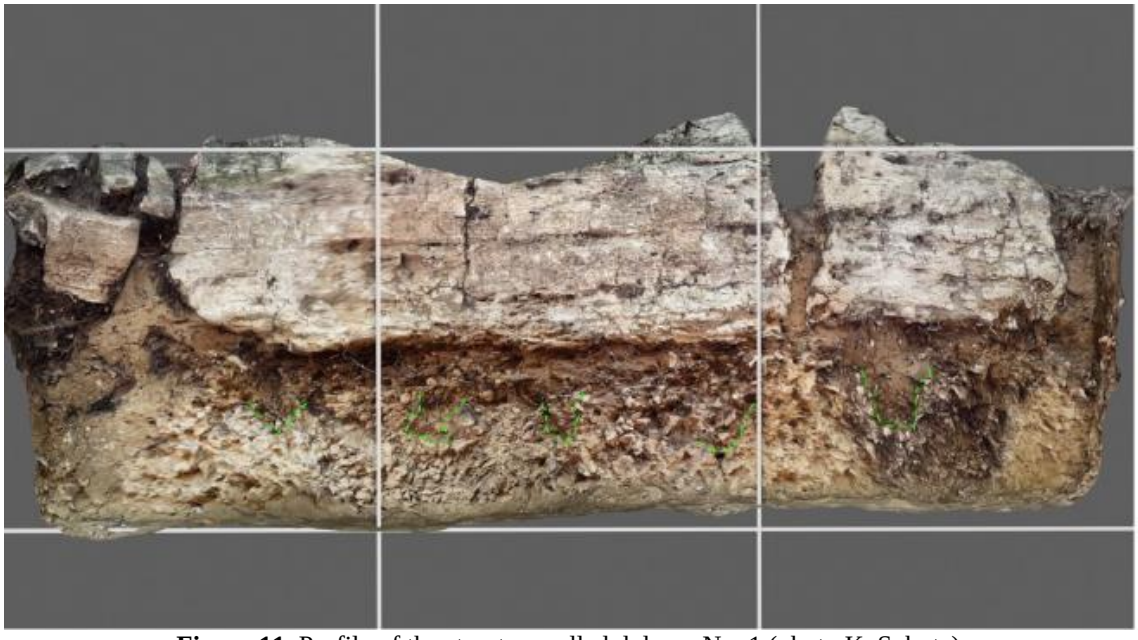


Figure 11. Profile of the structure called dolmen No. 1 (photo K. Sobota).
Visible sandy layer between the boulders and the weathered rocks

At least two features resemble dolmen structures [17]. The survey at dolmen No. 1/2022 revealed multi-stage excavations creating chambers perfectly matched to the stone blocks covering them. The distinct postholes found may be traces of wooden structures (megaxylons) preceding the construction phase associated with laying the stone blocks.

On one of the stones, now lying flat and surrounded by a stone enclosure, regularly arranged, small, circular depressions called cup marks (or cup and ring marks) were found (Fig. 12). These are Prehistoric artistic markings (?) known from megalithic sites in Europe, North America and Australia.



Figure 12. Two lines of small cup marks on the surface of a flat stone with a rock enclosure

Round, worked stones with a diameter of approximately 83 cm were also found at the top of the hill (Fig. 13), which corresponds to a megalithic yard [20]. The rock is not suitable for making millstones.



Figure 13. Round stones with a diameter of approximately 83 cm (megalithic yard)

The results of geophysical research showed at least two large barrow structures with separate chambers, ditches and traces of hearths at the summit [21].

The age of the megalithic structures on the Bukowa Góra elevation is unknown and controversial, both in light of the artifacts found and luminescence dating. The only artifact recovered from the site so far, from the spoil heap next to feature no. 4, is a flint arrowhead, most likely from the Early Bronze Age. During field exploration in arable fields at the foot of the Bokowa Góra within a 4-km radius, flint artifacts associated with various periods of the Stone Age were found [17]. However, these cannot constitute a basis for dating the megaliths.

Luminescence datings show that the blocks rest on Young Pleniglacial weathering cover. This is indicated by the 25.1(18) ka (GdTL-4622) date from the Gliwice Laboratory [22],

[23] and a series of TL datings from the Kielce Laboratory [24]: 23.0±3.4 ka (KIE-988), 21.8±3.3 ka (KIE-986), 18.5±2.8 ka (KIE-987), 17.7±2.6 ka (KIE-984), and 17.0±2.6 ka (KIE-985). Younger luminescence datings were obtained from under the stone blocks of object 4/2022 - 6.52(41) ka (GdTL-4621) and from under block No. 8 (see Fig. 9), which is part of the circle around the summit of Bukowa Góra and supported by a stone wedge - 3.56(26) ka (GdTL-5469).

CONCLUSION

The presented example of stone structures from Bukowa Góra demonstrates the need to intensify interdisciplinary research on Prehistoric megalithic structures in Poland. The term "megalithic" should be used here in a broader sense than that adopted in archaeology.

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TREE UPROOTING IN THE SUCHEDNIÓW AREA (KIELCE UPLAND) AFTER THE SEVERE STORM OF 23 JUNE 2025 – EVENT ANALYSIS

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ABSTRACT

Severe convective storms accompanied by strong wind gusts represent an important natural hazard affecting forested areas in Poland. On 23 June 2025, such an event occurred in the Suchedniów area (Kielce Upland), resulting in extensive tree uprooting. Tree uprooting (uprooting denudation) is a geomorphological process involving the extraction of soil and sediment together with tree root systems, followed by their short-distance transport and redeposition. The aim of this study was to analyze the meteorological and geomorphological conditions associated with the storm, with particular emphasis on tree uprooting. The research was based on field investigations, including measurements of uproot pit dimensions, soil sampling, and photographic documentation of storm-related damage. Radar imagery was used to assess the spatial characteristics of the event, while sediment samples were subjected to granulometric analysis. Field surveys in the Kruk Forest District showed that approximately 51 m³ of material was displaced over an area of about 2 ha, mainly on sandy soils. Some uproots displayed a distinct bipartite structure composed of humus-rich soil and lighter substrate material, separated by a sharp boundary related to the former root system. This structure suggests that similar storm-induced uprooting denudation may have occurred in the past, highlighting the long-term geomorphological significance of severe wind events.

Keywords: windthrow, tree uprooting, severe thunderstorm, strong wind, Kielce Upland

INTRODUCTION

A thunderstorm is a weather phenomenon characterized by the occurrence of atmospheric discharges accompanied by thunder [1]. Although not every convective cell generates hazardous weather phenomena, there are particularly destructive storm forms, including supercell thunderstorms [2]. These are often associated with violent wind gusts, torrential rainfall, and large hail. Strong winds during thunderstorms are most linked to intense downdrafts of cooled air within the storm cloud, referred to as a downburst. Depending on their spatial extent, microbursts and macrobursts are distinguished [3]. Significant wind gusts may also occur along squall lines [4]. Such phenomena can result in serious damage, including impacts on buildings, infrastructure, and forest stands.
In forested areas, the effects of severe winds frequently include windthrow and uproot denudation, involving the uprooting of soil together with the tree root system [5]. Although this phenomenon is most observed in the Sudetes and the Tatra Mountains [6], it also occurs in other regions of Poland, including the Kielce Upland, where it was recorded on 23 June 2025 in the Suchedniów Forest District.

METHODS

The primary objective of this study was to conduct a detailed examination of the meteorological and geomorphological conditions associated with the development and impacts of the investigated storm event, with particular emphasis on the occurrence and characteristics of tree windthrow. All fallen trees within the study area were measured in accordance with the methodology described by Norman et al. [7]. Each windthrow was treated as a rotational ellipsoidal root plate characterized by three unequal axes (Fig. 1). The measurement procedure involved determining the length, width, and depth of the root plate, followed by calculation of its volume using the formula:

$$V = \pi hda/6$$

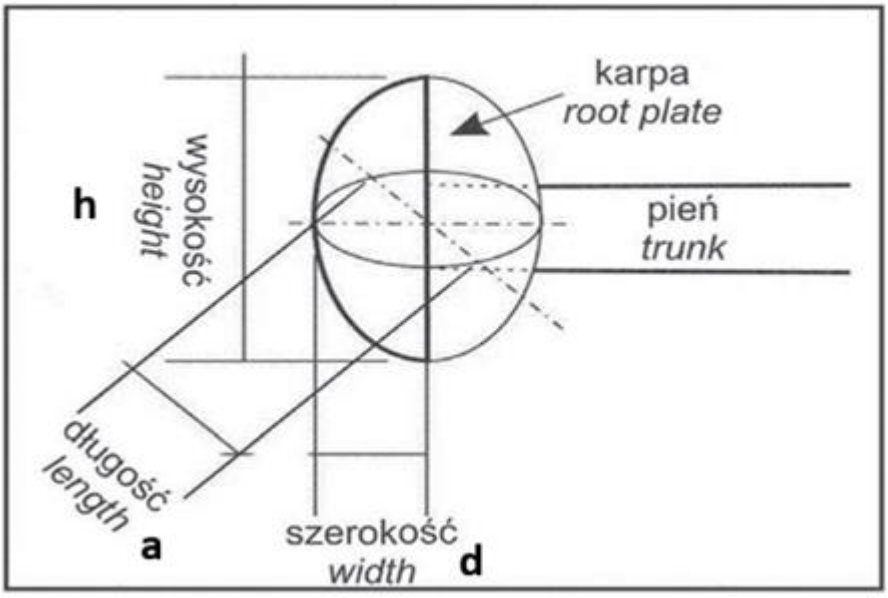


Figure 1. Main parameters of the root plate based on Pawlik 2012 [6] – modified.

In addition, comprehensive photographic documentation of storm-related damage was compiled, while radar data were employed to perform a spatial analysis of the event. Laboratory-based granulometric analyses of sediment samples were also conducted to determine grain-size distribution. The analytical results were graphically presented using the GRANULOM software.

STUDY AREA

The Suchedniów Forest District is an organizational unit of the State Forests under the authority of the Regional Directorate of State Forests in Radom. It is located in the Świętokrzyskie Voivodeship and encompasses areas within the Skarżysko, Kielce, Końskie, and Starachowice counties. The total area of the forest district is approximately 369 km², of which around 185 km² are forests managed by the State Forests [8]. According to the physical-geographical regionalisation of Poland, the Suchedniów Forest District is situated within the Małopolska Upland, part of the Kielce Upland microregion (Fig. 2.). It encompasses several mesoregions, including the Suchedniów Plateau, the Gielniów Hump, and the Świętokrzyskie Mountains [9], [10]. The landscape is

predominantly upland, with elevations exceeding 300 m a.s.l., and is dissected by numerous river valleys, chiefly those of the Kamienna River and its tributaries. Based on the nature-forest regionalization framework, the district's forested area falls within the Małopolska region, corresponding primarily to the Świętokrzyska Forest mesoregion. The area lies within the natural distribution range of the principal tree species commonly occurring in Polish forests [11].

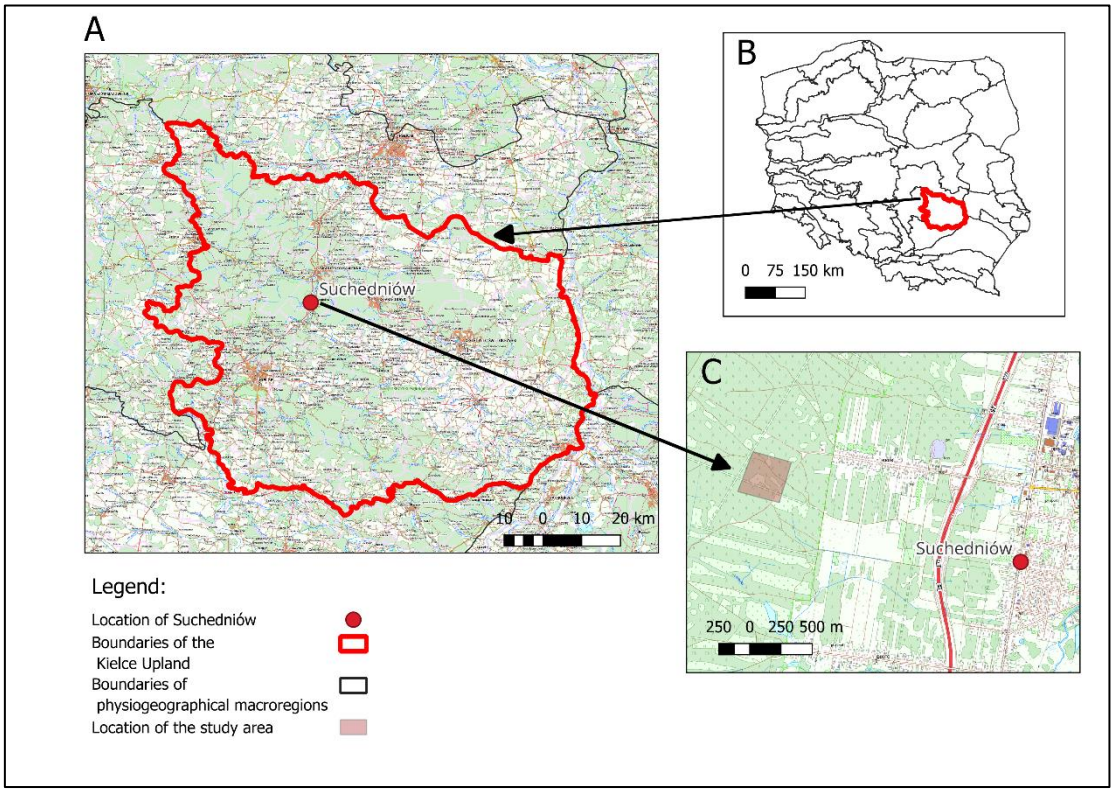


Figure 2. Location of the Kielce Upland within Poland (A), Suchedniów within the Kielce Upland (B), and the study area (C). Own elaboration based on GUGiK data [12].

Meteorological Situation

On 23 June 2025, Poland was under the influence of strongly heated tropical maritime air masses advected from the south (Fig. 3). Both the European Centre for Medium-Range Weather Forecasts (ECMWF) [13] and the Global Forecast System (GFS) [14] indicated that these air masses would exhibit significant instability, with convective available potential energy (CAPE) reaching 1200–1400 J/kg. Such conditions were favourable for the development of severe thunderstorms. Additionally, a cold front was rapidly advancing across the country, enhancing strong vertical wind shear in both the lower and upper troposphere, with wind speeds reaching up to 25 m/s. These atmospheric conditions promoted the formation of an organized linear convective system, characterized by violent wind gusts.

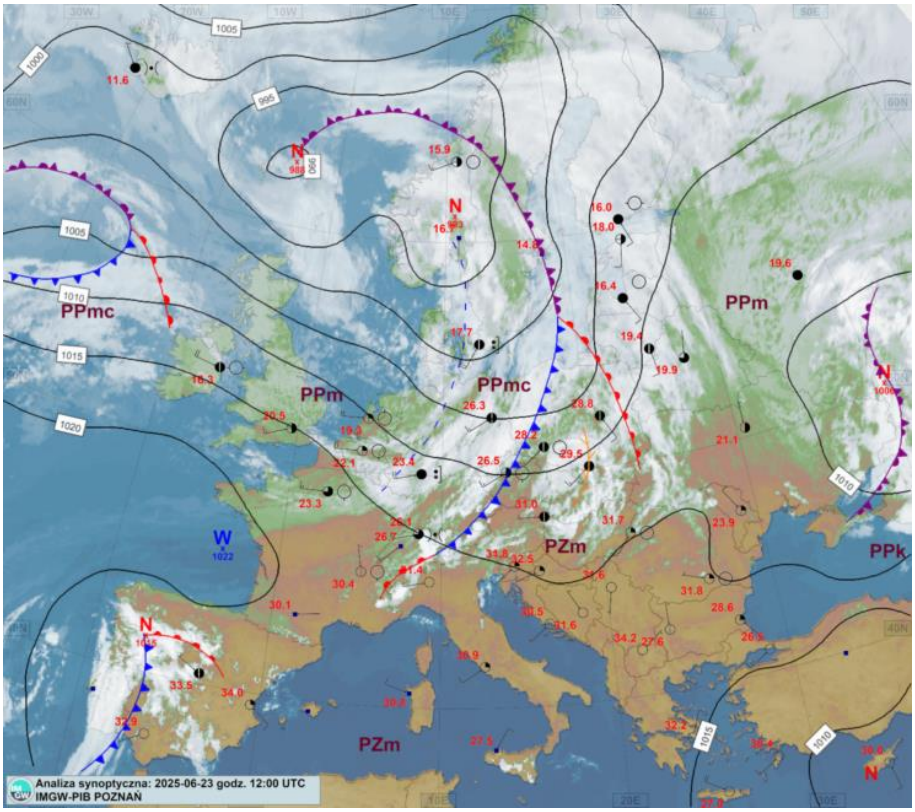


Figure 3. Synoptic map for 23 June 2025, 12:00 UTC, Meteo IMGW [15].

Storm Development

The thunderstorm developed around 17:00 over Lower Silesia. Relatively quickly, a convective system with a linear structure formed. By 18:00, a prominent shelf cloud had developed at its leading edge, the presence of which typically indicates the potential for severe wind gusts. The first wind-related damage was recorded in Silesia, including numerous fallen trees, damaged buildings, and affected power lines. The IMGW (Institute of Meteorology and Water Management) station at Szklarska Poręba registered a wind gust of 101 km/h. Reports from this area are also recorded in the European Severe Weather Database [16], with wind damage rated between 0 and 1.5 on the International Fujita Scale, suggesting probable local gusts of up to 180 km/h.

The convective system continued moving eastward. Its structure gradually disintegrated; however, the storm remained hazardous. Around 20:00, it reached the Kielce Upland. In the Suchedniów area, a bow-shaped segment redeveloped (Fig. 4). Unfortunately, no meteorological stations capable of measuring wind were located along the storm's path. The system caused extensive wind damage in the Suchedniów region, including damaged power lines and torn-off roofs. Numerous windthrows were recorded in the forests of the Suchedniów Forest District, along with the formation of uproots. The storm significantly affected the local dynamics of the forest ecosystem, and these areas were temporarily closed for safety reasons. The most severe forest damage was observed in the Kruk, Osieczno, Jastrzębia, Szałas, and Wilczy Bór forest compartments. Meteorologists from the European Severe Weather Database assessed the forest damage at IF1 on the International Fujita Scale (Fig. 5.). Wind gusts may have reached up to 150 km/h, although this occurred over a very limited area around Suchedniów. Less extensive wind

damage was also reported in other parts of the Kielce Upland, particularly in its southern region.

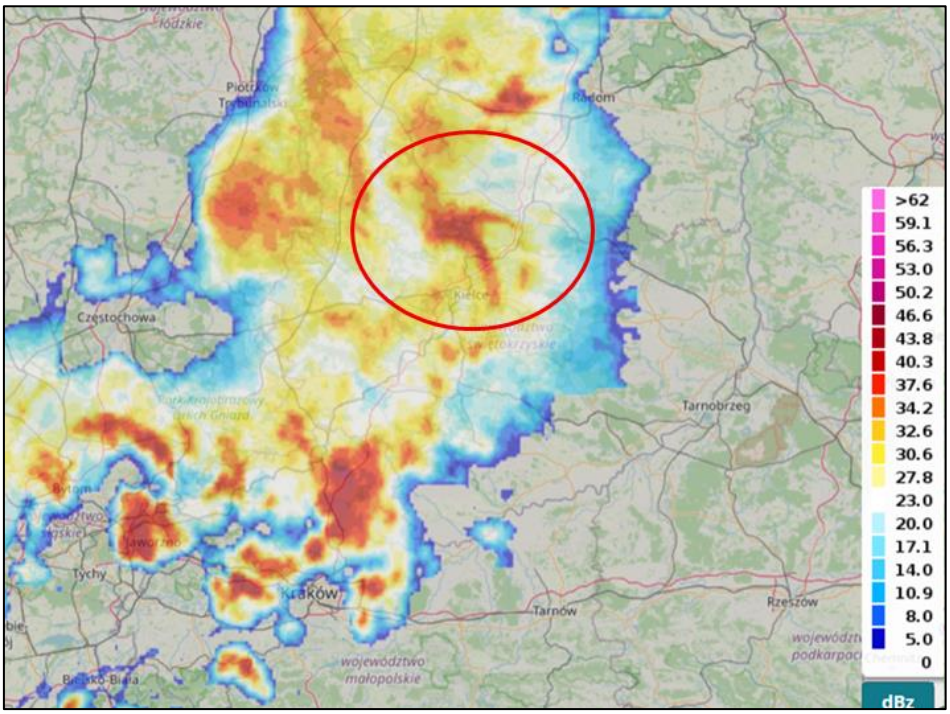


Figure 4. Radar scan from 23 June 2025, 19:20 UTC, Meteo IMGW [15]



Figure 5. Wind damage in the Suchedniów Forest District [17].

Tree uprooting in Kruk Forest Compartment

The study was conducted with the approval of the forest district authorities in the Kruk Forest Compartment, located in the immediate vicinity of Suchedniów. Measurements of root plates indicated that, in the surveyed area (approximately 7 ha), 14 trees had been uprooted, with a total volume of exposed soil amounting to 51 m³ (Table 1), averaging

3.64 m³ per fallen tree. The most frequently uprooted species was European spruce (Picea abies) and Scots pine (Pinus sylvestris). Additionally, fallen specimens of oak (Quercus spp.) and birch (Betula spp.) were also recorded.

Table 1. Dimensions of root plates and the volume of eroded material in the Kruk Forest Compartment

No.	Tree species	Height (m)	Length (m)	Depth (m)	Volume of eroded material (m^3)
1	Pine	5	5,74	0,57	8,56
2	Pine	3,74	3,69	0,35	2,53
3	Spruce	2,57	3,9	0,61	3,20
4	Oak	3,34	4,89	0,62	5,30
5	Birch	2,64	3,62	0,51	2,55
6	Pine	1,62	3,04	0,73	1,88
7	Pine	1,53	1,94	0,77	1,20
8	Spruce	4	5,2	0,6	6,53
9	Spruce	2,2	1,48	0,9	1,53
10	Pine	1,9	2,9	0,35	1,01
11	Pine	1,92	1,72	0,92	1,59
12	Pine	2,89	3,6	0,64	3,48
13	Spruce	2,8	3	0,7	3,08
14	Spruce	4,3	4,9	0,77	8,49

The largest root plate measured 5 m in height, 5.74 m in width, and approximately 0.57 m in depth. Granulometric analyses indicated that root plates primarily occurred on sandy soils dominated by medium- and fine sands or silty sands. In contrast, the largest root plates developed on sands containing coarser materials, including gravel (Fig. 6.).

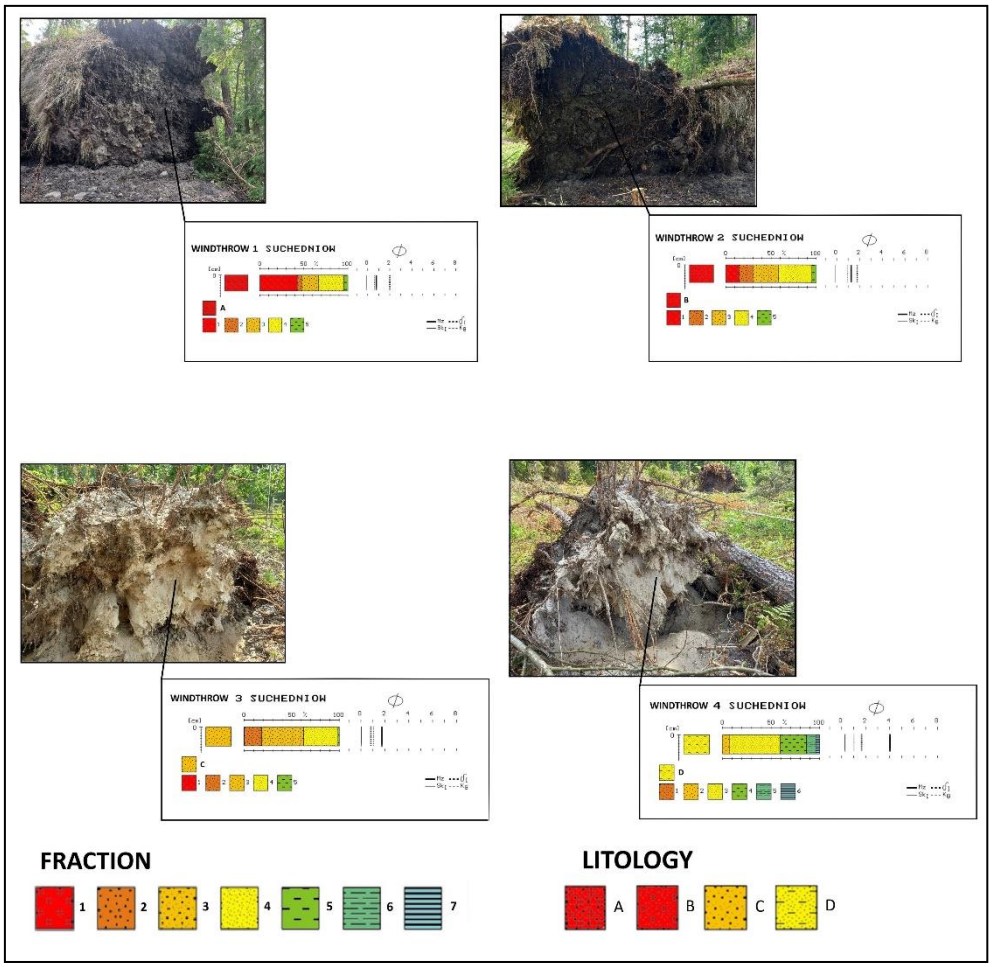


Figure 6. Granulometric composition of the root plates in the Kruk Forest Compartment, own elaboration. Fraction: 1 – gravel, 2 – coarse-grained sands, 3 – medium-grained sands, 4 – fine-grained sands, 5 – coarse-grained silts, 6 - medium- and fine-grained silts, 7 – clays Litology: A – sand with gravel, B - sand with occasional gravel, C - medium sand, D - loamy–silty sand. Folk–Ward parameters: Mz — mean grain size, σ_1 — standard deviation (sorting), SkI — skewness, KG — kurtosis.

An interesting observation was the color difference noted in some root plates (Fig. 7). Root plates typically exhibit a characteristic two-part structure: a dark, humus-rich section composed of the upper soil layers (layer A), and a lighter section consisting of subsoil material lifted by the root system (layer B). During the infilling of the cavity, the humus-rich portion is rapidly deposited, followed by the slow settling of subsoil material as it detaches from the roots [18]. Colour variations in the sediments may indicate that a given root plate formed at the site of a previous tree fall.



Figure 7. Root plate showing visible colour differentiation, photo: Wojciech Nadziałek.

CONCLUSION

The analyzed event constituted an extensive linear convective system that developed along a cold front displacing unstable tropical air mass. During its passage, the storm generated destructive wind gusts associated with downburst phenomena. In the forests surrounding the town of Suchedniów, the storm caused numerous tree falls, leading to the formation of root plates. Field measurements conducted in the Kruk Forest Compartment indicated that approximately 51 m³ of material was displaced from an area of 2 ha. Root plates occurred primarily on sandy soils dominated by medium- and fine-grained sands or clayey-silty sands. The largest root plates developed on sands containing coarser material, including gravel. Two-coloured root plate indicates previous occurrence of uproot denudation in the analyzed area.

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INTEGRATING HYDROMORPHOLOGICAL DATA INTO THE ASSESSMENT OF RIVER ECOSYSTEM SERVICES

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ABSTRACT

EU Member States monitor, in accordance with the Water Framework Directive (WFD, 2000/60/EC), the quality elements of water bodies, which subsequently inform the development of river basin management plans. Building on the EU Biodiversity Strategy 2030, there is growing recognition of how rivers contribute to ecosystem service provision and how management measures may influence these benefits. Given the time and resource demands of collecting environmental data, it is increasingly important to explore whether existing monitoring data can support estimates of ecosystem service provision and, at the same time, enable the identification of ecologically valuable and degraded river reaches. This study examines the potential of hydromorphological monitoring data collected under the Czech HYMOS methodology (developed in accordance with EN 14614:2020), using a single water body of the Olše River in northeastern Czechia. Five river reaches were assessed, revealing marked spatial differences in hydromorphological conditions, ranging from good to poor status. These contrasts highlight the ability of hydromorphological monitoring data to distinguish between river sections with differing ecological quality and management relevance, thereby supporting their use in identifying reaches with higher conservation value or greater restoration needs. Furthermore, many hydromorphological indicators can act as proxies for the capacity of river ecosystems to provide ecosystem services, including erosion control, sediment retention, habitat provision, thermal regulation, water availability, flood attenuation, and cultural benefits. At the same time, the study highlights

limitations of reach-based indicators that record only the proportion of anthropogenic pressures without their precise spatial localization. A more spatially explicit representation of pressures would improve the assessment of ecosystem service capacity and enable more robust evaluation of changes following restoration measures. Overall, the findings underline the value of hydromorphological monitoring as a key input for ecosystem-based river management and conservation planning.

Keywords: Hydromorphology, Ecosystem Services, River Basin Management Plans

INTRODUCTION

According to the Water Framework Directive (WFD, Directive 2000/60/EC) [1], it is the responsibility of Member States to assess the hydromorphological condition of watercourses as part of their ecological status assessment. However, the role of hydromorphology in ecological status assessments currently remains somewhat marginal, as it is primarily used to confirm a "high" status determined based on biological and physico-chemical elements [2], [3]. A comprehensive assessment of hydromorphology, including the evaluation of hydrological regime, river continuity, and morphological conditions, provides significantly broader potential for application. It provides key information for (i) delineating individual water bodies and identifying heavily modified reaches [4], (ii) designing the optimal placement of monitoring sites [5], [6], and (iii) identifying anthropogenic pressures and improving the understanding of pressure–response (cause–effect) relationships [7]. Such information is valuable for water managers in planning restoration measures, designing interventions to improve ecological status, and overall river management [8], [9]. Enhanced understanding of cause–effect relationships is particularly achievable through the application of modern hydromorphological assessment methodologies based on the updated standard EN 14614:2020 [10], which place greater emphasis on process-based aspects of river systems than previous habitat-oriented methods.

At the same time, the question arises as to what further potential exists for the use of data derived from hydromorphological assessments of water bodies. Over the past decade, increasing efforts have been made to systematically integrate ecosystem services assessments into river basin management plans [11], [12], [13]. Such an approach enables a stronger linkage between the assessment of ecological status, benefits for human well-being, and decision-making processes within river basin planning and management [14]. Ecosystem services assessments help to clarify the benefits provided by river ecosystems and to evaluate how proposed management measures may influence the delivery of these services. Improvement of the ecological status of water bodies should therefore not be understood solely as an environmental objective, but also as a means of enhancing the capacity of aquatic ecosystems to provide services from which society benefits [15]. This perspective may contribute to greater societal acceptance of management measures and to a more effective targeting of proposed interventions.

Although references to ecosystem services increasingly appear in river basin management plans across European Union Member States, their application remains largely fragmented and insufficiently integrated, limiting their practical translation into water management strategies. This may explain why the ecosystem services concept is only marginally addressed in the most recent third River Basin Management Plans. The main

barriers to its wider application include methodological inconsistencies, data constraints, and limited administrative capacity [16].
From this perspective, it is therefore appropriate to consider how data that are already routinely collected as part of regular water body monitoring can be more effectively utilised, and how such data can be systematically translated into ecosystem services assessments.
The aim of this article is to use the Olše River in the north-eastern Czech Republic as a case study (i) to assess the applicability of hydromorphological assessment data for identifying river reaches of high ecological relevance, including those potentially warranting legislative protection, and (ii) to propose a conceptual framework for using hydromorphological assessment data in ecosystem services assessments within the context of river basin management planning.

STUDY AREA

The Olše River originates in the Silesian Beskids in Poland and flows for approximately 16 km before crossing into the Czech Republic. The total length of the river from its source to the confluence with the Odra River is 89 km, and its catchment area covers 1,120 km². The geology of the catchment is dominated by easily erodible flysch, consisting of alternating layers of sandstones and clays, often calcareous in composition. The valley floor is composed of Quaternary gravels and sands, which, under natural or near-natural conditions, are reworked by the river to form extensive gravel bars along the channel. Tributaries of the Olše are mostly short, steep streams with high longitudinal gradients, contributing additional sediment to the main channel.
The hydrology of the Olše River is characterized by a pluvio-nival regime, with peak flood occurrences in spring due to snowmelt and in summer to early autumn as a result of intense precipitation events. The river supports characteristic vegetation of gravel banks and floodplains, including the association *Tussilagini farfarae-Calamagrostietum pseudophragmitae* Pawłowski & Walas 1949, with the endangered grass *Calamagrostis pseudophragmites* [17] as well as *Phalaris arundinacea*, *Petasites kablikianus*, *P. hybridus* and *Salix purpurea* [18].
Since the late 19th century, the Olše River has experienced extensive anthropogenic modifications, including channelization, embankments, weirs, ramps, and bed sills. Both these structural interventions and the concurrent reforestation of the catchment, which diminished sediment input, have promoted channel incision [19] and significantly disrupted the river's longitudinal and lateral continuity. In several reaches, the channel is incised down to the flysch bedrock.
Despite past channel modifications, repeated flood events, most recently the >100-year flood in 2024, have partially damaged riverbank structures and facilitated natural recovery of the channel. This has resulted in the formation of near-natural river reaches alongside regulated sections within the studied water body, corresponding to Olše from the confluence with the Lomná River to the confluence with the Ropičanka River (water body code HOD 0770; Figure 1). The catchment area upstream of the studied water body is 164 km², while the total catchment area of the monitored water body section is 221 km². The water body is 26 km long and passes through the towns of Jablunkov and Třinec. The average annual discharge at the Český Těšín gauging station, located in the lower part of the water body, is 7.43 m³/s. The average channel gradient is 0.4 %, ranging from 0.6 % in the upper reaches to 0.3 % in the lower reaches.

Morphologically, the near-natural reaches of the river exhibit sinuous planform with lateral gravel bars and, in some areas, multiple threads forming wandering channels. In contrast, the regulated reaches maintain a sinuous channel pattern, but gravel bars are generally absent or poorly developed. A large part of the water body is located within a Special Area of Conservation (SAC) under the EU Habitats Directive (92/43/EEC), which aims to maintain or restore natural habitat types and species of European interest; however, the current protection regime does not fully address hydromorphological conditions.

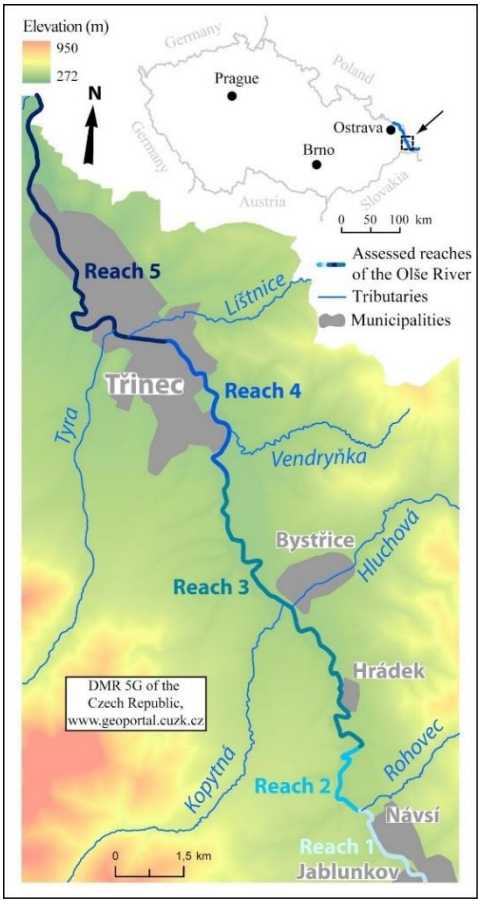


Figure 1. Overview map showing the location of the assessed reaches of the Olše River water body HOD 0770.

DATA AND METHODS

To assess the hydromorphological status and its elements – hydrological regime, continuity, and morphological conditions – we applied the HYMOS methodology [20], which has been officially approved by the Czech Ministry of the Environment for evaluating the hydromorphological condition of watercourses in the Czech Republic. The methodology was developed based on the requirements of EN 14614:2020 [10].

Since designated water bodies in European countries, including the Czech Republic, are often highly heterogeneous in terms of river types and the influence of anthropogenic pressures [21], it was necessary to divide the studied water body of Olše River into homogeneous reaches prior to the assessment. As the water body under study does not exhibit significant changes in valley slope, channel confinement, or stream size along its

length, the segmentation was based on the occurrence of notable changes in channel morphology, particularly in planform and cross-sectional modification, as well as on the presence of obstacles in the riverbed. Based on these criteria, the water body was divided into five reaches (Figure 1).

Field surveys were conducted during low flow conditions (1.3 m³/s at the Český Těšín gauging station). A 2 km-long part of the fifth segment downstream of the town of Třinec could not be assessed in the field because it is located on private property and was therefore evaluated using remote sensing data only.

During the surveys, in addition to recording the indicators used for scoring hydromorphological condition, precise locations of bank and bed stabilizations, channel modifications (cross-section and bed features), substrate alterations and other relevant features were documented. These data were subsequently used to create vector layers in GIS representing anthropogenic pressures and channel modifications. Based on this information, the indicators of the river channel most contributing to a deterioration of the hydromorphological condition, reflecting the influence of human modifications, were identified.

When analysing the potential use of hydromorphological assessment data for ecosystem services evaluation, we followed the list of ecosystem services defined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [22]. Based on an extensive literature review, indicators were selected and developed for eight ecosystem services, enabling the assessment of the level of provision of selected ecosystem services using data derived from the hydromorphological assessment.

RESULTS

Two of the five assessed reaches (2 and 3) achieved good hydromorphological status, representing the most valuable sections of the studied river (Table 1). Both reaches are characterized by a sinuous channel with alternate bars, locally transitioning towards a wandering pattern, which corresponds to the defined reference near-natural channel type (sinuous with alternate bars to wandering). In contrast, reaches 1, 4 and 5 exhibit a sinuous planform with a low representation of gravel bars.

Reaches 2 and 3 are characterized by a predominantly near-natural channel morphology, a relatively high diversity and frequency of geomorphic units typical for a gravel-bed river, and limited bank stabilization (Figure 2). Where present, bank modifications are mainly associated with bridges and transport infrastructure crossings. Slightly lower scores within this group were recorded for reach 2, where remnants of historical cross-sectional modifications and a somewhat higher proportion of stabilized banks persist. These alterations are reflected in a reduced frequency of occurrence of geomorphic units typical for the given river type, compared to reach 3.



Figure 2. a) restored river reach with extensive gravel bars, b) exposed bedrock resulting from channel incision, c) regulated river channel of the Olše in the town of Třinec.

Table 1. Basic characteristics of the assessed segments of the Olše River water body HOD 0770, including channel length and slope, and the results of the hydromorphological condition assessment and its elements (calculated scores and classification status).

Reach no.	Length (m)	Channel slope (%)	Hydro-morphological conditions		Hydrological regime		Continuity conditions		Morphological conditions	
			Score	Status	Score	Status	Score	Status	Score	Status
1	2505	0,6	0,41	3	0,68	3	0,33	4	0,33	4
2	2176	0,5	0,70	2	0,82	2	0,56	3	0,74	2
3	8616	0,5	0,73	2	0,82	2	0,60	3	0,82	2
4	4165	0,3	0,48	3	0,77	2	0,32	4	0,49	3
5	8430	0,4	0,36	4	0,59	3	0,21	4	0,29	4

High status (1): 0,85 ≤ Score ≤ 1,00; Good status (2): 0,70 ≤ Score < 0,85; Moderate status (3): 0,40 ≤ Score < 0,70; Poor status (4): 0,20 ≤ Score < 0,40; Bad status (5): 0,00 ≤ Score < 0,20 (Threshold values according to HYMOS methodology [])

Poor hydromorphological status was recorded in reach 5, which flows through the urban area of the town of Třinec and the industrial complex of the Třinec ironworks (Figure 2). Reach 1, located within the built-up areas of Jablunkov and Návsí, was classified at the lower threshold of moderate status, whereas reach 4, flowing through the suburban zone of Třinec, achieved a slightly higher score. This was primarily related to a lower extent of bank stabilization and the local presence of near-natural channel sections.

The dominant anthropogenic pressure negatively affecting the hydromorphological condition of the assessed reaches is the high density of stabilization structures and weirs located upstream of the study reaches. These structures significantly disrupt longitudinal continuity and natural sediment transport from the source areas of the catchment. In combination with historical channel modifications – particularly channel enlargement and alterations of both cross-sectional and longitudinal profiles – these pressures have led to progressive channel incision and a substantial reduction in regularly inundated floodplain areas. At several locations, the channel has incised down to the bedrock (Figure 2). As a result of these combined pressures, continuity conditions achieved only moderate status in reaches 2 and 3 and poor status in reaches 1, 4 and 5

Alterations of the channel planform affected approximately 58% of reach 1, 42% of reach 4 and 75% of reach 5, while modifications of the cross-sectional profile were recorded along 57%, 35% and 67% of the respective reach lengths. A reduced occurrence of geomorphic units was observed along 73% of reach 1, 39% of reach 4 and 67% of reach 5, and bank stabilization affected 57%, 23% and 69% of these reaches, respectively. Additional anthropogenic pressures contributing to the failure to achieve at least good status in reaches 1, 4 and 5 include intensive maintenance of riparian vegetation (tree

removal and mowing), the presence of transverse barriers within the channel (weirs and ramps), and extensive bank stabilization, which together limit bank erosion processes and disrupt lateral continuity. In reach 5, up to 24% of the reach length was affected by impounded conditions caused predominantly by abstraction weirs.

Table 2 summarizes the proposed conceptual framework linking hydromorphological assessment outputs with ecosystem services through key ecological processes and assessment indicators applicable in river basin management planning. Based on an extensive literature review, eight ecosystem services were identified that can be assessed using data applied in hydromorphological evaluations. These include data collected during field surveys, remote sensing data, hydrological data derived from gauging stations, flood inundation modelling and databases of water abstractions.

Five of the eight ecosystem services listed in Table 2 represent regulating services (habitat provision, thermal regulation, water dilution capacity, flood flow attenuation and erosion control), as they are underpinned by natural ecosystem processes and contribute to environmental regulation and stability. The proposed assessment indicators allow for the evaluation of the capacity of ecosystems to provide these services, reflecting their structural characteristics, natural conditions and current land-use patterns.

Two ecosystem services represent cultural services. Educational and scientific value was assessed based on the density of educational trails within the floodplain, while aesthetic service was assessed based on the occurrence of natural planform patterns. In both cases, the indicators represent the capacity for service provision, i.e. the potential attractiveness of the area under current land-use conditions rather than the actual level of service use.

The remaining ecosystem service addresses water supply, including abstractions for drinking water, agriculture and industry. In contrast to the other services, this indicator reflects the actual level of ecosystem service use rather than its potential capacity.

Table 2. List of ecosystem services together with the ecological processes and/or components providing the service and the indicators used for their assessment based on hydromorphological data. Provisioning ecosystem services are indicated in orange, regulating services in green, and cultural services in blue.

Ecosystem service	Ecological process and/or component providing the service	Indicator used for assessment
Water provisioning	Hydrological potential for surface water availability for drinking water supply, agriculture and industry	Water abstractions (m^3/year) [23], [24] Maes
Habitat provision	Maintenance of longitudinal continuity of the river	Anthropogenic fragmentation index
	Physical habitat conditions within the river channel	Assessment of morphological conditions [23] Maes
Thermal regulation	Shading and cooling of water by riparian vegetation	Linear extent of woody riparian vegetation along the river (%) [24]
Water dilution capacity	Dilution and downstream transport of pollutants by flowing water	Flow reduction due to water abstraction (%/year)
Flood flow attenuation	Transformation of flood flows	Extent of floodplain inundation (m^2 of flooded area / m^2 of floodplain), [23]
Erosion control and sediment retention	Floodplain capacity to reduce water erosion	Proportion of erosion-control effective surfaces within the floodplain (%) [24], [25]
Educational and scientific value	Landscape features enabling educational activities	Density of educational trails within the floodplain (km/km^2)
Aesthetic service	Landscape features enabling aesthetic appreciation	Occurrence of meandering sections and gravel-bed reaches with extensive bars and islands in high-gradient valleys (%)

DISCUSSION

Our assessment demonstrates that hydromorphological evaluation can effectively identify river reaches of high ecological value and provide a robust basis for assessing ecosystem services. Traditionally, hydromorphological data have been used primarily to support the identification of high ecological status under the WFD. As a result, hydromorphological assessments have so far not been systematically applied to a large proportion of water bodies across EU Member States, including within the third river basin management plans [26]. Our results show that hydromorphological data have broader applicability in river management and conservation planning. This is particularly relevant in the context of ongoing efforts to reverse biodiversity loss, as highlighted in the EU Biodiversity Strategy 2030, and in the proposed Nature Restoration Law, where hydromorphological information can inform restoration of terrestrial, coastal, and freshwater ecosystems (Article 4) and contribute to the re-establishment of natural river continuity and floodplain functions (Article 9).

Hydromorphological assessment based on process-oriented approaches provides a perspective on river systems that captures the cumulative imprint of past and ongoing anthropogenic pressures [27], [28]. In the Olše water body, this approach is illustrated through the assessment of five reaches. Reaches 2 and 3, which scored ‘good’ in the hydromorphological assessment, demonstrate how natural river processes can persist

despite historical interventions. In contrast, the more modified sections, particularly reaches 1, 4, and 5, reveal the long-term consequences of channel engineering, bank stabilization, and sediment disruption, consistent with patterns reported in European and global rivers [29], [30], [31].

These findings reinforce the value of hydromorphological indicators as tools for screening and prioritizing river sections for conservation or targeted restoration, rather than solely evaluating compliance with ecological status thresholds. By integrating structural and functional data, this approach provides context on the degree of modification across the river network, helping to interpret historical pressures and identify areas that retain key natural features. Protecting these relatively intact reaches is essential to prevent further degradation from interventions such as post-flood bank reinforcement, sediment extraction, or the construction of abstraction weirs, which could compromise the hydromorphological condition. The HYMOS methodology, standardized under EN 14614:2020 [10] and compatible with the Morphological Quality Index [32], ensures that such assessments are transferable across Europe, supporting evidence-based river basin management and restoration planning.

Hydromorphological monitoring data also provide a valuable foundation for ecosystem service (ES) assessments. While hydromorphological indicators themselves are not ecosystem services, they represent key parameters describing ecosystem state [33], [34]. Although these indicators primarily reflect the current ecosystem state, they can serve as effective proxies for evaluating the capacity to deliver certain services. For example, assessments of morphological conditions inform the potential for habitat provision, lateral continuity supports evaluation of flood flow attenuation, and hydrological regime alterations provide insight into water dilution capacity. In practice, this demonstrates that the distinction between state indicators and capacity proxies is manageable, and much of the data required to evaluate service provision capacity can be derived from existing hydromorphological monitoring.

Despite this potential, there are important limitations. These assessments are complex and require specialized expertise, with reliable data collection and interpretation dependent on appropriate sampling design, staff training, and quality control protocols [35]. Data coverage is often spatially uneven, which limits consistent applicability across all river sections. For example, in the Czech Republic, hydromorphology in third river basin management plans was assessed solely from remotely acquired data, excluding some relevant anthropogenic pressures [36]. Additionally, when data are collected for predefined sections, only the percentage occurrence of anthropogenic pressures is recorded, without precise spatial localization. This limitation may complicate future re-evaluation or the assessment of changes in capacity following restoration measures.

It is also important to note that hydromorphological data do not directly measure functional outputs of ecosystem services. Full integration of ES assessments into planning requires moving from quantifying service provision capacity to evaluating actual service flows and quantifying associated social benefits, which entails combining hydromorphological data with other relevant information [23], [37]. Nevertheless, hydromorphological information can support implementation of the EU Biodiversity Strategy 2030 by enabling targeted river protection, identifying free-flowing reaches, modelling the effects of restoration measures on free-flowing river functions, and guiding the efficient allocation of limited restoration resources [38].

CONCLUSION

This study highlights the critical role of hydromorphological assessments in understanding and managing water bodies. Hydromorphology provides an integrative perspective, capturing the long-term imprint of anthropogenic pressures on channel structure, continuity, and hydrological processes. Our findings demonstrate that hydromorphological evaluations can effectively identify river reaches of high ecological value and serve as a robust tool for prioritizing areas for conservation or restoration.
Beyond supporting ecological status assessments under the WFD, hydromorphological data offer a unique opportunity to assess the capacity of ecosystems to provide services, including habitat provision, flood regulation, and water quality maintenance. However, to fully harness this potential in river basin management, assessments must move beyond capacity indicators toward evaluating service flows and quantifying social benefits, integrating hydromorphological data with socio-economic and hydrological information. Given their relevance for both ecological assessment and ecosystem service evaluation, hydromorphological methods deserve greater emphasis in monitoring programs and policy frameworks. Strengthening their role will not only improve understanding of river functioning and long-term degradation trends but also enable evidence-based prioritization and planning of restoration measures. Ultimately, integrating hydromorphology more systematically into river management can support the sustainable conservation of river ecosystems while aligning with broader biodiversity and ecosystem service objectives.

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INTERACTION MAN-ENVIRONMENT CHANGES TRIGGERED BY CLIMATE FLUCTUATION IN THE ROMAN PERIOD: CASE STUDY FROM SOUTHERN POLAND

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UDC: [551.583:39]:94(438)"652"

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ABSTRACT

This article, using selected examples from various regions of southern Poland, including the Kraków region and the Nida Valley in Lesser Poland, attempts to determine the impact and nature of climate change and the accompanying events between the 3rd century BC and the 5th century AD on human life. Climatic fluctuations in Europe and local conditions played an important role in the settlement processes and the activities of the Przeworsk culture (PC) community. Very clear, multidirectional impact of climatic changes is documented by examples of detailed studies. The PC ecumene was not uniform, which caused regional differentiation of human impact, recorded in settlement forms and sediments. It consisted of "centres" of non-agricultural production, i.e. metallurgical in the Świętokrzyskie region and pottery centres in the Vistula valley, east of Kraków, relatively densely populated and significantly affecting the natural environment. Between these centres, occupying a relatively small area, there were regions used for agriculture, constituting a mosaic of arable land, pastures and forest areas, which resulted in low intensity of erosion-accumulation processes. Regardless of the large migration movements of the PC population to the south, the heterogeneity of the ecumene could also have caused local relocations to both production centres (equivalent to contemporary "village→city" migrations). This may be illustrated by the decrease in the population density of some agricultural areas after the Roman Warm Period (after 150 AD), for example, in the Nida valley and its left-bank, karst part of the catchment.

Keywords: geoarchaeology, Roman period, southern Poland, climate-man interaction

INTRODUCTION

The natural environment consists of seven components, divided into main and dependent. One of the main environmental elements, alongside geological structure and relief, is climate [1]. In the Holocene, long-term climate change trends were overlaid by shorter fluctuations (lasting from several decades to a hundred years), caused by various phenomena: feedback loops and exceeding threshold values of the Earth's geosystems, volcanism, and variable solar activity.
Climate change has always been an exogenous factor, but it also conditioned the demographic transformations and agrarian foundations of human life in the pre-industrial era. Not only more complex, but also simpler social and state structures depended on

them. Awareness of these interconnectedness and closer cooperation between archaeologists, historians, and natural scientists, as well as consilience, i.e., the integration of knowledge from such diverse fields, can be of enormous importance in the study of past environmental and cultural changes in various regions [2, there is literature]. The relationships between the environment and human activity have never been orderly or linear, and the influence of natural factors cannot be perceived as deterministic or reductionist, as prehistoric societies possessed a certain resilience to environmental stress. However, once a threshold was exceeded, a cascade of changes and a reorganization of the human-environment system occurred. This was not caused by a single catastrophic event (e.g., a flood or earthquake), but by long-term, significant environmental changes (e.g., climate fluctuations) across large areas. This led to a deterioration in living conditions and forced "adaptive behaviors in people faced with a direct existential threat" [3].

AIM AND METHODS OF THE STUDY

The importance of changes in the natural environment and their impact on human life and human choices, such as settlement and construction in the pre-Roman and Roman periods, are underestimated in Polish archaeology. This article, using selected examples from various regions of Poland, including the Kraków region and the Nida Valley in Lesser Poland, attempts to determine the impact and nature of climate change and the accompanying events between the 3rd century BC and the 5th century AD on human life. The analysis draws on numerous detailed studies, both published and unpublished, for each area. These studies utilized a variety of interdisciplinary methods used in paleogeographic and archaeological research (e.g., geological and geomorphological mapping, sedimentological analyses, radiocarbon and dendrochronological dating), which are discussed in detail in these studies.

CLIMATE FLUCTUATIONS

Three climatic subperiods are distinguished in the period under analysis [4], [2, see literature there](Fig. 1):
1) The Roman Warm Period (RWP): climatic optimum circa 200 BC–150 AD. This is a period of warm, humid, and stable climate, when solar irradiance was high and volcanic activity was low. The highest temperatures, higher than those of today, occurred in the mid-1st century AD, and then began to decline very slowly and unevenly.
2) The Roman Transitional Period (RTP): circa 150–450 AD. This is a period of climatic deregulation and global cooling, which followed the gradual and distributed decline of the thermal RWP. This was associated with a decline in solar activity, particularly in the 240s, although it was quite high (maximum around 300 AD) and stable in the 4th and 5th centuries. This effect may have been exacerbated by volcanic activity, such as the volcanic eruption in 169 AD and an even larger eruption in 266 AD. The RTP is divided into an early period (150–300 AD) and a later period (300–450 AD), which was warmer and dominated by the positive phase of the North Atlantic Oscillation (NAO).
3) The Late Antique Little Ice Age (LALIA): circa 450–700 AD. It began in the late 5th century, when many climate-forming factors overlapped with a general, astronomical cooling trend, with its coldest phase occurring around 530–680 AD.

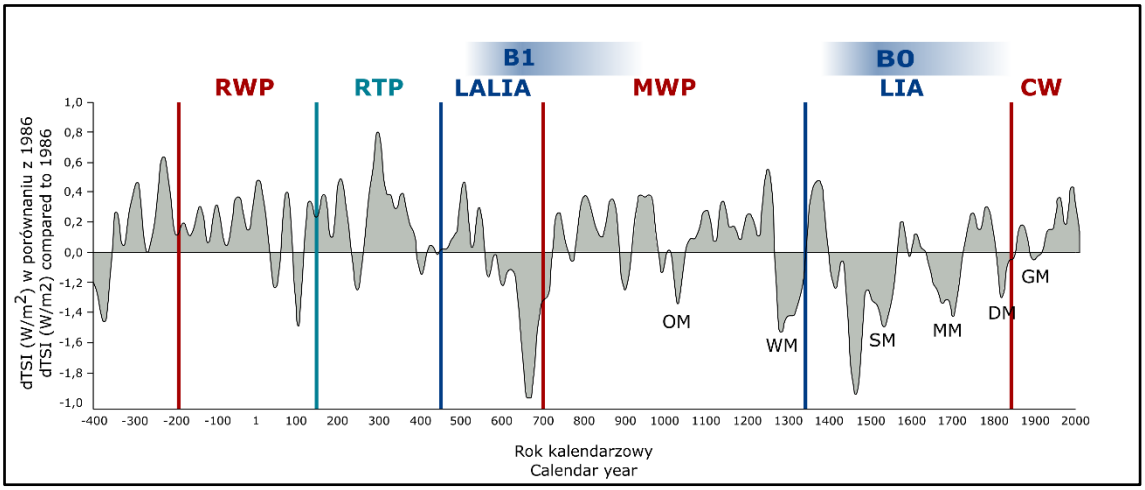


Figure 1. Total solar irradiance (TSI) based on ^{10}Be content [4, supplemented] based on data from [5] (draw by K. Żurek) Climatic periods: RWP - Roman Warm Period (ca. 200 BC-150 AD), RTP - Roman Transitional Period (ca. 150-450 AD), LLAIA - Late Antique Little Ice Age (ca. 450-700 AD), MWP - Medieval Warm Period, LIA - Little Ice Age, CW - Contemporary Warming; Bond Cold Events: B1 (530-900 AD) and B0 (1400-1850 AD); Sunspot minima: OM - Oort (1040-1080 AD), WM - Wolf (1280-1345 AD), Spörer (1420-1540 AD), Maunder (1645-1717 AD), Dalton (1790-1820 AD) and Gleissberg (1890-1910 AD)

RESULTS

Modlniczka site 2 near Krakow (Fig. 2) can be considered a key study on the spatial organization, function, and natural conditions of the development of Przeworsk culture (PC) settlements [2]. The origins of this settlement date back to the RWP, but its heyday occurred during the Younger and Late Roman Period (from the second half of the 2nd century to the first decades of the 4th century) or slightly later, i.e., in the upper Vistula River basin, during the humid, cooling phase of the RTP. It is very likely that – as was the case in the uplands of western Lesser Poland – such a climate favourably influenced agriculture and settlement conditions [6], [7]. The water supply for the settlement's inhabitants was provided by a local stream, and there was no need to build new wells, and the cold weather was not severe enough to require heating the interiors of the houses. All the work that required the use of fire, and was performed in furnaces and hearths outside houses and in clusters of hearths located away from residential buildings.

A change in the NAO phase around the mid-4th century caused a rather abrupt and distinct end to the humid phase. From around the mid-4th century to the mid-5th century, a warm and dry climate prevailed, which changed the natural conditions in the uplands and had dangerous consequences for agriculture and livestock farming, and ultimately seriously undermined food security for humans and animals. Due to a decrease in flow, the local stream no longer met water needs. All these changes caused the population to abandon this settlement around the mid-4th century. The fact that this was a well-planned action is evidenced by the burial of the remains in one place before the migration [2, see literature there]. This interpretation is supported by examples from climate history and contemporary observations, which point to drought as the main reason for the migration [8].

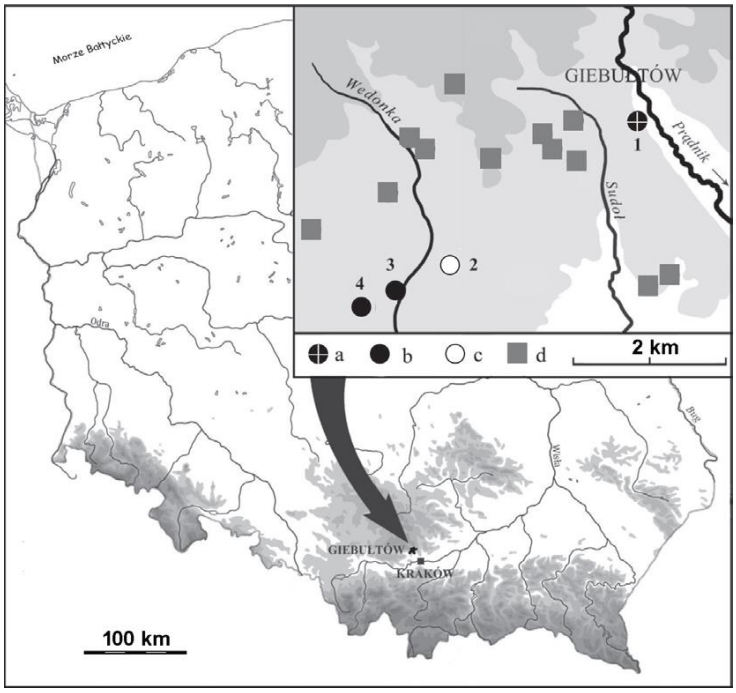


Figure 2. PC in the Giebułtów area, Kraków district, in the pre-Roman and early Roman periods, from the 2nd century BC to about the middle of the 2nd century AD [2] a – Early Roman period cemetery, b – Early-Late Roman period settlement; c – Early Roman period settlement. d – PC surface materials; Sites excavated: 1 – Giebułtów Site 1, Wielka Wieś commune; 2 – Modlnica Site 5, Wielka Wieś commune; 3 – Modlniczka Site 2, Wielka Wieś commune; 4 – Modlniczka Site 9, Wielka Wieś commune.

These general climatic trends, however, did not have a significant impact on the transformation of the settlement microregion in the Vistula Valley and the Raba River alluvial fan, which developed most intensively from the second half of the 2nd century AD to around the third quarter of the 4th century AD, i.e., during the RTP [9], [10] (Fig. 3). The collapse of settlement and the decline of highly developed non-agricultural production (pottery, bronze-making, jewellery) may have been related to the arrival of the Huns and, consequently, the weakening or even disappearance of trade [2], [11].

Local conditions [12], only partially shaped by climate, played a significant role in the development and activity of communities in these areas. Settlements, consisting of separate residential and industrial areas, were located primarily near the edge of the loess terrace, i.e., in the ecotone with the greatest biogeodiversity. This allowed for the agricultural use of fertile luvisols on the terrace, the coluvia at the foot of its edge for garden cultivation, and the exploitation of fodder and raw material resources from the floodplain. The incision of the Vistula riverbed and the narrowing of the active fluvial zone to the lower step of the floodplain enabled various forms of human activity in the valley floor. This facilitated access to raw materials, such as those for the production of vessels (overbank deposits, Miocene clays), and wood (oak) as fuel for workshops, as well as for construction purposes. On the Raba River alluvial fan (Fig. 4), in the absence of incision and fluvial activity, only the old (Eo- and Mesoholocene) meander belt of the river was suitable for settlement, elevated only about 1 m above the surrounding backswamps. Local conditions caused differences in the functioning of the two subregions [12], [9], [10], [2, see literature there].

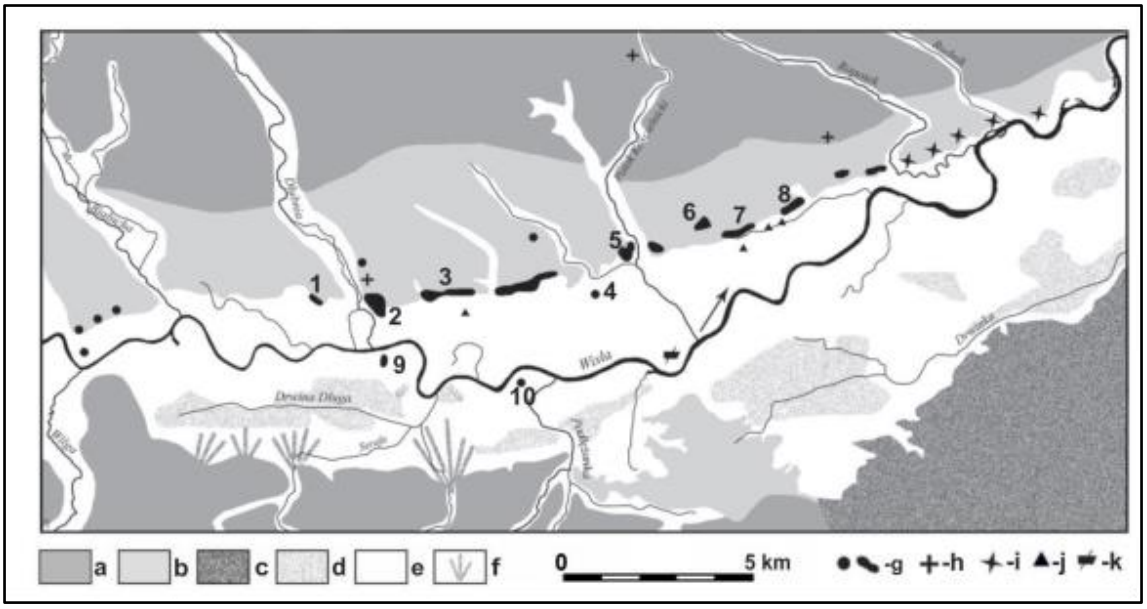


Figure 3. Settlement in the Roman period in the Vistula river valley, eastward of Kraków [2]
a – Proszowice Plateau, Gdów Upland; b – Pleistocene terraces covered with loess; c – Raba alluvial fan; d – alluvial plains functioning as flood basins in the Holocene (wide depressions within the floodplain); e – late glacial and Holocene floodplain; f – Holocene alluvial fans; g – deposits excavated; h – sites not excavated; i – graves; j – loose finds on the floodplain; k – dugout canoe; Selected sites dated from the 1st to the 4th c. AD: 1 – Kraków Mogiła, Site 1; 2 – Kraków Mogiła, Site 59; 3 – Kraków Pleszów, Site 17–20; 4 – Kraków Wyciąże, Site 6; 5 – Kraków Kościelniki Cło, Site 7, 65, 58A; 6 – Tropiszów, Igołomia-Wawrzeńczyce commune; 7 – Zofipole, Igołomia-Wawrzeńczyce commune, Site 1; 8 – Igołomia, Igołomia-Wawrzeńczyce commune, Site 1; 9 – Kraków-Przewóz, Site 2; 10 – Grabie, Wieliczka commune.

On the Vistula terrace, kilns carved into the loess were constructed, where gray pottery was fired on a potter's wheel, and only to a limited extent, storage vessels, as storage of products was possible thanks to storage pits dug in the loess. On the Raba alluvial fan, the insufficient elevation of the old meander belt meant high groundwater levels, periodic flooding, and frequent floods occurring during periods of cooling, humid climate, and periods of increased fluvial activity [12], hindered the firing of vessels in kilns built into the ground, and also prevented the construction of storage pits. This resulted in a high demand for the storage vessels produced here, which were used for "above-ground" food storage. Such production was facilitated by the raw materials prevalent in the area, which were of lower quality. They were suitable for making storage vessels, but were not suitable for producing gray ceramics with smooth and polished surfaces. Failures and significant difficulties during firing were confirmed by a high percentage of production waste, incomparably greater than similar waste on the Vistula terrace [2, see literature there].

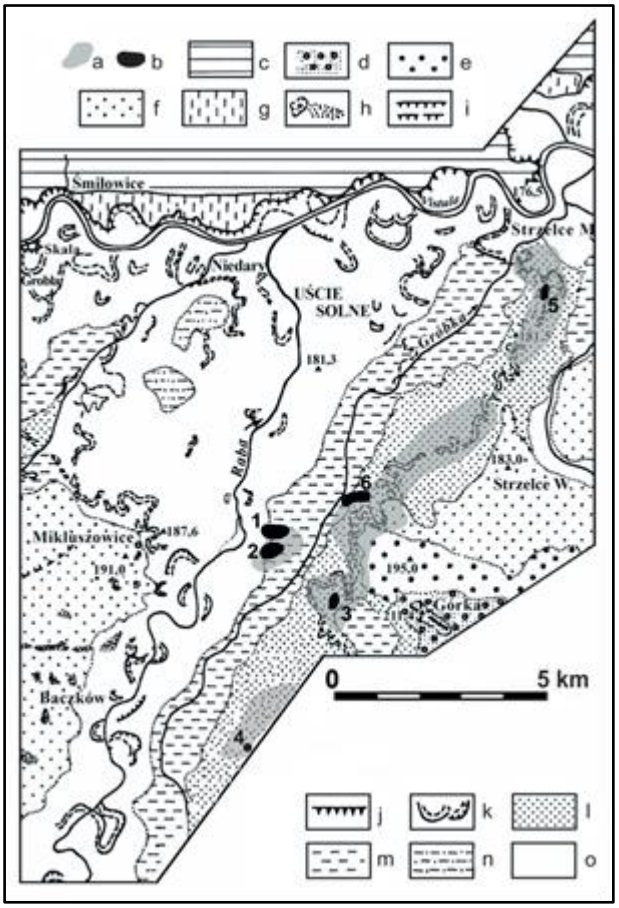


Figure 4. Settlement in the Roman period and geomorphological map of the Raba alluvial fan
a – Roman settlement zone, b – excavated settlements, c – Proszowice Upland covered with loess, d – denudated moraine and fluvioglacial plains from the San Glaciation; e – terrace from Middle Polish Glaciation (?); f – Vistulian terraces and alluvial fans; g – terraces covered with Upper Plenivistulian loess; h – dunes; i – erosion edges 0–10 m high; j – erosion edges over 10 m high; k – abandoned channels; l – meander belts with Holocene paleomeander systems; m – Late Vistulian backswamp basins; n – wet depressions; o – floodplain with current wide levee; Selected archaeological sites: 1 – Bessów Site 2, Bochnia commune; 2 – Bessów Site 3, Bochnia commune; 3 – Okulice Site 18, Rzezawa commune, 4 – Ostrów Szlachecki Site 2, Bochnia commune; 5 – Strzelce Małe Site 13, Szczurowa commune; 6 – Wrzępia Site 13, Szczurowa commune.

The humidification of the climate in the 3rd century until the mid-4th century favourably influenced settlement and agricultural conditions in the upland areas of western Lesser Poland [6], [7]. The number of permanent streams and the productivity of springs increased, facilitating agricultural use and settlement in the watershed areas. However, migration movements and a decline in population density resulted in a decrease in anthropopressure in the "agricultural" part of the Nida River basin after the RWP. This was reflected in the relatively small Mozgawka alluvial fan and the absence of proluvial fans and coluvial series [13], [14], [15]. Meanwhile, the development of the Nida bloomeries region in the lower reaches and interfluve of the Biała Nida and Czarna Nida rivers [16], [17], as well as the relatively intensive environmental transformations of the "industrial" part of the river basin, contributed to the intensification of fluvial processes, lateral migration of channels (subfossil trees in alluvia), and the formation of new series (cut and fill) of alluvia with remains of smelting and iron processing (macro-, microslags, and iron spherules). Deforestation, associated with the production of charcoal used in the

smelting process, triggered aeolian processes and the formation of buried soils [18], [19], [15].

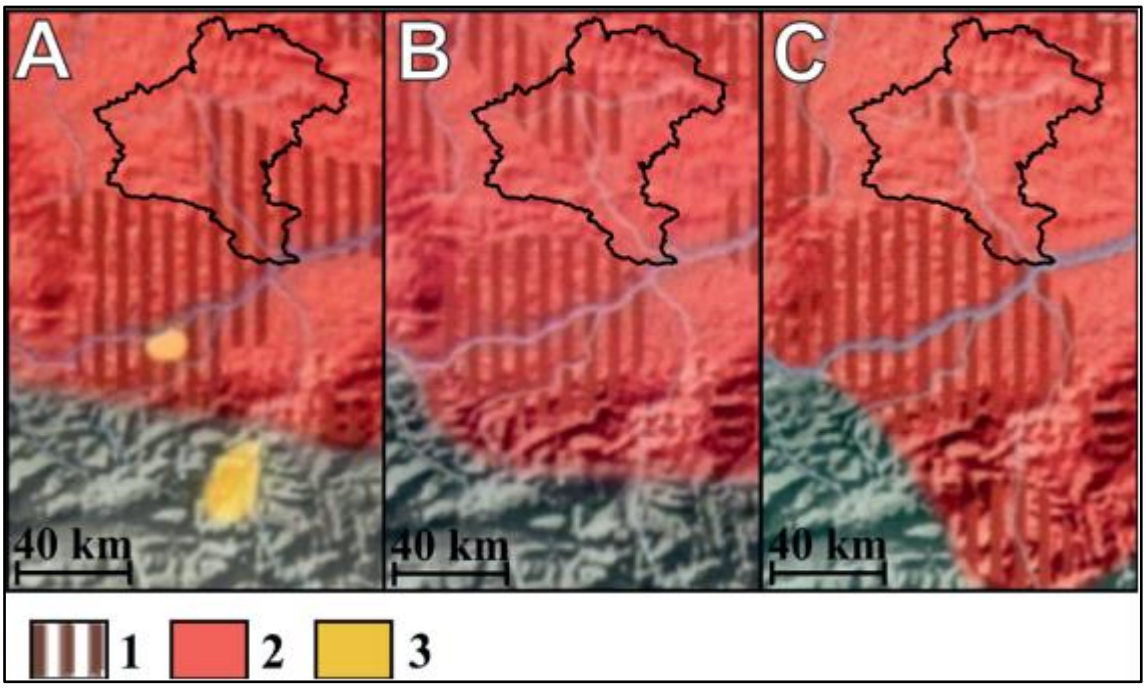


Figure 5. Changes in settlement density in Nida basin and surrounding areas as early (B1, B2) 0–150 AD (A), younger (C1a) 150–200 AD (B) and younger and late (C1b–C3) 200–350 AD (C) [15]
1 – densely populated area, 2 – Przeworsk culture, 3 – Puchov culture.

CONCLUSIONS

Climatic fluctuations in Europe and local conditions played an important role in the settlement processes and the activities of the PC community in southern Poland in the Roman period. Examples of detailed studies document the very clear, multidirectional impact of climatic changes. The PC ecumene was not uniform, which caused regional differentiation of human impact, recorded in settlement forms and sediments. It consisted of "centres" of non-agricultural production, i.e. metallurgical in the Świętokrzyskie region and pottery centres in the Vistula valley, east of Kraków, relatively densely populated and significantly affecting the natural environment. Between these centres, occupying a relatively small area, there were regions used for agriculture, constituting a mosaic of arable land, pastures and forest areas, which resulted in low intensity of erosion-accumulation processes.

Regardless of the large migration movements of the PC population to the south, the heterogeneity of the ecumene could also have caused local relocations to both production centres (equivalent to contemporary "village→city" migrations). This may be illustrated by the decrease in the population density of some agricultural areas after the RWP (after 150 AD), for example, in the Nida valley and its left-bank, karst part of the catchment.

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GENERATIONS OF PALAEOMEANDERS IN THE VALLEYS OF THE CZARNA NIDA AND BIAŁA NIDA VS. THE GENERATION OF PALAEOMEANDERS OF THE UPPER VISTULA RIVER.

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UDC: 902.65:551.435.13.07(438)"628.64"

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ABSTRACT

The research was conducted in the valleys of the Biała Nida and Czarna Nida rivers, located in the SW part of the Świętokrzyskie Voivodeship, within the southern sector of the Holy Cross Mts. The rivers have a lowland character, small slope and wide floodplains with numerous oxbow lakes and palaeochannels.
The methodology included desk based and field analyses. On the basis of the Digital Elevation Model (DEM), topographic maps and orthophotomaps, palaeochannels were identified, and then geomorphological mapping as well as hand drilling and sampling were carried out. The collected samples were subjected to grain size analysis and loss on ignition (LOI) determinations, while the age of meander cut-off was determined using radiocarbon dating of organic material.

Keywords: palaeomeanders, fluvial geomorphology, river channel evolution, Holocene, radiocarbon dating

INTRODUCTION

Palaeomeanders are one of the types of abandoned channels preserved in the relief of the valley floor. They constitute an important element of the palaeoenvironmental record in river valleys because they directly reflect channel development, flow parameters, the balance of erosion and accumulation and changes in the hydrological regime. Analysis of their geometry, infill sediments and the age of their cut-off allows reconstruction of both the course of former channels and the climatic-hydrological conditions during their activity.
The development of river channels in Central Europe was strongly dependent on climatic changes during the Quaternary. Under the glacial–interglacial cycle, alternating phases of erosion and aggradation occurred. At the end of cold periods, intensive vertical erosion dissected earlier accumulation covers (see Kalicki 2006 [1] and references therein). In the Holocene, under more stable and warmer climatic conditions, meandering systems with mainly bank erosion developed, and variability of their parameters reflects fluctuations in discharge.
Different generations of palaeomeanders were distinguished by European researchers, including H.J. Scharpff [2]; Klostermann [3]; E. Weidner [4]. One of the basic interpretative models is the concept of transformation of lowland channels by E. Falkowski [5], assuming the sequence: braided river – large meanders – small meanders – braided river (Fig. 1).

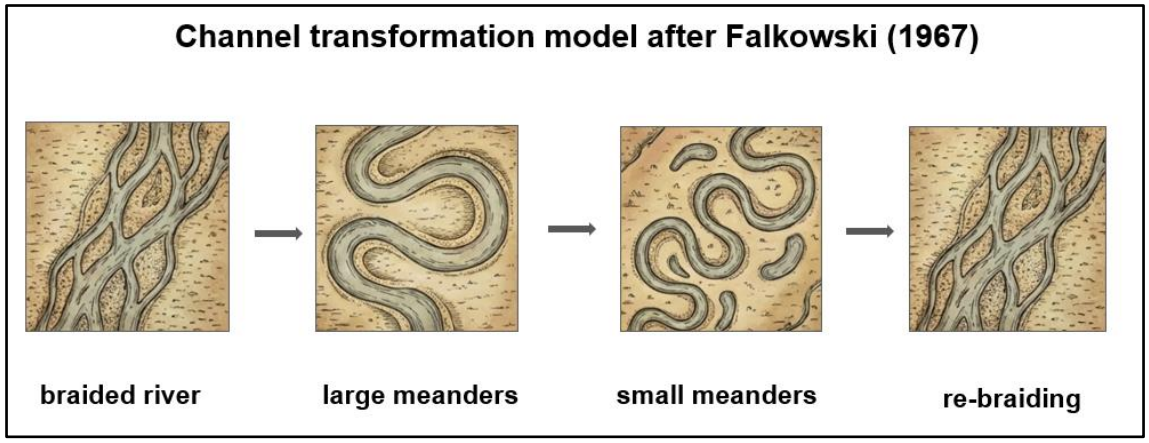


Figure 1. Channel transformation model according to Falkowski [5] by I. Biegalska

Subsequent researchers, e.g. S. Kozarski and K. Rotnicki [6], [7], Szumański [8], on the basis of studies of Polish lowland and Forecarpathians river valleys (e.g. the Warta, Prosna, San) confirmed the scheme of changes in channel pattern since the Late Glacial, distinguishing, among others, phases with large Late Glacial palaeomeanders and small Holocene palaeomeanders. This was confirmed on numerous rivers of the Central and Eastern European Lowlands (see Kalicki 2006 [1] and references therein).

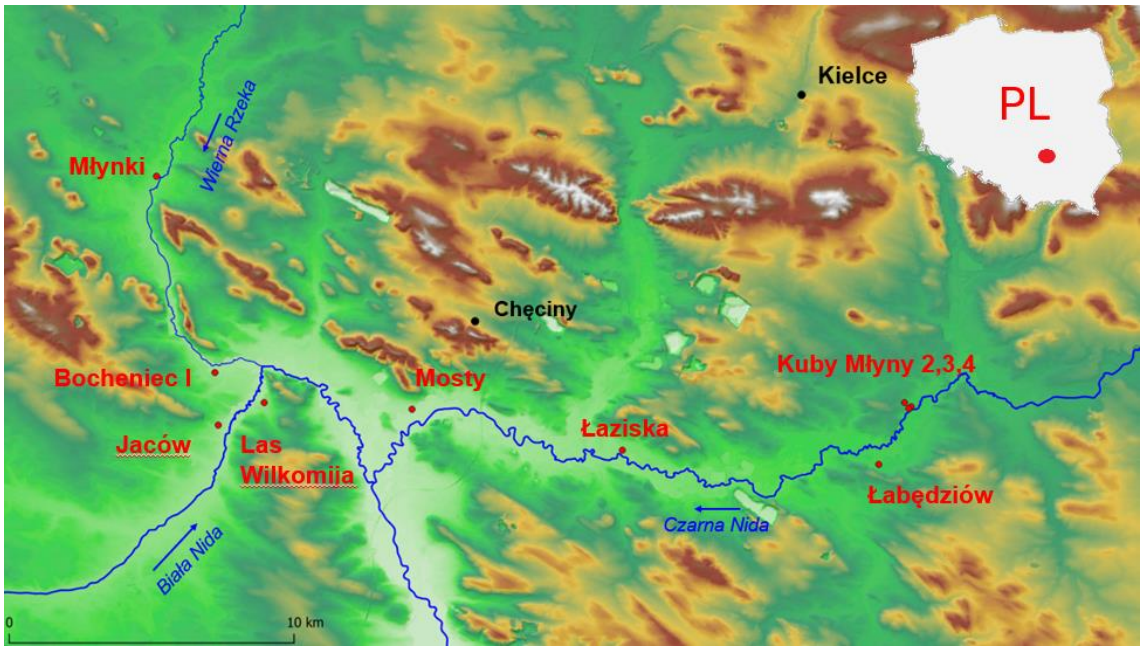


Figure 2. Location of the study area on the DEM with research sites

AIM OF STUDY

The aim of the study was to identify generations of palaeomeanders in the valleys of tributaries of the Czarna Nida and Biała Nida on the basis of analysis of the valley floor relief, morphometric features of palaeochannels and dating and lithofacies structure of their infills. The time of functioning of individual channel systems was determined and changes in river pattern and its parameters in the Late Glacial and Holocene were reconstructed [11], [12], [13].

The obtained results allow interpretation of palaeomeanders as a record of changes in fluvial activity and environmental transformations. The results were then compared with the palaeomeander generations of the Upper Vistula [9], [10].

METHODS

The research included desk-based, field and laboratory analyses. Reconstruction of palaeomeander generations was based on a multi-stage research procedure. First, on the basis of the Digital Elevation Model (DEM), topographic maps and orthophotomaps, potential areas of palaeochannel occurrence within the valley floors of the Biała and Czarna Nida were identified. Detailed geomorphological mapping was then carried out in the field to confirm the morphological interpretation and to select locations for field research. In selected locations hand sampling was performed to determine the estimated thickness of infill and the position of the deepest part of the palaeochannel. Hand drilling was then conducted and samples were collected for laboratory analyses.

Table 1. List of research sites [11], [12], [13], own elaboration; Green – Biała Nida, orange – Czarna Nida, blue – Wierna Rzeka

Site	River	Date (BP)	Cal. date	Author(s)	Channel width	Radius	Meander belt width	Period	Predominat sediments
Kuby Młyny 2	Czarna Nida	9670+45	9260-9110 BC	Krupa 2013	40	120-140	300-380	boreal	organic muds
Młynki	Wierna Rzeka	7790+100	6931-6453 BC	Kalicki et al. 2021				atlantyk	?
Kuby Młyny 3	Czarna Nida	6490+80	6590-6640 BC	Krupa 2013	20	45	?	atlantyk	organic muds
Bocheniec I	Wierna Rzeka	6430+100	5481-5216 BC	Kalicki et al. 2021				atlantyk	peat
Jaców 1	Biała Nida	6170+70	5306-4938 BC	Kalicki et al. 2024	40	80	300	atlantyk	peat
Wilkomija 1	Biała Nida	5830+70	4845-4501 BC	Kalicki et al. 2024	10-30	100	200	atlantyk	peat
Łaziska 2	Czarna Nida	4150+90	2910-2480 BC	Krupa 2013	18	55	100	subboreal	organic muds
Łabędziów 1	Czarna Nida	3800+80	2470-2200 BC	Krupa 2013	22	65	145	subboreal	organic muds
Mosty 1	Czarna Nida	3650+80	2300-1750 BC	Krupa 2013	60	120	300	subboreal	peat
Kuby Młyny 4	Czarna Nida	2530+80	810-410 BC	Krupa 2013	20	18	32	subatlantyk/ subboreal	organic muds

For clastic material, channel sediments, granulometric analysis was performed using the sieve method. Organic matter content in peats and peaty silts was determined by loss on ignition (LOI). The chronology of palaeomeanders was determined on the basis of radiocarbon dating of the base of palaeomeander infill. The obtained dates were interpreted, with certain reservations (according to Kalicki [1]), as the age of meander cut-off. Dating was performed in the Radiocarbon Dating Laboratory in Skała, Poland.

STUDY AREA

The research was conducted in the valleys of the Biała Nida and Czarna Nida rivers, located in the south-western part of the Świętokrzyskie Voivodeship. The study area lies within the Mesozoic margin of the Palaeozoic core of the Holy Cross Mountains and in the Nida Basin [14]. It is characterised by exceptionally high lithological variability of the substrate, which was of key importance for valley development during the Quaternary.

Both rivers constitute the main streams draining the western part of the region and join in the village of Żerniki, forming the Nida River — a left tributary of the Vistula River.

Both rivers have a lowland character, with small slope (about 0.4–0.8‰), wide floodplains and strongly developed meandering [11], [15]. The contemporary channels are clearly meandering, and oxbow lakes and palaeochannels are commonly present within the valley floor, forming multi-generation systems of palaeomeanders.



Figure 3. Comparison of DEM with field photograph (Las Wilkomija site), I.Biegalska

RESULTS

T. Kalicki [1], [9], [10] distinguished phases of an increase of fluvial activity in the Vistula River valley downstream of Kraków with channel changes: 9,800–9,600 BP, 8,800–8,000 BP, 6,700–6,000 BP, 5,500–5,000 BP, 4,500–4,000 BP, 3,500–3,000 BP, 2,700–2,600 BP, 2350–1800 BP, and from ~1800 BP to the present (including the Little Ice Age). The distinguished generations reflect variability of hydrological conditions and transformations of the river system associated with the Late Glacial and Holocene climate changes, manifested in the valleys by alternating phases of lateral erosion, channel incision and changes, trees fallen, an increased accumulation etc. (phases of an increase of fluvial activity [1], [9];).

In the Świętokrzyskie region, the basic study distinguishing palaeomeander generations is the work of J. Krupa [11] concerning the evolution of the Czarna Nida valley. The author, based on analysis of palaeochannel morphometry, their infill and chronological data, distinguished the following generations:

1. Late Glacial channels – the oldest oxbow lakes formed at the end of the Vistulian, large in size (channel width > 40 m, radius of curvature > 120 m, infill thickness about 2 m). They are characterised by a narrow thalweg zone and a wide meltwater bed, indicating river functioning under periglacial tundra type regime with high discharge variability.
2. Younger Dryas generation – wide and shallow transitional channels (25–30 m, infill ≤ 0.5 m), more straightened, showing a tendency toward braiding and mineral sediment aggradation in the cold Younger Dryas climate. These forms are interpreted as a transitional stage between meandering and braided systems.
3. Atlantic generation – small meanders (channel width about 8 m, meander length about 45 m, radius about 20 m) characterised by thicker organic mineral infill and deeper channel incision, indicating stabilisation of flows under the Early Holocene climatic warming.
4. Early Subboreal generation – a classic system of well developed meanders (channel width 18–22 m, meander length 100–145 m, radius 55–65 m), cut-off around 4500 BP. These forms indicate stable hydrological conditions and dominance of lateral erosion leading to intensive bend development.

5. Middle Subboreal generation – large, wide and shallower channels (about 25 m; meander about 160 m, radius about 120 m, infill thickness about 0.7 m), cut-off about 3650 BP. Reduced channel depth with simultaneous an increase in width indicates increased supply of alluvial material and dominance of aggradation processes.
6. Subboreal–Subatlantic transition generation – narrow (about 12 m), strongly incised palaeochannels with deep infill (about 2.5 m), documenting concentrated flow about 2530 BP. Their morphology indicates increased flow energy and renewed channel deepening, probably related to climatic changes and growing human impact in the catchment.

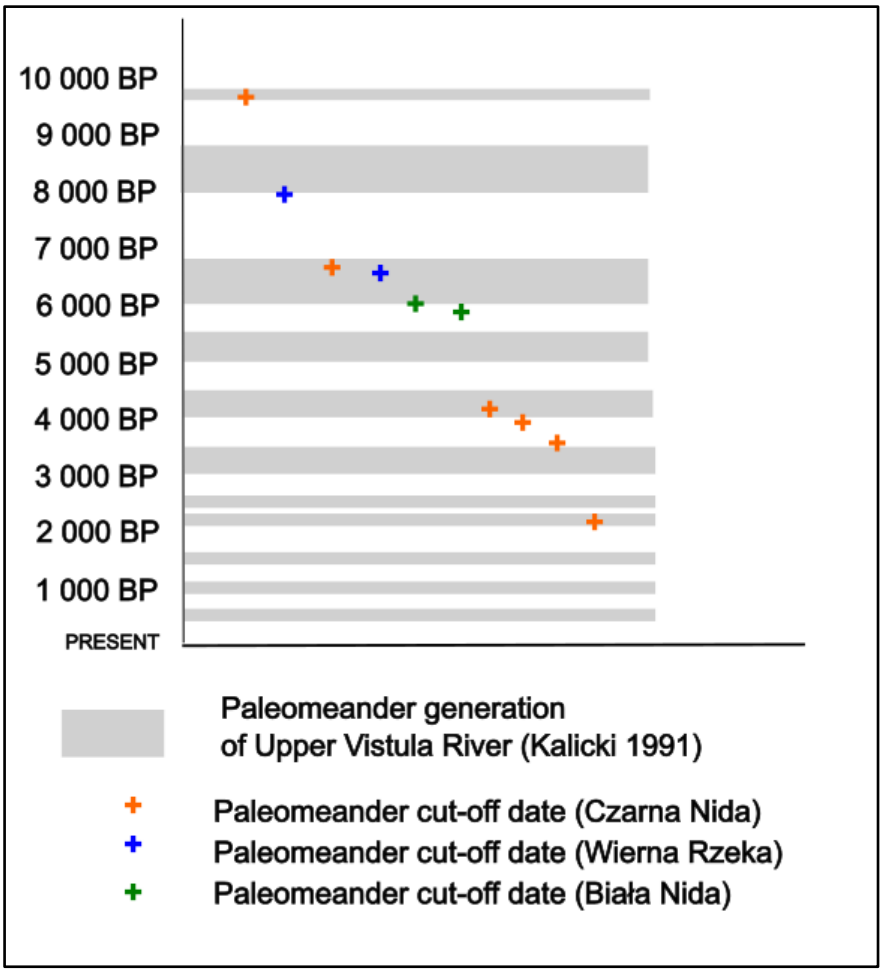


Figure 4. phases of an increase of fluvial activity in Upper Vistula valley also with channel changes [1],[9]

Recent research was conducted in the Biała Nida catchment, where oxbow lakes representing exclusively the Atlantic generation of meanders were identified. Obtained radiocarbon dates indicate functioning of the meandering system in this period (Młynki 7790±1000 BP, Bocheniec I 6430±100 BP [10], Jaców 6170±70 BP, Las Wilkomija 5830±70 BP [11]).
The obtained values fall within the chronological range corresponding to the Holocene climatic optimum, when stabilisation of environmental conditions favored development of well-formed meander forms and dominance of lateral erosion over processes typical of braided rivers — vertical accumulation.
The observed transformations of the river system should primarily be related to climate change, as they correspond to an increased fluvial activity recorded at that time in many

European valleys [1] (Fig. 3). Warming and an increased humidity led to stabilisation of flows, development of riparian vegetation and reduction of mineral material supply from slopes, which favoured concentration of flow in a single channel and formation of regular bends.

CONCLUSION

Dates obtained from ^{14}C analyses of organic sediments filling palaeomeanders in the valleys of the Czarna Nida and Biała Nida were compiled on a diagram together with palaeomeander generations distinguished in the Upper Vistula valley. The compilation shows clear chronological agreement. Most dates from the valleys of Nida tributaries concentrate within the same chronological intervals that in the Vistula valley correspond to phases of an increase fluvial activity. This means that transformations of channel patterns in the valleys of the Czarna and Biała Nida were not local in character but constituted part of a supra-regional response of Central European river systems to environmental change.
The formation and cut-off of meanders occurred during an increased frequency and magnitude of floods, leading to accelerated lateral migration of the channel and cutting of the meander neck. Thus palaeomeanders document episodes of destabilisation of thefluvial system, whereas organic sedimentation in oxbow lakes occurred during periods of a relative hydrological stability. Valley evolution therefore had a pulsating character — phases of fluvial activity alternated with periods of stabilisation during which they were filled with organic sediments.

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ENVIRONMENTAL INFLUENCES ON STEĆCI NECROPOLISES IN BOSNIA AND HERZEGOVINA: A SPATIAL ANALYSES

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ABSTRACT

Stećci are stone tombstones dating from the Late Middle Ages. The largest concentration of stećci has been recorded in Bosnia and Herzegovina, while a smaller number of sites are located in Croatia, Serbia, and Montenegro. Since their origin, stećci have been exposed to various destructive influences, both natural and anthropogenic. Among natural factors, the effects of weathering processes are particularly significant. Long-term exposure to sunlight, wind, rain, and snow leads to physical deterioration of the stone material, reduced legibility of inscriptions, and degradation of the aesthetic quality of decorative motifs on stećci. In addition to natural influences, anthropogenic impacts have also played a substantial role. Throughout history, stećci have been destroyed during wars, damaged during agricultural activities, or reused as construction material for various buildings. Due to the continuous endangerment of this exceptional cultural and historical heritage, the need for more effective protection measures has become evident. Stećci were inscribed on the UNESCO World Heritage List in 2016.
The aim of this paper is to examine the spatial distribution and analyse the influence of natural and anthropogenic environmental factors on stećci necropolises in Bosnia and Herzegovina. The methodological approach is based on the application of geospatial analyses using satellite and cartographic data, supported by GIS technologies, as well as on the analysis of relevant written sources. By applying GIS, the relationships between the locations of major stećci necropolises and natural conditions such as geological substrate, relief, and hydrographic characteristics are presented.

Keywords: stećci, environment, heritage protection, Bosnia and Herzegovina.

INTRODUCTION

Bosnia and Herzegovina is a country dominated by karst, but according to the authors who studied the karst of Bosnia and Herzegovina, there are no unique or precise data on the share of karst in relation to other rocks in Bosnia and Herzegovina [1]. Estimations start from 28% to as much as 65% [2], [3]. Since the area under the Dinaric Karst covers most of the territory of Bosnia and Herzegovina, this inevitably affected the lives of the inhabitants in the past. Analyzing the mutual relations between human influence and the environment throughout history, we can say that man did not just obey nature, did not take a simple place in a comfortable ecological niche in order to create a stable ecosystem;

rather, they created culture within that environment [4]. On the other hand, Mrgić-Radojčić states that the forms of medieval man actions on the environment did not only depend on the tools at his disposal, nor on the natural geographical conditions of the environment in which he lived, but also on the whole complex of social, cultural, religious and aesthetic perceptions, knowledge, and feelings [5].

As an example of this mutual relationship between the human influence and the environment are stećak tombstones – tombstones dating from the late Middle Ages. There is no doubt that the phenomenon of stećak tombstones is related to the mountainous Dinaric area and that their spread on the north is limited by Pannonian area. In addition to that, Bešlagić concludes on the basis of available data that the stećak tombstones are spread over almost the entire territory of BiH, except on the north where we could roughly drawline from Bijeljina to Banja Luka and on northwest to line Sanski Most – Drvar [6]. In the west, the stećak tombstones spreads to the Velebit mountain in Croatia, and in the east bordered by Durmitor mountain in Montenegro and the Drina river basin in Serbia. That the appearance of stećak tombstones is related to the area of the Dinaric Karst is also supported by the fact that most of these tombstones are carved from limestone. The use of stone as a natural resource, symbolizing the eternity and cultural identity of the people in this area, represents a symbiosis of nature and humans [7].

A significant number of stećak tombstones have been preserved to this day and they, as remnants of material culture, can give us information about past times and the lives of the people who lived in Bosnia and Herzegovina. The study of this mutual relationship between the stećak tombstones and the environment can, to a certain extent, give us information about the environmental history of the wider area where the stećak tombstones are located. It has been noted that living in a certain environment does not define an individual's entire life philosophy, but that the environment in which we live shapes our way of life, worldview, culture, and traditions [4]. Through the study of the history of relationships between humans, culture, and the environment, it is possible to gain deeper insight into the influence of the environment.

The aim of this paper is to examine the spatial distribution of stećci necropolises in Bosnia and Herzegovina and to analyse the influence of natural and anthropogenic environmental factors on stećci. Drawing on relevant literature, the paper analyses the phenomenon of stećak tombstones from the perspective of their interrelationship with the environment, understood as a prerequisite for their emergence, location, and certain specific features across the territory of Bosnia and Herzegovina. Using GIS methods, the most important stećci necropolises were identified and compared with environmental conditions, both those prevailing in the past and those reflecting the current state, including geological base (karst), relief, hydrography, but also population, road infrastructure, etc.

CHARACTERISTICS OF THE ENVIRONMENT IN MIDDLE AGES BOSNIA AND HERZEGOVINA

Starting from the definition of coverage of the medieval Bosnian state, there is no doubt that it originated in area of the Dinaric Mountains. In the early Middle Ages, the core of the Bosnian state was located in the central Dinaric area, which later became the geographical framework for political-territorial organization. At that time, the Bosnian state included the central part of the Dinaric area, encompassing the upper courses of the Bosnia and Vrbas rivers and the middle course of the Drina river [8]. Such a Bosnian state

was connected to the Adriatic area through important traffic communication, which passed thru valleys of rivers Bosna and Neretva [9].



Figure 1. Position of Bosnia and Herzegovina in Europe

Today's position of Bosnia and Herzegovina occupies a similar location. It is characterized by the dominance of mountainous relief compared to the plain, especially in the central part. Lowlands are in the north and southwest (Figure 1). It stands out for its abundance of hydrographic objects, as well as its rich biodiversity (especially forests). In the northern part of Bosnia and Herzegovina, the climate is moderate continental, in the central part it is mountainous, while in the southern part the climate is Mediterranean.

PHYSICAL-GEOGRAPHICAL CHARACTERISTICS AND INFLUENCES ON STEĆCI NECROPOLISES IN BOSNIA AND HERZEGOVINA

Dependence of stećak tombstones and natural features of Bosnia and Herzegovina, whose area is dominated by these cultural monuments, is obvious and is often related to lithological characteristics, and is related to the material from which these tombstones were built. Also, the number and position of stećak tombstones indicate that the stećak

tombstones are conditioned by certain natural conditions, as relief. The phenomenon of stećak tombstones is mainly related to the mountainous Dinaric area.
That stećak tombstones is related to the area of the Dinaric Karst is also shown by the fact that most of these tombstones are carved from limestone. Limestone rocks dominate in karst of Bosnia and Herzegovina [3]. Bosnian karst is an integral part of the Dinaric Mountain system, where it occurs in the form of holokarst (mainly in Herzegovina) and merokarst that dominates in Bosnia, as well as certain transitional types [10]. In tectonic terms, the Dinarides are divided into outer and inner, where karst of outer Dinarides have character of deeper and compact karst zones, while karst of inner Dinarides is shallower, fractured and mainly occurs in isolated forms (Figure 2).



Figure 2. Position of Dinaric Karst [11]

Precisely this relationship of lithological material determined the locations of the stećak tombstones. Solid and resistant limestone rocks have been predominantly used in the process of making these tombstones. From that point of view, it is not surprising that the vast majority of stećak tombstones are located in the karst terrains of BiH.
Stećci are most often carved from limestone. The quality of limestone varies from hard and compact limestone to limestone of lower hardness and compactness, depending on availability. Today we witness that due to differences in the quality of the material, some stećci have been preserved better and some less well. In areas where limestone was not available, the stone that was available was used. Thus, some stećci were made of slate, conglomerate, serpentine, tufa, granite and some other types of stone. However, limestone stećci are much more common, but are also extremely influenced by karst erosion and

ultimately the creation of a pedological substrate inhabited by communities of organisms that further accelerate the decomposition process.

Based on the methods applied in the process of GIS spatial analysis on smaller territories, has done spatial analysis of relief of Bosnia and Herzegovina [12]. Bosnia and Herzegovina has a hilly-mountainous relief. According to the hypsometric categories that were available from satellite imagery with a resolution of 25 m (Figure 3), in Bosnia and Herzegovina the most common terrains are at a height between 200-400 m (19.22%). When we add to these terrains category of heights of 400-600 m is, that percentage increases to over 32%, which makes a third of the territory of BiH. These are the heights that define hilly terrains. This is followed by low mountains, elevation of 600-1000 m with about 29% and medium high mountains (1000-2000 m) with a percentage of about 25%. The smallest ones are represented by lowlands (height of 0-200 m) and they cover about 13.6% of the territory, as well as high mountains (height over 2000 m) which cover small percentage of territory of BiH. The highest peak in BiH is Maglić (2386 m), on the mountain with same name, and the lowest point is in Neum, on Adriatic coast (0 m).

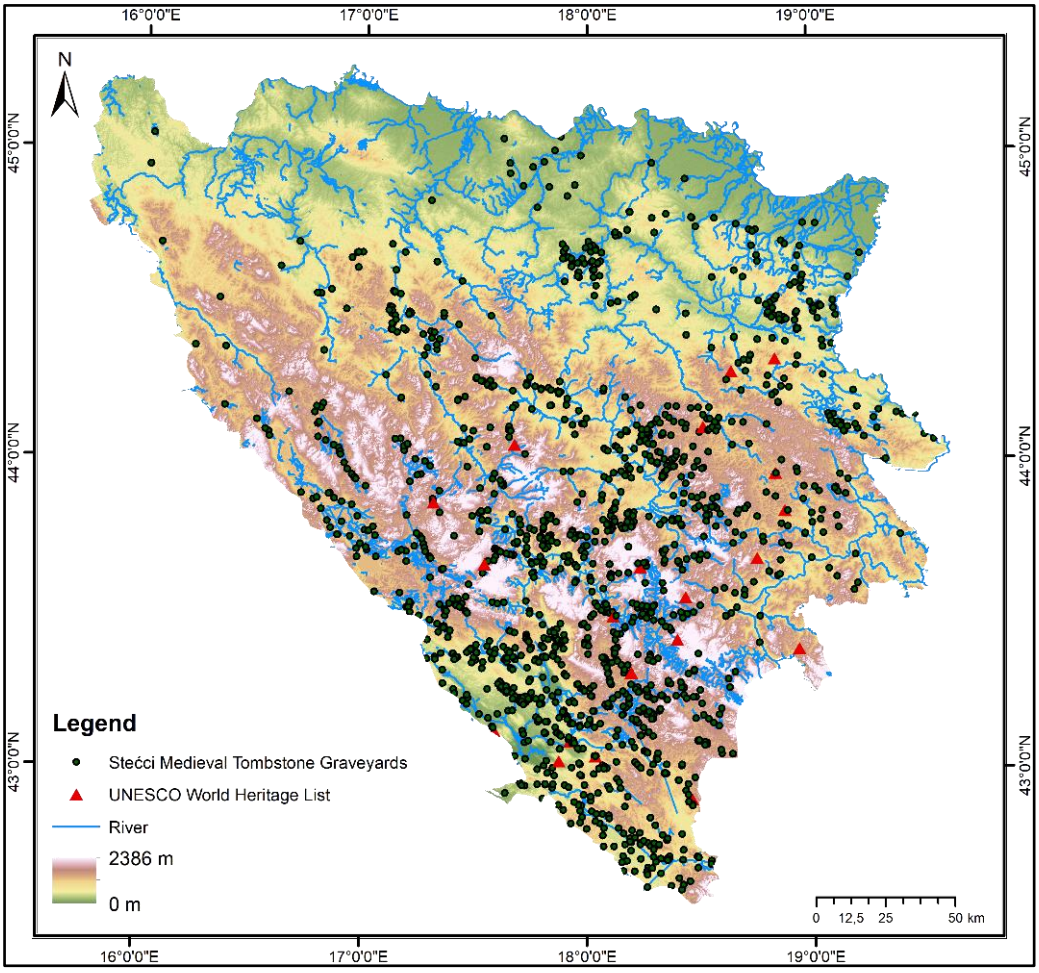


Figure 3. Physical/relief map of Bosnia and Herzegovina with locations of stećak necropolises

Relation between the presence of stećak tombstones and the hypsometric characteristics of BiH is presented graphically in Figure 4 Presence of stećak tombstones by altitude zones is most common from 200 to 1000 m, i.e. on hilly and low mountainous terrain. In the lowlands, the number of stećak tombstones is significantly lower in relation to the

total percentage of this relief category. Also, going to higher hypsometric zones, the number of stećak tombstones decreases and the highest-positioned necropolises are not registered at altitudes over 1800 m. This height distribution of the stećak tombstones indicates the interdependence of the living and working conditions of population with the natural basis of area. The way of life (cattle breeders) and enough water (springs, lakes) in waterless karst terrains were a sufficient precondition that necropolises of stećak tombstones can be found today in hypsometrically highest parts of Bosnia and Herzegovina (Figure 4).

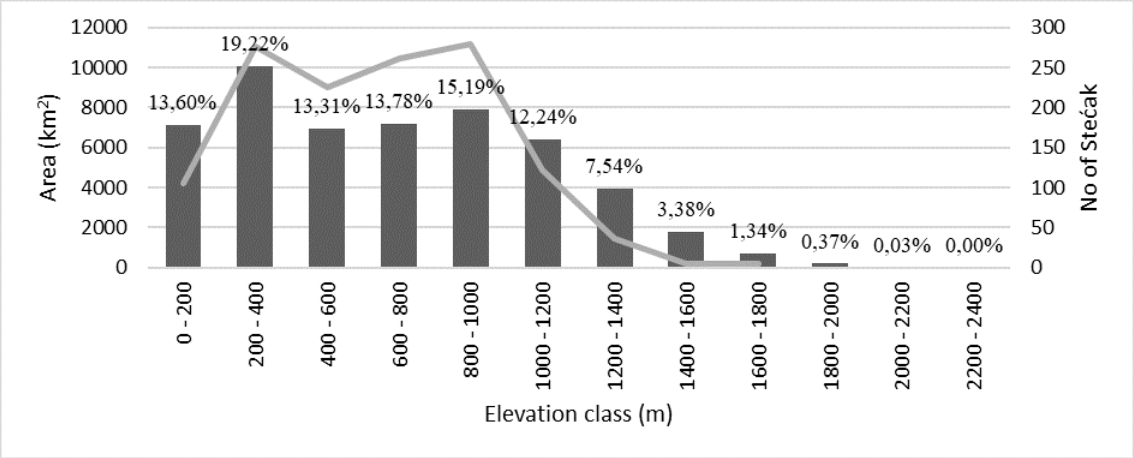


Figure 4. Analysis of the presence of stećak tombstones by height zones in BiH in relation to presence of individual hypsometric zones

Looking on climatic factors, territory of Bosnia and Herzegovina has very complex climatic characteristics. This is especially true in areas where Mediterranean and continental climatic influences collide or interweave. In areas where Mediterranean climatic influences predominate, in their pronounced or altered form, complex types of Mediterranean climate known as Adriatic or altered Adriatic climate have been established. This type of climate affects far south of the country. Relief structure of the Dinarides caused significant modifications of the typical midcontinental and Adriatic climate. Terrestrial air masses from the north and air flow from the south, with the existing scattered relief with variable altitudes and with a difference of 3° latitude, significantly influenced modifications of the basic climatic type. In the north of Bosnia and Herzegovina, the influences of typical temperate continental climate are significantly felt, and the central mountain-valley areas are under the influence of modified regime of midcontinental climate.

Given the climatic zone in which Bosnia and Herzegovina is located, in relation to the natural characteristics of the area, atmospheric conditions have an extremely negative impact on stećak tombstones. Exposed to the sun and wind, rain and snow, the stećci are increasingly losing their former beauty. Letters and artistic motifs are gradually erased, decorations lose their plasticity and almost become equal to the surrounding surface of the monument [13].



Figure 5. Nekropolis of Stećak on Zelengora, by Štirinsko lake at 1750 m above sea level (photo: Golianin, J.)

Bosnia and Herzegovina is rich in water. The general physical and geographical characteristics of its area, especially the climate, relief, geological structure and vegetation, contribute to the richness of inland waters, especially rivers. Rivers has always been a significant resource of Bosnia and Herzegovina. Bosnia and Herzegovina is rich by mountain lakes, which were more numerous in the past (some have disappeared up to day). Rivers and lakes had an influence on type and manner of livestock, which was especially significant due to the waterlessness in higher mountain zones (Figure 5).

The soils of Bosnia and Herzegovina are extremely heterogeneous and form a real pedological mosaic. They can be classified into several groups, and two of them are most common, automorphic soils and hydromorphic soils. During the formation of automorphic soils, precipitation water appears as the basic factor, and during the formation of hydromorphic soils, beside precipitation water participates in groundwater and flood waters. There is no doubt that better quality land has always been used for agricultural purposes, but also, some necropolises of stećak tombstones are located on them.

The pedological substrate also helps to monitor the decay of stećak tombstones, as evidenced by the discrepancy between a recent sketch of the stećak necropolis in Azdije near Ljubinje and the sketch drawn in Bešlagić's work some 50 years earlier. This difference can be explained by the possibility that monuments originally found within the churchyard later sank into the ground, which is a major issue in the study of so-called “forest necropolises” and necropolises in fields. Such a comparison is necessary to understand how quickly the stećak necropolises in Herzegovina are disappearing and deteriorating [14].

The analysis of natural characteristics showed that the basic economic activities of the population of Middle Ages Bosnia and Herzegovina are significantly determined by nature, so characteristics such as relief, climate, hydrography and pedological composition conditioned that the then population was mainly engaged in livestock [15]. This way of life of these inhabitants influenced the way of life and the attitude towards nature.

ANTHROPOGENIC ENVIRONMENTAL INFLUENCES ON STEĆCI NECROPOLISES IN BOSNIA AND HERZEGOVINA

Although there is a limited amount of data and historical sources on the settlement of the territory of Bosnia and Herzegovina in the Middle Ages, the presence of a large number of stećci, as well as their distribution and location, leads to the conclusion that during the medieval period there was a significant level of settlement, important economic activities such as livestock breeding and mining, and the necessary transport and communication routes. The geographical position determined that the territory of present-day Bosnia and Herzegovina has, since the earliest times, represented an important transit area. These communication routes, from the Antiquity and throughout the Middle Ages, followed the valleys of the Bosna and Vrbas rivers, connecting the Mediterranean region with the Pannonian and Central European areas.

With regard to the distribution of stećci, it can be observed that they are most densely concentrated along former medieval roads, both local and regional. The relationship to communication routes has been recognized as a very important spatial determinant in the establishment of stećci necropolises [16]. One of the reasons for such positioning was the need for their visibility to passers-by. Almost as a rule, stećci necropolises are located on elevated ground, along riverbanks, or in places that provide a good overview of the surrounding landscape [13]. In the Mrkonjić Grad area, stećci are most densely concentrated along the route of a road that for centuries connected the region with major traffic routes and neighboring areas [17].

The proximity of stone quarries played a decisive role in the selection of necropolis locations. Stone quarries are frequently found in the vicinity of stećci necropolises; thus, near a cemetery with stećci at the foothills of Mount Treskavica, a quarry containing remains of unfinished stećci has been identified [18]. Of particular interest is the manner in which such large stone blocks were transported over shorter or longer distances. Two methods of transporting stone blocks have been identified [19]. One method involved the use of wooden sledges, while the other relied on wooden rollers. Wooden sledges used for the transport of stećci were employed during the winter and were pulled by horses and oxen with the assistance of a large number of people. The second method of transporting stone blocks was used when the distance between the quarry and the necropolis was relatively short. In such cases, rollers made of oak or beechwood were used. Cases of wooden rollers left beneath the stećci themselves have been recorded and preserved to the present day, as they could not be removed due to the weight of the stone [19].

Numerous stećci necropolises in mountainous areas indicate that settlements once existed near these locations, where important social activities were carried out. Stećci can provide valuable insights for the study of medieval settlements. Necropolises with stećci are frequently located in areas that are now dominated by wilderness, extensive pastures, or forests [13]. It is evident that settlement patterns changed over the centuries, and that stećci serve as excellent indicators for studying such transformations.

Humans have frequently and deliberately destroyed stećci, during wars, in the search for treasure beneath the tombstones, in the construction of various buildings, and on cultivated land. In the areas of Vlasenica and Sarajevo, entire necropolises were used as building material for roads, cooperative houses, and residential buildings [6]. Many necropolises and inscriptions were destroyed during the renovations of churches in Herzegovina throughout the 19th and 20th centuries, with significant and irreparable damage inflicted on old necropolises located within churchyards [14]. It is now evident

that organized activities aimed at studying and protecting stećci in Bosnia and Herzegovina were insufficient and initiated too late [14] (Figure 6).



Figure 6. Stećci brought from various locations and exhibited in front of the National Museum in Sarajevo (photo Grmuša. M.)

The extent of stećci deterioration as early as the 1950s has been noted, with reference made to "monuments that are rapidly disappearing," and it was observed that the majority of these monuments are located on cultivated land, where they are almost beyond salvation [20]. Such treatment of stećci dictated a more serious awareness of the need for protection and the implementation of more effective measures in this regard. It should be noted that in regions where prejudices and fears regarding stećci persisted, and where local legends remained, the stećci are better preserved. There was a widespread popular belief that lightning or storms would strike anyone who disturbed the stećci [13].

CONCLUSION

Stećci tombstones represent a unique, autochthonous cultural and artistic phenomenon of Bosnia and Herzegovina, dating from the late Middle Ages, which is recognized both in Europe and worldwide. They exemplify the mutual relationship between human activity and the natural environment. Today, stećci are found throughout almost the entire territory of Bosnia and Herzegovina, with the exception of the northernmost regions. The phenomenon of stećci is closely associated with the mountainous Dinaric region. Stećci tombstones are typically carved from limestone, although differences in stone quality have resulted in varying levels of preservation. They are predominantly concentrated along former medieval roads, yet the location of nearby stone quarries had a decisive influence on the placement of necropolises. It is common to find quarries in the vicinity of stećci necropolises, sometimes even containing unfinished or partially worked stećci tombstones.

Since the inventory of stećci tombstones conducted during the Austro-Hungarian period, a constant decrease in their numbers has been observed. It has also been noted that awareness regarding the preservation and protection of these monuments remains underdeveloped. In addition to being affected by environmental factors, primarily atmospheric influences, stećci were mostly damaged through human negligence. They were frequently and intentionally destroyed, suffered damage during wars, were disturbed in the search for treasure beneath them, removed from arable land, and used as building material in the construction of various structures.

Given these circumstances, it became necessary to protect stećci tombstones not only at the national but also at the international level. Consequently, the UNESCO World Heritage Committee decided to inscribe stećci tombstones on the World Heritage List. A total of 28 necropolises with stećci tombstones have been registered as a serial nomination, 20 of which are located in Bosnia and Herzegovina, while the remaining eight are in Croatia, Montenegro, and Serbia. According to the UNESCO document Stećci – Medieval Tombstone Graveyards, the inscribed components are generally in a stable state of conservation with minimal interventions, although they are exposed to pressures from natural processes of physical deterioration. The document emphasizes the importance of continued development and implementation of active conservation programs based on the advice of expert conservators, as well as active community involvement in the management and maintenance of the sites [21]. Necropolises not under protection, either by local authorities or UNESCO, remain exposed to destruction, highlighting the ongoing need for effective measures to safeguard and preserve the remaining stećci tombstones.

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TRANSFORMATION OF THE ANTI-TANK DITCH DURING THE LAST 80 YEARS – CASE STUDY FROM THE BIAŁA NIDA BASIN (S POLAND)

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ABSTRACT

This study investigates selected remains of modern defensive structures located in the Biała Nida basin (Poland), focusing on factors that have shaped their current condition. The analysed features include several sections of an anti-tank ditch attributed to the German Reich, constructed as part of the A-1 defensive line against the Red Army in the final stage of World War II. Within a relatively small area, these structures were built on highly variable substrates, including fluvial sands and gravels, limestone rubble, and bedrock. Using an integrated approach that combines historical cartographic data, Airborne Laser Scanning (ALS) analyses, field observations and measurements, geomorphological assessments, historical sources, including military instructions, and GIS-based spatial analysis, the main degradation and transformation factors were identified. Natural components, including fluvial dynamics, slope processes, and soil erosion, are evaluated alongside anthropogenic impacts including land-use change, infrastructure development, and agricultural intensification. The results highlight the varying vulnerability of individual sites and demonstrate how the synergy of natural and human-induced processes contributes to differential preservation patterns, thereby enabling the identification and dating of other remains of modern defensive structures.

Keywords: anti-tank ditch, World War II, Biała Nida basin, denudation, geomorphology

INTRODUCTION

The anti-tank ditch that is the subject of this study is an element of the OKH Stellung A-1, a German Army High Command (Oberkommando des Heeres) defensive line constructed by the German Reich against the army of the Soviet Union. It was built in the period July 1944 – January 1945 on the orders of the Chief of the General Staff of the German Army High Command, Colonel General Heinz Wilhelm Guderian, and the construction was supervised by the Schutzstaffel (SS) [1]. This line is located in Poland and runs in an arc from the Pilica River to the Poprad River, along the Nida and Dunajec rivers, intersecting the Vistula River. The examined section ran in the western part of the Świętokrzyskie Voivodeship on the right bank of the Nida and Biała Nida rivers, forming the fortification line (Fig. 1). In the analysed area, this ditch represents two types: an anti-tank ditch on the plain and an escarpe built on the slope, constructed to stop the Workers'

and Peasants' Red Army vehicles attempting to cross the Biała Nida River in their westward offensive. The anti-tank ditch and the escarpe were constructed with hand tools using wooden measuring frames, utilising forced civilian labor (Fig. 2A) and formed part of other field fortifications, engineering structures, and obstacles [2], [3]. The Red Army crossed this line in January 1945 [4].

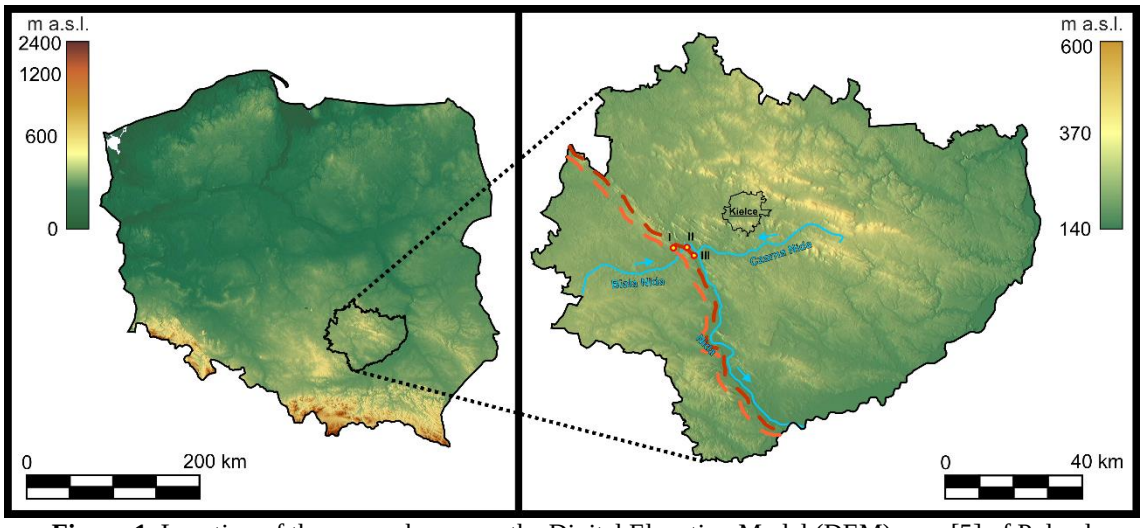


Figure 1. Location of the research area on the Digital Elevation Model (DEM) map [5] of Poland and the Świętokrzyskie Voivodeship with the location of research sites (I, II and III) and the World War II A-1 defensive line (double dashed lines: front red and rear orange)

The technical supervision of the A-1 and A-2 defensive lines (Fig. 1 – red and orange dashed lines) was exercised by the Organisation Todt, as well as the Baudienst im Generalgouvernement (Construction Service in the General Government for the Occupied Polish Region), and technical staff from the Haupttechnische Amt (Main Technical Office) in the General Government [6]. In addition to the regular German army, the works were supervised by the police and the Schutzstaffel (SS), with a specially appointed staff headed by SS-Gruppenführer (Lieutenant General) Jakob Sporrenberg, and the work began with the A-1 defensive line [2]. The supervision was aimed at carrying out the works in accordance with the guidelines (Fig. 2B), which enabled optimal adaptation of the form of the anti-tank ditches to the geological conditions and relief.

According to the German instructions of June 1, 1944, the German anti-tank ditch had a symmetrical, trapezoidal cross-section [7], [8]. Its depth was 2.5 m, increased by embankments 0.5 m high and 8–10 m wide. The upper section was 3.5 m wide, the flat bottom 0.3 m wide, and the wall angle was 55°. In stable ground, a larger ditch could be constructed: 3 m deep, 4.5 m wide at the top, and 0.3–4.5 m wide at the bottom, which resulted from varying the wall angles in the range of 55°–90°. The ditch embankments in such ground were 15–20 m wide. In less stable ground, it could be timbered [7]. Escarpes were used to prevent advances going up, while counterscarpes prevented descents, and collectively they are now called anti-tank ditches. According to German regulations, an escarpe should be created by cutting a flat platform at least 3 m wide into the slope, with a wall inclination ranging from 55 to 90°, the same as in the case of anti-tank ditches on plains. The minimum height depended on the wall inclination angle and was at least 1.43 m at 90°, and at least 2.5 m at 55° [7].

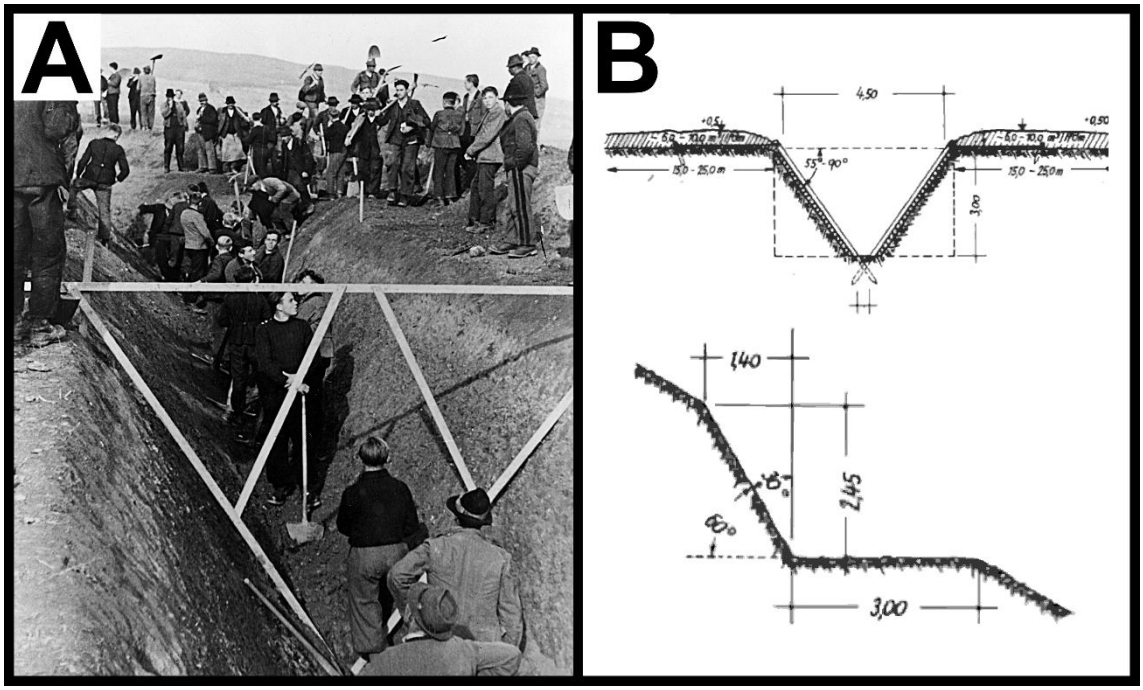


Figure 2. A – Forced labor while digging an anti-tank ditch (Photo by Klacanek 1944, National Digital Archives, Poland, inv. no. 3/2/0/-/6339), B – Diagrams from 1944 with examples of anti-tank ditch and escarpe [7]

AIM OF THE STUDY AND METHODS

The aim of the study was to identify World War II field fortifications in the lower section of the Biała Nida River using interdisciplinary methods, including field survey, ALS data analysis, and historical, geomorphological, and geoarchaeological research [9], [10]. It is important to examine the state of preservation of selected sections of the field fortifications. It depends on the influence of physiographic components in order to identify the dominant processes leading to the obliteration of traces of the World War II anti-tank ditch in the study area. For this purpose, three research areas were selected, differing in terms of geological structure, relief, and land development, where the described anti-tank ditch runs.

RESULTS

The fortifications in the studied section lacked permanent reinforced concrete structures, consisting instead of field fortifications, including firing trenches, an anti-tank ditch, infantry shelters, and vehicle revetments [2], [11]. The anti-tank ditch is clearly visible in the relief within the Świętokrzyskie Voivodeship along almost its entire length. Its sections along the Biała Nida River are particularly well-preserved.

The first (I) site is located near the estuary of the Łososina River (Wierna Rzeka), a left-bank tributary of the Biała Nida River (Fig. 3A). The fortifications were built mainly on a sandy-gravel terrace [12]. The relief is clearly flat and currently used for forestry (Fig. 3A, B). In addition to the well-preserved anti-tank ditch, there are many other elements of field fortifications, including older structures dating back to World War I, which are attributed to the Austro-Hungarian Monarchy (Fig. 3C). The anti-tank ditch is deep, but in some sections, areas of denudation processes and gradual filling of the bottom of the

form by colluvium are visible. In several places, a path runs through the ditch, where these processes are much more visible due to the poorer vegetation, especially in the unforested sections (Fig. 3A, B, C). In some sections, this form even exceeds 2 m in depth, considering the still well-preserved embankments on both sides of the ditch (Fig. 3D).

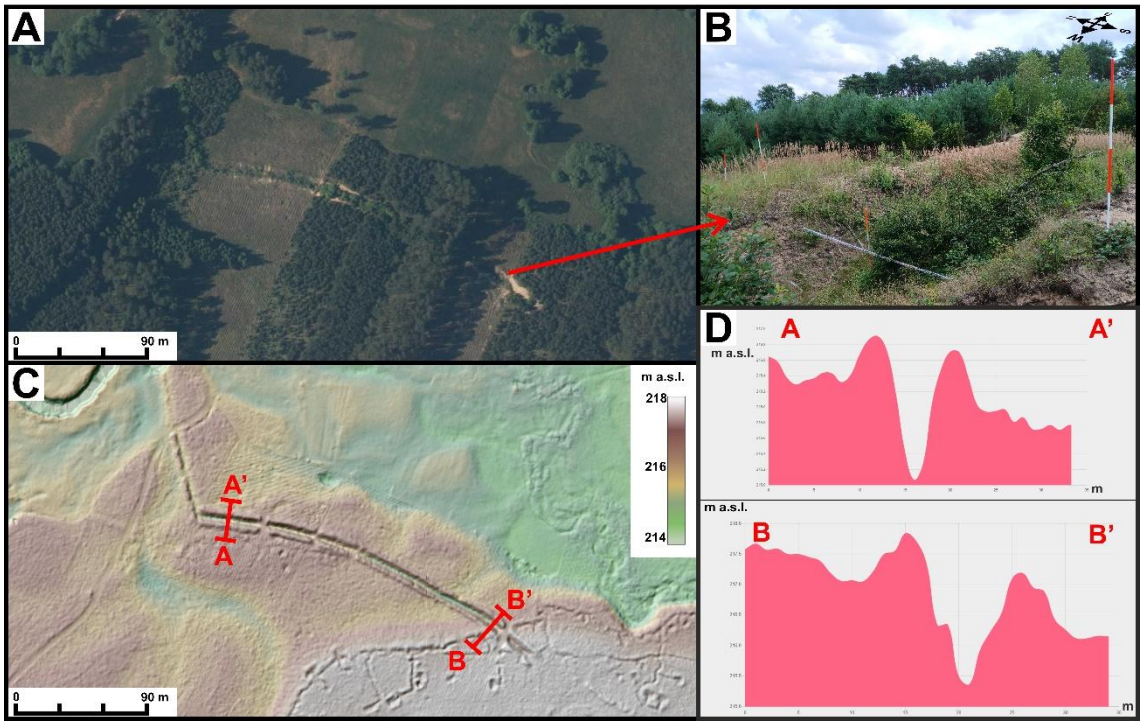


Figure 3. The first (I) study site: A – Area used for forest cultivation with location of anti-tank ditch [13], B – Dug in a sandy terrace anti-tank ditch section (Photo by J. M. Niebylski 2025), C – DEM with well-preserved remains of World War II field fortifications with cross-sections location [13], D – Cross-sections of anti-tank ditch

The second (II) site is located eastward of the first (I) on a steep, rocky, and densely forested slope of the Biała Nida Valley (Fig. 4A). A significant part of the anti-tank ditch was built on limestone outcrops (Fig. 4B, as escarpe), which are adjoined by narrow strips of sandy-gravel terraces [12], on which many elements of the other field fortifications have been preserved (Fig. 4C). The anti-tank ditch running through the rock outcrops is carved into them, creating a distinct, almost vertical scarp, approximately 3 m high, with a flat area below. Along the remaining length, this form has the classic character of a ditch reaching a depth of up to 3 m (Fig. 4D).

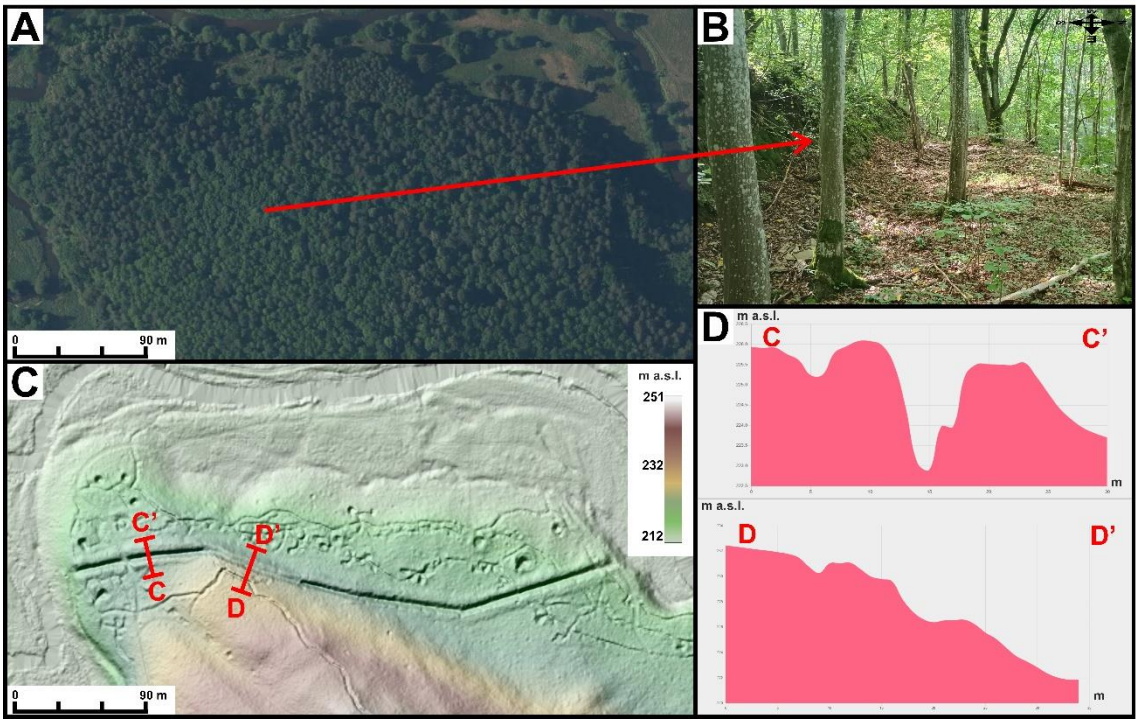


Figure 4. The second (II) study site: A – Difficult-to-access forest area with location of anti-tank ditch and escarpe [13], B – Dug in a rocky hillside escarpe section (Photo by P. Przepióra 2025), C – DEM with well-preserved remains of World War II field fortifications with cross-sections location [13], D – Cross-sections of anti-tank ditch and escarpe

The third (III) site, located in the estuary of the Biała Nida River, on the right, gentle slope of the valley, represents the most denuded section of the anti-tank embankment (Fig. 5A). Sands with silt intercalations and sands with fluvioglacial gravels dominate here [12]. Within the fluvial-denudational valley (Fig. 5B), there are small agricultural plots separated by narrow forest complexes (Fig. 5A). Within the agricultural areas, the study form becomes much flatter, and its average depth does not exceed 0.4 m (Fig. 5C). The ditch becomes more distinct again in the forested sections (Fig. 5A, B).

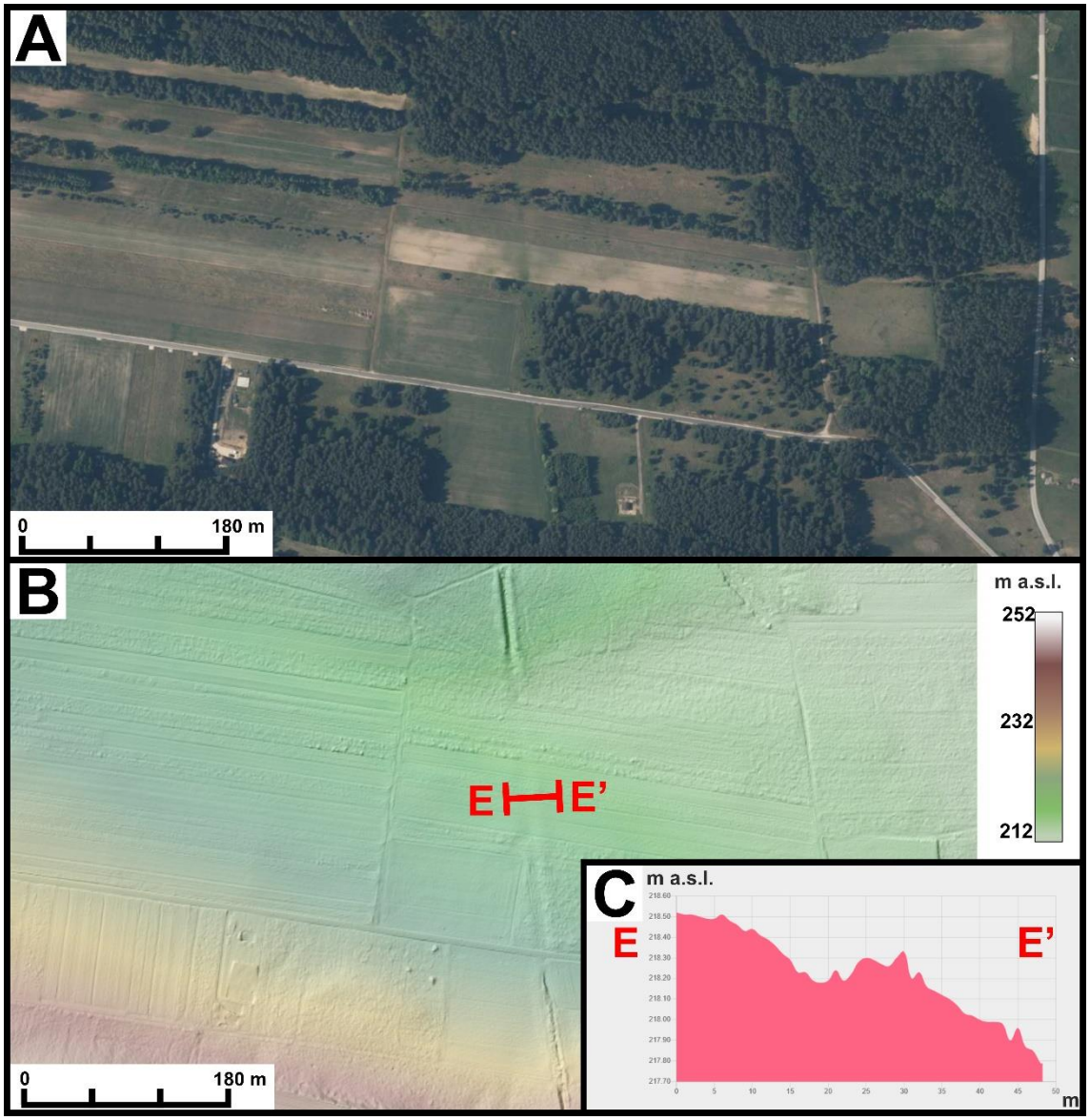


Figure 5. The third (III) study site: A – Area used for agriculture [12], B – DEM with obliterated in the field remains of World War II field fortifications with cross-sections location [12], C – Cross-sections of anti-tank ditch

DISCUSSION

All three selected sections (research sites) represent varying degrees of preservation of the World War II anti-tank ditch and associated escarpe. This variation is primarily due to the state of land use, although the geological structure and topography also play a significant role.

In the case of the first (I) site, the field fortifications are relatively well-preserved due to limited forest management, with this form best preserved in the forested sections. Although this area is composed primarily of sand and gravel [12], the slope is slight and characteristic of a terraced bottom of river valley. Denudation processes are more pronounced in areas frequented by human or animal paths across the anti-tank ditch. The limited vegetation growth in these areas leads to the movement of loose sands down the slope, filling the ditch floor with deluvia, especially during rainfall.

The second (II) site represents a completely different type of anti-tank fortification. Due to the steep sloping and rocky terrain, the method of constructing the anti-tank ditch is more varied. On the sandy-gravel terraces [12], a classic anti-tank ditch, bounded by embankments, occurs, while on the nearby limestone outcrops [12], the fortifications were carved into solid rock. Here, too, the anti-tank ditch has a distinct depression bounded by embankments, but its relief is much better preserved. For a short distance, the ditch transforms into an almost vertical wall as an escarpe. This is due to the engineers' use of natural topography in constructing the fortifications. Currently, the area is heavily forested, and the dominant limestone rocks in which the fortifications were built provide additional durability to the structures. They are best preserved in this studied section also due to the low, contemporary anthropopressure.
The third (III) site represents a section of an almost completely obliterated anti-tank ditch. This is primarily due to long-standing agricultural activity at this location. This is also confirmed by the fact that in nearby, forested sections, this ditch is much better preserved in relief, despite the identical geological structure as in the first (I) site, where sand and gravel with silt interbeds predominate [12]. The more pronounced loss of form at the third site may also be since the anti-tank ditch ran across a small, steeply sloping fluvial-denudational valley, where natural processes leading to erosion and backfilling are more intense.
The field fortifications, particularly the anti-tank ditch, are preserved to varying degrees due to various factors. However, modern development, which accelerates the erosion and accumulation processes of the over 80-year-old anti-tank ditch, outweighs the geological structure and relief. The intensification of these processes leading to the obliteration of the historic military fieldwork requires detailed analysis and further research. This will allow easier future interpretation of these forms in the field and, if necessary, ensure their appropriate protection.

CONCLUSIONS

The Biała Nida Valley bears very clear traces of warfare, mostly from World War II. Among the best-preserved forms is the clearly visible anti-tank ditch. It is part of the defensive fortifications built by the Third Reich in the final stages of the war. The over 80-year-old structure is preserved in varying degrees of condition, depending on the geological structure of the terrain on which it was built and the relief (mostly by the slope). However, modern land use is significant, especially accelerating the denudation processes of the World War II relics found here. The best-preserved sections of the anti-tank ditch and escarpe were carved into the steep limestone slopes of the valley, currently poorly accessible and intensely forested. The worst-preserved sections run through sandy and gravel alluvium used for agriculture, accelerating the denudation processes of the studied feature due to both natural and anthropogenic factors.

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SECTION

SOCIO-ECONOMIC GEOGRAPHY

THEORETICAL FOUNDATIONS OF THE BALKAN HEARTLAND: THE GEOGRAPHICAL PIVOT OF THE BALKANS

DOI: https://doi.org/10.18509/GBP26113t
UDC: 001.5:[911.3:32](497)

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ABSTRACT

The "geographical pivot of history", a concept introduced by Sir Halford Mackinder, represents a central idea and the cornerstone of geopolitics as a scientific discipline. Mackinder argued that the key to global power lies in the control of the Eurasian landmass, which he termed the "World-Island," thereby developing the theory of "geographical inertia", defined as the dependence of a state's spatial development on its geographical position and on the natural–historical tendencies of global development. The aim of this paper is to define and theoretically ground the concept of the Balkan Heartland, modeled after Mackinder's theory of geographical inertia. The central hypothesis rests on the claim that the Balkan Heartland, central region of the Balkans, constitutes the pivotal and core area of the Balkan Peninsula—an attractor of all significant and decisive historical and geopolitical events in the region. Establishing a parallel between the geographical pivot of world history and the geographical pivot of the Balkans requires isolating three key pillars of Mackinder's theory, which will serve as the foundation for formulating the concept of the Balkan Heartland. These three pillars are 1. Natural–physical characteristics; 2. Historical influence and migrations of Asian peoples; 3. The dualism of land and sea powers. This paper seeks to answer a single question: Can the Balkan Heartland be conceptualized as the pivotal zone whose strategic position has shaped the major historical and geopolitical turbulences of the region? Using the historical–geographical method, the paper applies the central postulates of Mackinder's theory as a basis for developing a new theory of the "geographical pivot of the Balkans."

Keywords: Balkan Heartland; Geographical Pivot; Geopolitical Inertia; Balkan Geopolitics.

INTRODUCTION

The process of adequately transferring a theory (or context) from one spatial setting to another involves systematic adaptation rather than mere copying. Moreover, it is crucial to identify the principles and mechanisms through which the original theory operates and then adapt them to the specific variables of the new environment [4]. The transfer of the theory of the "geographical Pivot of History"[1] to the space of the Balkan Peninsula[2] will proceed through several steps: 1. identifying the key concepts and assumptions of the original theory; 2. analyzing the new context by understanding the specific characteristics and dynamics of the new environment and assessing their compatibility; and 3. adapting and elaborating the theory [1]. The specific tasks to be addressed in this case include

[1] In the following text, the Heartland theory
[2] or just the Balkans

adding new analytical components unique to the Balkan Peninsula, constructing "bridges" by identifying connections between existing knowledge and new observations, and temporal extending the theory[3]. The study will employ the historical-geographical method—a multidisciplinary approach to the analysis of geographic characteristics and the causal relationships arising from the central position of the Balkan Heartland. Through an analysis of historical events that unfolded within the territory of the Balkan Heartland and its immediate surroundings, the historical significance of this area will be established. In order to more clearly determine the parallel between the world's "geographical Pivot of History" and the "geographical Pivot of History" of the Balkan Peninsula, it is necessary to single out three fundamental pillars of Mackinder's theory, on the basis of which the theory of the Balkan Heartland can be constructed. These pillars may also be interpreted as a methodological framework within which Mackinder conducted his research. They represent interrelated principles that guide how space, power, and historical processes are comprehended as a whole. The author of this paper defines these three pillars through an analysis of Mackinder's key texts, and they will be used in the paper as an instrument of "theory transfer," that is, as a means of translating Mackinder's core geopolitical assumptions from their original geographical and historical context to the Balkan Peninsula. In this sense, three key pillars are distinguished:

1. Physical-geographic characteristics;
2. Historical influence and migrations of Asian peoples; and
3. The sea-land power dualism.

By following these pillars, the paper seeks to answer the question of whether there exists a region on the Balkan Peninsula that can be characterized as a "piedmont" or "pivot" decisive for the turbulent developments that have accompanied it throughout history.

PHYSICAL-GEOGRAPHIC CHARACTERISTICS

In his book The Balkan Peninsula and the South Slavic Lands (1921), Jovan Cvijić identified the principal characteristics of the Balkans: the feature of connection and interpenetration, which facilitates the circulation of various movements (atmospheric, biological, and human), and its opposite—the feature of isolation and separation4. These components have shaped the historical and political landscape of the Balkans since the earliest times. Furthermore, with regard to natural regions, Cvijić distinguished two major geographical units (macro-regions) of the Balkans, separated based on morphological characteristics: the continental block and the Aegean region [14]. According to their features, Cvijić further divided the continental block into the Eastern (Balkan) region, the Central (Morava–Vardar) region, and the Western (Dinaric–Pindus) region. In that sense, the peninsula can be divided into approximately equal regions, one would obtain a single central region (the Morava–Vardar region) and three peripheral regions (the eastern—Balkan region, the western—Dinaric–Pindus region, and the southern—Aegean region) [14].

[3] By temporal extension, this paper refers to an analysis of global conditions at the time of the theory's emergence, the factors that led Halford Mackinder to formulate the Heartland theory, the subsequent critique of the theory, and examples of its practical application.

[4] According to Jovan Cvijić, there are three principal factors underlying the characteristic of connection and interpenetration: peripheral penetration, valleys and longitudinal routes, and gorges, mountain passes, and transversal routes. By contrast, the two main factors underlying the characteristics of isolation and separation are mountain massifs and the fragmentation of the relief into local basins [14].

The Morava–Vardar valley, which by its course connects the north and south of the Balkans and by its tributaries links the east and west, has often been described as the backbone of the Balkans. The Central region (or the Balkan Heartland) is bounded by the cities of Niš, Kosovska Mitrovica, Skopje, and Sofia. This region connects the two major natural areas of the Balkans identified by Cvijić—the Aegean region and the continental block. The Central Balkan region is linked via the Vardar River and its tributaries to the Aegean region, including southern Greece, Thessaly, Thrace, Epirus, and Macedonia. On the other hand, through the Morava River it is connected to the continental block, the Pannonian Plain, and the basins of the Sava and Danube rivers. Moreover, the Morava and Vardar rivers, together with their tributaries, connect rivers from three different drainage basins—the Adriatic, the Black Sea, and the Aegean—thus emphasizing the central position of this area within the Balkans.

The central Morava–Vardar region exerts a strong gravitational pull even on areas lying outside the drainage basins of these two rivers. This influence extends to the Dinaric Mountains and Croatia in the northwest, Herzegovina and Montenegro in the west, Epirus in the southwest, Thessaly and southern Greece in the south, the valleys of the Maritsa and Struma in the southeast, and the Black Sea in the east [14]. Throughout history, all major pedestrian, caravan, and wagon routes passed through this valley, as did later road–railway and pipeline corridors[5]. The most important transport routes of the Balkan Peninsula from antiquity to the modern era have been concentrated in this central region: the Roman *via militaris*, later restored as the Tsarigrad Road, connected Constantinople with the northwestern Balkans, while at the beginning of the twentieth century key routes of the Orient Express to Istanbul and Athens also passed through this area. Today, this same spatial axis is reflected in the routes of Corridors IV, VIII, and X. The two main nodal points of the Balkan Peninsula, Belgrade and Istanbul, are located at diametrically opposite ends of the peninsula, on its periphery, and their connection through the Central region has always been of crucial importance [5].

The parallel drawn between the global theory of the "Geographical Pivot of History" and its Balkan counterpart (the Central, Morava–Vardar region) lies in the fact that both share the characteristics of connection and interpenetration, as well as isolation and separation. The territory of the Central Balkan region occupies approximately 10% of the Balkan Peninsula[6], and the global Heartland encompasses around 10%—of the world's total landmass. In Heartland theory, the Arctic Ocean is described as "frozen," and Mackinder emphasizes that the Heartland lacks access to warm seas or oceans. Likewise, the Central Balkan region has no direct access to the seas surrounding the Balkan Peninsula. High mountain ranges, steppe plains, and the valleys of major rivers appear in both theoretical constructs. Particular attention is devoted to the favorable geographical characteristics of the North European Plain, which enabled unobstructed and large-scale migrations of Asian nomadic peoples into Europe. The Central region constituted a key corridor in the southward pressure of Asian peoples penetrating the Balkans and further into Central Europe. From antiquity to the modern era, this space has served as a link between two

[5] The Danube–Morava–Vardar–Aegean Sea Canal is an initiative dating back to the early twentieth century that envisages the creation of an artificial navigable waterway with a total length of 655 km (488.5 km consisting of existing riverbeds and 166.5 km of newly excavated canals). Its geopolitical and geostrategic significance for the continental countries of the Balkans and Central Europe would be immense, which is why this idea has attracted the attention of China and its Belt and Road Initiative [12].

[6] The approximate area of the Central region is comparable to that of present-day North Macedonia.

worlds (*catena mundi*).



Figure 1. Political-ethnographic sketch of Macedonia and Old Serbia; Source: Macedonia and Old Serbia, a work comprising selected texts from Jovan Cvijić's three-volume study Foundations for the Geography and Geology of Macedonia and Old Serbia, edited by Borislav Čeliković [15];



Figure 2. The Balkan Heartland
Source: https://en.wikipedia.org/wiki/Balkans, author's adaptation

HISTORICAL INFLUENCE AND MIGRATIONS OF ASIAN PEOPLES

At the beginning of the middle Ages, Slavs and Bulgars settled in the Balkan Peninsula (and thus also in the Central region), becoming the two largest population groups in the Balkans, beside the Greeks—a situation that has largely persisted to the present day. In the centuries that followed, conflicts among the Serbs, Bulgars, and the Eastern Roman Empire over dominance on the peninsula were frequent. The borders of these three states were often located precisely within the territory of the Central region, owing to its favorable geographical position. With the arrival of the Nemanjić dynasty to the Serbian throne, the Central region gained increasing importance and became the gravitational field of Serbian state expansion. The subsequent conquests of the Nemanjić dynasty were directed almost exclusively toward the acquisition and control of the Central region.
During the thirteenth century, the great Mongol conquests began, driving numerous peoples across the world into flight. Advancing along two main routes—through the "gates of the Peoples" and via Asia Minor—the Mongols, accompanied by Cuman, Turkic, Tatar, and other tribes, invaded and devastated Eastern and Southeastern Europe. They entered the Balkan Peninsula from three directions: from the north through Hungary, from the southeast via the Bosporus and the Dardanelles. This marked the beginning of a period of intrusions, conquests, and control of the Balkans by Asian peoples that would last until the early twentieth century. The Ottoman advance triggered migrations and metanastatic movements of the Orthodox population across the northern rim of the peninsula and into parts of Central Europe. In Balkan history, the Central region once again played a decisive role, this time in the expansion of the Ottoman Empire into

Europe. By controlling the Central region, the Ottoman Empire secured dominance over most of the peninsula for nearly five hundred years [13].

The concept of civilization is essential for understanding historical processes within the Central region. Cvijić's "zones of civilization" reveal the overlap of several civilizational types in the Central region—modified Byzantine and patriarchal as the dominant ones, alongside influences of Middle Eastern, Central European, and Western European civilizations (primarily in towns and cities), as well as the Turko-Oriental civilization [14]. As a cultural space where European and non-European influences intersect, the Balkans essentially constitute a culture of crossroads, of crucial importance for the formation of Balkan geopolitical horizons and worldviews. These have often remained insufficiently understood, misinterpreted both by neighboring peoples, and by the "great" powers [8]. One of the main critiques of Samuel Huntington's civilizational lines concerns their insufficient precision in defining civilizational boundaries in the Balkans. V. Dvorniković described Balkan civilizations as follows: "This colorful mosaic of peoples, indigenous and immigrant, found itself on such a windswept and dangerous geopolitical bridge between Europe and Asia that only perhaps the great 'gate of peoples' between the Urals and the Caspian Sea can be compared to the Balkans in this regard." [10].

Mackinder emphasized that the ideas forming a nation, as opposed to a mere aggregation of people, are usually adopted under the pressure of shared adversity and the common necessity of resisting an external force. He argued that Europe owes its civilization and its persistent need for unity to the pressures made by barbarians throughout history. He also viewed Europe and European history as subordinate to Asia and Asian history, since European civilization is, actually, the product of resistance to Asian invasion [3]. Progress and expansion in Europe, he believed, were driven by the need to respond to pressures emanating from Central Asia. Accordingly, the Heartland functioned as the pivot of all geopolitically transformative processes of historical magnitude within Eurasia [2]. A similar fate befell the Balkans, whose civilizational patterns emerged under strong Asian influence; however, unlike Europe, this region remained markedly heterogeneous and did not respond to external pressures by forming a unified pattern or unity. For the Balkans to overcome the perception of being merely a transitional zone or bridge between Europe and Asia, it is necessary to position itself autonomously as a supranational cultural region or to constitute itself as a unified geopolitical space.

THE SEA-LAND POWER DUALISM

In geopolitical terms, the Balkan Peninsula is situated within the global Rimland (or Inner Crescent). Historically, it has functioned as a "buffer" zone between great powers and represents an extension of Eastern Europe in the context of Mackinder's formula: "1. whoever rules Eastern Europe commands the Heartland; 2. whoever rules the Heartland commands the World-Island (Eurasia); 3. whoever rules the World-Island commands the seas (and thus the entire world)" [6]. Mackinder's Heartland theory, complemented by Mahan's Rimland theory, is still used after almost one hundred and twenty years as one of the principal geopolitical and geostrategic doctrines in the distribution of global power. According to Mackinder, the main historical axis of geopolitical confrontation unfolds along the line of struggle between maritime and land powers—between mobile, thalassocratic empires and stationary, land-based tellurocratic states [3].

The Balkan Heartland has historically been a site where the geopolitical rivalries of great powers intersect along the main axes of geopolitical confrontation. These include Germany's geopolitical vector toward the southeast (*Drang nach Osten*, extending toward Basra in Iraq and the Persian Gulf), Russia's geopolitical vector toward the southwest (seeking access to the Adriatic Sea), Turkey's vector toward the northwest (seeking access to the Central Europe), among others [12]. Through control of the Balkan Heartland, these forces seek to dominate all key points within the security belt oriented toward the East. For NATO, the Kosovo and Metohija and Balkan Heartland areas serves as a stronghold for trans-Balkan penetration from the Ionian and Adriatic Seas toward the Black Sea. By controlling all major geopolitical routes, NATO leaves limited room for the expansion of Russian and Chinese influence in the Balkans [11].

It is particularly significant that the Balkan Heartland has also been affected by the process of Balkanization as part of a broader historical–geopolitical process that covered the entire Balkan Peninsula. In general, the concept of "to Balkanize" signify the fragmentation of a unified space or political entity into smaller, often mutually antagonistic units, through process of violent disintegration into smaller, conflict-prone, and structurally fragile entities. Today, parts of the Balkan Heartland are integrated into the NATO alliance (those located in North Macedonia and Bulgaria). In addition, the territory of Kosovo and Metohija is de facto under NATO and KFOR jurisdiction, given that one of NATO's largest military bases outside the United States, Camp Bondsteel, is located there, also within the Balkan Heartland. The portion not included in NATO structures—the Serbian part of this area—can be easily observed and controlled from surrounding positions. The contemporary presence of NATO in certain parts of the Balkan Heartland can be interpreted as part of a broader strategy of stabilizing and controlling key communication and security nodes in the region, which simultaneously contributes to maintaining the existing geopolitical configuration and limiting alternative influences.

Jovan Cvijić was the first scholar to clearly emphasize the importance of communication lines linking Central Europe with the Balkans and Asia Minor, which also represent the shortest overland route to the Suez Canal. These routes not only connect the periphery with the center but also possess exceptional strategic significance both for Europe, as a space of power, and for the Balkans, as a zone of expansion. Consequently, the valleys of the Morava and Vardar rivers function as the internal center of the peninsula, organizing its geographical and political space [9]. Precisely for this reason, Cvijić was aware of the extremely complex geopolitical position of the Balkan Heartland, which has repeatedly generated destabilization processes throughout history, since the geostrategic role of the Morava, Nišava and Vardar valleys was permanently and structurally crucial [5].

From a military-strategic perspective, the Balkan Heartland is located within the European battlefield, i.e. the Balkan regional battlefield. When analyzing the situation, it is also necessary to consider the important communication beams that pass through the geospace of the Balkan Heartland. These include the bundle connecting Western Europe with the Middle East (linking Berlin, Vienna, Budapest, Belgrade, Niš, Sofia (Skopje), the Bosporus (Thessaloniki), Istanbul, and Basra); its close connection with the 45th-parallel bundle (connecting Marseille, Milan, Zagreb, Belgrade, Bucharest, and Rostov); and the bundle that is the Danube navigable route [7]. In addition, two further concepts should be incorporated into this analysis. The first is the Balkan geopolitical node—a dense network of geopolitical vectors of major global and regional powers whose bundles converge and intersect in the Balkans, with the Balkan Heartland being the point of

greatest density of this convergence. The second is the Balkan geopolitical arc—the axis of NATO's action on the Balkan Peninsula during the civil wars and the NATO intervention in the 1990s. This arc was realized along two directions: 1. "the Dinaric stronghold" (Dinarides), and 2. the Central region (with auxiliary access routes via the Pannonian Plain, the Adriatic Sea, and the Black Sea) [12]. Control of the entire Balkan Heartland enables control over the Morava–Vardar valley as the most significant meridional natural corridor in the Balkans, as well as the entire central maneuver space with its key communication nodes [7].

CONCLUSION

We live in a time of expressed uncertainty, in which what was considered indisputable until yesterday may already be called into question tomorrow. International relations, like other social sciences, is a discipline that faces the constant challenge of interpreting a complex and dynamic international environment, while possessing only limited capacity for reliable prediction of outcomes. For this very reason, history serves as a relatively stable point of reference for scholars of international relations, because although the present and the future are uncertain, the past is known to a greater extent—at least in those aspects that are not the subject of scholarly dispute. It is therefore no coincidence that the key theories of international relations were formulated and empirically tested precisely based on historical events. Although complete certainty regarding current and future global processes is unattainable, the analysis of historical patterns makes it possible to identify long-term trends and provides a framework for understanding the conditions under which these trends produced specific outcomes in the past.

In this sense, it is necessary to analyze existing phenomena through a different analytical and theoretical lens, one that allows for the reassessment of established interpretations and dominant narrative frameworks. Such an approach can contribute to the formulation of new answers and to the identification of potential solutions to the challenges facing an already structurally complex and persistently turbulent environment such as the Balkan Peninsula, particularly in the context of contemporary geopolitical and international dynamics.

The initial hypothesis of the paper, according to which the Central Morava–Vardar region represents the geographical pivot of the Balkan Peninsula, found support within the three distinguished pillars of Mackinder's theory. The natural-physical characteristics, the historical role in migratory and conquering movements of Asian peoples, as well as its position within the axis of confrontation between land and sea powers, indicate that this space does not function as a mere transit zone, but as a structural node in which key geopolitical processes of the Balkans are concentrated. In this sense, the Balkan Heartland can be conceptualized as a regional geographical pivot whose role is enduring rather than historically contingent. The concept of the Balkan Heartland does not imply a mechanical transposition of Mackinder's model to the regional level, but rather its functional and analytical adaptation within the limited geopolitical system of the Balkans. Therefore, the Balkan Heartland does not represent an equivalent of the global Heartland in terms of scale and reach, but an analogous position within regional relations of power, communication, and strategic accessibility.

By introducing the concept of the Balkan Heartland and applying the method of theory transfer, this paper seeks to contribute to the expansion of classical geopolitical thought through its adaptation to regional contexts. This approach opens the possibility for other

regions to be analyzed, with further empirical verification of the role of central communication zones in shaping long-term political and security dynamics. Future research may deepen this concept through comparative analyses of the Balkans with other geopolitically fragmented regions, thereby further testing the analytical utility of the Balkan Heartland concept.

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FOREST POTENTIAL AS A POLITICAL AND GEOGRAPHICAL CATEGORY OF THE REPUBLIC OF SRPSKA IN THE FUNCTION OF GEOPOLITICAL VALORIZATION OF TERRITORY

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ABSTRACT

The Republic of Srpska, given its diverse natural and geographical conditions and units, possesses significant natural potentials, which represent an important segment in assessing its geopolitical position through the lens of the "Geopolitics of Resources."
Forest resources represent one of the key natural and strategic potentials of the Republic of Srpska, which implies that forests have exceptional geopolitical significance, and therefore the establishment of a protection system and their monitoring carries not only ecological and economic premises.
The subject of research in this paper will focus on the articulation, analysis, and role of forest potential in the geopolitical valorisation of the Republic of Srpska. Additionally, the research will focus on identifying the connections and interactions between different categories of the given space - geopolitical, ecological, and economic.
The study is planned to be conducted using a research methodology based on historical, functional, and structural and functional methodological approaches, as well as using general methods (analysis, synthesis, concretization, generalization) and specific methods consistent with geographical research (comparative, spatial analysis), along with appropriate data processing techniques (statistical, cartographic, graphical, GIS analysis).
The results and objective of the research will indicate that the rational management of forest potential in the context of geopolitical valorisation represents one of the future guidelines for enhancing the regional and development identity of the Republic of Srpska not only in an economic sense, but also as a guideline for political and geographical stability.

Keywords: Natural potentials, Republic of Srpska, "Geopolitics of Resources," forest potential, geopolitical valorisation.

INTRODUCTION

In contemporary geopolitical constellations and in a time of accelerated scientific-technological development, changes occur within political-territorial communities as a response to changes in the international community as a whole. The action of a state is limited by resources that have special significance for each state, as well as by norms of international law regulating international relations and the international political system of values.
The last decade of the 20th century was marked by the end of the dualistic system and the affirmation of a unipolar order in international relations, while the beginning of the 21st

century represents a period in which its end is already visible and the contours of a new – multipolar order. In the first and second decades of the 21st century, the USA retained a leading role in international relations, whose military, economic and other dominance was still pronounced, but not unquestionable. Absolute unipolarity as a geopolitical order has already transformed into relative unipolarity with Russia and China as respectable geopolitical actors, and considering contemporary political-geographical processes in the international community, the world in the third decade of this century is increasingly "approaching" a multipolar order, which will undoubtedly unfold in several phases in the coming period, where the carriers of contemporary international relations are already visible (the USA, Russia, China, India, Iran, EU).

New guidelines of political-territorial organization in conditions of national integrations and subnational fragmentations, the spread of "new" democratic values, the emergence of new-old political ideologies, the multipolar world order, and neo-Eurasianism represent open questions in organizing modern political-geographical systems and new geopolitical approaches in understanding changes in the contemporary international community [1].

"Changes in the hierarchy of constellations among leading states in the world, as well as the reincarnation of the 'Silk Road', reaffirm the geospace of the Western Balkans, Bosnia and Herzegovina and the Republic of Srpska as a geopolitically attractive part of the 'Rimland', and the importance of geopolitical position and the role of natural potentials for the survival of a political-territorial community are once again actualized" [2]. The opinion about the minimalistic role of geographical factors in the global structure of the world order and contemporary expansionist goals in the world has definitely been overcome.

In accordance with such reflections, we can quote Professor Milovan Radovanović who emphasizes: "Geopolitics, which is meaningless and without subject matter without logical and objective grounding in regionalism and territoriality, both is and is not a science, which certainly depends on the level and skill of the (mis)use of geographical and all other relevant facts, theories, methods, goals, etc. At its highest, therefore scientific level, which cannot be disputed to its predecessors (Hegel, Ritter, Humboldt, Ratzel), and in Serbian-Balkan proportions not even to Cvijić, it is always in a critical latent position of 'slipping' from the scientific track into the mud of quasi-science and expansionist doctrine. Yet even as such a surrogate of geographical, historical, ethnological, demographic, economic and political science, geopolitics has, since the very emergence of nation states and their alliances, and especially in the present time, been a logical inevitability of political practice and a leading, or at least accompanying, doctrinal basis of regional-political, regional-economic and regional-strategic conceptions" [3].

The "Geopolitics of Resources" as a subdiscipline of geopolitics is an indispensable segment in contemporary international relations, because access and secure disposal of natural potentials and raw material bases determine international status and relations between political-territorial communities at local, regional and global levels. Natural potentials are located in space and function in time, which determines their geopolitical significance for a state or political-territorial community. We can conditionally divide them into those always necessary, such as water, air and land, and those whose importance has changed depending on historical-geographical or economic development of society as a whole (coal, oil, nuclear energy).

The Republic of Srpska possesses natural potentials that represent significant political-geographical components in evaluating its geopolitical position. Planned and rational use

of natural potentials represents one of the geopolitical priorities, because its geopolitical future will depend on optimal management of natural potentials. In accordance with such considerations, forest potential represents one of the most important natural resources of the Republic of Srpska.

DATA AND METHODOLOGY

The issue and subject of the research are defined by the title of the topic. Through this research we seek to point to the premise that, although we live in a time of globalisation, a scientific-technological and information revolution, there is an increasingly prevailing view that the basic geopolitical theories founded on the pronounced role of geopolitical position and deterministic postulates once considered to be subjective interpretations and retrograde reflections indeed have a firm grounding in contemporary international relations and are receiving their full affirmation and confirmation in the case of the Republic of Srpska, Bosnia and Herzegovina, and the Western Balkans region.

More precisely, space its effective control and natural potentials as a geopolitical category ("the geopolitics of resources") often determine the future of a particular political-territorial community.

The paper has been realised through general methods (analysis, synthesis, concretisation, generalisation) and special methods inherent to geographical and political-geographical research (comparative and spatial analysis), as well as data-processing techniques (GIS analysis, statistical and graphical techniques), in accordance with a historical, geographical, functional and dialectical methodological approach, in order to define an interdisciplinary problem area, establish priorities, and identify guidelines for the implementation of specific solutions.

The results and the objective of the research will indicate that rational management of forest potential in the context of geopolitical valorisation represents one of the future directions for enhancing the regional-development identity of the Republic of Srpska, not only in the economic sense, but also as a guideline for political-geographical stability, which implies political, socio-economic, demographic and ecological sustainability of the geospace.

Basic statistical data on the geospatial characteristics of the Republic of Srpska (area, population size, geographical coordinates), as well as the basic characteristics of forest and agricultural areas, are found in publications issued by the Institute of Statistics of the Republic of Srpska: *This is Republika Srpska 2025*; *Census of Population, Households and Dwellings in the Republic of Srpska 2013*, 2017; *Statistical Yearbook of the Republic of Srpska 2025*.

For the theoretical-methodological foundation of the paper, and for the study and analysis of the natural potentials of the Republic of Srpska, particularly forest potential as a political-geographical category, relevant scientific literature was used (Radovanović M., 1994; Zekanović I., 2019; Zekanović I., 2020), as well as proceedings from international scientific conferences (*Proceedings of the 4th Serbian Congress of Geographers with International Participation*, Belgrade, 2015; *Political Geography and Geopolitics in Russia: Historical Experience and Contemporary Developments*, Saint Petersburg, 2021; *Tourism in the Modern European and Eurasian Space*, Trebinje, 2022), more precisely scientific papers (Zekanović I., Živković M., 2015; Zekanović I., 2021; Zekanović I., 2022).

GEOSPATIAL CHARACTERISTICS OF THE REPUBLIC OF SRPSKA

The Republic of Srpska is an entity within Bosnia and Herzegovina whose area amounts to 24,641 km². It covers approximately 48% of the country's territory. In mathematical-geographical terms, it occupies the northern and eastern part of the geospace of Bosnia and Herzegovina, between 42°33'18" and 45°16'36" north latitude and 16°12'18" and 19°37'44" east longitude (Table 1,[4]). According to the results of the 2013 Census, it had 1,170,342 inhabitants [5].

Table 1. Geographic coordinates of the end points of the Republika Srpska

	North latitude	East longitude	Administrative-territorial units	Settlement
North	45° 16' 36"	16° 56' 08"	Kozarska Dubica	Donja Gradina
South	42° 33' 18"	18° 26' 45"	Trebinje	Podštirovnik
East	44° 02' 59"	19° 37' 44"	Bratunac	Žlijebac
West	44° 56' 52"	16° 12' 18"	Krupa na Uni	Srednji Bušević

Natural characteristics of the Republic of Srpska are conditioned by its belonging to different natural-geographical units. For that reason, it is characterised by a heterogeneous geomorphological, climatological, vegetational, pedological and hydrological structure.
It has an atypical territorial shape, consisting of two units: a north-western and an eastern one. The north-western unit, with a total area of about 12,200 km², extends along the lower courses of the tributaries of the Sava River (Una, Vrbas, Ukrina and Bosna) and largely encompasses three historical and geographical regional entities: Krajina, Posavina and Ozren. The eastern unit includes the geospace of Semberija, Romanija, the greater part of Podrinje and Eastern Herzegovina. Its area amounts to approximately 12,400 km².
From a geomorphological point, the northern parts is widely open towards the Pannonian Plain, to which hilly terrains and fertile river valleys are connected towards the south. Further south, the hilly terrain transitions into a mountainous area. At the extreme south, karst relief is represented, with all its surface and underground forms.
Different climate types within the geospace are the result of natural elements and the general circulation patterns of air masses over a broader area. The climate is influenced by several factors: geographical latitude, relief which is predominantly mountainous in character the proximity of the Adriatic basin, and continental masses, primarily the Eurasian landmass. For this reason, the following climate types are represented in this area: temperate-continental, continental, mountain, mountain-basin, and modified Adriatic climate types.
From a hydrological perspective, the geospace of the Republic of Srpska can be characterised as relatively rich in both surface and groundwater hydrological networks. The water potential is represented by the river courses of the Una, Sana, Vrbas, Bosna, Sava, Drina and Trebišnjica. In addition to the aforementioned larger rivers, the hydrographic network is also represented by lowland, mountainous and karst rivers, as well as natural and artificial lakes, and geothermal and mineral springs.
The vegetation is characterised by heterogeneity, resulting from the geographical position of the Balkan Peninsula and a specific spectrum of eco-geographical conditions, as well as pedological, climatic, biological and anthropogenic influences.
Thus, "within the Eurosiberian region, the geospace of the Republic of Srpska is differentiated into lower territorial units: the Illyrian, Moesian, Central European and Adriatic provinces. Furthermore, the vegetation areas of Srpska are differentiated into six

belts with 18 global phytocoenological units" [6].Alluvial brown soils characterise the peri-Pannonian area. The hilly-mountainous area is mainly represented by acidic brown and brown soils. In the geospace of Eastern Herzegovina, lithosols and regosols have developed, while the area of karst fields is characterised by brown soils and terra rossa.

THE GEOPOLITICAL DIMENSION OF THE NATURAL POTENTIALS OF THE REPUBLIC OF SRPSKA

The Republic of Srpska has natural potentials, the rational use of which will determine both overall socio-economic development and the quality of its geopolitical position. The most significant natural potentials are represented by the forest complex, hydropotential, agricultural land, mineral and ore resources, and climatic conditions.

The forest complex amounts to a total of 1,112,063 ha, or 45.13% of the total area of the Republic of Srpska. Within the forest structure, the largest areas are covered by mixed broadleaf and coniferous forests, 773,196 ha or 69.53%, while pure stands account for 338,867 ha or 30.47% of the total territory under forests. The state enterprise "Šume Republike Srpske" manages 798,606 ha of forest-covered area [7].

The largest timber reserves in the western part of the Republic of Srpska are found in the areas of the following administrative-territorial units (zones): Ribnik – Mrkonjić Grad – Šipovo, as well as parts of the municipalities of Istočni Drvar, Kupres in RS and Drinić, followed by the area of Mount Kozara (Gradiška, Kozarska Dubica and Prijedor) and the areas of the municipalities/city Kneževo – Kotor Varoš – Teslić. In the eastern part, the richest timber mass is possessed by the following areas:

a) the Romanija and Middle-Drina municipalities (Han Pijesak, Sokolac, Pale, Rogatica, Višegrad), b) the Upper-Drina area (Foča, Čajniče, Rudo and Kalinovik) (Figure 1, [8]).

The importance of the forest complex is considerable, as it provides raw materials and plays a significant role in the economic development and biological diversity of the geospace. The exceptional value of forest areas is also contained in the importance of their ecosystems. Forests, as a renewable resource, are of invaluable geopolitical value, therefore, the establishment of protection systems, monitoring of their health condition, as well as the development of a sustainable development concept and a strategy for forest resource management represent one of the primary obligations of the executive authorities in the Republic of Srpska.

The concept of sustainable development emerged in the early 1970s as a response to changes caused by the endangerment of natural resources, within which the forests of Europe and the world play a significant role. The three basic components of sustainable development are environmental protection, economic development, and social equity. In order to enable the implementation of sustainable development, the Rio de Janeiro Summit in 1992 adopted a global sustainable development plan through Agenda 21. Sustainable development represents the improvement of living conditions in such a way that key natural and social resources are maintained and developed over the long term [9]. The basic premises of sustainable development are founded on the rational exploitation of natural resources, efficient use of space, economic and technological efficiency, humanity, demographic development, and the protection and improvement of the environment. The leading principle of sustainable forest management is to encourage development that meets the needs of the present while enabling future generations to meet their own needs.

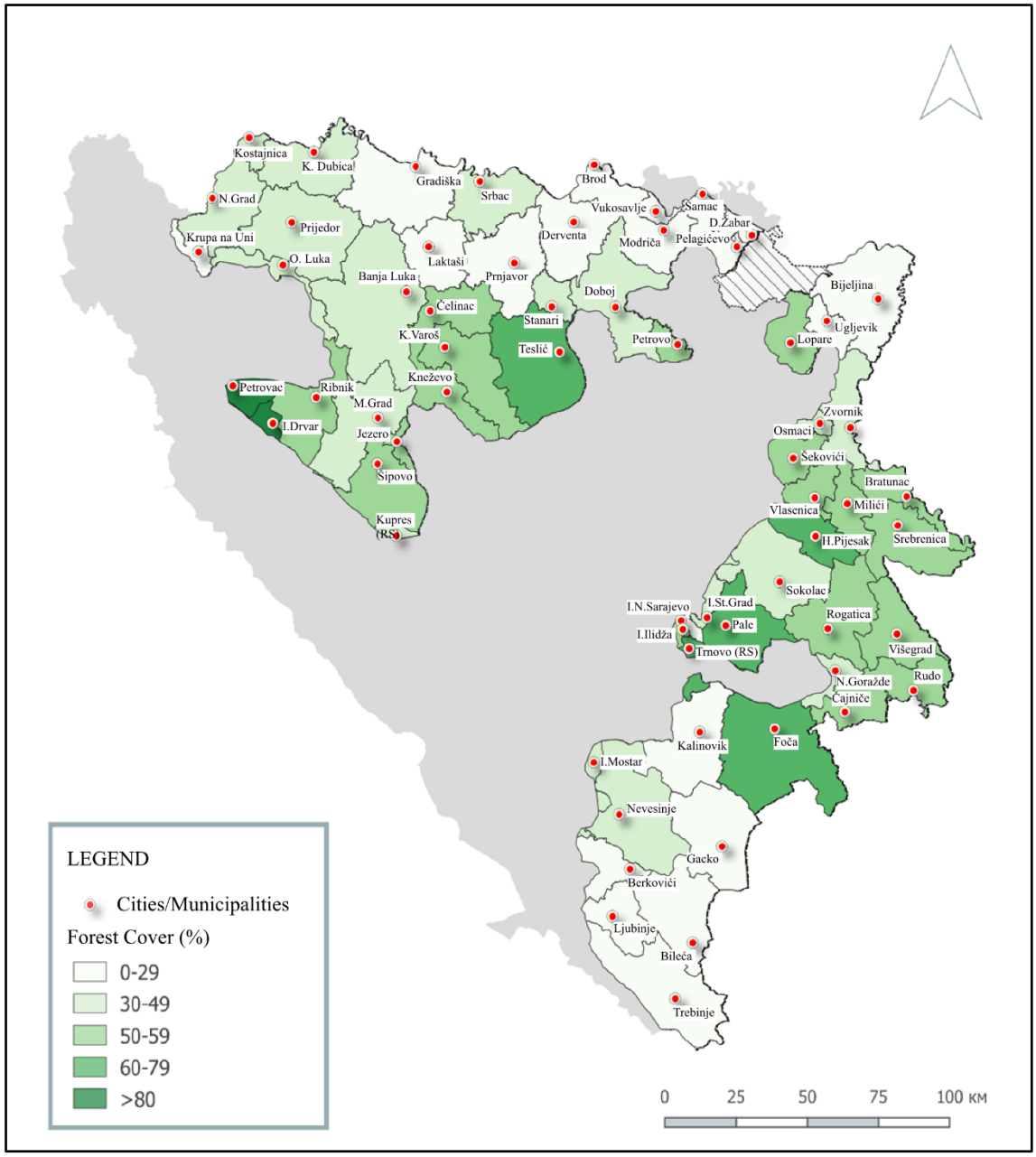


Figure 1. Forest potential according to administrative-territorial units of Republika Srpska

The Republic of Srpska is characterised by an abundance of water of excellent quality, and therefore water potential, together with the forest complex, is considered the most important natural development resource. The hydrographic network consists of lowland, mountainous and karst rivers, natural and artificial lakes, as well as thermal and mineral springs.

The hydrographic network belongs to the Black Sea and Adriatic Sea basins. The watershed between these two basins extends approximately along the mountain peaks of: Lebršnik – Čemerno – Zelengora – Lelija – Treskavica – Bjelašnica – Bitovnja – Makljen – Raduša – Cincar – Šator – Dinara. In karst areas, the watershed is not orographic, but is conditioned by a developed underground hydrography [10]. The axis of the Black Sea basin is the Sava River, which flows along the northern border of the Republic of Srpska for about 190 km (from the confluence of the Una River in the west to the Drina River in

the east). The course of the Sava River lies at a low elevation, and thus all major rivers of the Republic of Srpska flow into it (the Una with the Sana, Vrbas, Ukrina, Bosna and Drina). These rivers have composite valley characteristics with significant gradients and possess considerable hydroenergy potential (the Una, Vrbas and Bosna rivers about 14.3 billion cubic metres annually). Nevertheless, the hydroenergy potential of these rivers cannot be compared with the hydropotential of the Drina River. The Drina River is the largest tributary of the Sava. Its length amounts to 341 km, and the catchment area covers approximately 19,570 km² [11]. The south-eastern area (Eastern Herzegovina) hydrographically gravitates towards the Adriatic Sea, with the Trebišnjica River as the most significant watercourse. Unlike river flows, the Republic of Srpska is relatively poor in other water surfaces. It does not possess larger natural lakes, but has artificial hydro-accumulations on the Vrbas, Drina and Trebišnjica rivers, primarily aimed at the exploitation of hydroenergy potential.

The importance of hydrographic potential is based on the possibilities of hydroenergy exploitation and electricity production, since the hydropotential of rivers, together with coal reserves, forms the basis of electricity production in the Republic of Srpska. The estimated hydropower potential amounts to around 10,000 GWh annually, of which about 35% is utilised (HPP Višegrad, HPP Trebinje 1, HPP Trebinje 2 and HPP Bočac), as well as several smaller hydropower plants: HPP Bočac 2, Bogatići, Mesići, Tišća and Vlasenica. The Dubrovnik HPP is located on the territory of the Republic of Croatia and utilises the hydropotential of the Trebišnjica River basin. The production of this plant is currently shared in a 50:50 ratio between the Electric Power Utility of the Srpska and the Croatian Electric Power Utility.

Different geological structures and the composition of geotectonic units, as well as the heterogeneous hydrogeological function of rock masses, have influenced the formation of diverse aquifers. The southern part of the Pannonian Basin is quantitatively the richest in groundwater.

It is estimated that Srpska possesses around 80% of the estimated exploitable quantities of groundwater in Bosnia and Herzegovina. Posavina, with the lower courses of the Una, Vrbas, Bosna and Drina rivers, is quantitatively the richest groundwater region. Localities are found in Lijevče Polje, the wider area of the City of Bijeljina, and in the alluviums along the Sava River and the lower course of the Bosna River [12]. Numerous studies have shown the richness in mineral and thermo-mineral waters. These waters are mainly used for balneological and recreational purposes. On the basis of these potentials, several spa-recreational centres have already been built and established.

The hydrographic network provides broad opportunities for irrigation of arable land, development of fisheries, possibilities for river transport, and the promotion of fishing and spa tourism. Considering increasingly frequent scientific warnings about future crises in drinking and industrial water supply at the global level, hydropotential will gain even greater geopolitical importance and, alongside forest potential, is rightly considered the most important development resource of the Republic of Srpska.

The total area of *agricultural land* amounts to approximately 977,000 hectares [13], which represents around 40% (39.65%) of the total area of the Republic of Srpska. Utilised agricultural land accounts for about 401,269 ha (arable land and gardens 190.771 ha, orchards 21,682 ha, vineyards 647 ha, meadows 115,747 ha, pastures 72,422 ha) [7]. The entire lowland region possesses conditions for intensive crop and mixed crop-livestock production. Hilly-mountainous areas have ideal conditions for the development of fruit growing, while the region of Eastern Herzegovina is suitable for viticulture and

the cultivation of Mediterranean crops. Pastures and meadows in mountainous areas provide opportunities and a basis for livestock farming.
From a political-geographical perspective, food production, in addition to its existential dimension, has great geopolitical significance in the state planning strategy.
Ore and mineral raw materials, their significant reserves and diversity as natural potentials, should have a greater role in future economic development. There are realistic geological and mineral-genetic assumptions for the discovery of new deposits and the quantitative increase of existing reserves.
Lignite and brown coal are exploited in the mines of Ugljevik, Gacko, Stanari and Miljevina. Their total reserves are estimated at around 700 million tonnes. Iron ore is present at two locations: Ljubija–Omarska and Mokra Gora–Vardište. Confirmed reserves amount to about 350 million tonnes, and based on analyses of ore-bearing formations in the Ljubija locality, the metallogenetic potential is estimated at 800 million tonnes of new ore reserves. Manganese ores have been registered in the area of Mount Ozren, as well as in the surroundings of Šekovići, Čelinac and Rudo. Bauxite mines near Milići and Vlasenica form the basis for alumina production in the "Birač" factory in Zvornik. With their exploitable reserves (around 55 million tonnes), they represent the backbone of non-ferrous metallurgy development. Lead-zinc ore is exploited near Srebrenica (the Sase mine) [2]. There are several oil-geological potential sites, related to the areas of Posavina, south-eastern Herzegovina and Semberija. The exploration and exploitation of non-metallic raw materials are far behind the potential of these resources.
Climate, as a natural potential, is increasingly gaining a geopolitical dimension in the time of global climate change. Having four seasons within a relatively small territory such as the Republic of Srpska represents a geopolitical resource.

FOREST POTENTIAL AS A POLITICAL-GEOGRAPHICAL CATEGORY

The geospace of the Republic of Srpska is covered by forests at about 45%, which places it among political-territorial communities with a respectable (significant) forest potential. Forest cover varies from 10–15% in lowland areas (Lijevče Polje, Posavina, Semberija) and 20–30% in hilly areas, while in the hilly-mountainous areas of the inner Dinarides it ranges between 30–70% of the surface area, with forest cover composed of tall trees being least expressed in Eastern Herzegovina. Deciduous forests account for about 80%, and coniferous forests about 20% of the total forest fund.
The forest vegetation of Srpska can be divided into several belts: the belt of marshwetland ecosystems, the belt of floodplain forests, the belt of oak forests, beech forests, mountain pine forests, and sub-Mediterranean forests. The most widespread forest complexes are represented by oak forest areas. They extend across lowlands and lower hilly northern areas. Pedunculate oak is present in the north, along the banks of the Sava River and its larger tributaries (the Drina, Bosna, Ukrina, Vrbas and Una). On hilly terrains further south, forest communities of sessile oak and common hornbeam are found. Smaller localities of sessile oak and common hornbeam are also encountered in Eastern Herzegovina. Belts of beech forests, followed by fir and spruce forests, occupy the pre-Dinaric and Dinaric phytogeographical areas.
Thus, in higher mountainous areas, a mixed forest community of beech, fir and spruce has developed, where the main companions of beech forests are communities of maple, elm, ash and others. These forests are more represented in the eastern part (Mountains Majevica, Romanija, Jahorina, Treskavica, Zelengora) than in the western part of the

Republic of Srpska (Mountains Klekovača, Vitorog, Dimitor, Lisina, Čemernica, Vlašić, Borja, Ozren). Mountain pine forests represent the upper altitudinal limit of forests. Sub-Mediterranean vegetation characterises the area of Eastern Herzegovina and appears in the form of maquis. Sub-Mediterranean forests of downy oak, Turkey oak and black ash are today practically degraded. Within forest vegetation areas, particularly in hilly-mountainous regions, significant surfaces are covered by grass vegetation (meadows and pastures) [14].

Forests of the Republic of Srpska are categorised according to stand types, distinguishing pure stands (broadleaf or coniferous) and mixed stands (mixtures of broadleaf species, coniferous species, or both).

Within the forest structure, the largest area relates to mixed broadleaf-coniferous stands, 773,196 ha or 69.53%, while pure stands account for 338,867 ha or 30.47% of the total territory under forests. Representation and distribution by stand type are further categorised by ownership: state and private. Approximately 70% of forest-covered areas are managed by the state enterprise (Table 2, [7]).

Table 2. Forest areas – state as on 31 December 2024 (ha)

	Forest areas by type of ownership		
	total	in state ownership	in private ownership
TOTAL	1 112 063	798 606	313 457
Pure stands of	338 867	271 823	67 045
Broadleaves	303 777	243 499	60 278
Conifers	35 090	28 324	6 767
Mixed stands of	773 196	526 783	246 412
Broadleaves	449 947	234 888	215 058
Conifers	85 857	81 031	4 827
Broadleaves- Conifers	237 392	210 864	26 527

The largest share of forest area and forest land in the Republic of Srpska (state forests), according to categorisation, consists of high forests with natural regeneration (about 47%). This is followed by coppice forests with 23%, areas suitable for afforestation with 15.3%, areas unsuitable for afforestation with 6.9%, forest cultures with 4.8%, as well as 1.3% high degraded forests and 1.9% usurped forests and forest land (Table 3, Figure 2, [7]).

Table 3. Forest areas and forest lands by forest category, state forests – state as on 31 December 2024*

BROAD CATEGORY	AREA (ha)	%
Total	1 001 977	
High forests with natural regeneration	469 120	46.82
High degraded forests	13 381	1.34
Forest cultures	47 900	4.78
Coppices	230 494	23.0
Areas appropriate for afforestation and management	153 456	15.32
Areas inappropriate for afforestation and management	68 851	6.87
Usurpation	18 775	1.87

*Data taken over from hte cadastre of areas of the public enterprise „Šume Republike Srpske"

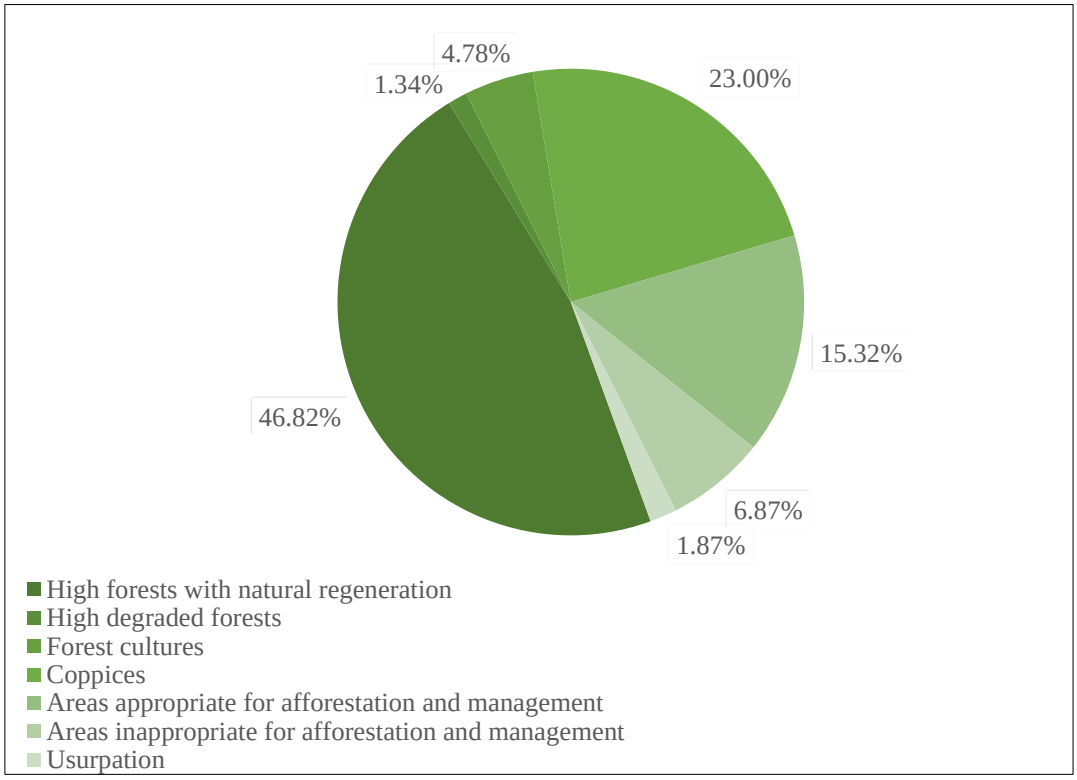


Figure 2. Forest areas and forest lands by forest category, state forests (%)

Forests in the Republic of Srpska are standardised through the international FSC certification (The Forest Stewardship Council™ – FSC). The objective of the FSC programme is to promote environmentally responsible, socially beneficial and economically sustainable management of forest complexes worldwide by establishing general standards and principles of sustainable development. Through the application of these principles, efforts are made to manage the forest fund [15].

The basic objectives of forestry policy in the Republic of Srpska are as follows:

- Preservation and improvement of forest conditions;
- Development of forestry as an economic sector and increasing its contribution to economic and social development;

- Development and maintenance of forest protection systems;
- Protection of forest ecosystems as natural assets and sustainable use of the biological diversity of forest resources;
- Valorisation and preservation of the cultural and social functions of forests;
- Economic profitability of the state forestry sector, in accordance with ecological and social requirements and sustainable development;
- Ensuring an efficient support system for private forest owners;
- Contribution to economic development, advancement of forestry and environmental protection;
- Application of multidisciplinary research and development of technologies in forestry and research institutions;
- Establishment of international cooperation in forestry [9].

The gross felled (exploited) timber volume in the forests of the Republic of Srpska in 2024 is lower compared to previous years (2020–2023) and amounts to about 2.5 million m³. Of this, approximately 2.5 million m³ relates to exploitation in the state sector, which is significantly higher than in the private sector and represents more than 90% of the total felled timber volume (Table 4, [4]).

Table 4. Exploitation of the forest complex of the Republika Srpska (thousand m^3)

	Gross felled timber				
	Total	in state ownership	in private ownership	Broadleaves	Conifers
2020	2 950	2 685	266	1 574	1 376
2021	2 890	2 475	415	1 558	1 332
2022	2 965	2 580	385	1 625	1 341
2023	2 789	2 465	324	1 518	1 271
2024	2 568	2 378	190	1 284	1 284

The condition of forests and the forest fund can be improved through management and better monitoring by the institutions of the Republic of Srpska through the following approaches and objectives:

- increasing forest-covered areas and their protection, i.e. afforestation of barren land, accumulation zones, roadside belts and areas around urban cores;
- consolidation of state forest holdings for the purpose of protection and more efficient management of forest belts;
- harmonisation of legislation with international standards and the adoption of improved strategies for the preservation, monitoring and protection of the forest fund.

Observing the current state of forests in the Republic of Srpska, it can be concluded that, from the perspective of a renewable natural resource, the forest ecosystems represent a unique complex. They constitute a national wealth and one of the fundamental potentials of present and future economic development. For that reason, the forest complex must be permanently renewed and utilised in accordance with national development priorities and goals.

In the Republic of Srpska there are officially three national parks, one nature park and three primeval forest reserves:

- Kozara National Park
- Sutjeska National Park
- Drina National Park

- Bardača Nature Park
- Perućica Primeval Forest
- Janj Primeval Forest
- Lom Primeval Forest.

The forest complex has always represented a national wealth and one of the fundamental potentials for present and future geopolitical valorisation, as well as a driver of the economic development of the Republic of Srpska. As a renewable natural potential, forests have a particular geopolitical significance. The problems is the location of the highest-quality forest complexes, which are mainly situated in the inter-entity border area, which still feels the consequences caused by the war conflict (lack of labour force, demographically abandoned and depopulated areas), which limits the possibilities for forest protection and monitoring systems as well as exploitation.

CONCLUSION

Observed through the prism of contemporary historical-geographical processes, but also through the overall historical development of a people and a political-territorial community as a whole, renewable natural potentials in the geopolitical context have been and remain a condition of "remaining" and "survival."

Renewable natural potentials, with their physical and economic characteristics, as well as their ecological, economic and political-geographical significance, represent potentials that condition or limit the sustainable development of a state community, region or society as a whole.

It can be stated that forest potential, as a renewable natural potential, is one of the most significant factors in the geopolitical valuation of the Republic of Srpska. Due to the great importance of forest potential, permanent renewal and responsible management of the forest complex are necessary, all in accordance with national development goals and strategies. Their exploitation should be planned and purposefully controlled, regardless of quantity and type, as they are one of the pillars of the economic development. For that reason, forests must remain preserved for future generations and for the geopolitical future of the Republic of Srpska.

The preceding statements indicate the necessity of developing strategies in the field of forest resource protection and forest management systems. During the development of strategies, analyses and monitoring, it is necessary to engage scientific experts from various fields, with particular emphasis on: risk management and protection of forest ecosystems from drought and fires, construction of irrigation systems, and in general, rational use of forest potential with the aim of more efficient control, as well as adaptation to the consequences of global climate change impacts on forest ecosystems. Among other things, strategy and continuous monitoring are necessary as a scientific basis for assessing and answering the question of whether certain changes in forest potential in the Republic of Srpska are caused by human activities or are the result of global climate change. It is also necessary to devote attention to education, training and raising public awareness about the importance of forest potential through the education system with clearly designed goals.

International cooperation within global environmental protection agreements, carried out within the countries of Southeast Europe and the Western Balkans, should be intensively continued. Joint action regarding the planned and rational exploitation of natural potentials, viewed through the prism of the cross-border concept of regional development,

would represent one of the guidelines for the geopolitical stability of the Republic of Srpska, Bosnia and Herzegovina, and the region as a whole.

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THE DEVELOPMENT OF URBAN-RURAL RELATIONSHIP AT THE EXAMPLE OF THE CITY OF GRAZ/AUSTRIA

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ABSTRACT

The aim of this paper is to use the example of Graz/Austria to illustrate the linkages and interdependencies between the city and the surrounding area and to assess the changes throughout the years. These changes are quantified according to a former study about the "Interaktionsraum Graz" by Wilhelm Leitner [5] with data bases from the year 1978. It should be demonstrated that the interaction area is highly dynamic.
The urban–rural relationship describes the complex interactions between cities and their surrounding areas. These relationships have become increasingly important as urban regions continue to expand and connect more closely with rural communities. Traditionally, cities served as centers of employment, education, and services, while rural areas provided agricultural products, open space, and natural resources. This creates strong functional linkages based on mobility, infrastructure, and economic exchange.
Overall, effective urban–rural relationships contribute to sustainable regional development. By recognizing their interdependence and fostering collaboration, cities and their hinterlands can achieve balanced growth, preserve natural resources, and improve quality of life for residents across the entire region.
The result shows a strong development of a so called “urban region” with potential for more co-operation but also stronger competition between the city and the prospering municipalities especially in the south of Graz.

Keywords: Urban-rural relationship, interaction area, city-region, selected indicators of relationship.

INTRODUCTION

This paper in hand deals with the relationship between the Austrian second largest city, namely Graz (appr. 300.000 inhabitants) and the surrounding area in regard to selected indicators of interaction. Generally, a city represents the central area and is used to describe as the concentrated area. A central area is characterized by a regional concentration of inhabitants and workplaces, accompanied by corresponding development and infrastructure as well as intensive internal socio-economic interconnections. The term “concentrated area” is often used synonymously with agglomeration area or urbanized area [7]. The defining unit for an agglomeration area is the relationship between population and job density. It must have a minimum population of 150,000 and a minimum area of 110 km² [6]. An alternative term for surrounding area is periphery. In the Diercke Dictionary of Geography, the peripheral area is a commonly used term for rural regions, especially those located far from major cities and densely

populated areas. The expression is intended to avoid the negative associations that might be linked to the term "rural area." Peripheral area indicates that these regions are considered to be on the edge from the perspective of centers of power, far removed from the economic and political centers of a country, and therefore disadvantaged in their economic and social development. Periphery itself is the designation for a location that is regarded as marginal in relation to a center or core area [6]. The fact that cities and surrounding areas should not be considered separately, but rather in an integrative view, is illustrated by the following quote [4]:

"No city could and can ever live and survive without its surrounding area"

There is a mutual dependence between the city as a central area and the surrounding region: while the city provides jobs and infrastructure needed by a population in the surrounding areas, it is the surrounding region that makes the existence and functioning of the city possible in the first place. In addition to water and air, which mostly come from the wider surrounding region, various raw materials, food, energy, and labor are examples of goods that the city needs from the surrounding region. The diverse interactions between the city and its surroundings make it necessary to network these areas and to consider them as an urban region. The population in surrounding areas is needed; in fact, it is the surrounding areas that enable the city to exist and function in this way. In addition to water and air, which usually come from the wider surroundings, various raw materials, food, energy, and labor are examples of goods that the city requires from the surrounding area. The diverse interactions between the city and its surroundings make it necessary to network these areas and to consider them as an urban region [4] [9].
The question arises whether the surrounding area and the city are in competition with each other and to what extent the city and the surrounding area influence one another. Does the countryside benefit more from the city, or the city more from the countryside?
It is clear that (large) cities are currently experiencing a boom, which is due to the economic opportunities in a city (population development of Graz: 1991: 237.810 inh.; 2001: 226.244 inh.; 2011: 261.726 inh.; 2010: 291.731 inh., 2025: 305.3124 inh.). The city and its residents are considered a pull factor for knowledge carriers, who are essential for the generation and application of knowledge in the working world. As a result, the city center is increasingly gaining importance as a place of residence. Voglmann et al. [10] point out that the ever-increasing flexibility required in the working world, for example due to more project-based work and the increasing intertwining of work and private life, leads to commuting becoming less attractive for some.
In this context, one also has to deal with the question of how the core city itself interacts with its immediate surroundings. The process of suburbanization, which has been widely observed in recent decades, is continuously intensifying, leading to more and more people centering themselves outside the city, in the suburbs. The suburb becomes a place of residence, while the offerings of the core city such as education, consumption, or leisure continue to be used [10] [2]. Furthermore, the expansion of (public) mobility also contributes to the shrinking of spatial boundaries. Conversely, growing prosperity and the emergence of different lifestyles and desired ways of living also lead to a certain degree of disentanglement, when various activities (living, working, shopping, provisioning, and leisure) are separated geographically, resulting in a clear functional separation [1].
In the specific case, the city of Graz and its surrounding area, as well as the resulting city-surrounding area relationship, are being examined to see how they have changed since

1979 and Wilhelm Leitner's study [5] (fig. 1) to the present day, and which trends are recognizable in the interaction area. This paper is a short outline of a bigger broadly based study.

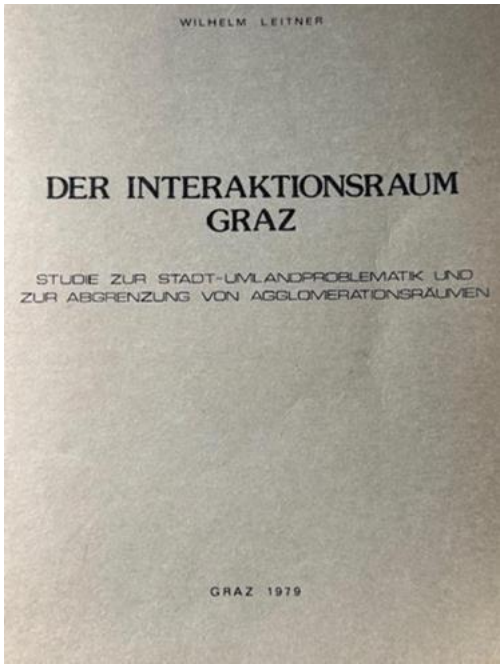


Figure 1. Leitner´s data and results from his study of the year 1979 is the starting point for our comparison period).

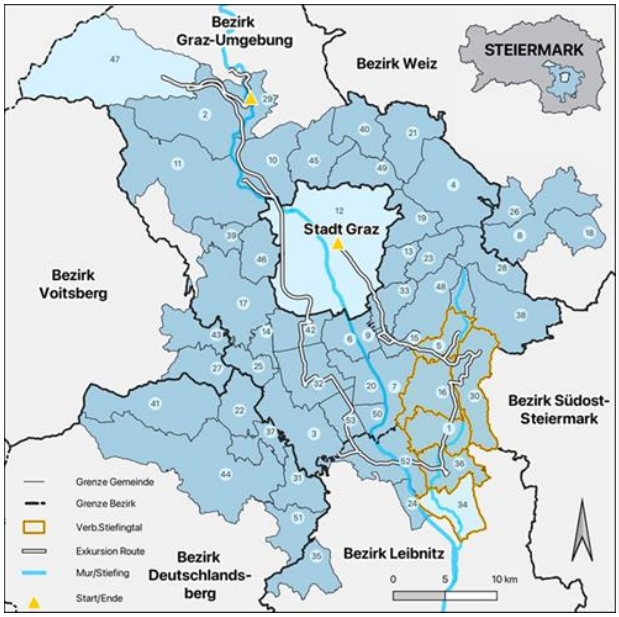
THE GRAZ INTERACTION AREA

Interaction area Graz in the year 1979

In connection with the concept of interrelation space, Leitner mentions the term interaction space. This refers to a space that is influenced by socio-economic and geomorphological factors and has a center that co-determines developments throughout the entire space. Other characteristics of an interaction space include commuting, increased population mobility, different conditions regarding job availability, and a low proportion of employees in the agricultural sector.

In the report "Interaction Area Graz," Leitner [5] analyzed how these city-surrounding area relationships look in Graz and the surrounding regions. The focus is explicitly not on Graz and individual surrounding districts, but rather on the municipalities around Graz, which, according to Leitner, form the Graz surrounding area. What is characteristic of interaction spaces is that they are independent of administrative units and often go beyond administrative boundaries.

The study area consists of a total of 53 municipalities, including the city of Graz. The majority of the municipalities are located in the district of "Graz-Surrounding (Graz-Umgebung)", only a few are located in neighboring districts (fig. 2).



1	Allerheiligen bei Wildon	28	Nestelbach bei Graz
2	Deutschfeistritz	29	Peggau
3	Dobl-Zwaring	30	Pirching am Traubenberg
4	Eggersdorf bei Graz	31	Preding
5	Empersdorf	32	Premstätten
6	Feldkirchen bei Graz	33	Raaba-Grambach
7	Fernitz-Mellach	34	Ragnitz
8	Gleisdorf	35	Sankt Andrä-Höch
9	Gössendorf	36	Sankt Georgen an der Stiefing
10	Gratkorn	37	Sankt Josef (Weststeiermark)
11	Gratwein-Straßengel	38	Sankt Marein bei Graz
12	Graz	39	Sankt Oswald bei Plankenwarth
13	Hart bei Graz	40	Sankt Radegund bei Graz
14	Haselsdorf-Tobelbad	41	Sankt Stefan ob Stainz
15	Hausmannstätten	42	Seiersberg-Pirka
16	Heiligenkreuz am Waasen	43	Söding-Sankt Johann
17	Hitzendorf	44	Stainz
18	Hofstätten an der Raab	45	Stattegg
19	Kainbach bei Graz	46	Thal
20	Kalsdorf bei Graz	47	Übelbach
21	Kumberg	48	Vasoldsberg
22	Lannach	49	Weinitzen
23	Laßnitzhöhe	50	Werndorf
24	Lebring-Sankt Margarethen	51	Wettmannstätten
25	Lieboch	52	Wildon
26	Ludersdorf-Wilfersdorf	53	Wundschuh
27	Mooskirchen		

Figure 2. The map shows the city (Stadt) Graz and the surrounding municipalities. ("Bezirk" means district; "Grenze" means border). Map made by Flor and Außerlechner)

Research Methods

In the study in hand, a multi-method approach was chosen to answer the introductory research questions regarding developments in the Graz interaction area. Multimethod research designs combine qualitative and quantitative approaches, which offers the advantage of applying various methods with different objectives.

A large part consists of literature analyses, with the work of Leitner (1979) on the Graz interaction area in the 1970s serving as a starting point, particularly in relation to identifying and interpreting changes. This study also employs a form of qualitative method, observation. However, the observation was not carried out as strictly scientific observation; rather, various aspects were observed through targeted site visits to the study area. and documented, which had been defined in advance. The focus of the observations was on visual data, which were recorded to capture as many details of the study area as possible. In addition, this work includes thematic maps that were created independently based on calculations and quantitative analyses. The purpose of thematic maps is to graphically represent selected spatial content while also depicting abstract facts, structures, and relationships [3].

Changes in the Graz Interaction Area

The Graz interaction area has changed significantly since Leitner's investigations in 1979. The core city of Graz has remained exactly the same size, but the overall area has greatly expanded in the years up to 2021 in the categories of 'supplementary area' and 'urbanized zone,' while parameters for the categories of the more peripheral municipalities in the Graz surroundings, the 'outlying zone' and the 'far periphery,' are no longer applicable today and have completely disappeared. The slightly larger portion is taken up by the 'supplementary area' zone with 31 municipalities. The 'urbanized zone' consists of 21 municipalities**.**

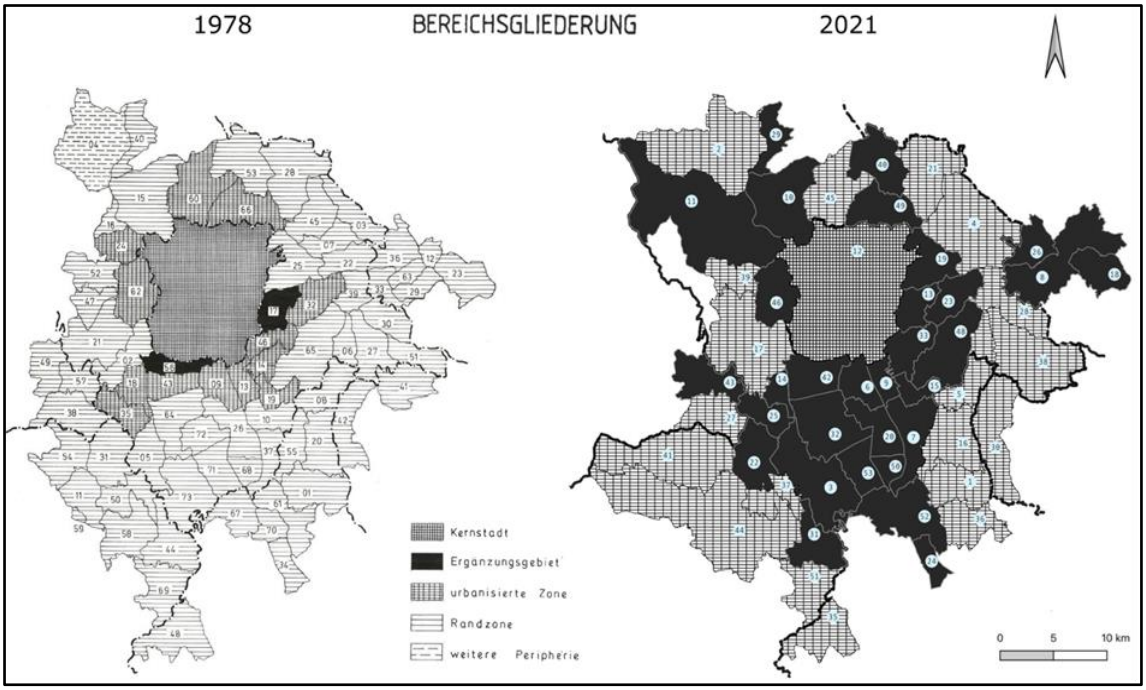


Figure 3. The comparsion between 1978 and 2012 shows the strong development of surrounding municipalities to supplementary area and urbanized zone. Map made by Flor and Außerlechner)

In figure 3 one can see the absolute changes of the categories in square kilometers, followed by a visual representation of the temporal changes of the interaction area with its depicted categories. This already makes it clear that since the publication of the study and up to 2021, there has been an enormous change taken place. The exact derivation of the zoning classification will be discussed in the following chapter.

Changes in Zoning

The Graz interaction area extends south to St. Margarethen and Lebring in the Leibnitzer Field and north to the market town of Peggau. To the east, it stretches over the hills to the Raab Valley near Gleisdorf, including the municipalities of Petersdorf II and Hofstätten an der Raab. To the west, it includes the areas up to St. Johann/Köppling in the Kainach Valley and St. Stefan ob Stainz in the Stainz-Kainach Hills, and in the southwest, it reaches as far as the Sausal. This spatial distribution results from developments along main traffic axes.

Leitner divides the Graz interaction area into five zones. These had been newly calculated in the recent study and compared with the data from 1978 what leads to following quantitative results:

- (1) Core city of Graz (always 128 km^2)
- (2) Supplementary area (increase from 19 km^2 1978 to 626 km^2 2021)
- (3) Urbanized zone (increase from 153 km^2 1978 to 615 km^2 2021)
- (4) Fringe zone (decrease from 807 km^2 1978 to 0 km^2 2021)
- (5) Outer periphery (decrease from 39 km^2 1978 to 0 km^2 2021)

Leitner developed a comprehensive methodology for delineating the Graz interaction area based on urban planning, socio-economic, and infrastructural criteria. The starting point was the calculation of an interaction value, which is derived from the population and the employed workforce at the location per area (in km^2):

$$\text{Interaction Value} = (\text{Population} + \text{Working Population}) / \text{Area (km}^2) \times 100$$

The assessment of the zones was carried out by calculating average values for key indices such as population density, employment structure (agriculture and service employment rate), and commuter rate. These average values served as a benchmark to classify the individual municipalities according to their conformity with the respective zone types. Another indicator used by Leitner is the agricultural rate, which refers to the proportion of the population dependent on agriculture. Due to the currently marginal role of agriculture and difficulties in obtaining up-to-date data, this indicator was excluded.

Since the classification in 1979, the spatial and socioeconomic structures around Graz have changed significantly. Processes of (sub-)urbanization, technological advances, and social change have intensified the interactions between the city and its surrounding areas. New transport networks and settlement expansions have led to earlier zones becoming more mixed. Today, many areas that were once peripheral or supplementary zones have been almost entirely integrated into the urban area through suburbanization. For example, if the criterion cited by Leitner, the share of employment in the agricultural sector, is applied, it turns out that all municipalities considered in the study area would have to be assigned to the first three zones. Only 18 municipalities have an agricultural employment rate of over 10%, with Sankt Andrä-Höch having the highest rate at 22.9% of employees in the agriculture and forestry sector.

No municipality exceeds the 30% that Leitner identified as characteristic for municipalities in the peripheral zone. There have also been significant changes in terms of employees in the service sector, with the lowest proportion of service sector employees found in Lebring-Sankt Margarethen at 23.9%, while this municipality stands out for its unusually high proportion of employees in the industrial sector (75.6%). Only in a few other municipalities, such as Hart bei Graz, Lannach, and Übelbach, is the proportion of service sector employees below 50%. In Leitner's classification, municipalities with over 90% of commuters to the core city are considered part of the complementary zone, while in the peripheral zone less than 60% of employees commute. The variance in the commuter rate has decreased compared to 1979; in 2020, this proportion ranges from 69.5% in Gleisdorf to 88.5% in Werndorf [8]. These demographic and economic changes make the reclassification of municipalities according to Leitner’s criteria more difficult.

The characteristic of population density is also no longer directly comparable due to municipal mergers, as the areas of the municipalities have also changed significantly. Nevertheless, this criterion can be taken into account by considering the current sizes of the municipalities. Therefore, population density, the agricultural employment rate, the service sector employment rate, and the commuting rate are used as the main classification criteria for municipalities for the year 2021.

The allocation was calculated as follows: the municipalities are assigned to groups based on the following logical combinations of characteristics: A municipality belongs to the supplementary area zone if it meets at least three of the following conditions:

1) few workers in the primary sector: $\leq 3.5\%$
2) many workers in the tertiary sector: $\geq 65\%$
3) net commuter balance not strongly negative or positive $\geq -12\%$
4) high population density: ≥ 150 inhabitants/km²

If more than half, i. e. 3 criteria are met, the municipality belongs to the supplementary area.
A municipality belongs to the urbanized zone if it meets at least three of the following conditions:
1) relatively many workers in the primary sector: > 3.5% but < 7%,
2) fewer workers in the tertiary sector: < 65% but > 55%,
3) negative commuting balance - strongly negative: < -12% but > -50%,
4) low population density: < 150 inhabitants/km².

Population Development 1971-2021

According to the 2021 ÖROK survey, both the population of the city of Graz and the district of Graz-Surrounding grew by around 12 percent from 2011 to 2021. This corresponds to the ÖROK regional forecast 2021 to 2050, which predicts that by 2050, large cities and their surrounding areas will experience significant population growth [8]. Particularly in the immediate vicinity of Graz's city center, the population increased disproportionately (fig. 4). Specifically, in the southern part of Graz in the cluster of Seiersberg-Pirka, Premstätten, Haselsdorf-Tobelbad, and Lieboch, population growth of 95-131% can be observed. Similarly, in the Hausmannstätten and Hart bei Graz areas, which are near neighboring municipalities, significant growth can be seen. With 145% and 162%, these two municipalities show the highest percentage increase in our observation area.
The proximity to the city center and the local presence of businesses in the observed communities allow conclusions to be drawn about population development. In the district of Graz-Umgebung, migration is concentrated in the region south of the city center, with occasional outliers in the north. The population development of the municipalities in the Stiefingtal is below average compared to other municipalities. Empersdorf, Heiligenkreuz bei Wildon, and Allerheiligen bei Wildon show moderate inflow, also due to their relative proximity to the city of Graz. The peripheral municipalities of St. Georgen an der Stiefing, Ragnitz, and Pirching am Traubenberg experience even lower development of population.

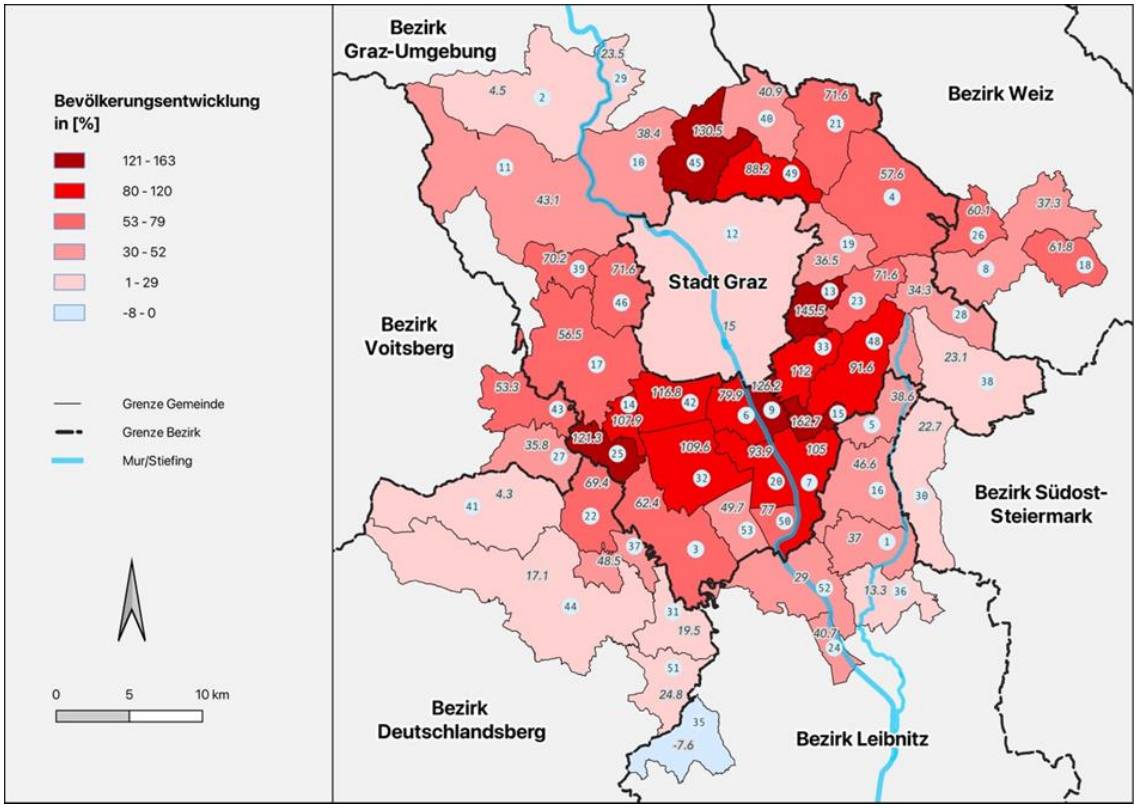


Figure 4. Graz and the surrounding with population development (Bevölkerungsentwicklung). (Map made by Flor and Außerlechner)

Development of Commuter Traffic 1971-2021

The commuter rate consists of people commuting into the town and residents commuting out of it. While municipalities throughout the study area generally have an outbound commuter rate of around 80%, there are larger differences in the inbound commuter rate, which can often be attributed to local companies or larger concentrations of jobs in the area (fig. 5). For example, Raaba-Grambach, located near Graz and marked with number 33 in our study, has an inbound commuter rate of just under 92%. The close proximity to Graz makes the town attractive not only for workers but also for companies looking for industrial locations. For instance, Raiffeisen, Mercedes-Benz, and Magna have all located parts of their company headquarters in Styria in Raaba-Grambach. At the same time, overall commuting patterns have hardly changed, since as early as 1971 most people living in Raaba-Grambach commuted for work. On the other hand, we have purely residential communities, which, although steadily increasing in population, show significantly less commuter frequency. An example of this would be Hitzendorf, which, like Raaba-Grambach, is directly adjacent to Graz. There, the total incoming commuter rate is 41%, while 82% leave the town on their way to work. In the more northern Stiefingtal, commuter traffic has grown strongly to very strongly, whereas the southern communities show zero growth in this respect. The expansion of connections from the Stiefingtal to surrounding communities and to the city center benefits, among others, commuters who can cover longer work routes in a shorter time.

Also noteworthy are municipalities in which, in addition to a variety of companies, there are individual company sites that have high commuter traffic. Strong pull factors for commuters are municipalities such as Seiersberg-Pirka (Seiersberg Shopping Center,

2,100 employees), Premstätten (AMS-Osram, 1,300 employees), or Gratkorn (Sappi, 1,200 employees).

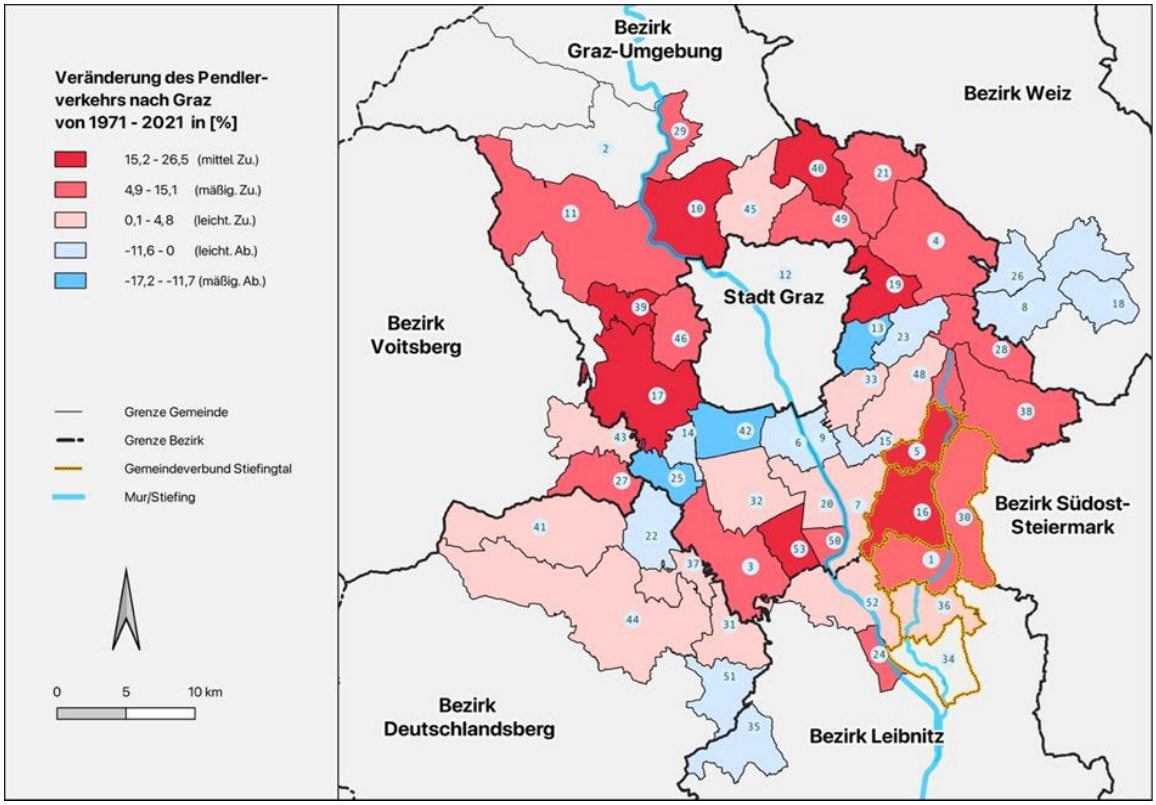


Figure 5. Graz and the surrounding with commuter traffic (Pendlerverkehr).
(Red to blue means from mid increase to stronger decrease of commuter traffic).
(Map made by Flor and Außerlechner)

Land Price Development 1971-2021

A general trend of price increases can basically be observed in property prices. In particular, in Zone 2 of the interaction area in 2021, the expansion zone, prices for land have risen above average (fig. 6). Municipalities in the urbanized zone generally increase at a slower rate than those in direct proximity to the core city, but there are other, although smaller, cities such as Gleisdorf that contribute to a city-suburb relationship and are therefore also more affected by price increases. The distance of the observed municipality from the core city significantly influences the price development of the area. Furthermore, prices also rise sharply with population growth and the increasing attractiveness of core cities themselves, but it should be noted that this is an absolute price increase by factor X. Thus, prices in municipalities that were already at the original survey level of data from 1979 was relatively expensive, rising less sharply than previously unattractive municipalities. Nevertheless, one can observe trends in price increases, as prevailing in the south of Graz and considered alongside the previously discussed population growth, resulting in an interplay between the increases in both land prices and population numbers.

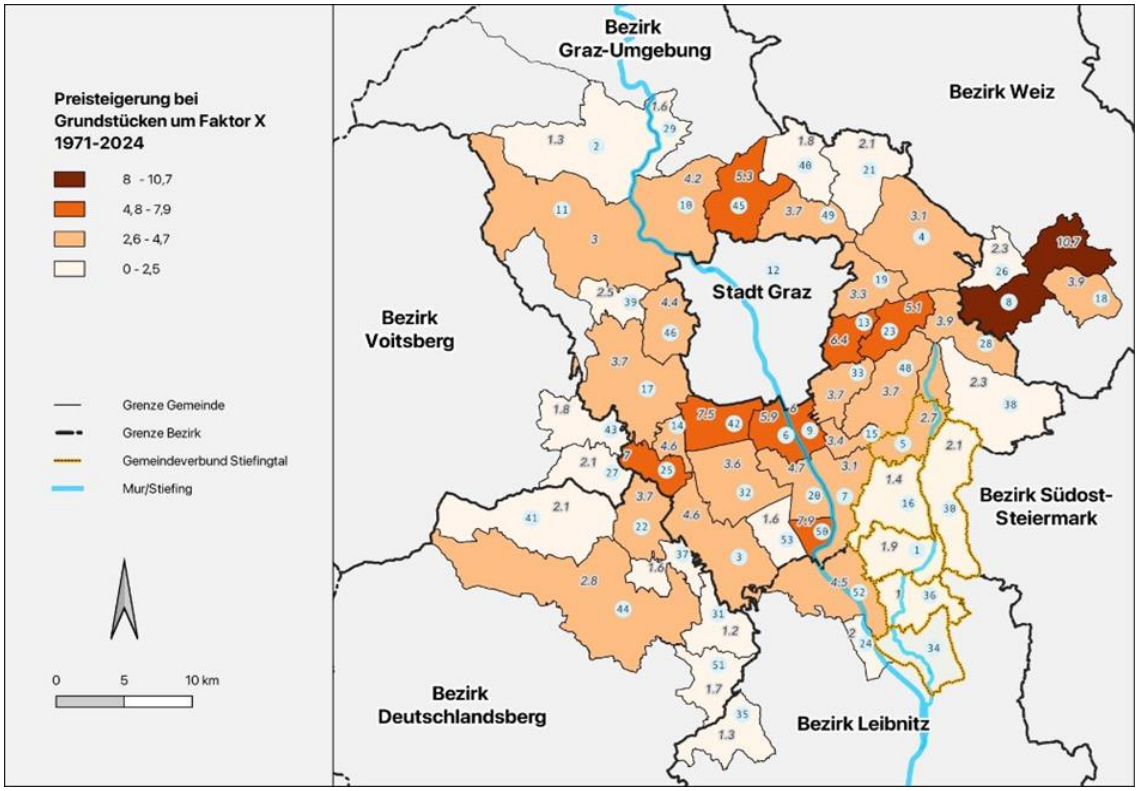


Figure 6. Development of price for land.
(Map made by Flor and Außerlechner)

Current Socioeconomic Structures in the Graz Interconnection Area

Commuter Rate 2021

The commuter rate/balance (fig. 7) of the study area shows that especially the core city of Graz itself, Raaba-Grambach, and Lannach have a strong surplus of commuters. This is due to the location of large employers, which represent strong pull factors for commuters. Other municipalities in the immediate vicinity of Graz show partly small increases in the commuter rate, while other municipalities adjacent to Graz to the west of the core city show strong deficits in the rate. There are few municipalities with a neutral commuter rate; most municipalities show a strong deficit, with few having a slight surplus, and the three aforementioned municipalities showing a very strong surplus.

The municipalities of the Stiefingtal area all show a strong commuter deficit, with the distance to the core city acting as a trigger for the decreasing deficit with increasing distance can represent, as the workers tend to pursue local jobs rather than commuting to more distant places.

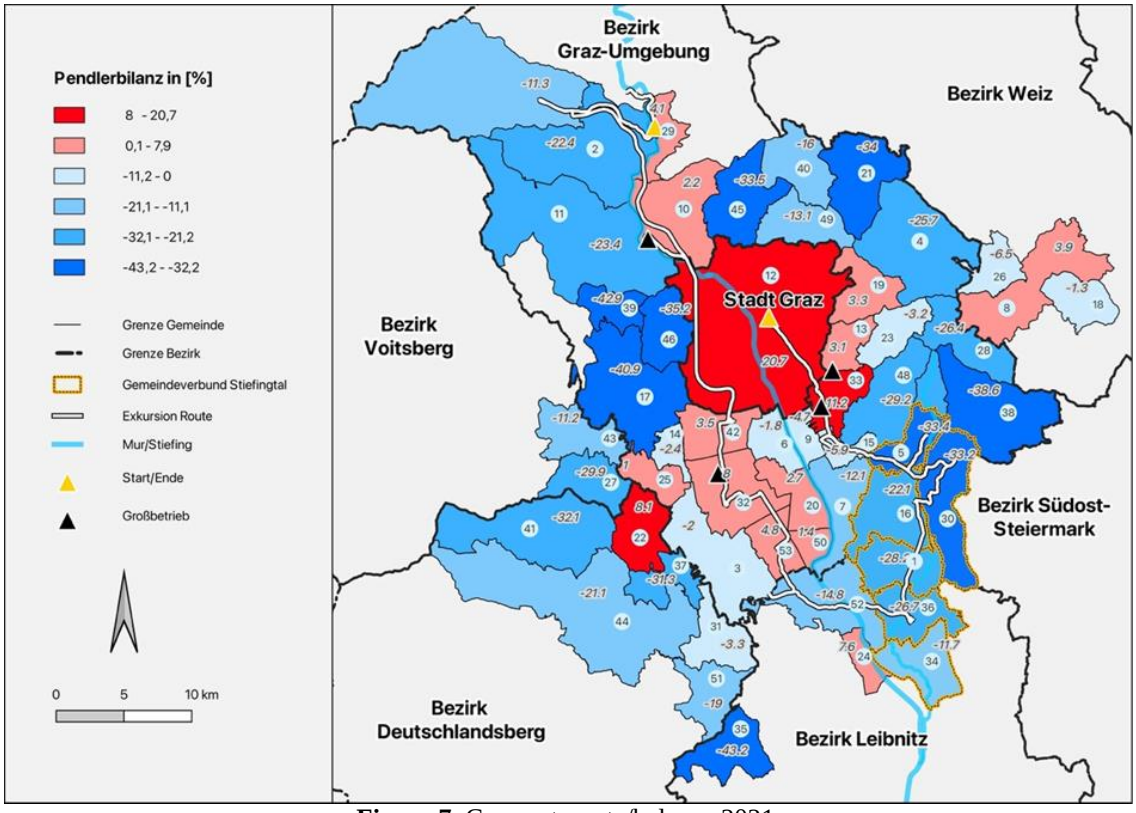


Figure 7. Commuter rate/balance 2021.
(Map made by Flor and Außerlechner)

Agricultural Employment Rate 2021

The agricultural employment rate (fig. 8) has decreased overall in the study area. Only three peripheral municipalities - Übelbach, St. Stefan ob Stainz, and St. Andrä-Höch - have more than 5% of workers employed in agriculture and forestry. The further one moves away from the core city of Graz, the more workers there are in the agricultural sector, and vice versa. The city of Graz has the lowest rate with 0.3% of workers, and the municipalities south of Graz itself mostly have around 1-2%. The eastern part of Graz's surrounding area, including the Stiefingtal, consistently has around 3% of workers in agriculture and forestry, while the area around Gleisdorf shows a decline again.

The Stiefingtal region has a very uniform agricultural employment rate, with all municipalities in the range of 3.3-4.3%, placing them in the upper middle range compared to the other municipalities in our study area. This presents a strong contrast to the neighboring municipalities in the west, which already show significantly less agriculture.

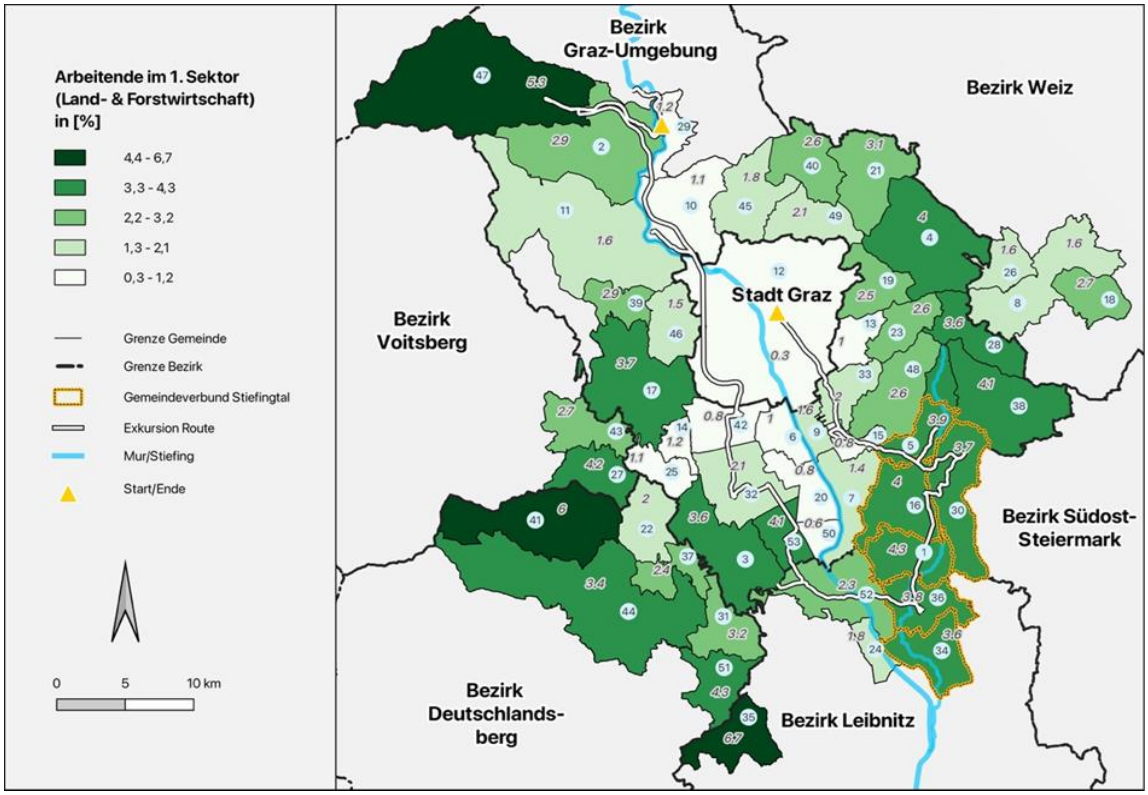


Figure 8. Agricultural employment rate (Arbeitende im 1. Sektor, Land- und Forstwirtschaft). (Map made by Flor and Außerlechner)

Service Employment Rate 2021

The service employment rate (fig. 9) shows that the core city of Graz, along with the neighboring communities to the north and east, has a very high service rate of over 80%. Communities in the south of Graz have a lower service rate than what would be expected from the previously shown agricultural employment rate, as the industrial sector is concentrated there. Furthermore, the tertiary sector also decreases the further one moves away from the core city or from other densely populated communities. Nevertheless, the rate itself remains very high, with the lowest category at 58%.

The service rate in the communities of the Stiefingtal is mixed. While communities like Allerheiligen bei Wildon (1) still record a higher rate, the community in the Stiefingtal is practically a hotspot for services. Directly adjacent communities Heiligenkreuz am Waasen (16), Pirching am Traubenberg (30), and Sankt Georgen an der Stiefing (36) are already in a lower category, and the distant communities of Empersdorf (5) and Ragnitz (34) also one category lower.

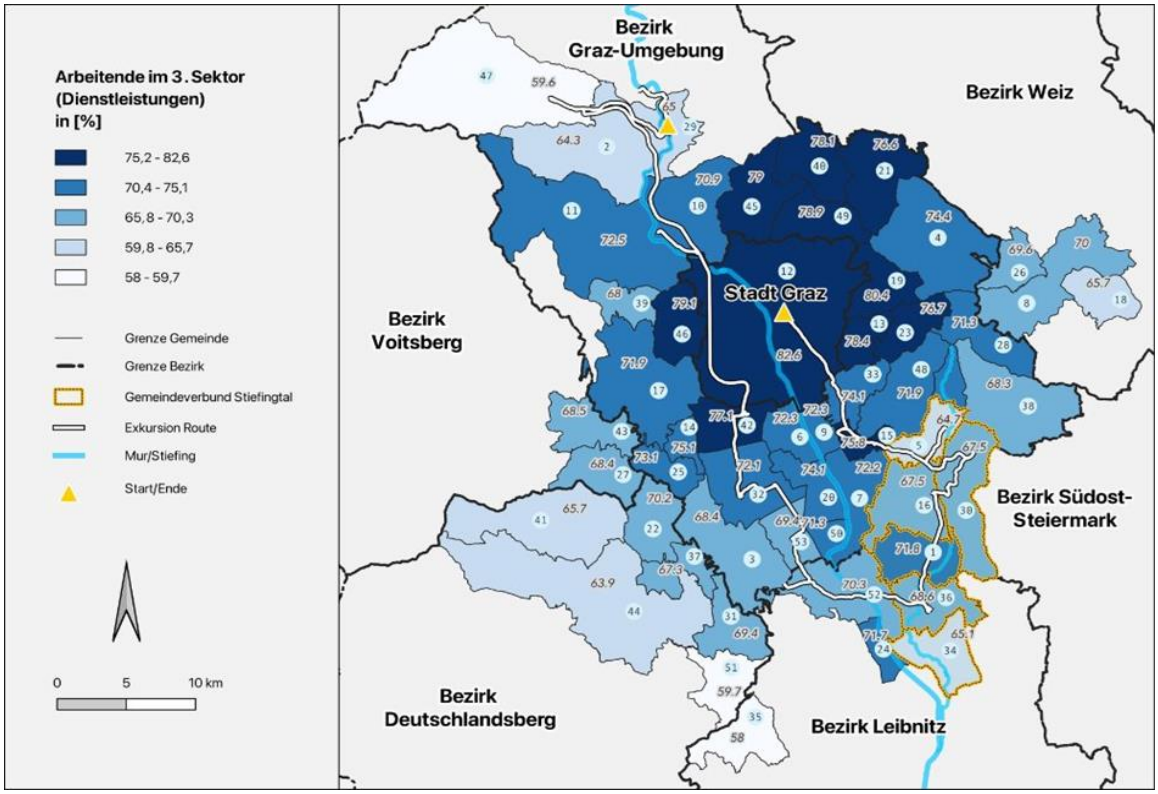


Figure 9. Service employment rate (Dienstleistungen, 3. Sektor).
(Map made by Flor and Außerlechner)

Primary School Density 2021

The availability of schools, primarily primary schools, is an important factor in family planning and often influences the migration of people into communities. For compulsory schools, one must always consider the school districts, which usually coincide with municipal boundaries and rarely differ, for example, when they follow the municipal boundaries prior to the 2015 municipal structural reform. Thus, primary school density is an indicator of the educational offerings at the primary level in individual municipalities. At Statistics Austria, both the number of primary school students per municipality and the absolute number of primary schools in the municipality are recorded (fig. 10). This allows for an assessment of the relative availability of primary schools in the municipalities. A high value in Fig. X indicates a relatively high availability of primary schools. Clear regional differences are visible. Dark blue municipalities have a high school density (1.6 – 1.9 schools per 100 children), while light blue to white areas indicate a lower or minimal school density. Noteworthy are the balanced to high school densities in the peripheral areas, which indicate good accessibility to schools there. In particular, some northern and southern municipalities show a high density, partly due to smaller school locations but also a lower number of students. In areas close to the center, school locations are more centralized, which reduces the density and sometimes results in longer school journeys for children. In the Stiefingtal municipal association, there is a very varied school density: while some municipalities have a high number of schools relative to the number of children, others have significantly lower provision. This may be related to close networking and possible cooperation between municipalities to secure the educational infrastructure. Especially in rural areas, where school commutes are playing

a central role. A municipal association can offer strategic advantages, for example by optimizing school bus routes or promoting jointly used school locations.

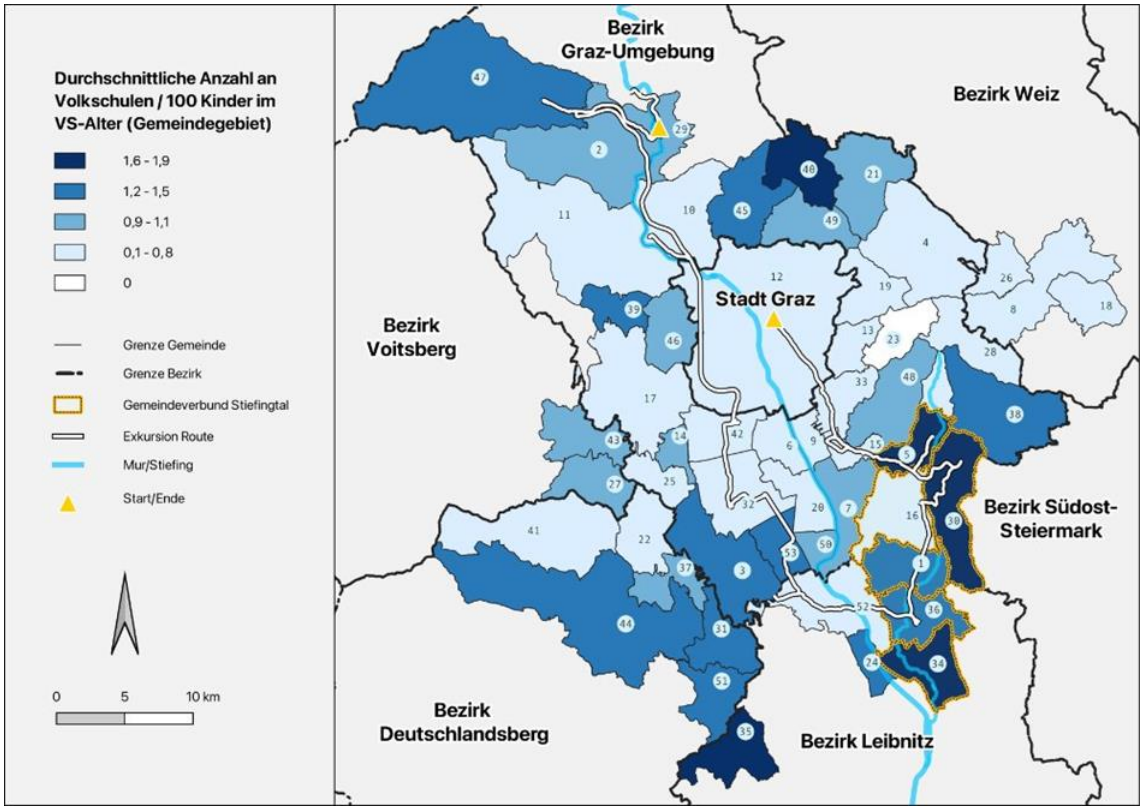


Figure 10. Average amount of primary schools per 100 pupils within municipalities.
(Map made by Flor and Außerlechner)

Medical Care Area 2021

Medical care in the study area is measured based on the density of general practitioners. The values show how many general practitioners are available per 1,000 inhabitants in the municipalities. Noticeable are the individual gaps with a density below 0.4, while peripheral municipalities such as Ragnitz in the Stiefingtal have a density of over 2. The individual hotspots in density are partly due to the generally low population in the municipality, while in more populous areas like Lieboch, group practices raise the average. The northern part of the study area generally shows a slightly higher density than the south (fig. 11).

The majority of municipalities in the Stiefingtal are in the mid-range in terms of doctor density. Visible outliers are the municipality of Heiligenkreuz an der Waasen with a very low density, and Ragnitz with a comparatively very high doctor density. Due to the generally low population density of the area and the surrounding physician density, it can be assumed that local medical care is also covered by them.

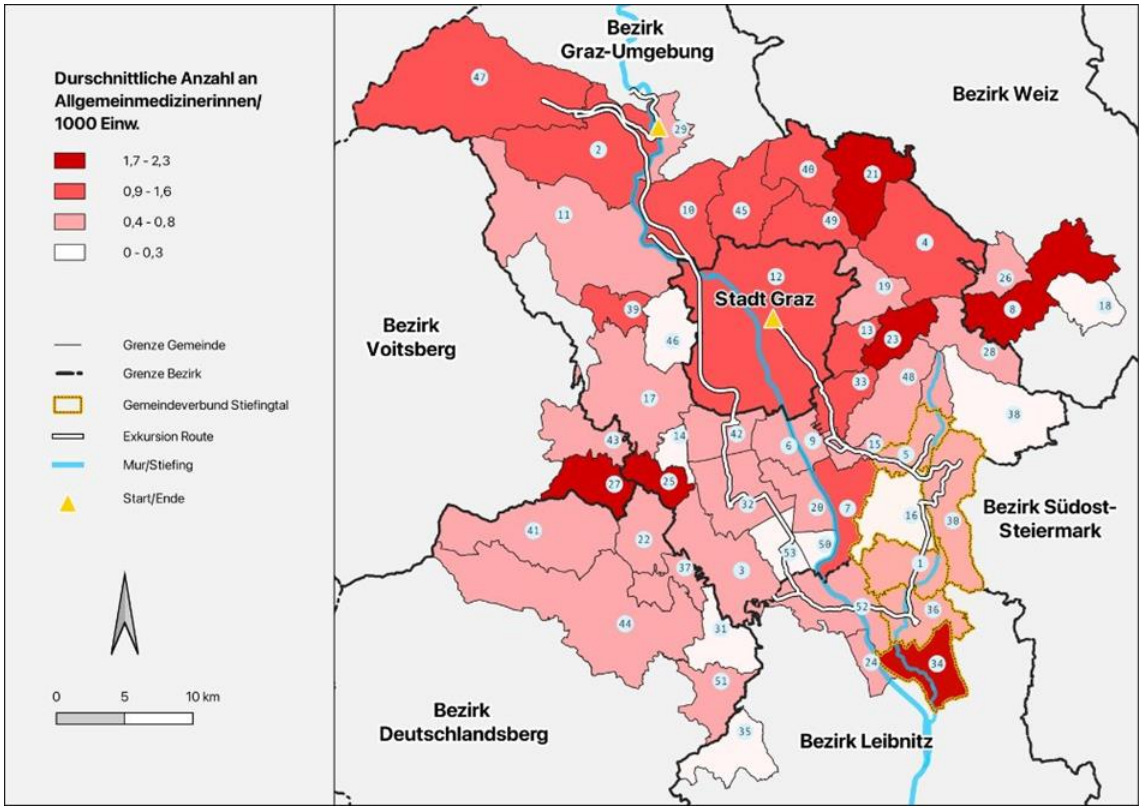


Figure 11. Average amount of doctors per 1000 inhabitants.
(Map made by Flor and Außerlechner)

Supermarket Density 2021

The supermarket density is calculated in relation to the area of the municipalities (fig. 12). "Low" means that a supermarket is on average more than 4 km away. "Medium" means that the supermarket is on average no more than 4 km but at least 2 km away, and "High" indicates that the supermarket is on average less than 1.5 km away. The supermarket density and accessibility are high in the city center and Seiersberg-Pirka, while only in individual other municipalities is this availability medium. Most municipalities in the study area have low availability, with some, mostly peripheral municipalities, having no local supply within the municipal area. Local supply in the Stiefingtal is average to below average, with no municipality in the "medium" or "high" categories. The low availability of supermarkets suggests not only longer driving distances but also closing of smaller shops in the inner parts of villages and a strong commuting between the outer periphery and the urbanized zone. The case of Seiersberg-Pirka, a supermarket exactly at the border between the city of Graz and Seiersberg-Pirka municipality regularly leads to disputes. This might also be one of some other reasons why there is more and more vacancy of shops in the inner city of Graz (fig. 13).

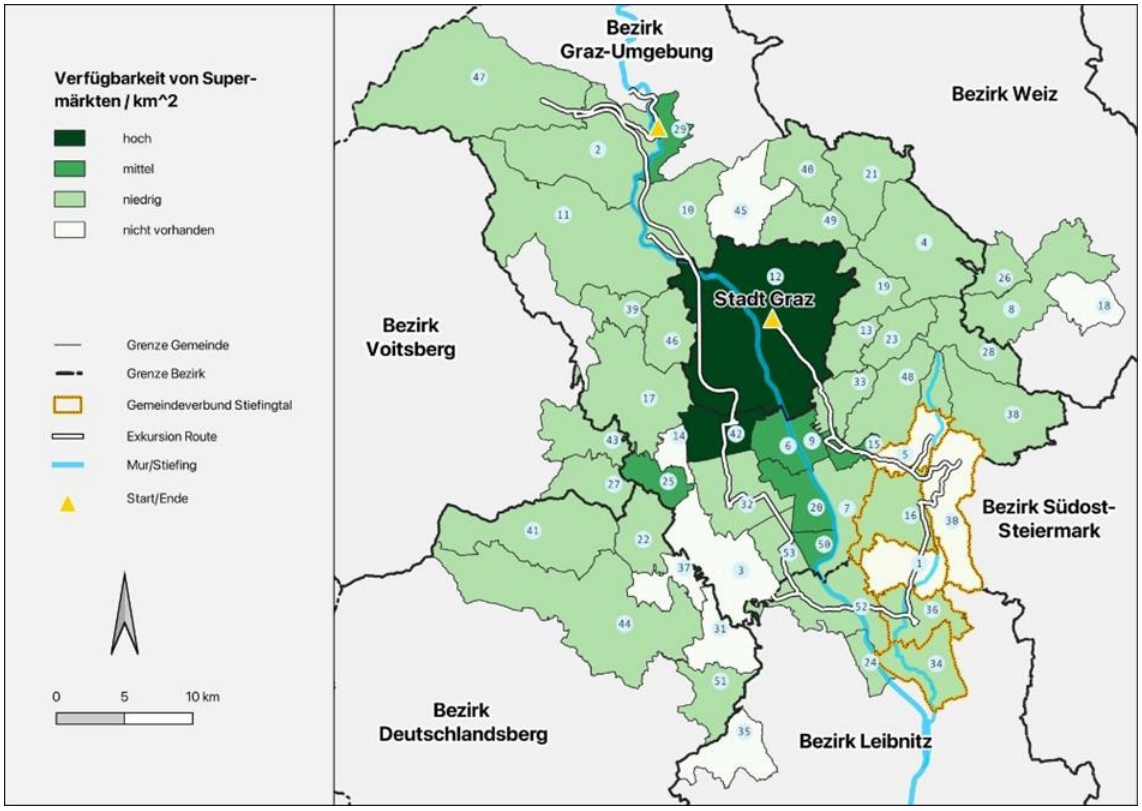


Figure 12. Availability of supermarkets. (from dark green: high to bright green low; white: none). (Map made by Flor and Außerlechner)



Figure 13. Vacancies in the inner city of Graz and booming highly frequented shopping center in the neighboring municipality Seiersberg. (Photo W. Fischer and google earth)

Field Survey

As part of the internship, a field survey was conducted. This took place on Thursday, November 28, 2024, from 9:00 AM to 4:00 PM. The survey aimed to examine the city-surroundings relationship of the Graz interaction area and its surroundings. The focus was, among other things, on the fulfillment of functions of individual municipalities and the resulting functional separation. Due to the vastness of the study area and the distance between the different locations, the majority of the excursion was conducted by car, while the on-site survey was carried out on foot. The starting point was Peggau train station north of Graz, and the route went from north to south and back to the city center. To maintain a consistent thread, not every stop of the field survey is treated with the same level of detail. The focus is mainly on peculiarities. The first stop was in Übelbach, the

northeastern most municipality of the study area. Noteworthy here was the size of the municipality, with just under 2,000 residents. The availability of land can also be seen in the municipality's agricultural employment rate. Furthermore, the company "Gaulhofer" in Übelbach was notable, as it significantly contributes to the city-suburb relationship of the municipality with Graz, since employees come not only from the surrounding area but also from Graz itself. This was confirmed through a parking lot survey and the examination of license plates in the company parking lot during working hours. The next municipality studied, Gratkorn, located to the north adjacent to Graz, differs significantly. Due to its proximity to the core city and with companies such as Sappi and NXP Semiconductors, the municipality has a positive commuter balance. Clear signs of urbanization are also evident in the structure, with increased sealing and soil compaction. An investigation of the characteristics of the employees was not possible due to the fences around the company parking lots. Subsequently, we visited the Seiersberg Shopping Center in Seiersberg-Pirka as an example of a municipality in direct competition and proximity to the core city. Located close to the core city, the Seiersberg Shopping Center has been a point of contention in the relationship between the core city and the neighboring municipality for years. In addition, the supply of jobs makes the shopping center the most important employer in the municipality, leading to a positive commuter balance.

The second part of the field survey was the route into the Stiefingtal. There, one could clearly recognize the regionalization and distance to the core city. The function of the municipalities mainly serves residential purposes, and the agricultural employment rate is also higher in the Stiefingtal than the average in the study area. The thesis regarding the use of municipalities for residential purposes is also supported by the existence of new primary schools, which, among other things, can serve as an indicator of immigration. On the way back to Graz, the sudden change from one municipality to another became visible. While in the northernmost municipality of the KLAR region Stiefingtal, Empersdorf, a very provincial municipal structure is still visible, it changes noticeably in the neighboring municipality of Hausmannstätten and even more so in close proximity in Raaba-Grambach. The settlement of companies such as Magna or Raiffeisen leads to a visible transformation of the municipality from a residential function to the primary function of work. of work. The strong increase in land prices and population, coupled with a very high level of commuting, supports this theory. The study supports our theory of the functional separation of interaction space and the clearly noticeable strong distinction in the identity of individual communities caused by the factors previously discussed, such as the agricultural employment rate.

Analysis

The Graz interaction area has changed significantly since the publication of Leitner's 1979 report, as expected. While the 1979 report could clearly distinguish five categories of municipalities within the interaction area, using the same indicators today, only two categories can be differentiated. Although the area of the interaction space has hardly grown and the core city has remained the same, none of the municipalities can currently be assigned to the categories of outer zone and periphery as defined in 1979. The municipalities are now roughly evenly divided into the complementary area and the urbanized zone. The KLAR region Stiefingtal is entirely classified under the urbanized zone. With the exception of one municipality, Sankt Andrä-Höch, all localities within the interaction area have experienced population growth. Particularly municipalities south of

the core city are growing disproportionately strongly. Commuter traffic is also increasing in many municipalities of the study. In municipalities with very strong population growth, the commuter balance increases only slightly or even decreases. This is, in turn, a phenomenon of strong population growth, since the places that were already heavily dependent on commuters in 1979 cannot grow as much in the statistics as those with newly created jobs. Alongside population development, land prices also rise. Places with strong population growth near the core city are also exposed to significant increases in land prices. The agricultural employment share, which was still relevant in 1979, has changed significantly up to the present. Hardly any municipality today exceeds the 5% share of employees in the agricultural sector. However, the pattern shows that the distance to the core city also plays a role in agricultural employment. The further away one moves from Graz, the higher the share. The situation is exactly the opposite for the service sector share. Even in the lowest municipalities, this only decreases below 60% even in the smallest municipalities where the agricultural employment rate exceeds 5%. The core city itself and the directly adjacent municipalities have the highest rate. For the quality of life of the residents of the interaction area, the availability of local supply, medical care, and in the case of children, the density of primary schools, is also decisive. The density of primary schools is organized according to school districts, which mostly coincide with the municipal boundaries before the municipal structural reform in Styria in 2015, and in this respect, small municipalities such as those in the Stiefingtal are shown with a very high density, even if these municipalities themselves have only one primary school. The doctor-patient ratio varies greatly, but places without their own availability of doctors are the exception. With regard to basic provision with supermarkets, there is good coverage in the core city and in the southern surrounding area. Communities with poor accessibility usually have particularly low density. Generally, density decreases outward from the central city.

CONCLUSION

The municipalities usually fulfill individual functions such as housing, industry, or services, and through networking with surrounding municipalities, they are able to enhance these functions while neglecting subordinate functions. This leads to an increasingly interconnected daily life and the handling of everyday matters of the people in the municipalities. This functional separation is also reflected in commuter flows, which can indicate in which municipalities people increasingly live and in which the industrial and service sectors are disproportionately developed. Here, the core city itself plays a significant role, as municipalities in its immediate vicinity benefit more from the companies that settle there, as observed during field visits in Raaba-Grambach or Gratkorn. The core city itself benefits considerably from the city-surroundings relationship, as it partially allows the workforce to live in surrounding communities with residential functions. At the same time, the city benefits when employees prefer to live outside its own city limits, as this can help relieve pressure on inner-city housing.

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GEOGRAPHIES OF KNOWLEDGE AND ASYMMETRICAL EPISTEMIC ORDERS

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ABSTRACT

Global knowledge continues to flow along unequal and often invisible hierarchies. The concept of epistemic injustice highlights the ethical and moral consequences of such asymmetries, showing how certain groups' knowledge is undervalued, with implications for careers, wellbeing, and social recognition. This paper examines how knowledge is constructed, contested, and maintained across universities, research institutes, cultures, languages, and geopolitical contexts. Extending beyond postcolonial frameworks, we explore a variety of contexts in which epistemic marginalization shapes knowledge and authority. Adopting a geo-epistemic perspective, we show how entrenched biases influence what counts as legitimate knowledge and who gets to decide, while also revealing constraints faced by scholars across diverse settings. This approach supports rethinking expertise, confronting exclusionary norms, and cultivating a more inclusive, dialogical, and globally aware academic practice.

Keywords: epistemic injustice; geo-epistemics; higher education; higher education; university

INTRODUCTION

Knowledge is never produced in a vacuum (1–5). It emerges within complex social, institutional, and spatial contexts, shaped by historical legacies, political structures, and material conditions, yet it often aspires to universality and claims global relevance (6–9). Whilst claiming factual universality might be rhetorically powerful, philosophically such notions are a lot thornier [10]. In this paper, we adopt Mignolo's assertion [11, p. 1] that "all knowledges are situated and every knowledge is constructed". The conceptual lens of the geographies of knowledge emphasizes that knowledge is fundamentally spatially situated; its creation, validation, and circulation are inseparable from the specific places, institutions, and networks in which it is embedded [12]. From the layout of research universities and the distribution of funding to the invisible hierarchies of academic publishing and the dominance of certain languages, these spatial and institutional arrangements profoundly influence whose knowledge is recognized, valued, and disseminated [13–15].

(Geo)epistemic asymmetry is a typical manifestation of the global knowledge order. In terms of philosophical conceptions and theoretical approaches, this order is dominated by Western-centric frameworks, which require scholars from the rest as "local informers" of

empirical information commissioned for the needs of certain research in the so-called "area studies" [16]. The established global order is asymmetrical, an amalgamation of diverse knowledge systems, traditions, theories, conceptual frameworks, and specific agendas produced by scholars in different macroregions of the world [17]. As a constituent part of this global order, there are knowledge systems within smaller cultural and spatial domains which, in line with Mignolo's terminology [11, p. 4], include the so-called "places of non-thought (of myth, non-western religions, folklore, underdevelopment involving regions and people)".

This paper examines the asymmetries in established geographies of knowledge, with a particular focus on higher education. Here, the university is understood as a geographic site of knowledge production. Applying a "geographies of knowledge" lens to this subject explores, amongst other things, how institutional power, linguistic dominance, regional hierarchies, and geopolitical positioning shape not only the production of knowledge but also its circulation and perceived legitimacy. Within this broader framework, asymmetrical epistemic orders emerge as a particularly compelling illustration of how spatial hierarchies structure the international academic landscape. In other words, spatial arrangements and processes are understood to be causally related to the (unequal) distribution of authority, recognition, and legitimacy in global knowledge, through both deliberate action and unintended consequences. These asymmetries reveal that knowledge is not simply about truth or intellectual rigor; it is also deeply intertwined with questions of power, access, and symbolic authority [18–20]. Understanding these dynamics requires careful attention to the material and relational infrastructures through which knowledge flows, as well as to the persistent structural and cultural biases that determine what is considered valid, important, or universally applicable in the global scholarly community.

For purposes of demarcation, this paper restricts itself to merely mentioning the geographical and institutional anchoring of knowledge production (section 2), resulting asymmetrical epistemic orders on a global scale (section 3), and higher education as a critical node (section 5). Finally, we offer some suggestions about what can be done to achieve a more equitable form of knowledge production that is not ignorant of these geographical pressures (section 5), before presenting our conclusion (section 6).

KNOWLEDGE AS GEOGRAPHICALLY AND INSTITUTIONALLY ANCHORED

Higher education institutions occupy a central and inescapable position in the production, validation, and dissemination of knowledge, which is why their mission and purpose have remained greatly contested questions over the centuries [21–27]. Yet the spatial and geographic conditions under which knowledge acquires authority, legitimacy, and societal impact are rarely examined in a systematic manner. Knowledge is never placeless; it is profoundly anchored in specific locations, institutional frameworks, and socio-political arrangements [28]. Universities, research centers, and other knowledge-producing institutions act as both sites and conduits of knowledge, mediating its creation and circulation through complex networks of funding, infrastructure, policy, and academic norms [29] These networks are far from neutral or evenly distributed, privileging certain regions, languages, and epistemic traditions while marginalizing others, and in doing so reproducing historical hierarchies and structural inequalities in global knowledge systems [30]. Finally, people interact in a ritualistic fashion that

involves administrative, bureaucratic, and embodied interaction at the physical place of the university, with scaling interactions that are difficult to appreciate in day-to-day conduct [31].

Spatial theory offers a particularly illuminating lens through which to understand these dynamics by emphasizing that space is not simply a physical or material container but also a conceptual, ideological, and socially lived construct. To put it poetically, the tapestry of existence [32] is shaped by our own choices [33] as we are shaped by it [34] in a perpetual feedback loop. Hence, knowledge is shaped not only by the material infrastructures of research laboratories [35], libraries [36], digital networks and institutional repositories [38], but also by the ideologies [39] norms [40] and expectations [41] embedded in academic evaluation [42], disciplinary boundaries [43] and global rankings [44]. In the race for better positioning within the global knowledge order, more and more countries are investing in scholars and research facilities and promoting internationalization to establish at least one world-class research university. Such an achievement is "seen as central to the global knowledge economy and the production and dissemination of new knowledge" [45, p. 9].

Simultaneously, knowledge is experienced relationally, through the professional networks [46], collaborations [47] and identities of scholars themselves [48]. In this sense, the demarcation between fact and fiction is a constantly negotiated process [49], where knowledge production is always mediated through the interplay of perceived, conceived, and lived spaces, which together determine what is recognized and valued within international academic networks. For various non-dominant communities situated in geo-epistemological spaces beyond the Global North, the knowledge framework proposed by de Sousa Santos [50] known as knowledge-as-emancipation, may serve as a potential solution. This framework empowers marginalized communities to resist the Western tradition of enforcing knowledge as a norm (knowledge-as-regulation), or the second paradigm of knowledge during the modern period. Knowledge-as-emancipation encompasses a journey from a state of ignorance, which the author termed 'colonialism', to a state of understanding that he called 'solidarity' [50].

In a geographic sense, the mainstreaming of locally produced knowledge endeavors to achieve global relevance, and in the process, it frequently encounters significant structural and epistemic obstacles. For example, scholarship originating outside the Global North often confronts systemic barriers that limit its recognition and legitimacy [51]. This applies regardless of whether the place of origin is the Global South, Eastern Europe, post-socialist nations, or marginalized communities within dominant countries. Such knowledge may be dismissed or devalued through labels such as "local," "peripheral," or "secondary," which effectively marginalize contributions that do not conform to dominant epistemic standards [52]. Conversely, research produced in Western, Anglophone, or historically dominant institutions is more readily valorized, often framed as universal, authoritative, or inherently superior. These dynamics reveal that both material spatiality and the geography of meaning are inseparable from questions of epistemic legitimacy. Here, the constellations of contemporary knowledge are deeply shaped by context, power relations, and historical legacies [53].

Institutional and infrastructural arrangements further reinforce these spatial hierarchies [54]. The architecture of global academic recognition, such as journal indexing systems [55], peer review practices [56], university rankings [57], and research assessment frameworks [58] systematically privileges established centers of knowledge while marginalizing peripheral institutions and scholars. Metrics and indicators, though often

presented as objective or meritocratic, function as instruments of epistemic power, granting disproportionate authority to certain regions, languages, and epistemic traditions [59]. Funding policies, collaborative networks, and international consortia further entrench these inequities, conferring material and symbolic advantages on institutions that already occupy dominant positions in the global knowledge landscape [60]. Language acts as another critical vector of inequality: the predominance of English as the global medium of scholarship privileges Anglophone institutions and researchers, while constraining the visibility, circulation, and perceived credibility of knowledge produced in other languages [61]. As a result, even high-quality research originating from historically marginalized regions may remain largely invisible or undervalued, reinforcing entrenched epistemic stratification and perpetuating the asymmetrical distribution of authority within the global academic system [62].

In this light, understanding knowledge as geographically and institutionally anchored reveals the deeply political and spatially situated nature of epistemic authority [63]. Knowledge is never simply a neutral or universal commodity; it is produced, legitimized, and mobilized through networks of spatial, institutional, and cultural relations that embed hierarchies and power differentials into the very processes of scholarship itself. By recognizing these dynamics, scholars can begin to map the uneven terrain of global knowledge, uncover the mechanisms that sustain asymmetries, and explore pathways toward more equitable, pluralistic, and contextually grounded epistemic practices. This unevenness creates absurd situations and may make the "center" of globalized science even more powerful at the expense of researchers from poorer, economically developing countries. Ersoy [64] provides examples of how scholars from countries such as Brazil and Turkey are compelled to take out loans or consider selling their homes to participate in the prestigious annual International Studies Association conferences. As the author suggests, there is an irresistible magnetic force that compels scientists and doctoral students to embark on these journeys, sometimes willingly incurring substantial financial burdens. These personal choices are intricately linked to the global institutional framework of science, which perpetuates asymmetric privileges in the production, distribution, and consumption of knowledge.

ASYMMETRICAL EPISTEMIC ORDERS

The "geographies of knowledge" lens provides an overlooked perspective for understanding why epistemic hierarchies exist, persist, and are reproduced across time and space. One of the most visible and consequential manifestations of these dynamics is the asymmetrical global order of knowledge, where authority, recognition, and the circulation of ideas are profoundly uneven across regions, institutions, and languages [65-67]. Fricker's [68] concept of epistemic injustice sheds light on the ethical and social ramifications of these inequalities, illustrating how scholars and communities are systematically marginalized when their knowledge is undervalued, ignored, or dismissed. Researchers operating in the Global South, Africa, Eastern Europe, and post-socialist nations frequently encounter structural and symbolic barriers that limit their intellectual participation, restrict career advancement, and diminish the visibility of their work. These inequities are maintained not only through institutional dependency and material constraints but also through entrenched cultural hierarchies that elevate Northern epistemologies as the default and presumed universal standard [69]. The situation is further complicated by intersecting axes of exclusion: gender, race, and class disparities

amplify the challenges faced by already marginalized scholars, reinforcing entrenched patterns of underrepresentation within the global academic landscape [70].

Processes of evaluation and recognition, often framed as neutral or purely meritocratic, are central mechanisms through which these asymmetries are sustained. Scientometric indicators, journal impact factors and hierarchical rankings systematically confer authority on scholars situated in dominant centers [71], while scholars from peripheral regions are frequently compelled to adapt their research to meet externally imposed norms simply to be heard [72]. In practice, the geographic, cultural, or contextual specificity of research produced in the Global South or other marginalized regions is often treated as a liability, requiring justification or translation into the conceptual frameworks of dominant epistemologies [73]. Conversely, research originating in Northern institutions is frequently granted universal legitimacy without due introspection [74–75]. This formalized inequality underscores that epistemic asymmetries are neither accidental nor peripheral anomalies; rather, they are embedded in the structural, methodological, and symbolic practices that define the circulation and validation of knowledge on a global scale.

Yet these asymmetries are neither uncontested nor fixed. Across disciplines and regions, scholars and institutions are experimenting with strategies to challenge and transform the existing order. Inclusive evaluation frameworks that prioritize quality, originality, and ethical significance over conventional impact metrics are beginning to reshape scholarly recognition [76]. Collaborative research initiatives, grounded in regional epistemologies and developed with local communities, counter extractive paradigms and foster mutual accountability [77]. Multilingual and multimodal dissemination practices help overcome linguistic and cultural barriers, increasing the visibility of historically marginalized knowledge. Beyond structural measures, redistributing epistemic power requires sustained dialogue, critical reflexivity, and intellectual humility. Transformation entails not only questioning who speaks and who is heard, but also cultivating epistemic care, respect, and reciprocity, recognizing diverse knowledge systems as equally valid. In this sense, asymmetrical epistemic orders are both a product of entrenched hierarchies and a site of potential resistance, offering fertile ground for reimagining global knowledge as inclusive, dialogic, and attentive to the geographies in which it is produced [78].

HIGHER EDUCATION AS A CRITICAL NODE

Universities occupy a uniquely central position within the global knowledge ecosystem, serving simultaneously as nodes of epistemic stratification and as potential engines for transformative change [79]. As previously noted, they are not neutral spaces of inquiry; the very ideas used to structure these spaces are themselves contested [80]. Our conceptual frameworks actively shape what counts as knowledge, which voices are amplified, and whose insights circulate widely across disciplines and borders. By producing, validating, and disseminating knowledge, higher education institutions function as gatekeepers, determining which ideas gain traction and which are relegated to the margins, while also consolidating norms about how societal and research impact ought to be evaluated [81]. Decisions made within these institutions carry profound and often underappreciated implications for the configuration of global knowledge hierarchies, including research agendas, funding priorities, curriculum design [82], faculty recruitment, and publication or evaluation policies. Each choice, from grant allocation to journal selection for promotion or tenure, embeds assumptions about epistemic authority,

disciplinary legitimacy, and geographic relevance, creating cumulative effects that can either reinforce or challenge existing inequities.

The influence of universities extends beyond formal structures and policy mechanisms. Their spatial location, institutional history, and socio-cultural context shape how knowledge is produced, circulated, and interpreted. Research originating in well-resourced, historically dominant institutions tends to achieve wider recognition, more frequent citation, and greater mobility across international networks, whereas work from smaller or underfunded universities may struggle for visibility regardless of quality or rigor. Similarly, universities mediate knowledge circulation through relationships with funding agencies, professional associations, and global consortia, often reproducing systemic advantages for certain regions, disciplines, or epistemologies.

At the same time, universities hold the potential to act as agents of epistemic transformation. By critically reflecting on their own practices and engaging in deliberate, inclusive, and contextually grounded knowledge production, higher education institutions can disrupt entrenched hierarchies and foster alternative epistemic futures. Initiatives such as regionally oriented research collaborations, multilingual publishing, co-created and participatory methodologies, and equity-focused evaluation frameworks exemplify ways in which universities can cultivate more pluralistic and ethically informed knowledge ecosystems [83–84]. Transformative potential emerges not only from structural interventions but also from cultural shifts within the academy: cultivating reflexivity, humility, and openness to epistemic diversity allows scholars and administrators to question long-standing assumptions about universal standards, disciplinary dominance, and what constitutes "high-quality" knowledge [85].

Recognizing universities as critical nodes involves acknowledging their dual role as both sites of power and potential sites of resistance. They are at the same time instruments through which asymmetrical epistemic orders are maintained and platforms through which these orders can be contested, reshaped, and reimagined. Imagining alternative epistemic futures requires not merely including marginalized voices but fundamentally rethinking the relational, spatial, and institutional mechanisms through which knowledge is produced, validated, and circulated. Higher education, in this sense, is not merely a passive arena for knowledge but an active participant in shaping who is heard, what is valued, and how global knowledge hierarchies might evolve toward greater justice, plurality, and contextual sensitivity [but see 86].

TOWARDS A MORE EQUITABLE KNOWLEDGE ORDER

Addressing asymmetrical epistemic orders requires interventions that are both structural and relational, aimed at reshaping the very foundations through which knowledge is produced and evaluated. Structural changes involve rethinking institutional hierarchies, funding allocations, publication practices, and evaluation metrics that currently privilege dominant centers, languages, and epistemologies. It is not enough to simply invite more voices onto existing platforms; rather, the platforms themselves, along with the rules that govern recognition and legitimacy, must be transformed. Relational interventions, by contrast, emphasize sustained dialogue, collaboration, and mutual accountability among scholars from diverse regions and epistemic traditions. These interactions foster epistemic pluralism and encourage the development of frameworks that value originality, rigor, societal relevance, and contextual insight over mere geographic origin, institutional prestige, or adherence to standardized metrics [87].

Central to this endeavor is the integration of perspectives from Central and Eastern Europe, Africa, South Asia, Latin America, and other regions of the Global South into mainstream theoretical debates, university curricula, and the practical implementation of research. These contributions challenge dominant Northern epistemologies not by rejecting them outright, but by highlighting their assumptions, blind spots, and cultural biases. At the same time, Northern institutions must actively engage in reflexive practices, acknowledging their positional privilege and the ways in which their dominant standards have historically marginalized other epistemic communities. Redistributing resources, networks, and institutional influence to empower scholars from historically peripheral regions is essential for cultivating a knowledge ecosystem that is genuinely global, dialogic, and attentive to diverse lived experiences. Lastly, in addition to the necessity for universities and other academic institutions to adopt a more assertive approach towards Western/Northern-centric paradigms of scientific inquiry, scholarly subjects operating within various civilizational and linguistic frameworks should also strive for greater assertiveness in advancing and showcasing their intellectual contributions [72].

Global knowledge systems are not fixed or immutable; they are dynamic arenas shaped by ongoing negotiation, contestation, and co-creation. Asymmetrical epistemic orders reveal the profound entanglement of knowledge with geography, power, institutional authority, language, and historical legacies, yet they also illuminate pathways for transformation. By foregrounding the spatial, institutional, and ethical dimensions of knowledge, scholars and universities can challenge hierarchical structures and foster epistemic justice. Practices such as collaborative research grounded in local realities, multilingual publication strategies, and inclusive evaluation processes not only increase the visibility of marginalized knowledge but also expand the conceptual and methodological horizons of global scholarship.

Higher education institutions, as both nodes of authority and potential sites of innovation, are uniquely positioned to advance this transformative agenda. By embracing reflexivity, humility, and openness to epistemic diversity, universities can create spaces where knowledge is co-produced across boundaries, where ‘peripheral’ actors are recognized as legitimate co-creators rather than mere ‘local informants’ or data sources, and where evaluation criteria reflect context-sensitive rather than uniform global standards. By deconstructing Western epistemological models, which are abundant in biases, it becomes feasible to relativize them and change their role from an ultimate starting point to one of multiple cultural and epistemic structures [88]. A more equitable knowledge order thus emerges not as a top-down imposition or a tokenistic inclusion of marginalized voices but as an ongoing, dialogic, and collectively negotiated process that acknowledges the complex interplay of power, context, and expertise. In such an order, knowledge becomes not a tool of exclusion or hierarchy, but a shared, plural, and dynamic resource capable of addressing the diverse and pressing challenges of our interconnected world [89–90].

The geographical approach to the structuring of knowledge within the global system can introduce a heightened sensitivity to various regional and national schools of higher education and knowledge production [75]. However, it also conceals a real risk of reinforcing the dominance of traditional hegemons and Anglo-American theories, publication practices, and institutions. Al-Hardan & Go [91, p. 35] also note that it is generally accepted that dominant social theory originates from the “West”. Thus, the solution to the issue of diversifying scientific output lies in identifying “non-Western” ideas by localizing, for example, “local”, “Asian”, “African”, or “Southern” thinkers who are in search of intellectual spaces “beyond” the “West” and the “Global North”. This

indicates that if a scholar resides in or comes from a “non-Western” or “non-European” location, their ideas should be valued solely because of that geographical origin.

CONCLUSION

Knowledge is inherently situated, emerging within specific social, institutional, and spatial contexts that shape what is recognized and valued in the global knowledge system. The concept of geographies of knowledge highlights that knowledge is never placeless or neutral, but always produced, validated, and extended through particular places, institutions, networks, and infrastructures. Asymmetrical epistemic orders exemplify how authority, recognition, and circulation are unevenly distributed across regions, languages, and institutions, reflecting historical legacies, institutional practices, and contemporary power hierarchies.

Addressing these asymmetries requires structural and relational interventions: fostering dialogue among diverse scholars, adopting pluralistic evaluation criteria, integrating perspectives from historically marginalized regions, and redistributing institutional influence and resources. Higher education institutions play a central role in shaping these spatial hierarchies, mediating which knowledge is amplified and which perspectives are marginalized. By attending to the spatial, institutional, and ethical dimensions of knowledge, universities can move beyond reproducing asymmetrical orders toward cultivating a more inclusive, contextually grounded, and dialogic global knowledge system.

A geo-epistemically informed perspective underscores that knowledge is relational, spatially embedded, and politically charged. Transforming global knowledge systems demands reflexivity, sustained dialogue, and attention to the material and institutional conditions that produce inequities. Through this lens, knowledge becomes a shared, situated, and dynamic endeavor, capable of reflecting the diverse realities of a globalized world.

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TOURIST LENGTH OF STAY: CHALLENGES FOR OHRID (NORTH MACEDONIA)

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ABSTRACT

This paper analyzes the stay patterns of tourists visiting Ohrid, the most famous tourist destination in North Macedonia. It reveals critical insights into seasonal tourism dynamics from 2000 to 2024. Using standard statistical calculations, the study assesses the average length of stay for domestic, foreign, and total tourists, alongside monthly variations and long-term trends. Results indicate a clear decline in the average length of stay for all categories relative to the average period, particularly after 2012. A slight a year-on-year peak appeared among foreign tourists in 2021, representing a post-COVID recovery that briefly exceeded the average. Domestic tourists stay significantly longer on average (5.68 days) than foreign tourists (2.53 days), likely due to familiarity and proximity, while the total average of 4.51 days, tends to mask the sharper drop among foreigners. A deeper monthly analysis uncovers distinct seasonal patterns: while summer months (July and August) drive peaks for both groups, domestic tourists exhibit 2.5 times higher (142% longer stays) than foreign visitors. Conversely, spring, autumn, and winter months maintain brief stays of 2 days or less, confirming Ohrid's profile as a summer-oriented destination. Theoretically, this study integrates length-of-stay metrics into the tourism seasonality theory. Empirically, the findings assist local governance to incorporate the destination's dual-market insights when creating tourism development plans aimed at extending foreign stays and balancing domestic seasonal peaks.

Keywords: Length of stay, Tourism, Ohrid, Tourism planning.

INTRODUCTION

Ohrid, North Macedonia, is the most famous summer tourist destination in the country, attracting a diverse mix of domestic and international visitors. It is a UNESCO mixed transboundary World Heritage site, recognized for both its natural and cultural significance [21, 22]. In 2024, Ohrid accounted for nearly one-third of national tourist arrivals (363,718) and overnights (1,194,516) [20], demonstrating that tourism is a vital sector for both the local and national economies.

However, despite a consistent increase in total tourist arrivals, tourism in Ohrid has experienced a decline in the average length of stay (LOS). This trend is evidenced in broader literature [1, 2, 4, 8, 11] with a consensus that LOS is a critical metric for quantifying tourism impact on economic development and regional planning [3, 5, 6, 9]. The global trend toward 'stay compression', where tourists take more frequent but shorter trips, presents a significant challenge for destination management [15]. While arrival numbers may remain high, the shortening duration of the visits threatens the depth of economic impact and local sustainability [1]. The 'summer-peak' phenomenon is particularly evident in lake-based destinations and carries numerous economic risks [10],

attracting more domestic tourists who tend to stay longer due to their proximity to the destination opposite to foreigners [14].
This study investigates stay patterns in Ohrid from 2000 to 2024 to determine how global trends manifest locally. Given that the sampled period is characterized by both steady growth and a consistent decline in the average LOS starting after 2012, this research aims to disaggregate the data between domestic and foreign tourists. In doing so, it reveals the 'dual-market' dynamics that are often hidden by aggregate statistics.
Furthermore, the objective of this paper is to integrate these LOS metrics into the broader framework of tourism development of Ohrid, specifically addressing the challenges of seasonality [16] and the destination's shifting role as a transit destination for foreign tourists [13]. By providing detailed longitudinal analysis, this research offers empirical evidence to assist local governance in creating development plans that aim to extend foreign stays and balance extreme domestic seasonal peaks.
Following the introduction, the paper is organized as follows: Section 2 outlines the methodology, while Section 3 presents the main results and discussion. Finally, the paper concludes with a summary of key findings, research limitations, and suggestions for future work.

METHODOLOGY

The research employs a quantitative longitudinal approach, analyzing a 25-year sample period from 2000 to 2024. To gain a more in-depth understanding of the long-term trends in Ohrid's tourism lifecycle, the study employs a comparative period analysis wherein the data is split into two sub-periods: 2000-2011 and 2012-2024. This division is based on 2012 being identified as a structural break point.
The data is limited to registered accommodation providers sourced from [20], ensuring high reliability and official standing. The primary metric utilized is the LOS, calculated based upon equation (1):

$$LOS = \frac{Total\ overnights}{Total\ tourist\ arrivals} \qquad (1)$$

The analysis specifically segments tourists into domestic and foreign categories. This is important to prevent the 'masking effect', a statistical phenomenon occurring when analyzing total tourist data where high domestic averages obscure a significant collapse or high volatility in foreign stay durations.
LOS is recognized as a critical indicator of a destination's economic development and managerial efficiency [6]. Unlike tourist arrival figures, which merely quantify volume, LOS provides a deeper measurement of the 'depth' of destination consumption and the overall quality of the tourism product.

RESULTS AND DISCUSSION

The findings revealed a clear divergence between market segments in Ohrid, which is rooted in robust seasonality. Figure 1 illustrates the disparity between domestic and foreign tourists by comparing average LOS curves, where the total average LOS curve serves as a baseline for conclusions.

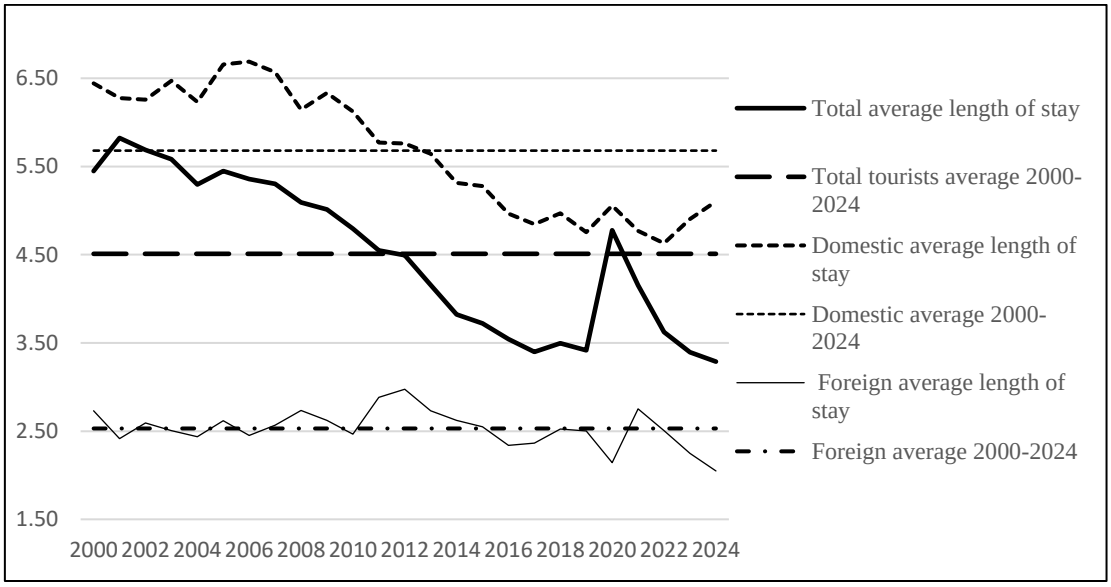


Figure 1. Comparing average LOS in Ohrid, 2000-2024 (in days)
Source: Author's calculations on [20]

From Figure 1, it is noticeable that domestic tourists maintained a significantly higher average stay of 5.68 days, while foreign tourists averaged only 2.53 days. While the total combined average stands at 4.51 days, this acts as a deceptive 'masking' metric that obscures the sharper decline and high volatility observed within the foreign market. By plotting domestic and foreign behaviors side-by-side, Figure 1 highlights a structural gap suggesting that Ohrid maintains a stable domestic base in contrast to a highly transient foreign trend.

This finding suggests that Ohrid has completely divergent triggers in tourism supply when attracting tourists. The two markets differ not just in volume, but in fundamental perception as well. Domestic tourists generally visit Ohrid during summer for 'sun and lake' tourism. On the other hand, foreigners stay for very short periods, treating the destination as a transit node, thereby confirming the findings of [13].

Furthermore, Figure 1 reveals another interesting finding that Ohrid is a destination in transition. Namely, while the total LOS appears relatively stable at first glance, a critical point is noted after 2012, when a long-term decline commenced. This shift may be attributed to the changing profile of regional tourism, where increased accessibility to competing Mediterranean destinations and the rise of low-cost air travel have influenced visitor stay patterns. The specific market dynamics are further elucidated by isolating the behaviors of each group, i.e., domestic, foreign, and total tourists.

Figure 2 highlights the relative stability of the domestic market as a constant base for the local economic development of Ohrid. During the sampled period, domestic tourists accounted for an average of 61% of arrivals and 76% of overnights. Due to the famous Lake Ohrid, domestic tourists primarily visit for recreational purposes, reaching an average stay nearly double that of foreign tourists. This stability suggests a high degree of brand loyalty among domestics, who perceive Ohrid as a reliable, stationary summer destination.

Figure 2 also illustrates the same downward trend starting in 2012 that was previously noted in Figure 1, further supporting the characterization of Ohrid as a destination in transition. Although the total LOS may appear relatively stable at first glance, a critical turning point occurred after 2012, marking the beginning of a long-term decline. While

the average LOS for domestic tourists over the entire sampled period was 5.68 days, the 2012 break point initiated a substantial reduction. Specifically, the average LOS for the 2000–2011 sub-period was 6.33 days, which is 11.4% higher than the 2000–2024 baseline average. In contrast, the average for 2012–2024 fell to 5.08 days, or 10.6% below the baseline. A direct comparison between these two sub-periods reveals a decline of nearly 20%, as the stay shortened from 6.33 to 5.08 days.

Such a loss of 1.25 days necessitates a serious analysis of the underlying causes of this shortening of stay. From a destination management perspective, this contraction suggests that while Ohrid remains a primary choice for domestic travelers, the 'depth' of their consumption is eroding. This may be driven by shifting economic constraints on domestic households or a transition toward more frequent but shorter weekend trips.

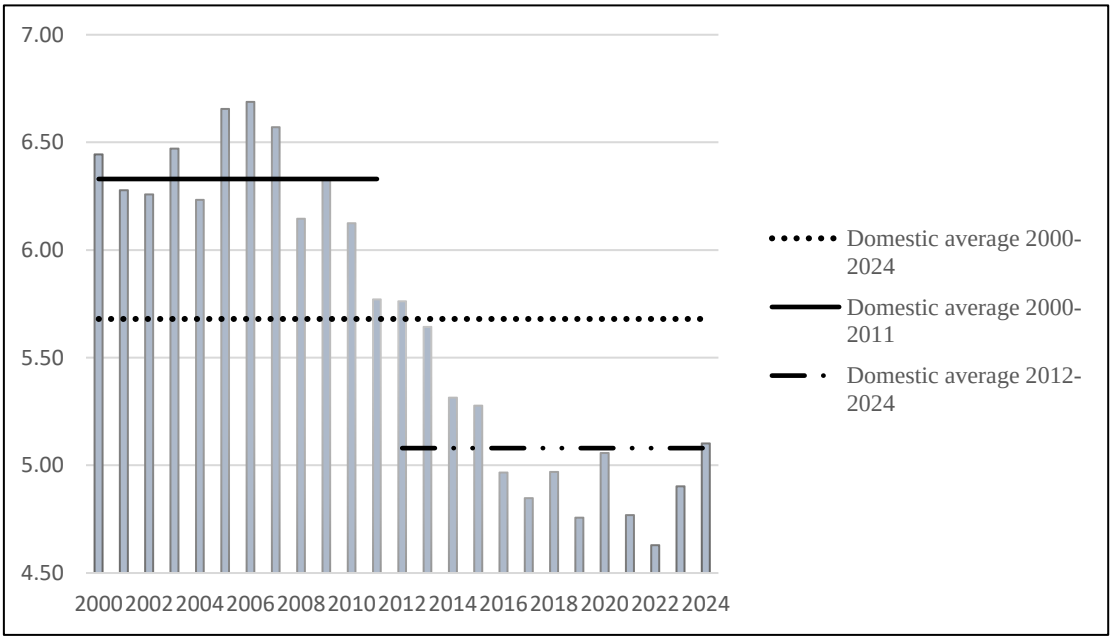


Figure 2. Domestic tourists average LOS in Ohrid, 2000-2024 (in days)
Source: Author's calculations on [20]

In stark contrast, Figure 3 tracks the volatility of the foreign market, showing a similar trajectory between the two sub-periods. Figure 3 captures a significant peak in 2021, interpreted as a 'rebound effect' following the COVID-19 pandemic [12], during which foreign tourists, predominantly regional travelers, stayed longer. However, this spike did not last long as the foreign average returned to its downward path as soon as global travel corridors reopened. This confirms that foreign stays are increasingly 'thinning,' as visitors remain only long enough to visit the Old Town before continuing their holidays in neighboring countries such as Albania or Greece.

Unlike Figure 2, which illustrates a large discrepancy between the LOS of domestic tourists across the two sub-periods, Figure 3 does not reveal such a significant gap. There was only a 2% decline in LOS for the 2000–2011 period compared to the baseline (2000–2024), where the LOS decreased from 2.59 to 2.53 days. The second sub-period noted an identical decline of 2%, from the 2.53-day baseline to 2.48 days. A cumulative drop of 4% in foreign tourism demand does not imply a serious reduction in LOS over these

periods. Nevertheless, this trend indicates a necessity for a clearer definition of Ohrid's brand image to strengthen its position within the international tourism market.

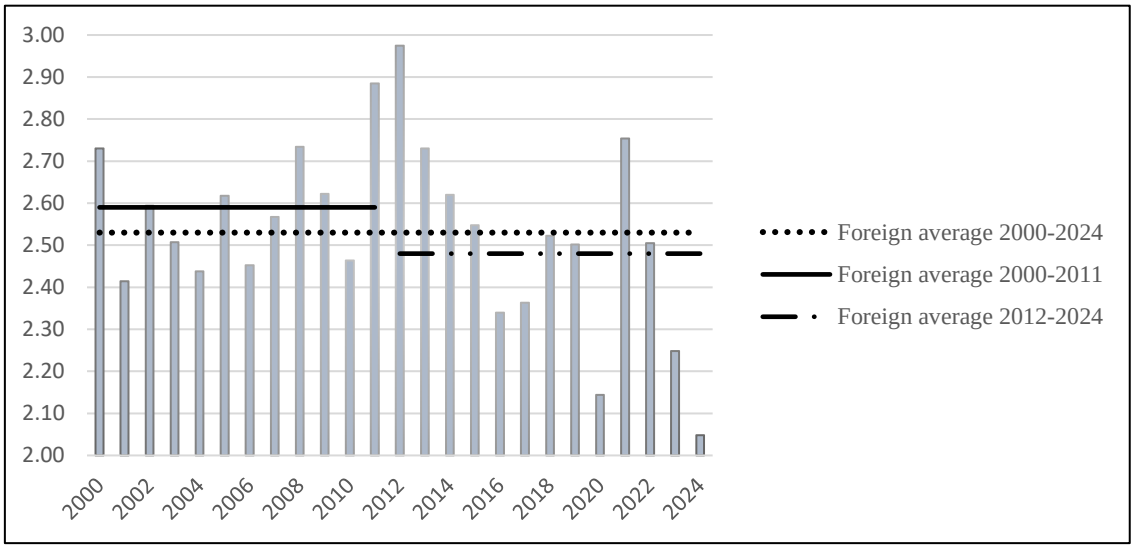


Figure 3. Foreign tourists average LOS in Ohrid, 2000-2024 (in days)
Source: Author's calculations on [20]

Figure 4 illustrates the cumulative impact of domestic and foreign arrival trends by displaying the total average LOS. This visual is important as it clearly demonstrates the 'masking effect,' wherein the significantly longer domestic stays hide the marginal contribution of foreign stays. Specifically, the total average LOS remains high enough to obscure the fact that the foreign market is effectively eroding. If local authorities rely solely on this aggregate figure, they risk overlooking Ohrid's critical transition into a transient node for international tourists [23].

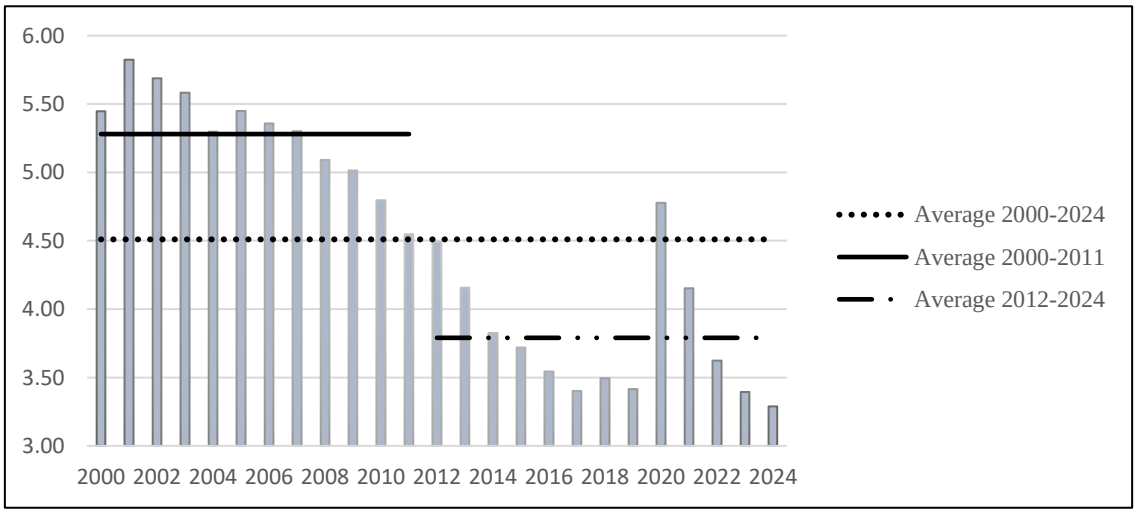


Figure 4. Total average LOS in Ohrid, 2000-2024 (in days)
Source: Author's calculations on State Statistical Office (n.d.)

Finally, Figure 5 provides an explanation for the 'masking effect', outlined previously in Figure 4, by presenting the monthly distribution of the average LOS for domestic and foreign tourists. It clearly visualizes the extremely high concentration of domestic tourism demand during the peak summer months of June, July, and August vis-à-vis the moderate

demand from foreign tourists. These three months encompass almost 70% of total domestic arrivals and 88% of overnights, in contrast to a modest foreign share.

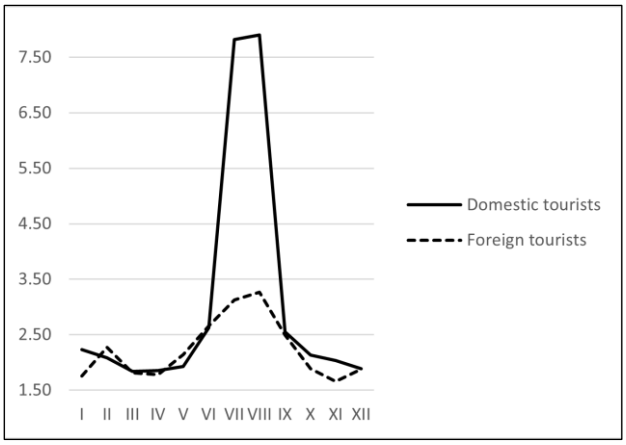


Figure 5. Average domestic vs foreign LOS per month, 2000-2024
Source: Author's calculations on [20]

Seasonality remains the dominant driver of these figures, with domestic stays in peak months being 142% longer (2.5 times higher) than foreign stays. During the 'shoulder' and winter seasons, however, stays for both groups drop to two days or less, confirming Ohrid's rigid profile as a single-season destination [7]. Theoretically, these findings validate tourism seasonality theory while adding a layer regarding market segmentation [1]. The data suggests that seasonality affects not just visitor volume, but the very nature of the stay itself.

CONCLUSION

The study investigates the stay patterns of tourists visiting Ohrid from 2000 to 2024, concluding that the destination faces two major challenges:

1. A strong dual-market divergence between domestic 'vacationers' and foreign 'passers-by'. These necessities address the decline in the average LOS observed since 2012 and create strategies to extend foreign stays.
2. Deep-rooted seasonal dynamics. This requires smoothing the massive peaks when domestic tourists stay 142% longer than foreigners.

Analysis of total average LOS reveals that it is heavily buoyed by domestic tourists. When analyzing seasonal dimension, it was found that summer months exhibit dominant domestic demand, while stays in the shoulder and winter seasons drastically collapse. This gap indicates that domestic visitors treat Ohrid as a primary summer destination for long vacations, whereas foreigners view it as a transient stop within a broader regional itinerary.

These results urge a need for policy intervention and developing local tourism development plans to bridge these gaps and mitigate discrepancies. The study recommends active destination management and tourism planning along with activities to diversify off-season offerings. Furthermore, the detected decline since 2012 suggests that mass arrivals have pushed the destination to 'fast tourism' practicing quantity over quality and neglecting sustainable development. To address these structural challenges, local governance should consider shifting the global outlook of Ohrid from 'mass

tourism' toward 'niche' products. Mass tourism continues to provoke negative impacts such as urban degradation [17], overcrowding [18], and the disruption of residents' quality of life [19].

Strategically, adding new experiences, such as hiking in Galichica National Park or religious heritage tours, may better position Ohrid within regional frames, so tourists can add an extra night to their itinerary As the LOS drops significantly outside of summer, focus must shift to shoulder-season programming and adding extra activities beyond peak months that favor longer stays in the destination.

The study has certain limitations that must be acknowledged. First, it relies primarily on official statistical data regarding registered overnights, which may not fully account for unregistered ('ghost tourists') in private accommodations. Second, the research does not capture qualitative motivations for the stay or departure. Future research could also incorporate visitor surveys to triangulate these findings with psychographic insights, providing a deeper understanding of the development of both domestic and foreign tourism markets in Ohrid.

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PAST AND FUTURE TRENDS IN NORTH MACEDONIA'S WORKING-AGE POPULATION

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ABSTRACT

Future demographic trends need to be identified in order to understand, prepare for, and address their consequences on the future economic and overall development, particularly in the Republic of North Macedonia and its eight statistical regions. This paper analyzes past and projected changes in the working-age population, with a focus on population aging within the working-age cohorts (15–64).
Population projections for North Macedonia and its regions were developed using the cohort-component model for the years 2031, 2041, and 2051. The analysis focuses on the population aged 15–64 and compares these projections with census data from 2002 and 2021 to assess long-term changes and future trends.
The results show a decline in the younger cohorts of the working-age population and an increase in the older cohorts, particularly in the East, Vardar, Pelagonia, Southeast and Northeastern regions, while regions such as Polog, Skopje and Southwest show the highest concentration in the middle-aged cohorts. At the national level, a comparison between the last census year and the final projection year of 2051 indicates a projected population decrease of 209,047 persons aged 15-64.
The results point to pronounced working-age population aging in at least half of the regions. Regions that currently have larger younger cohorts are projected to shift toward higher concentrations in middle-aged groups. Overall population decline is expected to affect all sectors, increasing the risk of labor shortages. These trends suggest a growing need for policy responses.

Keywords: Working-Age Population, Population Aging, Population Projections, North Macedonia

INTRODUCTION

This paper examines changes in the working age population of the Republic of North Macedonia and its eight statistical regions over the period 2002 to 2051. It analyses historical and projected trends in order to assess expected developments in the population aged 15 to 64.To understand these developments, it is necessary to consider the broader demographic context. North Macedonia has experienced population decline driven by negative net migration, low fertility, and negative natural increase. In 2021, the total fertility rate was 1.6, natural increase was -5.4, and net migration was -0.5. The aging index reached 1.01, indicating that the population aged 65 and over outnumbered the

population aged 0 to 14.[7] These indicators reflect a shift toward an increasingly aged population.Within this broader process, changes are also visible inside the working age population itself. Younger cohorts entering the labor market are smaller than older cohorts approaching retirement. As a result, the internal distribution of the population aged 15 to 64 is shifting toward older age groups. An increasing number of individuals are transitioning into retirement, which reduces the relative size of the economically active population and has implications for labor markets and pension systems.This shift in age structure is also reflected in the median age of the population. In 2021, the median age in North Macedonia was 40.89, meaning that half of the population was younger than this age and half was older. This represents an increase from 35.14 in 2002. Although North Macedonia remains below the European Union median age of 44.2, it follows a similar regional pattern. Serbia recorded a median age of 44, Croatia 45.3, Greece 45.5, and Bulgaria 46.4. Only Kosovo at 30.6, Albania at 37.6, and Montenegro at 39.3 had lower values.[8] Despite remaining below the EU average, the population of North Macedonia is both declining and aging.The labor force has been widely examined in domestic economic literature as a key factor of development. Early studies address the population as a source of labor, focusing on reserves, unemployment, and methodological issues [1]. Human potential, labor force circulation, unemployment, and past labor force trends are analyzed by Dimitrievska and Janeska [2,3,4,5], as well as Janeska [6]. Employment, unemployment, and activity rates are analyzed by Ristevski [7], while Ivanovska [8] focuses on the educational structure of the labor force. Population aging and the expected shortage of young working cohorts are examined by Ristevski [9]. More recent studies address the relationship between unemployment and economic development measured by GDP [10], youth labor market activity and inactivity, as well as employment and unemployment trends among young people [11], and the effects of the Covid 19 pandemic on the economy and the labor force [12] and the affects that labor force is expected to have on the economy of North Macedonia [13]Population aging has been examined in domestic demographic literature over several decades. Daskalovski [14] analyses the demographic dimensions of population aging in Macedonia. In 2001, several authors contribute to the topic from different perspectives, including Simovski [15] and Kartalov [16] on general demographic aspects, Gerasimovski [17] and Janeska [18] on regional characteristics, and Dimitrieva [19], Dimitrieva and Janeska [20], and Kjurciev [21] on the relationship between population aging and the workforce, including historical trends and projected changes expected by 2020. Broader demographic change and aging are further discussed by Grozdanovski and Noshpaloska [22]. More recent studies focus on structural and socioeconomic implications, including accelerated aging, population decline, and the reduction of young and working age cohorts [23], municipal differences between urban and rural areas [24], the impact of aging on unemployment in North Macedonia and the European Union [25], and long term population projections up to 2070, with emphasis on increasing dependency ratios and pressure on pension and healthcare systems [26].

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[8]https://ec.europa.eu/eurostat/databrowser/view/DEMO_PJANIND__custom_2132335/bookmark/table?lang=en&bookmarkId=04287bed-5283-4ece-b7b0-293802358ae7&c=1645435878840

METHODOLOGY

Data on past demographic trends were obtained from the State Statistical Office of North Macedonia, the official statistical institution of the country. The data includes the 2002 and 2021 population censuses, as well as yearly data on fertility, mortality, and migration used by the authors to produce the population projections.
The 2002 and 2021 census data were used to analyze historical trends on working age population and to compare them with projected values for 2031, 2041, and 2051. The population projections were developed using the Cohort Component Model, which projects the population forward by aging cohorts and applying assumptions on fertility, mortality, and migration. The projections were implemented using the software Spectrum and age-sex structure was used as the basis from the most recent census (2021), corresponding to the most recent census, while the projection horizon extends to 2051 in order to capture medium and long-term demographic developments.
The Cohort Component Model requires separate inputs for fertility, mortality, and migration. In this study, Total Fertility Rate (TFR), Life Expectancy (LE), and Net Migration Rates (NMR) were used. Consistent data for all three components are available only for the period 2014–2021 and earlier years were not included which may affect the results, particularly in the later years of the projection horizon.
Although projection studies often present multiple scenarios, this paper presents only the expected trajectory.

Fertility

Fertility projections are based on the Total Fertility Rate - TFR. Projected values are calculated as the average of linear and logarithmic extrapolations of the historical trend for the period 2014–2021. The linear function produced higher projected values which were too optimistic, while the logarithmic function produced lower values which were very pessimistic. The average of the two functions was therefore used as the projected trajectory. The projected TFR increases over the analyzed period; however, this does not imply that the absolute number of births will increase.
The mathematical specification used for the extrapolation is presented below.

$$TFRaverage = \frac{TFRlinear + TFRlogaritmic}{2}$$

Therefore;

$$TFRaverage = \frac{(a + bx) + (c + dln\,(x)\,)}{2}$$

In the equation, a and b are coefficients that describe the trend and are calculated separately for each region, since TFR values differ across regions. The variable x represents time in years, where the first year of the analysed period – 2014 is marked as 1 and the last year – 2051 is marked as 38.

Mortality

Mortality is represented through life expectancy - LE at birth. Life expectancy for males and females was projected using a linear extrapolation only on the national data of the historical trend for the period 2014–2021, while the regional values were later calculated using coefficients derived from the national average. Only the linear function was applied here since the linear extrapolation was more suitable to represent the extrapolated life expectancy over time. The projected values indicate an increase in life expectancy for both genders over the projection horizon.

$$LElinear = a + bx$$

In the equation, *a* and *b* are coefficients that describe the trend and are calculated separately for each region, since LE values differ across regions. The variable *x* represents time in years, where the first year of the analysed period – 2014 is marked as 1 and the last year – 2051 is marked as 38.

Migration

Migration is calculated separately for males and females and is expressed through net migration rates - NMR. Based on the historical trend for 2014–2021, both linear and logarithmic extrapolations were constructed. The linear function produced higher projected values which once again were very optimistic, while the logarithmic function produced lower values which were very pessimistic. The average of the two functions was used as the projected trajectory.

This approach was applied to all regions and both sexes, except for the Skopje region. Skopje is the only region with positive net migration and is expected to maintain positive values over the projection period. For this region, only the logarithmic function was applied, as it produced projected values that were more consistent with the observed trend. Based on this methodology, net migration rates are projected to decline in almost all regions for both sexes, with the exception of the Skopje, Polog, and Southwest Region, where positive trends are expected.

$$NMRaverage = \frac{NMRlinear + NMRlogaritmic}{2}$$

Therefore;

$$NMRaverage = \frac{(a + bx) + (c + dln\,(x)\,)}{2}$$

In the equation, *a* and *b* are coefficients that describe the trend and are calculated separately for each region, since NMR values differ across regions. The variable *x* represents time in years, where the first year of the analysed period – 2014 is marked as 1 and the last year – 2051 is marked as 38.

Regarding the working age population, there are several definitions. According to the International Labour Organization - ILO, the working-age population generally refers to people aged 15 years and older, although upper age limits may vary across definitions [27]. For the purposes of this research, the definition used by the Organization for Economic Co-operation and Development - OECD is applied, which defines the working age population as individuals aged 15 to 64 [28]. This measure can be expressed either as

an absolute number or as a percentage of the total population, depending on the context of the analysis.

Research Hypothesis

The fertility hypothesis

Fertility projections are uncertain, as fertility trends are influenced by social, economic, and political factors that are difficult to predict over the long term. As the projection horizon extends further from the jump-off year, the level of reliability decreases. For this reason, projected values for 2031 are expected to be closer to actual outcomes than those for 2051.

At the national level, the projected TFR reaches 2.05 in 2051, indicating an increase from 2031 with a recorded value of 1.81. In terms of regional differences, the Pelagonia region for example is the only region projected to record a decline in TFR, from 1.45 in 2031 to 1.42 in 2051. The remaining seven regions show increases over the same period. By 2051, the Skopje and Polog regions are projected to have the highest TFR values, while Pelagonia remains the lowest. The other regions also record increases during the projection period.

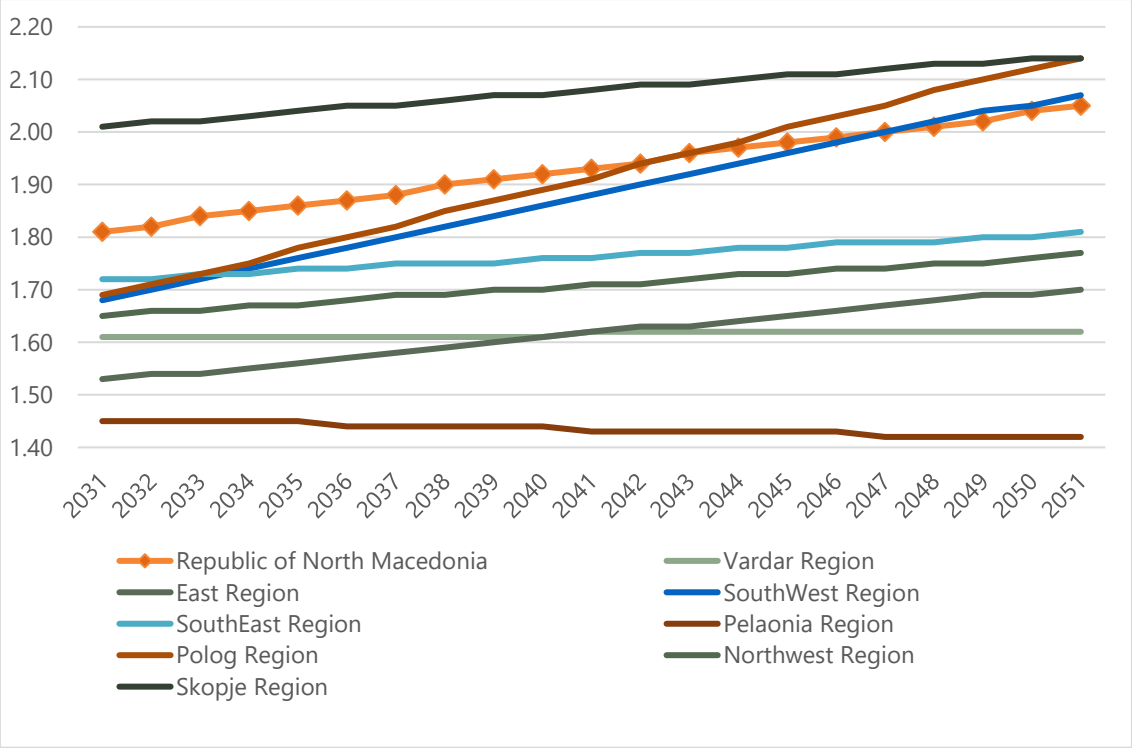


Figure 3. Projected TFR values for the period 2031–2051. Source: Author's own calculations

The mortality hypothesis

Between 2031 and 2051, life expectancy for men is projected to increase by approximately 2.5 years at the national level, rising from 73.19 years in 2031 to 75.61 years in 2051. These projections are based on a linear trend and do not account for potential external influences such as disasters, wars and epidemics.

At the regional level, male life expectancy is projected to be highest in the Skopje region and lowest in the Pelagonia region, with a difference of about 1.3 years. Women are projected to have higher life expectancy than men throughout the period. In 2031, the difference between female and male life expectancy is close to four years, while by 2051 it narrows slightly to around three and a half years.

For women, life expectancy is also projected to increase between 2031 and 2051, though the overall rise is slightly smaller than for men, at approximately 2 years. At the national level, life expectancy for women increases from 77.3 years in 2031 to 79.22 years in 2051, representing a gain of 1.92 years. Despite the smaller increase, women continue to have higher life expectancy than men throughout the projection period. At the regional level, the highest values are recorded in the Skopje region, while the Polog region has the lowest, with a difference of about two years.

The longer life expectancy of women is not related to North Macedonia only, but reflects a broader global pattern. The difference between male and female life expectancy is linked to a combination of biological, environmental, and lifestyle factors. While genetic and hormonal differences contribute to this gap, behavioral factors such as smoking, alcohol consumption, and occupational risks also play an important role [29].

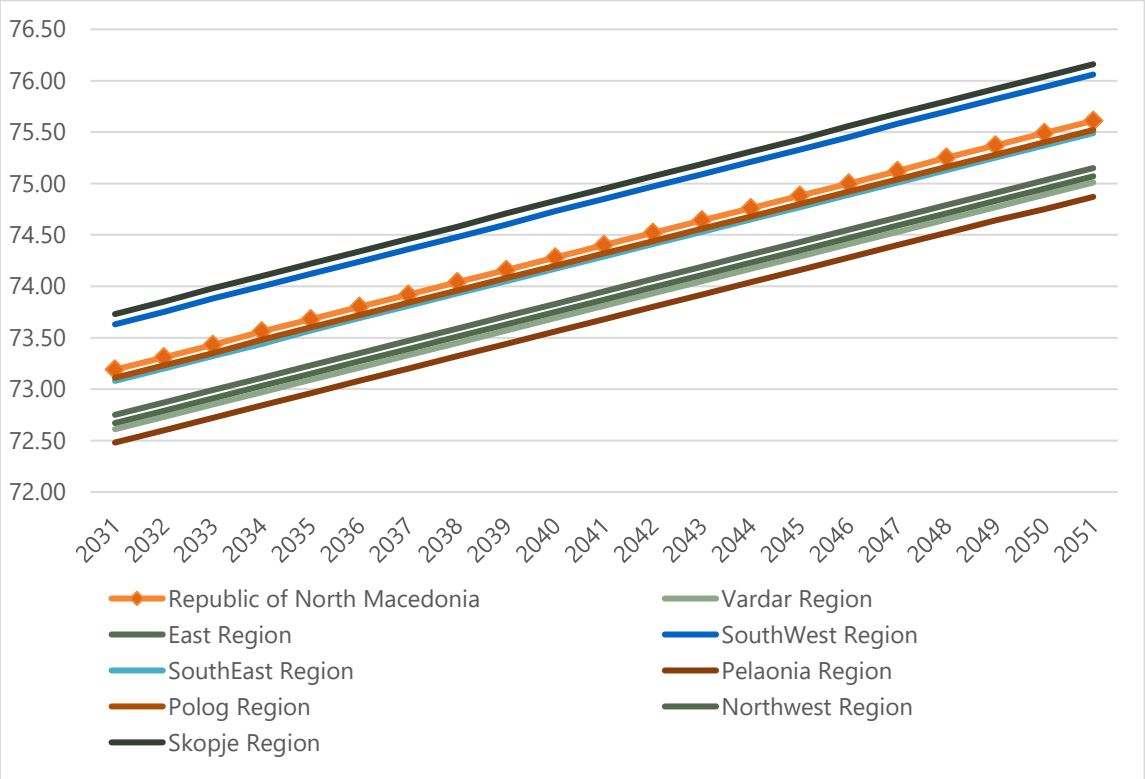


Figure 4. Projected LE values for males for the period 2031–2051
Source: Author's own calculations.

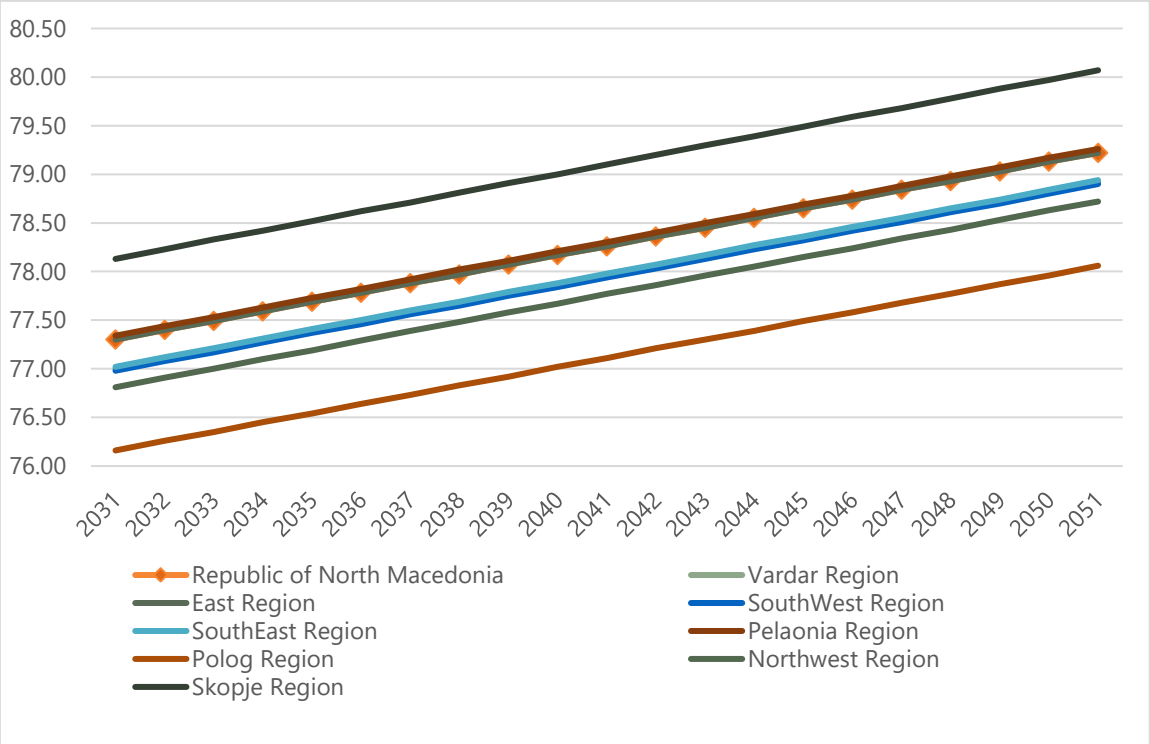


Figure 5. Projected LE values for females for the period 2031–2051
Source: Author's own calculations

The migration hypothesis

At the national level, the net migration rate for men remains negative throughout the projection period, declining from -0.02 in 2031 to -0.03 in 2051. The overall change between the first and last projected year is limited and reflects differences across regions. As with fertility and mortality, the Skopje region records the highest values. Its net migration rate is projected to increase slightly, from 1.93 in 2031 to 1.99 in 2051. The Polog and Southwest regions are the only regions projected to shift from negative to positive net migration rates, with the change being more pronounced in the Southwest region, where the rate moves from 0.2 in 2031 to 1.8 in 2051. All other regions maintain negative values throughout the period, with the Vardar region showing the lowest projected rates, declining from -3.3 in 2031 to -5.69 in 2051.

The analyzed data indicate that migration is more pronounced among women than men, as reflected in higher net migration rates. At the national level, the net migration rate for women remains negative, declining from -0.04 in 2031 to -0.08 in 2051. Skopje and Polog are the only two regions that are projected to have positive values in 2051, with the only difference being that, although Skopje shows higher values, the net migration rate in Skopje is projected to decline from 1.39 in 2031 to 1.24 in 2051, while the rate in Polog is expected to increase from -0.21 in 2031 to 0.46 in 2051.

All other regions have negative and decreasing values (except Southeast region that is expected to increase but still remain negative). The Vardar region is projected to experience the largest decline in its female population, with the net migration rate worsening from -3.26 in 2031 to -5.33 by 2051.

Differences between men and women are also evident within regions. The largest gap is observed in the Southwest region, where the male net migration rate in 2051 is projected to be positive with 1.8, while the rate for women remains slightly negative with -0.1. In

contrast, the Pelagonia region shows higher net migration values for women than for men, although both remain negative (-2.42 for men and -0.65 for women in 2051). Overall, the projections indicate continued immigration at the national level, with regional and gender differences in its intensity.

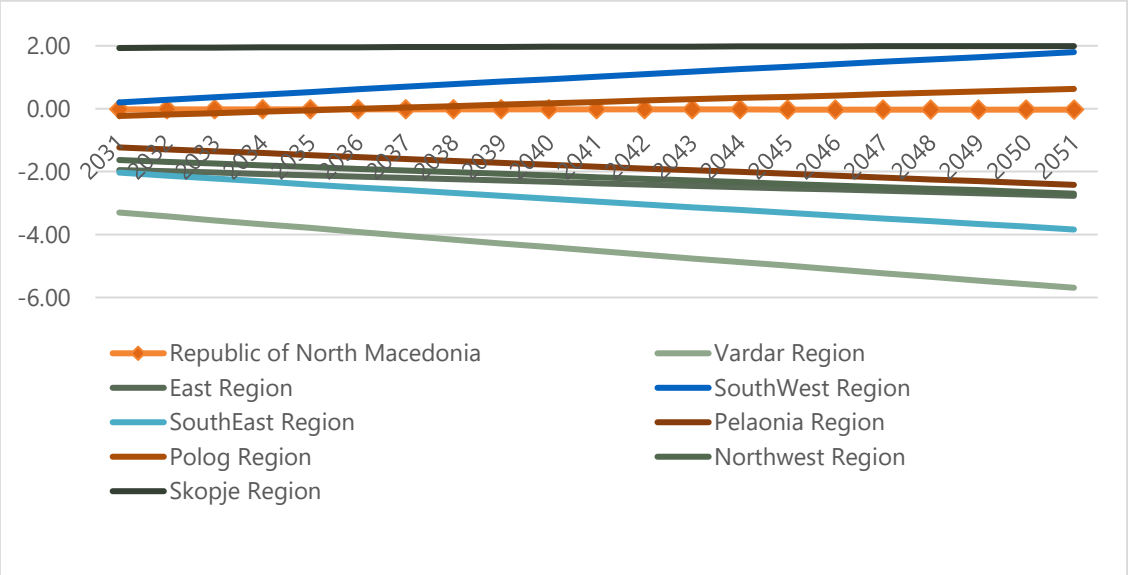


Figure 6. Projected NMR values for males for the period 2031–2051
Source: Author's own calculations

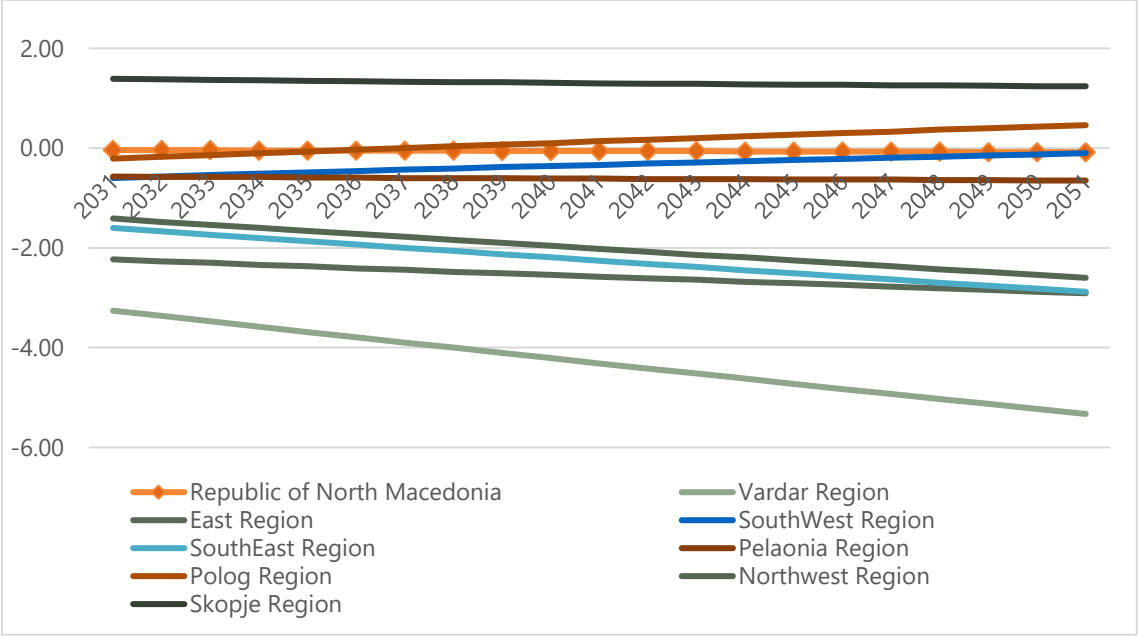


Figure 7. Projected NMR values for females for the period 2031–2051
Source: Author's own calculations

PAST TRENDS ON WORKING AGE POPULATION

In the analysis of the working age population, a decline has been observed between the last two censuses. In 2002, the number of people in this age group was 1,381,352, and by

2021, this number had decreased to 1,210,035. This corresponds to an absolute decrease of 171,317 people and a percentage change of -12.4%.

This declining trend is also present at the regional level. All regions, including the Skopje region, recorded a reduction in the number of working age individuals, although the magnitude of change differs across regions. For example, the East region shows the largest decline in both absolute numbers and percentage change of -23.56%. Substantial declines were also recorded in the Polog and Southwest regions. In the Polog region, the working age population decreased by 29,019 people (-14.4%), while in the Southwest region the decline amounted to 28,120 people (-19.1%).

The Skopje region, which has the highest population concentration with approximately one third of the total population residing in the capital, also recorded a decline in the working age population. However, this decrease was the smallest among all regions, amounting to 9,513 people, with a percentage change of -2.36%.

Changes are also visible when the working age population is examined by five-year age groups. In all regions except Skopje, the largest decline occurred in the youngest cohort (15–19), both in absolute and relative terms. At the national level, this group decreased by 61,387 persons between 2002 and 2021, representing a decline of 37.11%. In the East and Southwest regions, the reduction approached 50%, indicating a substantial contraction of this age group over the nineteen-year period. At the same time, the largest increase was recorded in the older working age cohorts, with those aged 60–64 in almost all regions. At the national level, this group increased by 34,973 people between 2002 and 2021, corresponding to a growth of 38.94%. The Eastern and Southeastern regions recorded the highest increases in this age group, with the number of persons aged 60–64 nearly doubling during the same period. The regional difference suggests an "urban pull" toward the capital, even as the country as a whole faces a "graying workforce" that points toward growing pressure on the pension and healthcare systems with fewer young workers to support them.

Table 1. Working age population in the 2002 and 2021

	Year	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	Total
Republic of North Macedonia	2002	165422	161945	153461	148281	149837	146902	142688	127760	95234	89822	1381352
	2021	104035	106553	116145	123101	127381	128186	126444	125643	127752	124795	1210035
	Absolute change	-61387	-55392	-37316	-25180	-22456	-18716	-16244	-2117	32518	34973	-171317
	Percentage change	-37.11	-34.20	-24.32	-16.98	-14.99	-12.74	-11.38	-1.66	34.15	38.94	-12.40
East Region	2002	14375	14187	13209	12621	13653	14592	14418	12917	9670	8457	128099
	2021	7447	7911	8297	9272	9691	10106	10236	10698	11711	12555	97924
	Absolute change	-6928	-6276	-4912	-3349	-3962	-4486	-4182	-2219	2041	4098	-30175
	Percentage change	-48.19	-44.24	-37.19	-26.54	-29.02	-30.74	-29.01	-17.18	21.11	48.46	-23.56
Northeastern	2002	14155	13868	13306	12419	12785	12342	11881	10334	7588	7297	115975
	2021	9537	9987	10074	9961	10082	10536	10606	10528	10764	10174	102249

	Absolute change	-4618	-3881	-3232	-2458	-2703	-1806	-1275	194	3176	2877	-13726
	Percentage change	-32.62	-27.99	-24.29	-19.79	-21.14	-14.63	-10.73	1.88	41.86	39.43	-11.84
Pelagonia Region	**2002**	17905	17500	15782	15378	16741	17826	18559	16063	11765	12226	159745
	2021	11063	11214	12419	13641	14710	14557	14086	14335	15359	16197	137581
	Absolute change	-6842	-6286	-3363	-1737	-2031	-3269	-4473	-1728	3594	3971	-22164
	Percentage change	-38.21	-35.92	-21.31	-11.30	-12.13	-18.34	-24.10	-10.76	30.55	32.48	-13.87
Polog Region	**2002**	28455	26001	24490	24262	23793	21167	17250	13954	10945	10608	200925
	2021	15700	16427	18645	18468	17799	17064	16889	17539	17705	15670	171906
	Absolute change	-12755	-9574	-5845	-5794	-5994	-4103	-361	3585	6760	5062	-29019
	Percentage change	-44.83	-36.82	-23.87	-23.88	-25.19	-19.38	-2.09	25.69	61.76	47.72	-14.44
Skopje Region	**2002**	44309	46394	46147	44443	41901	39625	41359	40752	30501	26967	402398
	2021	35092	34884	37917	41423	43507	44280	43017	40006	37646	35113	392885
	Absolute change	-9217	-11510	-8230	-3020	1606	4655	1658	-746	7145	8146	-9513
	Percentage change	-20.80	-24.81	-17.83	-6.80	3.83	11.75	4.01	-1.83	23.43	30.21	-2.36
Southeastern Region	**2002**	13975	13621	12706	12331	13089	13201	13015	10954	8396	7784	119072
	2021	7752	8019	8538	9096	9929	9975	10083	10420	11428	11674	96914
	Absolute change	-6223	-5602	-4168	-3235	-3160	-3226	-2932	-534	3032	3890	-22158
	Percentage change	-44.53	-41.13	-32.80	-26.23	-24.14	-24.44	-22.53	-4.87	36.11	49.97	-18.61
Southwestern region	**2002**	19865	18267	16812	15942	16336	16129	14381	12162	8607	8724	147225
	2021	10188	10657	12050	12203	12175	11955	12123	12182	12772	12800	119105
	Absolute change	-9677	-7610	-4762	-3739	-4161	-4174	-2258	20	4165	4076	-28120
	Percentage change	-48.71	-41.66	-28.33	-23.45	-25.47	-25.88	-15.70	0.16	48.39	46.72	-19.10
Vardar Region	**2002**	12383	12107	11009	10885	11539	12020	11825	10624	7762	7759	107913
	2021	7256	7454	8205	9037	9488	9713	9404	9935	10367	10612	91471
	Absolute change	-5127	-4653	-2804	-1848	-2051	-2307	-2421	-689	2605	2853	-16442
	Percentage change	-41.40	-38.43	-25.47	-16.98	-17.77	-19.19	-20.47	-6.49	33.56	36.77	-15.24

Source: State Statistical Office and author's own calculations

PAST TRENDS ON POPULATION AGING

The aging index represents the ratio between the population aged 65 and over and the younger population, usually defined as those under 15 or under 20 years of age. In this case, the population aged 0-14 was used as a reference group. The critical threshold value

of the aging index is 40.0% (or 0.40). When the index exceeds this value, the population is considered to have entered the stages of demographic aging [30].
Between 2002 and 2021, all regions in North Macedonia, i.e., the entire territory, recorded an increase in the aging index, indicating a shift toward older age groups. At the national level, the aging index doubled from 0.50 in 2002 to 1.01 in 2021. This means that by 2021, the population aged 65 and over outnumbered the population aged 0–14.
All regions follow this pattern. In the Eastern region, the aging index increased more than two and a half times, from 0.61 to 1.52. In the Pelagonia region, it rose from 0.85 in 2002 to 1.31 in 2021. Although the Polog region remains the youngest, the index also increased, from 0.30 to 0.70, indicating that the aging process is present in this region as well. A similar increase was observed in the Skopje region, where the aging index rose from 0.48 to 0.90.

Table 2. Population aging in 2002 and 2021

Year	Aging index	Republic of North Macedonia	East Region	Northeastern Region	Pelagonia Region	Polog Region	Skopje Region	Southeastern region	Southwestern region	Vardar Region
2002	Average age	35,14	36,71	34,32	38,49	31,41	35,44	35,74	33,70	36,63
	Young population (0-14) in %	21,08	18,40	22,62	17,83	26,05	20,31	19,83	23,38	18,71
	Young and mature population (0-39) in %	59,59	55,82	61,12	52,81	67,80	58,91	58,17	62,75	56,19
	Old population (60+) in %	10,63	11,16	10,26	15,09	7,89	10,09	10,71	10,17	11,46
	Aging index	0,50	0,61	0,45	0,85	0,30	0,50	0,54	0,44	0,61
	Stages of demographic aging (According to the aging index)	4	5	4	6	4	4	5	4	5
2021	Average age	40,89	44,13	40,24	42,96	38,31	39,83	42,49	41,10	42,29
	Young population (0-14) in %	16,95	13,80	16,98	14,97	18,64	18,59	15,80	15,99	15,60
	Young and mature population (0-39) in %	48,38	42,17	49,43	44,93	53,24	50,35	45,00	48,28	45,47
	Old population (60+) in %	17,17	21,02	16,18	19,65	13,03	16,69	18,89	16,87	18,47
	Aging index	1,01	1,52	0,95	1,31	0,70	0.9	1,20	1,06	1,18
	Stages of demographic aging (According to the aging index)	6	7	6	7	5	6	6	6	6

Source: State Statistical Office and author's own calculations

RESULTS AND DISCUSSION

This analysis examines how the working-age population (15-64) is expected to change over the next three decades (2031-2051) and more specifically the total size of the population and internal age structure across five-year cohorts.

The total working-age population in North Macedonia is projected to decline from 1,145,357 in 2031 to 1,000,988 in 2051. This is a decrease of 144,369 people over 20 years or 12.6%. The decline is present in all regions with different intensity.

In absolute numbers, the Pelagonia region is forecasted to have the largest loss with a reduction of 27,814 people, however the steepest percentage decline is projected in the Vardar Region, which is projected to contract by nearly one third (29.79%). In contrast, Skopje is forecasted to have the smallest decline, losing only 7,274 people or 1.83%. This reflects Skopje's role as the main economic center with the largest labor market which is projected to strengthen its dominance in the national workforce, holding about 34.7% of the total working-age population in the country in 2031, 36.8% in 2041 and nearly 39% by 2051. This concentration is likely to deepen regional disparities, driven by internal migration toward better employment opportunities and public services in the capital.
Beyond the overall decline, the age structure is also shifting. Most regions are set to transition towards older working-age cohorts, especially those that are going to experience deepest demographic aging like East, Pelagonia, Vardar Southeast and Northeastn region. This will create a workforce that is more rapidly shrinking and increasing the average worker age. In contrast to these regions, there are Skopje, Polog and Southwestern regions that are experiencing younger demographic profiles and different patterns. They are expected to maintain a stronger concentration in the middle working ages for much of the projected period. By 2051 however, Polog and Southwest Region are forecasted to shift toward older cohorts as its cohorts that were previously middle-aged, grow old.
Although almost all regions by 2051 are projected to have more people nearing retirement rather than young people entering the workforce, Skopje region is the only exception with its expected growth in younger workers, with age groups 25-29 recording an increase of 6.34% between 2031-2051 while age groups 30-34 and 35-39 recording an increase of 9.86% and 9.07% respectively.

Table 3. Working age population in 2031, 2041 and 2051

	Year	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	Total
Republic of North	2031	108,895	105,000	103,305	105,733	115,531	121,726	125,767	124,545	120,050	114,805	1,145,357
	2041	93,413	97,079	107,712	103,767	102,158	104,530	113,800	118,680	120,097	114,583	1,075,819
	2051	91,280	91,064	92,039	95,652	106,417	102,541	100,660	102,087	109,112	110,136	1,000,988
	Absolute change	-17615	-13936	-11266	-10081	-9114	-19185	-25107	-22458	-10938	-4669	-144369
	Percentage change	-16.18	-13.27	-10.91	-9.53	-7.89	-15.76	-19.96	-18.03	-9.11	-4.07	-12.60
East Region	2031	7,117	6,998	6,941	7,423	7,967	8,938	9,405	9,744	9,644	9,695	83,872
	2041	5,585	5,816	6,575	6,461	6,516	7,104	7,695	8,613	8,904	8,901	72,170
	2051	5,007	5,009	5,014	5,250	6,129	6,136	6,259	6,832	7,301	7,928	60,865
	Absolute change	-2110	-1989	-1927	-2173	-1838	-2802	-3146	-2912	-2343	-1767	-23007

	Percentage change	-29.65	-28.42	-27.76	-29.27	-23.07	-31.35	-33.45	-29.89	-24.29	-18.23	-27.43
Northeastern Region	**2031**	9,048	8,678	9,247	9,601	9,752	9,711	9,849	10,190	10,005	9,575	95,656
	2041	7,422	7,668	8,557	8,195	8,857	9,296	9,474	9,375	9,327	9,298	87,469
	2051	7,048	6,995	6,818	7,072	8,085	7,845	8,563	8,968	8,999	8,618	79,011
	Absolute change	-2000	-1683	-2429	-2529	-1667	-1866	-1286	-1222	-1006	-957	-16645
	Percentage change	-22.10	-19.39	-26.27	-26.34	-17.09	-19.22	-13.06	-11.99	-10.05	-9.99	-17.40
Pelagonia Region	**2031**	10,826	11,284	10,774	10,949	12,215	13,415	14,440	14,079	13,351	13,041	124,374
	2041	8,501	8,974	10,459	10,913	10,468	10,695	11,944	13,014	13,731	12,893	111,592
	2051	7,518	7,713	8,079	8,548	10,109	10,634	10,211	10,371	11,384	11,993	96,560
	Absolute change	-3308	-3571	-2695	-2401	-2106	-2781	-4229	-3708	-1967	-1048	-27814
	Percentage change	-30.56	-31.65	-25.01	-21.93	-17.24	-20.73	-29.29	-26.34	-14.73	-8.04	-22.36
Polog Region	**2031**	16,506	15,823	15,502	16,271	18,434	18,179	17,508	16,559	16,043	16,042	166,867
	2041	13,033	14,515	16,479	15,773	15,426	16,146	18,190	17,728	16,694	15,170	159,154
	2051	13,606	13,377	13,181	14,636	16,533	15,752	15,299	15,822	17,454	16,423	152,083
	Absolute change	-2900	-2446	-2321	-1635	-1901	-2427	-2209	-737	1411	381	-14784
	Percentage change	-17.57	-15.46	-14.97	-10.05	-10.31	-13.35	-12.62	-4.45	8.80	2.38	-8.86
Skopje Region	**2031**	39,994	37,713	36,837	36,529	39,256	41,982	43,648	43,592	41,154	36,793	397,498
	2041	37,524	38,533	41,659	39,331	38,014	37,194	39,382	41,434	42,096	40,521	395,688
	2051	38,004	38,058	39,171	40,131	42,816	39,997	38,200	36,829	38,157	38,851	390,214
	Absolute change	-1990	345	2334	3602	3560	-1985	-5448	-6763	-2997	2058	-7284
	Percentage change	-4.98	0.91	6.34	9.86	9.07	-4.73	-12.48	-15.51	-7.28	5.59	-1.83
Southeastern Region	**2031**	8,169	7,683	7,399	7,609	8,278	8,891	9,680	9,586	9,494	9,525	86,314
	2041	6,665	6,865	7,617	7,140	6,971	7,288	8,001	8,567	9,168	8,758	77,040
	2051	6,177	6,054	5,978	6,189	7,084	6,755	6,674	6,991	7,583	7,881	67,366
	Absolute change	-1992	-1629	-1421	-1420	-1194	-2136	-3006	-2595	-1911	-1644	-18948
	Percentage change	-24.38	-21.20	-19.21	-18.66	-14.42	-24.02	-31.05	-27.07	-20.13	-17.26	-21.95
Southwestern	**2031**	9,845	9,882	10,040	10,480	11,956	11,976	12,032	11,523	11,534	11,167	110,435
	2041	8,914	8,636	9,855	9,876	10,012	10,419	11,818	11,708	11,516	10,622	103,376
	2051	9,137	9,133	9,072	8,780	9,947	9,904	9,962	10,243	11,387	10,917	98,482
	Absolute change	-708	-749	-968	-1700	-2009	-2072	-2070	-1280	-147	-250	-11953

	Percentage change	-7.19	-7.58	-9.64	-16.22	-16.80	-17.30	-17.20	-11.11	-1.27	-2.24	-10.82
Vardar Region	**2031**	7,390	6,939	6,565	6,871	7,673	8,634	9,205	9,272	8,825	8,967	80,341
	2041	5,769	6,072	6,511	6,078	5,894	6,388	7,296	8,241	8,661	8,420	69,330
	2051	4,783	4,725	4,726	5,046	5,714	5,518	5,492	6,031	6,847	7,525	56,407
	Absolute change	-2607	-2214	-1839	-1825	-1959	-3116	-3713	-3241	-1978	-1442	-23934
	Percentage change	-35.28	-31.91	-28.01	-26.56	-25.53	-36.09	-40.34	-34.95	-22.41	-16.08	-29.79

Source: Author's own calculations

With regards to population aging, North Macedonia is projected to record a continued increase in the aging index, indicating a growing proportion of older individuals relative to younger ones. The national aging index is projected to rise from 1.15 in 2031 to 1.23 in 2051.

At the regional level, the Vardar region is projected to experience the largest increase, from 1.44 to 1.87. This implies that by 2051 the population aged 65 and over will be almost twice the size of the population aged 0–14. The Eastern region is forecasted to reach similarly high levels, with an aging index of 1.89, while the Pelagonia region follows closely with a projected value of 1.85.

In contrast, the Polog and Skopje regions are expected to remain relatively younger. Their aging index values are projected to remain close to 1, slightly below 1 in 2031 and slightly above 1 in 2051. This indicates a shift from a more balanced age structure toward a growing predominance of older age groups over time.

Table 4. Population aging in 2031, 2041 and 2051

	Aging index	**Republic of N.Macedonia**	**East Region**	**Northeastern Region**	**Pelagonia Region**	**Polog Region**	**Skopje Region**	**Southeastern region**	**Southwestern region**	**Vardar Region**
2031	**Average age**	41.50	44.94	41.23	43.68	40.10	39.90	43.10	41.83	43.37
	Young population (0-14) in %	16.16	13.11	15.91	13.54	16.47	18.25	15.17	15.68	14.61
	Young and mature population (0-39) in %	46.81	40.59	47.89	42.86	49.76	49.48	43.88	46.50	42.97
	Old population (60+) in %	18.65	23.66	18.05	21.41	16.23	16.53	21.51	19.13	21.11
	Aging index	1.15	1.80	1.13	1.58	0.99	0.91	1.42	1.22	1.44
	Stages of demographic aging (According to the aging index)	6	7	6	7	6	6	7	6	7
2041	**Average age**	41.99	45.53	42.15	44.51	41.01	40.21	43.48	42.11	44.54
	Young population (0-14) in %	16.43	13.40	15.94	13.33	16.82	18.34	15.50	16.76	13.99
	Young and mature population (0-39) in %	46.39	40.04	45.94	41.92	47.76	49.89	43.98	45.76	41.63

	Old population (60+) in %	19.62	24.49	19.58	21.98	17.72	17.66	22.26	19.85	22.82
	Aging index	1.19	1.83	1.23	1.65	1.05	0.96	1.44	1.18	1.63
	Stages of demographic aging (According to the aging index)	6	7	6	7	6	6	7	6	7
2051	**Average age**	42.20	45.92	43.07	45.46	41.15	40.32	43.66	42.01	45.72
	Young population (0-14) in %	17.13	13.92	15.76	13.28	18.11	19.05	16.11	17.53	13.96
	Young and mature population (0-39) in %	46.52	39.86	44.44	40.27	47.76	50.38	44.23	46.47	40.50
	Old population (60+) in %	21.13	26.29	21.34	24.62	18.67	19.27	23.72	20.60	26.14
	Aging index	1.23	1.89	1.35	1.85	1.03	1.01	1.47	1.18	1.87
	Stages of demographic aging (According to the aging index)	6	7	7	7	6	6	7	6	7

Source: Author's own calculations

The following section compared changes in the working-age population over two periods: 2002-2051, which captures demographic changes for a half-century, and 2021-2051, which reflects projected developments from the most recent census year to the end of the projected horizon.

At a national level, the working-age population is projected to decline by 380,364 people between 2002 and 2051, which represents a reduction of 27.54%. This change indicates that in the first half of the 21st century, North Macedonia is projected to lose more than a quarter of its working-age population. This decline is present in all regions, with different intensity.

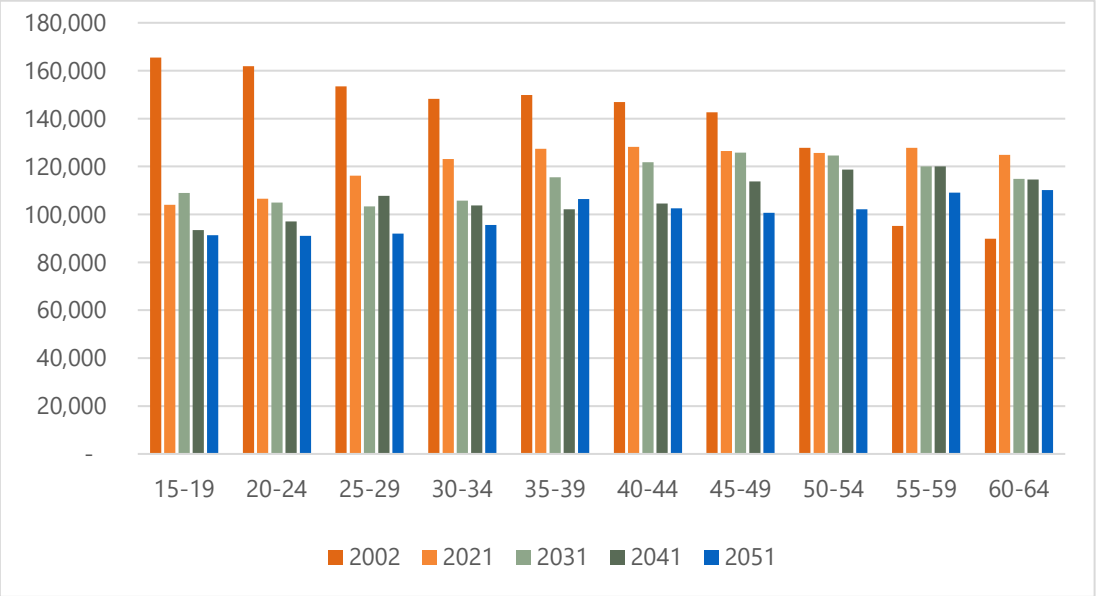


Figure 8. Working-age population in North Macedonia for the period 2002-2051
Source: Author's calculations

The East region is forecasted to record the largest decrease with a projected decline of 52.49% which amounts to 67,234 people, followed by Vardar region with an expected decline of 47.73%. It is worth noting that Pelagonia, the Northeast, and Southeast regions are also projected to record substantial declines, with losses ranging from 22% to 40% over the fifty-year period. In contrast, regions with a more balanced old people to young people ratio such as Polog and the Southwest region, experience smaller long-term declines while the Skopje region is projected to have the smallest reduction over the fifty-year period with only 3.03%. This is a result of a high concentration of economic activity and bigger opportunities in the capital.

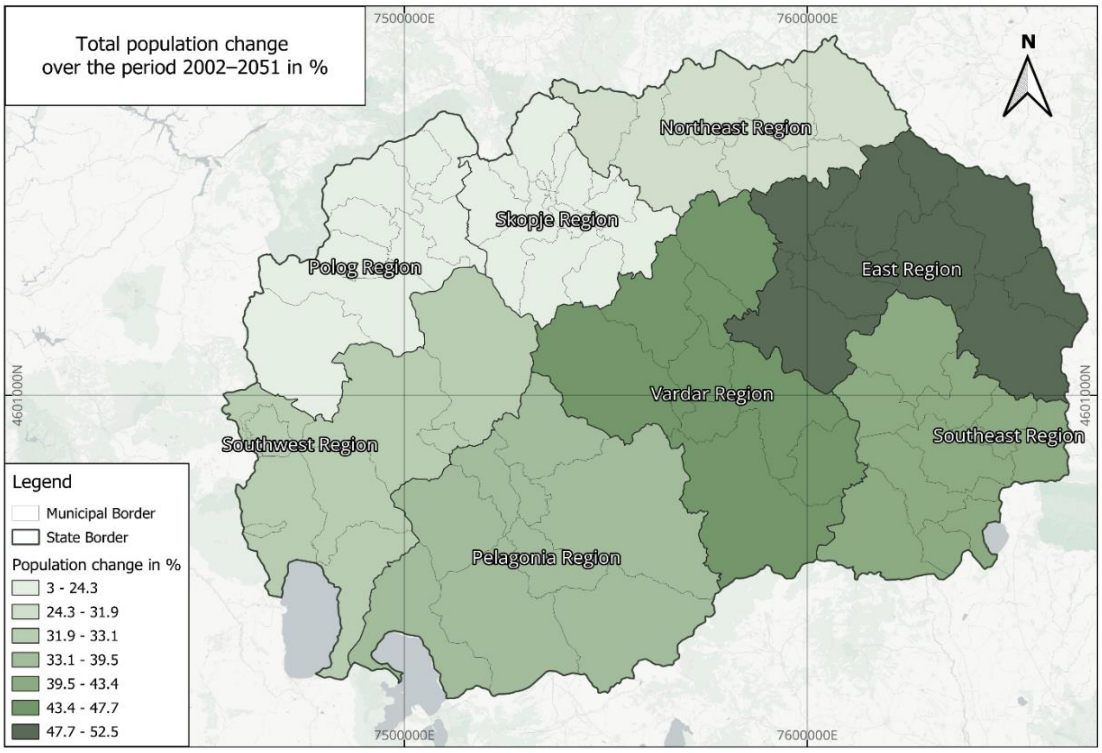


Figure 9. Total population change over the period 2002-2051 in %
Source: Author's calculations

When analyzing the shorter period 2021-2051, the projected national decline is 209,047 or 17.29%. In this period, the Vardar region is forecasted to record the largest decline with 38.33% while Pelagonia is expected to have the largest absolute decrease with 41,021 persons. Once again, all regions are projected to decline with Polog region and Southwest region showing more moderate reduction. Skopje is once again set to have the smallest decline with 0.68% or 2,671 persons.

The age structure analysis further illustrates the depth of demographic change. Over the period 2002-2051, all regions except Skopje are projected to lose more than half of their youngest working-age cohorts (15-19 and 20-24). At the national level, the decline is 44.82% for the 15-19 cohort and 43.77% for the 20-24 cohort. At the same time, older working-age cohorts (55-59 and 60-64) are forecasted to increase nationally by 14.57% and 22.62%, respectively, although this pattern differs across regions.

For the period 2021-2051, the national average shows that the most noticeable changes occur among middle-aged cohorts, particularly those aged 25-49 with projected decline

of around 20%. The regions with the highest levels of demographic aging, like Vardar and East regions, this decline is more than 30% across most age groups, with Pelagonia following with a decline of more than 25% and the Southeast region with an expected decrease above 20%. For comparison, the Polog region shows uneven changes, with increases in some younger cohorts and positive values in the 60-64 group. The Skopje region in projected to increase in several young age groups, while experiencing reduction in some middle-aged cohorts.

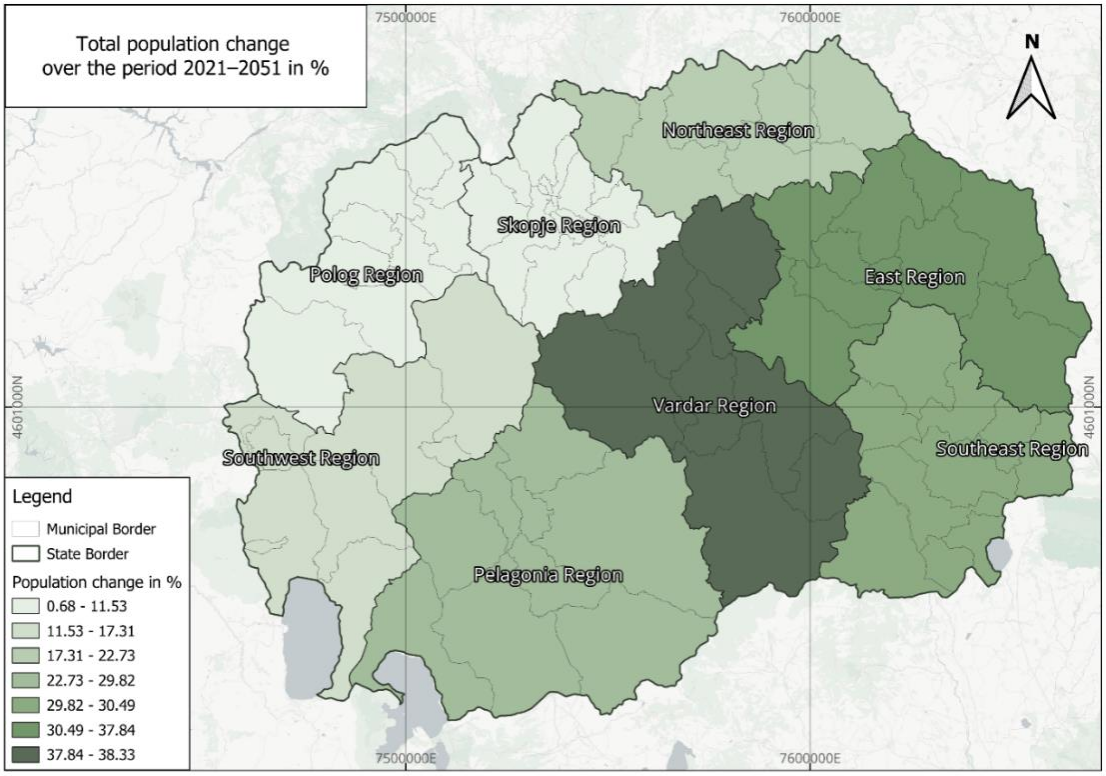


Figure 10. Total population change over the period 2021-2051 in %
Source: Author's calculations

When comparing the two periods, we notice that the most significant structural shift occurred between 2002 and 2021. During this 19-year period, the working-age population declined sharply, and the aging index doubled from 0.5 to 1.01, showing a transition from relatively young to older population. This also means that the young cohorts outnumbered the older cohorts nearing retirement. Although the most drastic change occurred in this nineteen-year period, 2021-2051 is projected to deepen the imbalance. Even though the projected decline is forecasted to be 17.29% the structural change already occurred by 2021. The aging index continues to increase but at a slower rate (from 1.01 to 1.23), which suggests a consolidation of an already aged population rather than a new phase of demographic transition so it's safe to assume that the projected period will reflect continuation and not a new demographic transition.

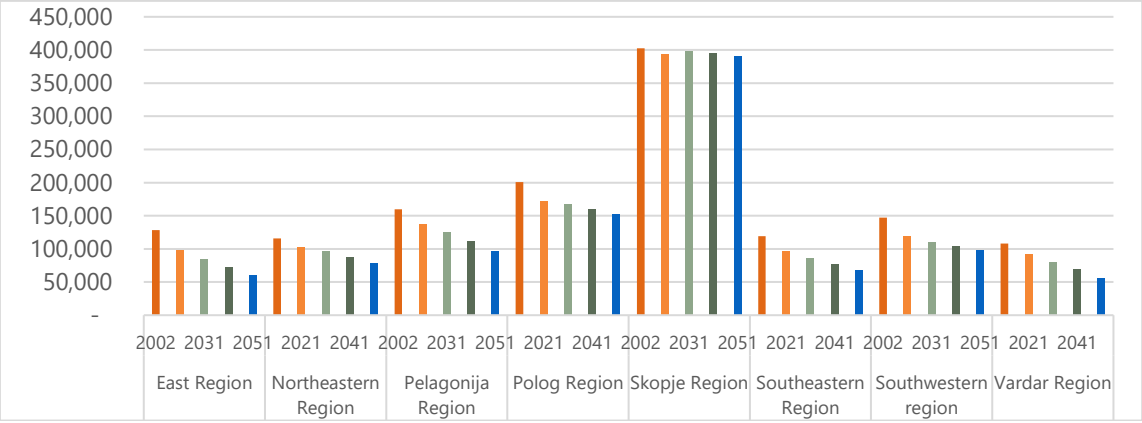


Figure 10. Changes in the working-age population for the period 2002-2051
Source: Author's calculations

The regional differences analyzed here are the same structural factors that existed long before the study period. One noticeable trend is that the Vardar and Eastern region already had an older age structure in 2002 which means that the aging in these two regions had happened even earlier. This is a result of weaker regional economy and high emigration rate towards Skopje and abroad.
The Polog and Southwestern regions had a younger population, especially in 2002, which slowed the aging but it did not prevent long-term decline. By 2051, even these regions are projected to follow the aging trends as the other regions, while their younger cohorts move towards retirement. Both regions have a higher share of Albanian population, whose demographic behavior differs than the national average, since they follow more traditional values and have higher fertility rates, lower female labor-force participation rate etc, which helps explaining their slower aging.
Skopje shows a completely different pattern. Being the only region with a positive net migration rate with the largest concentration of economic activity along with better access to public services, it retains larger share of the working-age population, which as a result creates regional disparities. While the other regions are experiencing workforce decline, Skopje is projected to have nearly 39% of the national working-age population by 2051.

Table 5. Total Population Change (Absolute and Percentage), 2002–2051 and 2021–2051

	Republic of North Macedonia	East Region	Northeastern Region	Pelagonia Region	Polog Region	Skopje Region	Southeastern Region	Southwestern region	Vardar Region
Absolute change 2002-2051	-380364	-67234	-36964	-63185	-48842	-12184	-51706	-48743	-51506
Absolute change 2021-2051	-209047	-37059	-23238	-41021	-19823	-2671	-29548	-20623	-35064
Percentage change 2002-2051	-27.54	-52.49	-31.87	-39.55	-24.31	-3.03	-43.42	-33.11	-47.73
Percentage change 2021-2051	-17.28	-37.84	-22.73	-29.82	-11.53	-0.68	-30.49	-17.31	-38.33

Source: Author's own calculations

CONCLUSION

Based on the analysis of both historical and projected data, three distinct structural patterns emerge across the fifty-year period 2002–2051.

Regions that are projected to lose more than half of their youngest working-age cohorts (15–19 and 20–24), without compensatory growth in other age groups over the fifty-year period, are also the regions that record the highest population aging. This applies to the Vardar, Eastern, and Pelagonia regions, and to a certain extent the Southeastern region. These regions are experiencing the most severe long-term contraction and are projected to lose between 20% and 30% of their working-age population across most cohorts in the period 2021-2051.

The Northeastern region follows a slightly different pattern. Although it also has a sharp decline in younger cohorts of around 50% over the fifty-year period, it shows some increase in older working-age cohorts (55–64). This reflects continued population aging. However, these changes are less pronounced than in the previously mentioned regions.

The Polog and Southwest regions show another distinct trajectory. While they also experience a decline of approximately half of their youngest cohorts, they record increases in older working-age groups (55–64) and maintain stronger middle-aged concentrations in 2031 and 2041. By 2051, however, these middle cohorts age into the upper working-age groups, leading to a structure that increasingly resembles the more aged regions.

The Skopje region stands out. Unlike the other regions, it shows projected growth in younger cohorts and maintains a large concentration of middle-aged individuals. This suggests greater workforce stability compared to the rest of the regions and a continued concentration of working-age population in the capital, thus creating regional disparities.

There trends suggest that there is a need for policies that focus on increasing labor force participation, especially in woman and older workers, while also supporting economic measures that are targeting regional development especially in the regions that are facing significant labor shortages. Over time, continued population aging will also put pressure on the pension and healthcare system in North Macedonia.

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WINE GEOGRAPHICAL INDICATIONS: COMPARATIVE ANALYSIS OF CROATIAN AND MACEDONIAN LEGISLATIONS*

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ABSTRACT

This study analyzes the legal framework regulating geographical indications (GIs) in a societal and economic context and assesses their importance for the economy. The authors employ historical, comparative, and normative methods to explore geographical indications across various categories of goods and services. The analysis specially refers to geographical indications in the wine industry, particularly from the aspect of their main function: to enhance value by indicating a product's origin and quality characteristics. The text provides an analysis of the Croatian legal framework and assesses how closely the Macedonian legal sources align with EU legislation. Several conclusions are presented regarding the necessity for ongoing training of producer groups, the business sector, and pertinent agencies to enhance the acknowledgment, enforcement, and protection of GIs.

Keywords: intellectual property, geographical indications, wine industry, Croatian law, Macedonian law

INTRODUCTION

Geographical indications possess not only legal implications as an industrial property right, but also considerable economic value. The market can be dominated through product quality and its consistent maintenance. The protection of geographical indications serves to inform consumers that items bearing certain geographical indications have distinct features. Geographical indications serve as a quality assurance, providing an additional guarantee function. The utilization of protected geographical indications for labeling items from a certain region promotes and markets the product, highlighting its unique characteristics derived from the area's natural conditions and the traditional expertise of its producers [1].
Regarding previous studies on GIs importance in the respective countries, in 2017, research conducted by Mesić, Božjak, and Cerjak on GIs in agrifood products in Croatia indicated that the majority of consumers anticipated that their protection would enhance their confidence in product safety, as well as that protection schemes could improve market and tourism offerings, thereby increasing the income of farmers producing protected products, all of which contribute to the economic development of Croatian rural areas [2]. Furthermore, specifically on legal aspects on wines, several authors, such as

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Milotić, have presented the arguments for protection of Teran in Istria, elaborating ampelographic, enological and legal aspects, specially from the scope on the rules of origin, production, and labeling [3].
Macedonian legal scholarship has also affirmed the economic importance of wine Gis, as well as the characteristics of the legislation. Such views are presented in several works by Polenak Akimovska, Bučkovski, Naumovski, Gavrilović, Vučen and Zlatev. These authors have reitirated the strategic role of GIs for wines, mainly since they viticultural geographical indications allow differentiation of products on the market due to their attractiveness and quality which signals certain "extra-territoriality" when promoting them outside the national market, which represents an advantage in comparison with other industrial property rights [4] [5].

CROATIAN LEGAL FRAMEWORK

Croatian wine act

The Croatian Wine Act [6] is completely harmonized with the EU legislation. Hence, the review below presents the provisions of the law and the corresponding provisions in the appropriate regulation(s). For instance, the general provisions (Articles 1–6) of the Croatian Wine Act define the scope of the legislation, key concepts, and institutional framework for regulating the wine sector. These provisions align with the basic definitions and scope established under Regulation (EU) No 1308/2013 of the European Parliament and of the Council, which lays down the common organization of agricultural markets and defines wine sector terminology at EU level, as well other EU Regulations: 1306/2013; 2019/33;) 2019/3; 606/2009 ; 2018/273; 2018/274; 251/2014[6].
The provisions on classification and protection of wines by origin (Articles 7–21) establish the system of protected designations of origin (PDO) and protected geographical indications (PGI). These articles regulate geographical delimitation, authorized grape varieties, production methods, yield limits, and product specifications. They implement and correspond directly to Articles 92–111 of Regulation (EU) No 1308/2013, as well as Commission Delegated Regulation (EU) 2019/33 and Commission Implementing Regulation (EU) 2019/34, which govern PDO/PGI applications, specifications, and protection in the wine sector [6].

Table 1. Key Provisions of the Croatian Wine Act of 2019 Regarding the Concept and Registration Procedures (Source: Authors' Considerations)

Section	Articles	Topic	Key Rules / Process
Geographical Indications	30–43	PDO and PGI system	- **PDO:** Wine fully produced in a defined area; quality essentially linked to origin. - **PGI:** At least one production stage linked to region; broader geographic link.
Application Process	30–43	Registration procedure	1. Application submitted to Ministry with product specification. 2. National committee reviews legal/technical compliance. 3. 60-day public objection period. 4. If approved → temporary national protection. 5. Sent to European Commission for EU registration.
Administrative Flexibility	30–43	Procedure adjustments	Rules allow objections, amendments, withdrawal, and cancellation of protected names.
Traditional Wine Terms	44–47	Traditional designations	- Must comply with EU requirements. - Registered nationally first. - Can be submitted for EU approval. - Removed from register if EU rejects protection.
Labeling Rules	48–50	Consumer protection & labeling	- Must follow EU and national law. - No misleading information on origin/quality. - Only approved wines can use PDO/PGI or traditional terms. - Additional rules ensure clarity and prevent confusion.

The section on vineyard planting and production potential (Articles 22–29) regulates vineyard authorization systems, planting rights, and vineyard registers. These provisions implement the EU vine planting authorization regime which controls vineyard expansion across Member States to ensure market balance and prevent overproduction.

The regulatory framework for wine and aromatized wine products establishes a comprehensive system for the protection, control, and marketing of products with geographical and traditional designations. Articles 30–43 introduce the system of geographical indications, distinguishing between Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI). PDO applies to wines produced entirely within a strictly defined geographical area, where quality and characteristics are essentially linked to that origin, while PGI applies to broader regions where at least one stage of production is connected to the area. The protection process begins when producers or producer groups submit an application to the Ministry, including a detailed product specification outlining origin, production methods, and product characteristics. A specialized national committee conducts a preliminary review to assess legal and technical compliance. If the application is complete and valid, it is published for a 60-day public objection period. If no valid objections are raised or disputes are resolved, the product receives temporary national protection and is forwarded to the European Commission for final EU-level registration. The system also regulates objections, amendments to specifications, withdrawal of applications, and cancellation of protected names, ensuring flexibility within a controlled legal framework [6].

Articles 44–47 regulate traditional wine terms, which must comply with EU requirements to be protected. These terms are registered nationally and may be submitted for EU-level

approval. If the European Commission rejects protection, the term is removed from the national register, ensuring that only legally valid designations remain in use. Strict labeling rules are established in Articles 48–50 to ensure transparency and consumer protection. All wines must be labeled according to EU and national legislation, and labeling must not be misleading regarding origin, quality, or characteristics. Only wines that comply with approved specifications may use protected designations (PDO or PGI) or traditional terms. Additional rules govern the presentation of protected names to avoid consumer confusion.

The regional wine organizations are regulated with articles 51-54. These organizations are aimed at promoting wines from specific regions, managing marketing strategies, and strengthening the identity of geographical indications. A system of regional branding is introduced to support recognition of regional wines, with internal rules governing the use of marketing labels. Articles 55–59 define conditions for placing wine on the market. Wine may only be sold after passing administrative checks, laboratory analysis, and where necessary sensory evaluation, followed by official approval from the competent authority. Only compliant and properly labeled wines may be marketed. Sales are generally limited to sealed containers, although controlled exceptions allow bulk sales and wine-by-glass service in hospitality establishments [6].

Articles 61–63 regulate fruit wines, requiring producers to be officially registered. Fruit wines are categorized and must follow approved production methods. Before being placed on the market, they must undergo laboratory and sensory testing, and only compliant products are authorized for sale. Article 64 governs advertising, allowing promotion just for wines with protected designations of origin (PDO or PGI). Advertising must refrain from targeting minors, promoting excessive drinking, or implying health, social, or personal advantages associated with alcohol. The framework for aromatized wine products is established in Articles 65–67, which impose stringent criteria for production, composition, and labeling in compliance with EU legislation, notably Regulation (EU) No 251/2014 and food information directives under Regulation (EU) No 1169/2011. Products with protected geographical indicators must adhere strictly to their authorized standards.

The safeguarding of aromatized wine product designations via a procedure akin to the registration of wine PDO/PGI is regulated in Articles 68–74. Applications presented to the Ministry are subjected to a national expert evaluation, subsequently followed by publishing and a period for public objections. In the absence of unresolved objections, temporary national protection is conferred prior to submission to the European Commission for ultimate registration. Articles 75–78 regulate the administration of protected names, permitting modifications to specifications via standard or streamlined procedures based on the extent of alterations. Protection may be revoked if requirements are unmet, and applications may be retracted prior to final approval. A mandatory conformity control system is established in Article 79, requiring producers to prove compliance with approved specifications. Authorized agencies conduct inspections and issue certificates of conformity, and only certified products may be marketed under protected names, ensuring traceability and consumer protection.

Articles 80–82 regulate laboratories and sensory evaluation systems. Only accredited laboratories operating under ISO standards may conduct chemical analyses, while sensory evaluation is performed by trained expert panels approved for organoleptic assessment. The administrative and on-site inspection systems are introduced by Articles 83–91. Authorities conduct both document-based checks and risk-based field

inspections. Inspectors have broad powers, including access to facilities, sampling, document review, enforcement orders, and the ability to suspend production or sales. In urgent cases, immediate oral decisions may be issued to prevent risks to health or evidence of integrity.

Furthermore, articles 92–94 regulate sampling and laboratory testing procedures. Samples are taken in multiple copies to ensure fairness and allow independent verification. If products comply, the state covers testing costs, while non-compliance results in costs being borne by the producer. Dispute resolution mechanisms include second and third analyses. Finally, Articles 95–97 set out enforcement measures and operator obligations. Producers must fully cooperate with inspections, and obstruction may result in sanctions or rejection of applications. Authorities may impose temporary bans, withdraw or destroy non-compliant products, or require reprocessing under strict conditions. Producers are financially responsible for violations and cannot claim compensation for resulting losses. The misdemeanor provisions are set up in articles 98-100, while the final and transitional procedures are in the articles 101-108 [6].

Overall, the system creates a highly structured legal and administrative framework ensuring that wine and aromatized wine products are authentic, traceable, properly labeled, and compliant with both national and EU standards. It combines geographical protection, strict quality control, scientific testing, and strong enforcement mechanisms to protect consumers and support the reputation of regional wine production.



Figure 1. Examples of wines with Protected Designation of Origin (PDO): Zlatna Vrbnička Žlahtina and Plavac Mali from Pelječac), Source: Authors' Archive

MACEDONIAN LEGAL FRAMEWORK

In a comprehensive GI context, Macedonian legislation encompasses the Law on Industrial Property (LIP) [7], the Law on the Quality of Agricultural Products (LQAP) [8], the Law on Wine [9], and the Law on Agricultural and Rural Development (LARD) [10]. Macedonia has ratified international conventions and agreements pertaining to geographical indications and appellations of origin, such as the Lisbon Agreement for the

Protection of Appellations of Origin and Their International Registration, along with its Stockholm Act [11]. The country is a signatory to the 1994 Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement) and the 2006 Central European Free Trade Agreement (CEFTA). The LIP employs the phrase "geographical names" (Macedonian: geografski nazivi), highlighting: (1) designations of origin (Macedonian: *oznaki na poteklo*) and (2) geographical indications (Macedonian: *geografski oznaki*).

Since 1993, the LIP has introduced the appellation of origin, regarded as a superior kind of protection. Since 2002, the LIP has established a new category of "lower protection" in addition to the appellation of origin, termed geographical indication, influenced by European Union legal terminology.

In October 2010, a special LQAP [8] was instituted to streamline the national and international registration of protected geographical indications and protected appellations of origin for agricultural products. This legislation also instituted the Traditional Guaranteed Specialty (Macedonian: *oznaka za garantiran tradicionalen specijalitet*) for traditional agricultural and food products with recognized distinguishing characteristics. The LQAP has been amended to comply with EU Regulation 1151/2012.

The LARD provisions are relevant to the economic importance and roles of geographical indications and appellations of origin. LARD delineates that high-quality agricultural products are those cultivated in compliance with standards that guarantee historical uniqueness. LARD provides opportunities for public financial assistance to achieve improved quality standards in the manufacturing of these commodities (Article 106).

Law on Wine

In 2024, a new Law on Wine (hereinafter: LW) was introduced, following the inconsistency of the previous law and its secondary legislation. The new LW ensures alignment with Regulation (EU) No 251/2014 on the definition, description, presentation, labelling, and protection of geographical indications of aromatized wine products and the Commission Delegated Regulation (EU) 2019/33 of 17 October 2018 supplementing Regulation (EU) No 1308/2013 of the European Parliament and of the Council regarding applications for protection of designations of origin, geographical indications and traditional terms in the wine sector, the objection procedure, restrictions on use, amendments to product specifications, cancellation of protection, and labelling and presentation) [12]. It also aligns with Commission Implementing Regulation (EU) 2019/34 of 17 October 2018 laying down rules for the application of Regulation (EU) No 1308/2013 of the European Parliament and of the Council concerning applications for protection of designations of origin, geographical indications and traditional terms in the wine sector, objection procedures, amendments to product specifications, the register of protected names, cancellation of protection and the use of symbols [13], as well as Regulation (EU) No 1306/2013 of the European Parliament and of the Council [14].

A pertinent reference concerning geographical indications of wines in the Republic of Macedonia is the Law on Wine, specifically the stipulations outlined in Chapter V, which addresses the registration and protection of wine geographical name with protected designation of origin (PDO), protected geographical indication (PGI) and traditional wine names. LW generally overrides the provisions of IP Law and the LQAP, considering that

the LW constitutes a kind of special legislation. This is solid ground for a comprehensive analysis will be conducted to clarify the framework of geographical indication protection for wine, emphasizing its essential structure and ramifications [1].

To establish GIs protection, the areas suitable for production of wine with GI are classified as 1) regions and areas, 2) vineyards, localities, and habitats [9].

According to LW , the designation of origin is a name, including a traditionally used name, used to describe a wine that meets the following requirements: 1)originates in a specific place, region or, in exceptional and duly justified cases, a country, 2)the quality or characteristics of which are largely or exclusively influenced by the geographical area and its natural and human factors, 3) is produced from wine grapes originating exclusively from the defined geographical area, and 4) all wine production processes take place entirely in the defined geographical area[9].

On the other hand, a geographical indication is a name, including a traditionally used name, used to describe a wine that meets the following requirements: 1) originates from a specific place, region or, in exceptional and duly justified cases, a country, 2) has a specific quality, reputation or other characteristic attributable to the geographical origin, 3)is produced from at least 85% of wine grapes originating from the defined geographical area and 4) all wine production processes take place entirely in the defined geographical area.

Furthermore, LW prescribes that the designation of wines with a designation of origin could also be carried out by non-geographical terms, defining that the non-geographical terms may be used only if, through long-term use in trade, they have become generally known as traditional for the designation of wine [9].

In terms of Article 60 of the LW, considering the geographical indication and the traditional names, the wine is classified as 1) wine with geographical indication (WGI); 2) wine with controlled origin (WCO), and 3) wine with controlled and guaranteed origin (WCGO). WGI, WCO and WCGO are entirely produced from recommended and approved grape varieties for production of wine.[9].



Figure 2. Example of a wine with controlled origin (WCO) (BOVIN Muscat Temjanika Wine) and a wine with control and guaranteed origin (WCGO) (BOVIN Dissan) from the Tikveš wine geographical area , Source: Authors' Archive

Procedural issues

In terms of Article 68 of LW, a GI for wine is protected by entering the Register of Wine with protected geographical indications upon a previous application. The application must contain an Elaboration which clarifies the production and designation of wine with a GI. LW contains detailed provisions in separate articles namely: Article 63 (applicants and application), Article 64 (review committees); Article 65 (procedure for review of the application), Article 66 (opposition procedure), Article 67 (decision for protection and registration), Article 71 (initial and subsequent acquisition of the right of use), Article 72 (amendment and supplements to the Elaboration), Article 74 (annulment of the registration), Article 75 (protection of GIs); Article 76 (international protection); Articles 77-78 (Protection on EU level); Article 79 (Control) and Articles 80-81 (Verification). The analysis of the provisions indicated that the approach is much more advanced than the previous Law on Wines, initially enacted in 2010 and amended ins several occasions as well as its secondary legislation [9].

Table 2. Key Provisions of Macedonian Law on Wines of 2024 (Source: Authors' Considerations)

Phase	**Step / Aspect**	**Relevant Article (LW)**	**Description**
Application Phase	Application for GI protection	Article 68	GI protection is granted through entry into the Register of Wine with protected geographical indications, based on a prior application.
	Application requirements	Article 63	Specifies eligible applicants and formal requirements.
	Elaboration (mandatory document)	Related to Art. 68	Must detail production methods and designation rules for the GI wine.
Examination Phase	Review committees	Article 64	Competent bodies responsible for examining applications.
	Review procedure	Article 65	Defines the process of formal and substantive examination.
Opposition Phase	Opposition procedure	Article 66	Enables third parties to challenge the application.
Decision Phase	Decision and registration	Article 67	Authorities decide on protection and registration.
	Entry into register	Article 68	GI is officially protected upon registration.
Post-Registration Phase	Right of use	Article 71	Regulates acquisition and use of the GI.
	Amendments to Elaboration	Article 72	Allows updates or modifications to the Elaboration.
	Annulment of registration	Article 73	Provides grounds for cancellation of GI registration.

Phase	Step / Aspect	Relevant Article (LW)	Description
Protection & Enforcement	Protection of GIs	Article 75	Defines legal protection and enforcement measures.
	International protection	Article 76	Covers protection beyond national borders.
	EU-level protection	Articles 77–78	Regulates protection within the EU framework.
Control Mechanisms	Control	Article 79	Establish monitoring systems.
	Verification	Articles 80–81	Ensures compliance with GI requirements.
Context	Legislative context	—	The current law is more advanced than the 2010 Law on Wines and its amendments.

DISCUSSION

Following prior presentations and debates regarding the Croatian and Macedonian systems for the protection of geographical indications (GIs), particularly concerning wines, it can be determined that both legal frameworks predominantly align with the system established by the European Union. Moreover, regarding their structure, the fundamental core legal sources (*Laws on Wine: Zakon o vinu; Zakon za vinoto)* in both instances exhibit analogous characteristics.

In Croatia, the protection of geographical indications is embedded within both national legislation and directly applicable EU regulations. National laws primarily regulate procedural aspects, such as the designation of competent authorities, control bodies, and enforcement mechanisms, while substantive rules on registration and protection derive from EU law. This ensures a high level of legal certainty and consistency, especially regarding the scope of protection, rights of use, and mechanisms for objection and cancellation. This refers to protected designations of origin (PDOs), protected geographical indications (PGIs), and traditional specialties guaranteed (TSGs).

Geographical indications are economically significant in Croatia, especially in the wine, olive oil, and traditional cuisine sectors. Croatian producers have effectively employed geographical indications as a marketing strategy to enhance regional identity and product quality. This has resulted in elevated product pricing, as well as advancements in rural development, conservation of traditional production techniques, and a rise in tourism in areas linked to prominent geographical indications. The Croatian approach prioritizes the collective aspect of geographical markers. Producers organized in collectives generally commence the registration process, and the entitlement to utilize a Geographical Indication (GI) is conferred upon all producers within the specified geographical region who adhere to the product specifications. These requirements are meticulously defined and rigorously enforced, guaranteeing that the quality, reputation, and attributes are associated with the geographical origins.

Similarly, Macedonian law establishes both a general regime for protection and several sectoral regimes. However, it goes a step further by introducing a general regime that

covers GIs for all types of products (regulated by LIP) [7], not only agricultural products and foodstuffs. In this respect, the influence of the Lisbon Agreement is clear. Furthermore, while the European Union maintains special regimes for spirit drinks, aromatized wines, and grapevine products, Macedonian legislation provides special regimes specifically for agricultural products, foodstuffs, and wine [1].
Nevertheless, legal regulation itself serves only as a vehicle for the realization of the economic effects of geographical indications. The law grants certain rights and entitlements that companies and other entities may use to promote their products and achieve economic benefits. However, these benefits can only be realized if geographical indications are properly registered and subsequently used in practice. Hence, Macedonian legislation on GIs can be assessed from both a legal and an economic ratio, with the understanding that the practical functionality of the legal framework ultimately determines the extent of economic benefits.

CONCLUSION

Geographical indications, like trademarks, play an important role in attracting consumers, particularly in the wine sector, by linking products to a specific region and highlighting their distinctive qualities derived from local natural conditions and traditional expertise.
Procedurally, Croatia benefits from clearer and more user-friendly rules, largely due to the experience gained through its implementation. The process of registration involves both national examination and subsequent scrutiny at the EU level, which enhances the credibility and recognition of Croatian GIs on the international market. Furthermore, once registered at the EU level, Croatian GIs enjoy protection across all Member States, significantly expanding their market reach:
Concerning the Macedonian approach, wine geographical indications are strategically significant in several ways: they help differentiate products in both domestic and international markets, enhancing their appeal and competitiveness; they generate added economic value since consumers are often willing to pay higher prices for regionally certified wines; and they support the preservation of biodiversity, local traditions, and natural resources while also contributing to tourism development. Moreover, they are especially beneficial for smaller and family-owned wineries seeking to expand and improve their production. Overall, strengthening geographical indications requires not only legal and economic support but also continuous education and awareness among producers, institutions, and the wider business community to ensure effective use and protection of these designations.
The analysis demonstrates that while the Macedonian system of geographical indications is also largely aligned with the European Union model and even exceeds it in scope by introducing a general regime applicable to all products, its effectiveness and practical implementation is expected to face challenges, especially regarding the registration, and economic utilization. In this context, it should also be noted that the new Law on Wines introduces a clearer and more structured framework in line with EU standards , although its applicability and impact are yet to be assessed. However, similar to other industrial property rights, that legal alignment alone is insufficient without efficient enforcement and practical use.
Consequently, to reinforce the Macedonian wine GI's protection system and amplify its economic influence, there is a distinct necessity for augmented collaboration between the two countries especially via joint ventures, collaborative training programs, and the

networking of Macedonian and Croatian researchers, specialists, business sectors, and relevant stakeholders, which would promote knowledge exchange, capacity enhancement, and the implementation of best practices in the domain of geographical indications.

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TRANSFORMATION OF RELIEF AND WATER NETWORK IN THE KOLLOSI REGION (SOUTHERN CYPRUS) IN THE MIDDLE AGES – A HISTORICAL AND GEOGRAPHICAL ANALYSIS

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ABSTRACT

Spatial analysis utilized GIS tools, old maps and historical data, as well as paleogeographic data from a salt lake on the Akrotiri peninsula. Cyprus was home to one of the oldest civilizations in Europe, reaching its greatest glory between 1291 and 1374. After the fall of Acre (1291) to the Mamluks, rapid economic development occurred, and the island played a crucial role in Levantine trade. The Medieval economic boom was based on the cultivation and processing of sugarcane - a period known as the "Frankish Sugar Age". The cultivation of cane and the production of sugar by the Knights of St. John and the Venetians are associated with the Castle of Kollosi and the settlement at Episkopi. The castle held strategic importance in the administration of southern Cyprus. The Knights of St. John constructed an irrigation system for the sugarcane fields, as well as an aqueduct and pipelines to bring water from the Kouris River for use by the watermill and sugar refinery. However, the amount of available water was variable and determined by climatic changes (drought) at the beginning of the Little Ice Age and the lowering of groundwater levels associated with the sea level drop. However, the most significant and devastating impacts were caused by human factors – warfare with the Genoese and Mamluks, the suppression of the Templar Order, and the involvement of the Hospitaller Order on the island of Rhodes. This negatively impacted the economy of the study area and the entire Kingdom of Cyprus, as well as its geopolitical position in this part of the Mediterranean.

Keywords: Cyprus, Kolosi, Middle Ages, Geography, History

INTRODUCTION

Cyprus is located in the eastern Mediterranean and has been a strategic point and supra-regional trade centre since ancient times (Fig. 1). It was home to one of the oldest civilizations in Europe, reaching its greatest glory between 1291 and 1374. After the fall of Acre (1291) to the Mamluks, rapid economic development occurred, and the island played a crucial role in Levantine trade. The Medieval economic boom was based on the cultivation and processing of sugarcane. Thanks to the Arabs, the first sugarcane plantations were established in the Mediterranean region as early as the 7th century, in

Syria, Palestine, and later in Crete and Cyprus. However, sugarcane processing only began with the Latin conquest of the island in 1191 and the arrival of the Order of Saint John. Sugarcane then became the island's main crop, a period known as the "Frankish Sugar Age".

Its location at the obduction zone of two lithospheric plates (Anatolian and African) [1] results in significant tectonic activity, numerous earthquakes [2], and uplift movements, marked by elevated marine terraces in the coastal relief. However, the southern part of Cyprus near Limassol (Lemesos) is very weakly uplifted – 0.02 mm/year [3], and sea level fluctuations in the last 2500 years (Fig. 2) range from −1.15±0.13 m (OSL: 2150 ka) to +0.5 m (OSL: 770 ka = ca. turn of the 12th/13th century AD) and a further drop of -0.41±0.13 m (OSL: 480 ka = ca. end of the 15th century AD) [4]. The study area (Fig. 1) consists of chalks and marls of the Miocene Pakhna Formation [5] exposed on the hills surrounding the Pleistocene/Holocene Kouris alluvial fan [6], [7], as well as on the hills of the Akrotiri Peninsula around the Salt Lake located there [8] (Fig. 3).

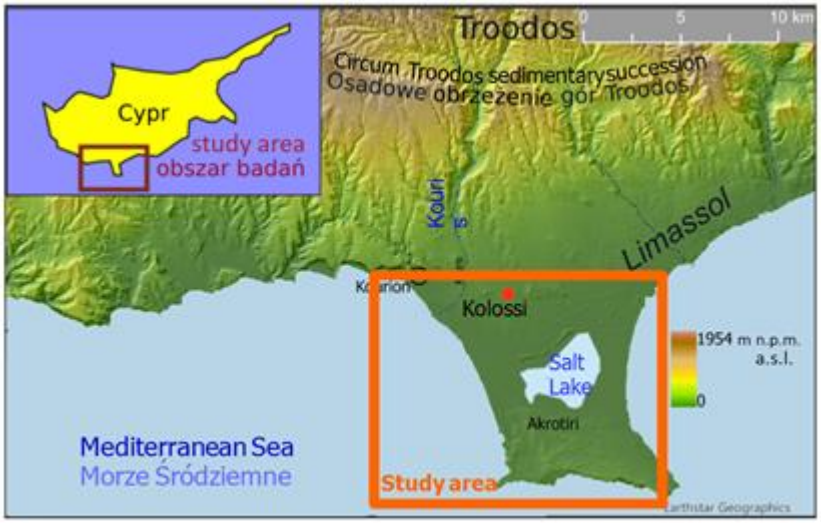


Figure 1. Location of study area ([7] changed). Hypsometric map made classical method and based on the Digital Elevation Model (DEM developed on the basis of the SRTM mission [12]) of southern Cyprus. The boundary of the sedimentary margin of the Troodos Mountains (Circum Troodos Sedimentary Succession) according to [9]

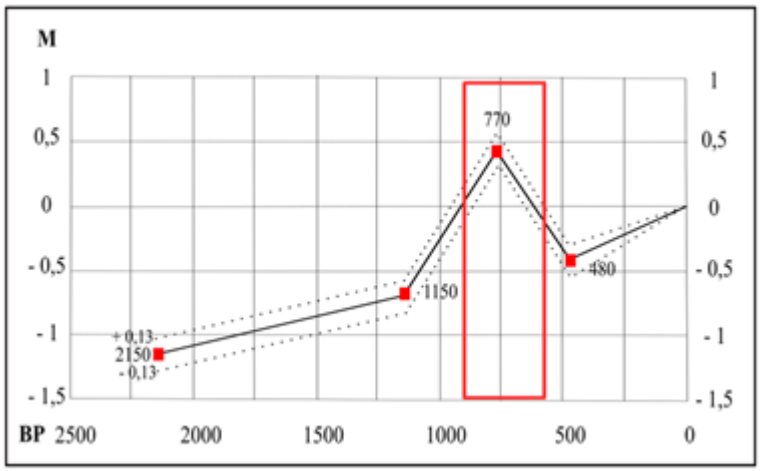


Figure 2. Sea level changes near study area. Period of study indicate by red box ([4], supplemented)

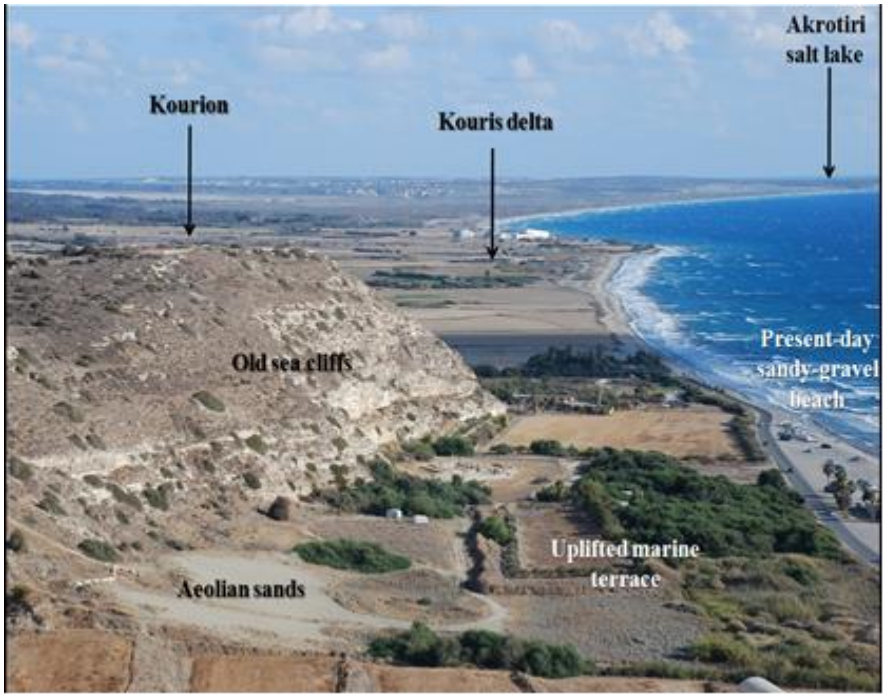


Figure 3. Relief of study area with outcrops of the Miocene Pakhna Formation near ancient Kourion, The Pleistocene/Holocene alluvium of Kouris river, the Pleistocene uplifted marine terrace and lagoon cut-off in the Subatlantic - Salty Lake on Akrotiri Peninsula (photo T. Kalicki)

AIM AND METHODS OF STUDY

The aim of the historical-geographical analysis was to determine the role of the Knights of St. John and the Venetians in sugarcane and vine production, as well as the geomorphologic and hydrographic changes in the Kouris alluvial fan associated with this activity and the function served by the Medieval castle at Kolossi. Spatial analysis utilized GIS tools, old maps and historical data, as well as palaeogeographic data from a Salt Lake on the Akrotiri peninsula.

Palaeogeographic and historical data documenting environmental and climatic conditions at the beginning of the Little Ice Age and the volatile and unstable geopolitical situation during the 13th-16th centuries were analyzed.

The methods can be divided into geoinformatics, historical, geomorphologic, and climatologic. GIS data, particularly raster data (DEM), were used. Based on this data, a geoinformatics model of potential hypothetical castle locations and a runoff model were developed.

RESULTS

Historical and Environmental Data

From the 13th to the 15th century, rivalry between Genoa and Venice took place in Cyprus, which led to the division of the island into spheres of influence [10]. In 1210, on the initiative of the Frankish King, Hugh I of the Lusignan dynasty, the old castle at Kolossi, now in ruins, was built on the Kouris alluvial fan (Fig. 4). As shown by the geoinformatic model of potential (hypothetical) castle locations, the location was not determined by defensive factors (Fig. 5), but by its location on the limit of a flat, fertile, and arable area (Fig. 6).



Figure 4. Ruins of Old castle in Kolossi built in 1210



Figure 5. Geoinformatic model of potential (hypothetical) castle locations and the location of Kolossi Castle on a hillshade map (based on [11], [13])



Figure 6. Location of Kolossi Castle on the northern limit of the cultivated areas on the plain of the Pleistocene Kouris alluvial fan on a hillshade map (based on [12]). Basemap based on satellite images from the Copernicus mission [14]

In the 14th and 15th centuries, the largest agricultural sector in Cyprus was cereal cultivation, primarily barley and wheat, and to a lesser extent oats. The main export product was carob, the distribution of which was controlled by the Genoese through the port of Famagusta. Numerous farms (in the 14th century, the number of Cypriot villages was 493) cultivated beans, lentils, peas, flax, and linseed. On the slopes of the Troodos and Kyrenia Mountains, and in the study area on the slopes of the carbonate hills of the Pakhna Formation, favourable conditions existed for the growth of olive trees and vines. These provided olive oil, sesame oil, honey, and wax, and wine was produced [15]. However, by the end of the 13th century, sugarcane had been introduced to Cyprus, which led to a significant restructuring of the agricultural structure.

The cultivation of cane and the production of sugar by the Knights of St. John and the Venetians are associated with the Castle of Kollosi and the settlement at Episkopi. The castle held strategic importance in the administration of southern Cyprus. The plains of the Kouris alluvial fan in the study area were used for industrial-scale sugarcane cultivation by the Knights of the Order of St. John from 1291. They began cultivating and processing sugarcane in Kolossi, and the sugar and molasses produced were exported to Europe. After the fall of Acre and the Kingdom of Jerusalem (1291) [10], they benefited from the migration of skilled workers to work on plantations and in processing plants. Dry summers and the regime of the Kouris River necessitated irrigation of fields, and water was necessary for sugar and molasses production. This resulted in a transformation of the watercourse and canal system on the Kouris alluvial fan in the 14th century.

In 1305, the Knights Hospitaller became involved in the civil war in Cyprus between King Henry II and his brother Almaric, supported by the Knights Templar [15]. Simultaneously, in 1309-1310, they moved the order's headquarters (Convent, hospital) to Rhodes, where they established a sovereign state [16]. However, the Knights Hospitaller who remained in Cyprus regained their possessions after 1312 and took over those previously belonging to the Knights Templar (the order was dissolved in 1308). These were divided into three Commanderies, the most important of which, the Grande Commandery, was based in Kolossi [17]. In 1347–1348, the Black Death, a plague pandemic probably brought by sea from Syria, swept through Cyprus, killing between one and two-thirds of the island's population, and in 1347–1352 decimating the European population [18]. The demographic crisis enabled the aggression of, among others, the Turks against the fortress of Kyrenia in northern Cyprus. However, in the south of the island, after the pandemic, in the 14th century, the Hospitallers expanded the system of canals for irrigating sugarcane plantations, as well as pipelines and aqueducts (1365–1374), which brought water from the Kouris River to the entire sugar refinery complex built in the 14th century near the castle at Kolossi [19] (Fig. 7). The largest canal connecting the Kouris riverbed and the Salt Lake in Akrotiri was probably built during this period. This canal served the purpose of irrigating sugarcane plantations and simultaneously draining water used during cane processing at the Kolossi sugar mill to the western part of the Salt Lake in Akrotiri. The canal is marked on some historical maps, e.g., those from 1562, 1612, and 1682 [8].



Figure 7. The sugar mill complex (14 th century) and aqueduct (1365-1374) at Kolossi (photo T. Kalicki)

From the 1370s, the Cypriot possessions of the Knights of St. John began to feel the effects of the crisis that affected the Kingdom of Cyprus and was caused first by the war with the Genoese (1373-1374), who were finally expelled from Famagusta in 1468, then by the Mamluk invasions (1425-1426) [17]. Attacks by the Genoese in 1373, then by the Mamluks in 1402, 1413, 1425, 1426, and a series of earthquakes led to the ruin of the castle in Kolossi (Fig. 4). However, in 1454 it was rebuilt by the Grand Commander Luis de Magnac (Fig. 8).



Figure 8. New castle at Kolossi built in 1454 (photo T. Kalicki)

In 1401, the Hospitallers competed with the Venetians, who owned Episkopi in the second half of the 14th century [17], for access to the Kouris River and unlimited use of water resources needed for sugarcane cultivation and sugar production [10]. This may have been the result of climatic changes at the beginning of the Little Ice Age. A significant drying was observed in Lake Nar (Anatolia, ca. 250 km N of Cyprus) from ca. 1400 and continued throughout the 15th century [20]. Also, the lowering of sea level by almost 1 m/300 years (Fig. 2) caused increasingly lowering of groundwater level, and consequently, drying of habitats and the need for increasingly intensive irrigation of crops. The limited amount of freshwater used for irrigation and in the Kolossi sugar mill, which was discharged into the NW part of the Salt Lake on the Akrotiri Peninsula, did not sweeten of water the entire lake. Therefore, in cores from the E part of the lake (see [8]), there are no series of freshwater inflows in the uppermost part of the profiles.
Wars with the Genoese and Mamluks caused losses and a decline in income for the Hospitallers, and in 1488, their property in Kolossi became the property of the Venetians. According to Venetian data, in 1490, Cyprus had a population of approximately 106,000 and 800 villages. Sugar production and export from the island ceased completely between 1489 and 1571 after the Venetians took control. In the 17th century, the cultivated fields were occupied by cotton, for which demand was growing in Europe.

CONCLUSION

The transformations presented here demonstrate the complex interdependence of geopolitical and environmental factors shaping ownership changes, cropping patterns, and hydrographic patterns, using the example of a small agricultural region administered from the castle at Kolossi. Sugarcane plantations, dependent on an extensive anthropogenic irrigation system, played a crucial role here. However, the amount of available water was variable and determined by climatic changes (drought) at the beginning of the Little Ice Age and the lowering of groundwater levels associated with the sea level drop. However, the most significant and devastating impacts were caused by human factors – warfare with the Genoese and Mamluks, the suppression of the Templar Order, and the involvement of the Hospitaller Order on the island of Rhodes. This negatively impacted the economy of the study area and the entire Kingdom of Cyprus, as well as its geopolitical position in this part of the Mediterranean. Also crucial were the Venetians and Genoese's search for new trade routes to directly acquire and sell new goods.

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LOCAL AGRITOURISM BUSINESS CONCEPTS AS A PLACE-SENSITIVE STRATEGY TO EMPOWER RURAL COMMUNITIES IN ALBANIA

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ABSTRACT

This article develops a theoretical and empirical framework for understanding place-based rural development as a strategy to counteract the structural forces of commodification, centralization, and territorialization that shape contemporary socio-ecological crises. It argues that rural marginalization is not a natural condition but the outcome of political-economic and discursive processes that privilege urban growth models while systematically devaluing local specificities. In response, the paper proposes a strategic triad—decentralization, decommodification, and relational spatial concepts—as the normative and analytical foundation for strengthening rural communities. Places are conceptualized not as static containers but as relational, material, and discursive assemblages that can function as resources for emancipatory practice, participation, and collective empowerment. Commons are introduced as an exemplary institutional form through which local communities can partially detach essential goods and services from market logics while expanding democratic self-governance.
The second part of the article applies this framework to agritourism in Albania. Based on qualitative case studies of three agritourism enterprises—Sabriu Guest House, Kulla Hupi, and Mrizi i Zanave—the study examines whether and how agritourism can function as a decentralized, commons-like strategy of rural development. The findings indicate that, despite private ownership structures, these initiatives operate through dense local networks of cooperation, shared production systems, and participatory economic practices. They generate economic diversification, support local employment, foster ecological awareness, and strengthen community cohesion. At the same time, their transformative potential remains contingent upon municipal embedding, infrastructural development, and protection against re-commodification. The article concludes that agritourism can contribute to sustainable rural development when embedded in broader governance frameworks that prioritize collective agency, social justice, and relational connectivity beyond territorial boundaries.

Keywords: decommodification, decentralization, deterritorialization, municipalism, commons

GLOBAL CHALLENGES OF COMMODIFICATION, CENTRALIZATION, AND TERRITORIALIZATION

Contemporary socio-ecological crises—climate change, the erosion of social reproduction, demographic aging, and political alienation—cannot be understood as isolated phenomena. Instead, they reflect deep structural changes in capitalist societies that manifest spatially in specific patterns [1]. Three interconnected processes are especially important here: commodification, centralization, and territorialization [2; 3].

Commodification involves the gradual shifting of essential goods, services, and social relationships into market-driven entities. Housing, energy, mobility, health care, care work, and education are increasingly treated as commodities, with access mainly determined by purchasing power [4]. This trend is not purely economic but is also reinforced legally and politically. Property and contract laws favor private ownership and capital accumulation, while collective usage is systematically marginalized or disadvantaged [5]. Consequently, social reproduction becomes more externalized and individualized, causing significant gaps in service provision—especially in rural areas with limited purchasing power and aging infrastructure.

Centralization functions as the political-institutional counterpart to economic commodification. Decision-making, investment, and innovation are concentrated in a small number of urban nodes, while rural areas are functionally reduced to supplier, compensation, or extraction spaces [6]. This spatial asymmetry is reinforced by national and supranational governance logics, funding regimes, and digital and infrastructural networks [2]. Centralization thus entails not only the concentration of power but also the standardization of norms, procedures, and evaluation criteria that systematically devalue local specificities.

Territorialization ultimately describes the dominant spatial logic of modern statehood. Social belonging, rights, and participation opportunities are connected to clearly defined spaces that are internally uniform and organized in an exclusionary way externally [7]. While this logic makes political control and legal systems easier, it also creates social barriers and prevents recognition of relational and translocal life realities. Territorial imaginaries influence not only political institutions but also scientific analyses, statistical methods, and public discourses. In their broad form, they help sustain social inequalities [4].

Taken together, commodification, centralization, and territorialization generate a structure of "sustainable non-sustainability," in which crises are not perceived as system failures but as functional by-products of market rationality [1]. For rural areas, this implies a double marginalization: they are affected by both economic devaluation and political and discursive marginalization [2].

Regional Challenges of Demographic and Climate Change, of Regional Disparities and Peripherization

The global structural processes outlined above materialize at the regional level in specific forms of peripherization. Rural areas are particularly affected by demographic change. The outmigration of young and highly educated populations, increasing ageing, and selective in-migration not only transform population structures but also reshape local labor markets, social networks, and political capacities for action [3]. These developments should not be interpreted as quasi-natural by-products of modernization but rather as the outcome of political-economic decisions that systematically privilege urban growth models.

Demographic change worsens existing disparities. Falling population numbers often cause the withdrawal of public and private infrastructure, which then speeds up outmigration. In many rural areas, this creates a self-reinforcing cycle of infrastructural decline, social separation, and political marginalization [2]. These processes are closely connected to centralized governance and funding models that prioritize efficiency through economies of scale and do not adequately consider local needs.

Climate change acts as a multiplier of crisis within these regional transformation processes. Rural areas often bear the ecological burdens of energy transition, resource extraction, or intensive agricultural production without receiving a proportional share of the economic benefits. At the same time, responsibilities for adaptation and transformation—such as renewable energy production, sustainable mobility, or regional food systems—are increasingly shifted to the local level without providing adequate resources or decision-making authority [8]. As a result, climate change worsens existing inequalities between centers and peripheries.

Regional disparities do not manifest solely between prosperous core regions and structurally weak peripheral areas but also in the form of so-called internal peripheries within formally affluent states. These spaces are characterized by limited access to infrastructure, services, and political decision-making processes. Discursively, they are often constructed ambivalently: on the one hand as deficient, backward, or dependent; on the other as resource-rich, authentic, or close to nature. This ambivalence legitimizes extractive development models that mobilize local resources for supra-regional needs without sustainably strengthening local value creation or self-determination [9].

A key driver of these dynamics is the urban-centric view, which normatively elevates urban lifestyles and economic forms while construing rural spaces as functionally subordinate. Urban attributes such as openness, innovation, and creativity serve as implicit benchmarks for development, whereas rural development trajectories appear deficient or lagging [2]. Alternatively, place-based development models grounded in local cooperation, social proximity, and ecological embeddedness are thereby systematically marginalized.

In summary, peripherization arises not as a physical location but as a relational process that is constantly recreated through political, economic, and discursive practices. For place-based strategies aimed at strengthening rural communities, this means the need not just to offset these processes but to directly address their root causes.

Strategic Orientations: Decentralization, Decommodification, and Relational Concepts

Against the backdrop of the global and regional challenges described above, three strategic orientations can be identified that form the conceptual foundation of place-based development strategies: decentralization, decommodification, and the establishment of relational spatial concepts. These orientations should not be understood as isolated measures but as interrelated political, economic, and socio-spatial trajectories.

Decentralization aims to redistribute decision-making and power to the local level. In contrast to state-centered or market-liberal governance models, it does not imply a romanticized notion of local autarky but rather polycentric arrangements that link local autonomy with translocal responsibility. Decentralization entails taking local knowledge bases, social networks, and institutional capacities seriously and strengthening them politically without disconnecting them from overarching normative and legal frameworks.

From a social-geographical perspective, decentralization is closely linked to the question of agency. Local communities can only act as agents of societal transformation if they possess real decision-making and dispositional capacities. Centralized systems, by contrast, tend to level local diversity in favor of standardized solutions and to delegate responsibility downward without transferring power [3]. Decentralization thus represents not primarily an organizational but a power-political strategy.

Decommodification constitutes the second central orientation. It refers to the partial decoupling of essential goods and services from market logics and their re-embedding in contexts of social reproduction. In rural areas, this particularly concerns housing, energy provision, mobility, social infrastructure, and basic services. Collective forms of use and ownership allow use values to be prioritized over exchange values, thereby opening new spaces for social security and collective responsibility [10].

The significance of decommodification lies not only in material relief for low-income households but in the re-politicization of social reproduction. When provision is no longer organized exclusively through markets, questions of need, justice, and sustainability become objects of collective negotiation once again [4]. At the same time, decommodification remains inherently conflictual, as it challenges established property and power relations [5].

The theoretical framework integrating these orientations is provided by relational spatial concepts. Relational geographies understand space not as a pre-given container but as a constellation of social, material, and discursive relations produced and transformed through concrete practices [11], [12]. Places are thus not closed entities but nodes within networks of varying reach, simultaneously locally embedded and translocally connected. For place-based strategies, this perspective is essential because it provides an alternative to territorial spatial logics that rely on homogenization and exclusion. Relational spatial concepts allow us to recognize local specificities without reducing them to stereotypes and to define responsibility not by territorial borders but through the quality of relationships. In this way, they create new forms of political agency that connect local autonomy with global responsibility.

Taken together, decentralization, decommodification, and relational spatial concepts can be understood as a strategic triad forming the basis of place-based development approaches. For rural communities, this means that their future viability depends less on external integration into overarching growth models than on their capacity to self-determine how to organize local resources, relationships, and meanings while remaining translocally connected.

Places as Resources of Emancipatory Practice, Participation, and Empowerment

The preceding considerations have shown that place-based strategies cannot be justified solely by a normative preference for the local. Rather, they require a conceptually precise understanding of place as an active resource of societal practice. From a social-geographical perspective, places are neither static containers nor mere backdrops for social action; rather, they are both outcomes and preconditions of social, material, and discursive processes.

This understanding first emphasizes the material aspect of places. Places are shaped by their natural and constructed environments—buildings, infrastructures, landscapes, and technical systems—that either enable or restrict action. This materiality is not fixed but relationally mediated: it influences social practice without completely determining it. For rural communities, this means that existing material resources—such as shared spaces, agricultural land, or local infrastructures—can be starting points for collective action [2].

Beyond materiality, the relational constitution of places is central. Places emerge through social relations, networks, and power structures that are locally grounded yet translocally intertwined. From this perspective, the local is never isolated but always part of broader relational assemblages [11]. For place-based strategies, this implies that local

development cannot be confined to endogenous resources; it also depends on the quality of relationships among actors, places, and scalar levels.

A third, often underestimated dimension concerns the discursive constitution of places. Places are narrated, described, and evaluated—in political programs, media representations, and scientific analyses. These discursive constructions are not neutral; they structure perceptions of possibilities and limits. Rural areas are frequently portrayed in dominant discourses as deficient, backward, or dependent, while urban spaces are associated with innovation and openness. Such narratives contribute to the reproduction of unequal power relations and constrain local self-perception and claims to agency [13].

Against this backdrop, places can be conceptualized as potential spaces of emancipatory practice. Emancipation does not primarily denote individual self-realization but collective processes of appropriation, negotiation, and self-organization. Participation is therefore not reduced to formal consultation procedures but understood as an everyday practice of collective decision-making. Empowerment emerges from collective control over material resources, social relations, and symbolic meanings.

Especially in rural communities, social proximity, spatial closeness, and shared daily practices can create favorable conditions for such processes. However, proximity is not inherently inclusive. Places can also serve as spaces of social closure, power imbalances, and exclusion. Emancipatory place-based strategies must therefore critically address internal hierarchies, gender dynamics, class positions, and migration-related differences [4].

Emphasizing places as resources of emancipatory practice thus does not entail a romanticization of the local but rather a politicized re-reading of socio-spatial relations. Places become arenas in which global crisis dynamics are rendered tangible and, at the same time, actionable. For place-based strategies aimed at strengthening rural communities, this entails deliberately enhancing material, relational, and discursive place resources and translating them into open and participatory arrangements.

Commons as an Exemplary Strategy of Place-Based Development

Building on the preceding conceptual considerations, commons can be understood as an exemplary—but not exclusive—strategy of place-based development. Commons are not primarily defined as specific goods or resources but as a social practice of commoning: the collective organization of use, responsibility, and decision-making beyond market and state logics [10], [14]. For rural communities, commons open up specific opportunities to anchor material provision, social reproduction, and political participation locally while remaining translocally connected.

From a social-geographical perspective, commons are always rooted in specific places. They arise within tangible spatial contexts where material resources, social relationships, and discursive meanings intersect in particular ways. In this sense, commons directly build upon the place resources discussed in the previous chapter. Shared infrastructure, collectively used land, or local service arrangements form the material basis; trust, reciprocity, and formal rules shape relational aspects; and stories of solidarity, responsibility, or autonomy influence the discursive layer.

At the same time, research on the commons has shown that collective resource use does not automatically produce fair or inclusive outcomes. Classic studies on common-pool resources have shown that stable commons need institutional arrangements that clearly outline access rules, decision-making processes, and conflict-resolution mechanisms [10]. More recent critical social-geographical contributions also highlight that social

inequalities, power imbalances, and unequal capital endowments still exist within commons arrangements. Especially in rural areas, there is a risk that existing social hierarchies—based on class, gender, or background—are recreated.

A key critique addresses the positivist idealization of communal practices in parts of the commons literature. Concepts like community, trust, or resilience are often viewed as inherently positive without systematically examining their social conditions and mechanisms of exclusion. Empirical studies show that socially homogeneous groups tend to benefit more from commons projects, while marginalized populations usually remain excluded or have limited access [3]. For place-based strategies, this highlights the importance of explicitly connecting commons to social justice and poverty reduction.

In this context, municipalist and communitarian approaches gain relevance, as they conceptualize commons not as isolated micro-projects but as elements of broader local self-governance. Municipalism aims to strengthen local democratic institutions and to politically secure collective forms of ownership and use [15]. For rural areas, this implies embedding commons within municipal strategies of public service provision, regional development, and infrastructure planning rather than treating them as voluntary supplements to state or market provision.

Commons can thus be interpreted as an interface between decentralization and decommodification. They expand local decision-making and action capacities while simultaneously, at least partially, removing essential goods from market logics. Their emancipatory quality, however, crucially depends on institutional embeddedness, social openness, and reflexive capacity. Without these conditions, commons risk either remaining politically marginal or being absorbed into market-oriented dynamics.

For place-based strategies focused on strengthening rural communities, this results in a nuanced understanding of the commons. They are neither universal cures nor merely niche experiments, but conflictual, context-dependent practices of societal change. Their power lies in making global crisis dynamics manageable at the local level and in testing collective agency. Their limitations, however, highlight the need for political framing and translocal networks. In this way, commons form a key—but not the only—building block of place-based development strategies, which the second part of this article will examine.

Agritourism in Albania: An Overview and Characteristic Forms

Over the past decade, agritourism has become one of the most dynamic areas of rural development in Albania. Situated at the crossroads of agriculture, tourism, and local cultural heritage, agritourism has been increasingly promoted by the Albanian government, international donors, and local entrepreneurs as a way to diversify rural economies, generate income, and combat depopulation. National policies, such as the National Strategy for Sustainable Tourism Development and the “100+ Villages Programme,” explicitly recognize agritourism as a key sector for rural areas.

Empirically, agritourism in Albania features a diverse range of initiatives. These include small, family-run guesthouses and farm stays, as well as larger, professionally managed farm-to-table restaurants and multifunctional rural tourism complexes. A key aspect of the Albanian situation is that many agritourism ventures are not solely based on traditional farming. Instead, many operate as hybrid businesses that rely on networks of local farmers to source food and raw materials, while tourism services are provided by separate entrepreneurial entities [17]. Iconic examples like Mrizi i Zanave illustrate this model, combining local agricultural production, culinary tradition, and tourism experiences through cooperation with hundreds of nearby rural households.

Spatially, agritourism projects are unevenly distributed but becoming more widespread. Early development was focused on regions with strong cultural landscapes and tourist visibility, such as Gjirokastër, Berat, Korçë, the Albanian Alps (Theth, Valbona), and coastal hinterlands. More recently, agritourism units have also increased in peri-urban and accessible rural areas near Tirana, Durrës, and Lezhë, reflecting both market proximity and infrastructural benefits [16]. Most certified agritourism units highlight local cuisine, organic or traditional food production, limited accommodations, and experiential offerings like participation in farming activities, food processing, or cultural events [28].

Despite its rapid growth, the sector still exhibits structural asymmetries. Official certification figures remain relatively low compared to the estimated number of active initiatives, reflecting regulatory barriers, limited administrative capacity, and uneven access to information and funding. Additionally, demand-side promotion remains underdeveloped, with public policies mainly focused on boosting supply rather than coordinating regional agritourism networks or value chains [16].

Agritourism and the Theoretical Framework: Convergences and Tensions

When assessed against the theoretical foundations developed in the previous sections—decommodification, decentralization, deterritorialization, municipalism, and places as resources of emancipatory practice—agritourism in Albania reveals both significant convergences and critical tensions.

From a decommodification perspective, agritourism could shift economic activity away from mass tourism and industrial agriculture toward practices focused on use-value, rooted in local food systems, cultural heritage, and social relations. Many Albanian agritourism projects highlight short supply chains, on-site food processing, and the promotion of traditional knowledge. In doing so, they partly detach rural livelihoods from volatile agricultural commodity markets and global tourism value chains [17], [18]. However, this potential for decommodification remains fragile. As demand increases, there is a risk that agritourism experiences themselves become commodified and standardized, reinforcing branding, exclusivity, and price-based access, which can limit social inclusiveness.

Decentralization constitutes another key point of alignment. Agritourism initiatives often emerge from local entrepreneurial agency and rely on place-specific resources, knowledge, and networks. They help diversify rural economies beyond centralized agricultural or industrial development models and can strengthen local governance capacities when embedded in municipal strategies. Nevertheless, empirical evidence from Albania indicates that many initiatives remain weakly institutionalized at the municipal level and are poorly integrated into broader local development planning. This limits their transformative potential and exposes them to market dependencies and external shocks.

In terms of deterritorialization, agritourism projects illustrate relational spatial practices that link local places to transnational networks of tourists, consumers, and cultural imaginaries. Instead of depending on territorially limited development ideas, successful agritourism efforts work through relational geographies that connect rural Albania to global tourism markets, diasporic networks, and worldwide conversations on sustainability and authenticity. At the same time, these links can create new dependencies and imbalances, especially when local participants lack bargaining power within tourism value chains.

Municipalism provides a critical lens for assessing whether agritourism can be embedded in democratic local governance structures. While Albanian agritourism policies rhetorically emphasize community development, empirical studies suggest that most initiatives function as private or family-based enterprises rather than as collectively governed commons. Opportunities for municipal coordination, cooperative ownership, and collective benefit-sharing remain underdeveloped, despite their relevance for long-term sustainability and social equity.

Streifeneder [19], in his approach to define "authentic agritourism and differentiate it from countryside tourism," provides reasonable arguments to support local non-commercial agritourism companies in order to protect the interdependence between sustainable agriculture and tourism. Therefore, his emphasis on authenticity is clearly outlined to prevent a dominant profit-driven touristic effort "[…] to lower the risk of commercial hotel-like enterprises misusing the positive image of agritourism […] (p. 252), and to address the "[…] commodification of the rural world" (p. 256). However, to maintain the authenticity of agritourism—meaning decentralizing, decommodifying, and deterritorializing activities—some ambiguity in definitions is necessary. From this perspective, it is not essential to require that "[…] agricultural activities are predominant over the touristic ones […]" (p. 252), as farms can "[…] practice intensive agro-industrial […] farming" (ibid.). Additionally, the types of activities and interactions at agritourism farms can vary widely and are not confined to a territorial definition of farmland (p. 256). The Albanian agritourism projects, which the author has empirically studied, demonstrate a notable diversity of farming and tourism activities that still follow a local, network-oriented, and commons-like strategy.

Agritourism and Sustainable Rural Development: Opportunities and Challenges

The broader tourism literature consistently highlights rural tourism and agritourism as potential drivers of sustainable rural development. According to the UN World Tourism Organization [20], rural tourism can contribute to economic diversification, job creation, cultural heritage preservation, and environmental conservation, while mitigating depopulation and regional inequalities. In Albania, these opportunities are particularly salient given the structural challenges facing rural areas, including outmigration, aging populations, and limited access to services.

Agritourism offers specific advantages compared to conventional tourism. It tends to generate higher local multiplier effects by sourcing goods and services locally, fostering backward linkages to agriculture and crafts, and extending tourism benefits beyond peak seasons. Empirical studies indicate that agritourism contributes to income diversification and resilience, especially for small and medium-sized farms and rural households [21], [22].

However, agritourism faces several challenges. Infrastructure gaps, limited professional training, seasonal fluctuations, and unequal access to capital restrict the sector's growth. Additionally, without proper regulation and governance, agritourism could lead to environmental pressures, land-use conflicts, and social exclusion. Experiences from other European contexts show that tourism benefits can escape local economies if ownership structures and supply chains are not locally rooted [23].

In Albania, these challenges are compounded by weak coordination between agricultural, tourism, and rural development policies. While donor-funded programs and fiscal incentives have stimulated investment, long-term strategies for skills development, cooperative governance, and territorial integration remain insufficiently developed.

Economic, Ecological, and Social Potentials of Agritourism in Local Contexts

Economically, agritourism in Albania shows strong potential to boost farm incomes, generate jobs, and promote local entrepreneurship. While revenues from agritourism rarely fully replace agricultural earnings, they offer vital diversification that strengthens household resilience [21]. Comparative studies across Europe indicate that small and medium-sized farms benefit more significantly from agritourism, a trend that aligns with the Albanian context, where land fragmentation and limited capital are common [22].

Ecologically, agritourism can incentivize environmentally sustainable practices by linking economic value to landscape preservation, biodiversity, and traditional farming methods. Many Albanian agritourism projects emphasize organic production, low-intensity agriculture, and the conservation of cultural landscapes. Nevertheless, ecological benefits are contingent on governance arrangements and carrying-capacity considerations. Unregulated growth may increase resource consumption, waste generation, and pressure on fragile ecosystems, particularly in mountainous and coastal hinterlands.

Socially, agritourism holds substantial emancipatory potential. Studies on women's empowerment in rural Albania demonstrate that agritourism creates opportunities for income generation, entrepreneurship, and social recognition, challenging traditional gender roles and enhancing women's participation in decision-making [24]. Agritourism also fosters social cohesion by reinforcing community identities, intergenerational knowledge transfer, and local pride. At the same time, benefits are unevenly distributed, and marginalized groups may remain excluded unless explicit inclusion strategies are pursued.

From a shared resources perspective, agritourism can serve as a practical form of commoning when resources, knowledge, and benefits are collaboratively managed. Cooperative marketing efforts, shared infrastructure, and municipally supported networks are promising but underused strategies in Albania. Without such arrangements, agritourism risks falling into individualized entrepreneurial models that limit its transformative potential.

Agritourism as a Place-Based Commons-Oriented Strategy: Concluding Reflections

In summary, agritourism in Albania demonstrates both the opportunities and challenges of place-based development approaches. Its strengths include the ability to leverage local resources, reconnect agriculture with tourism, and create economic, ecological, and social benefits at the local level. When aligned with principles of decommodification, decentralization, deterritorialization, and municipalism, agritourism can support empowering rural communities and fostering community development.

However, realizing this potential requires moving beyond fragmented, market-driven initiatives toward more integrated governance frameworks. Strengthening municipal capacities, fostering cooperative and commons-based models, and embedding agritourism within broader rural development strategies are essential steps. In this sense, agritourism should not be understood as an end in itself, but as a situated practice within a wider transformation of rural places as spaces of collective agency, participation, and sustainable livelihoods.

Empirical Study of Agritourism in Albania: Methodology and Case Studies

To examine the empowering, commons-like mechanisms of local community strategies, three agritourism businesses in Albania have been studied empirically. We aim to assess their ability to develop economically, ecologically, and socially to counteract the dominant forces of commodification, centralization, and territorialization. Although the three examples vary in size and the ratio of farming to tourism activities [19], they are similar in establishing neighborhood networks, encouraging local self-organization, and fostering a sharing economy. Additionally, all three are located in peripheral regions, far from the nearest urban center. All three agritourism businesses are privately owned commons.

The three case studies are:

- **Sabriu Guest House** is located in the small village of Rabdisht, 6 km east of Peshkopi near the North Macedonian border. The guest house offers double rooms and dormitories and includes a community kitchen for guests. Sabriu features a garden and a small farm growing fruits and vegetables for its own use. Due to increasing tourist demand, several villagers have renovated their homes to provide bed & breakfast services in partnership with Sabriu Guest House. Others have expanded their fruit and vegetable production, also working with Sabriu. Rabdisht village has been chosen as one of six Albanian villages by the Albanian Ministry of Tourism and Environment to compete for the "best tourist villages of the world" [25].
- **Kulla Hupi Guest House** is located near the village of Fushë-Bulqizë, 60 km northeast of Tirana. It is a restored tower that offers single and double rooms, dormitories, and a breakfast area. They also sell local food produced in the guest house's garden and the surrounding area. Like in the case of Sabriu, Kulla Hupi works with local residents to supply fruits and vegetables for the guest house's visitors. They promote authenticity and the region's cultural heritage [26].
- **Mrizi i Zanave** is an agritourism business located in the village of Fishta, 30 km southeast of Shkodra. It is the first agritourism company in Albania (opened in 2010) [27] and the largest of the three examples, with 120 staff members. It offers rooms from one to four bedrooms in a renovated shepherd's hut, along with a campsite, a large restaurant, and a shop that sells local foods. The tourist complex is surrounded by farmland and has its own food processing facilities, producing cheese, ham, syrup, liquor, wine, marmalade, and more. Similar to Kulla Hupi and Sabriu, Mrizi i Zanave has expanded its agricultural and tourism activities by working with residents in nearby villages. The number of participating residents, through providing apartments and agricultural products, is significantly higher than in the other two cases.

The interviews were conducted with the individuals managing the agritourism businesses. In the case of Sabriu Guest House, it was the couple; for Kulla Hupi, it was the male operator; and for Mrizi i Zanave, it was the head of the kitchen and the owner of the company. They are listed as follows:

agritourism company	interview partners
Sabriu Guest House	IP_SGH
Kulla Hupi Guest House	IP_KHGH
Mrizi i Zanave	IP_MiZ_I and IP_MiZ_II

The interviews were conducted in August 2025.

RESULTS

Even though they are privately owned, all three agritourism companies function as commons-like, decentralized, and collectively self-organized institutions. All interviewees explicitly expressed commitment to economic, social, and ecological sustainability. Not only do the guest houses benefit from local cooperation, but the farmers and apartment owners involved also gain. Local farmers benefit from a network that organizes food production and regional distribution collectively (IP_SGH). Seventy to eighty percent of all food products offered at Kulla Hupi Guest House come from nearby villages (IP_KHGH). In Mrizi i Zanave, 30 to 35 farmers participate in a production network that collaborates to produce wine, cheese, fruits, and vegetables. Similarly, village residents benefit from Sabriu Guest House, as it helps accommodate tourists when it is fully booked. Sabriu Guest House manages check-in and check-out procedures for participating local residents. Additionally, a cooperative information infrastructure has been established in Mrizi i Zanave with residents from five surrounding villages who offer apartments—either newly built or renovated—due to the rising demand for beds in Mrizi i Zanave (IP_MiZ_I, IP_MiZ_II).

In this respect, the three agritourism companies represent social-spatial networks of relations that merge with the territorial ones, with their political and legal agendas.

Private ownership of guest houses does not limit a participatory economy. Local cooperation follows the principle of slow and steady economic growth, avoiding a focus on profit. This cooperation has developed smoothly over the past five years (IP_SGH, IP_KHGH) or 15 years (IP_MiZ_I) since the renovations of the main buildings began. However, investing in rural outskirts can be difficult due to banking loan restrictions in ‘undervalued areas’ (IP_MiZ_II). For example, owners of Mrizi i Zanave purchased land along the coast and used it as collateral. Ideals also seem important, as the owner of Kulla Hupi pointed out: he was born in the village, moved to Greece for a few years, and later returned to renovate the castle tower. “What is easy to achieve is less valuable” (IP_KHGH); or: “To promote local community wealth is more important than to become individually rich” (IP_MIZ_II).

Furthermore, decommodifying strategies can be inferred from the occupational context. All three interviewees emphasized that all staff working for the guest houses are locals. They successfully addressed the brain drain problem that many rural areas face. For example, most employees at Mrizi i Zanave studied tourism economics elsewhere and then returned to their villages to work for the agritourism company. In farming, the goal was (and still is) to establish traditional Albanian food production and sell it regionally. Through this steady networking strategy, relationships among residents have strengthened.

To succeed in all three aspects of sustainability, transport and communication infrastructure is essential. Infrastructure also helps address issues related to commodification, territorialization, and centralization. While road infrastructure has improved in the Rabdisht-Peshkopi and Fishte regions, it still faces challenges in the Fushë-Bulqizë area. Public transportation between Tirana Airport and Peshkopi is well developed for travelers heading to Sabriu Guest House (IP_SGH).

Communication networks are used extensively in all three cases. Social media tools and booking platforms are essential for promoting agritourism in Albania (IP_SGH, IP_KHGH, IP_MiZ_I). In addition to these virtual and local collaborative networks, regional networks play a vital role in knowledge sharing. Agritourism operators learn

from each other's experiences in integrating their self-organized businesses into a regional economic infrastructure (IP_KHGH). These regional networks are not necessarily confined to Albania but may extend to neighboring countries such as North Macedonia, Kosovo, or Montenegro (IP_SGH).
The interview partner of Mrizi i Zanave, owner of the agritourism company (together with his brother), drew a meaningful conclusion from his statements: the communist period destroyed much of Albania's traditional heritage and local knowledge. With their large farming associations, they overlooked the importance of ecological requirements and regional differences. Today, challenges include developing a new identity as a farmer and a better understanding of a farming economy that combines social and ecological knowledge. As a result, he sees increased regional investment in agricultural education and a strategy to survive economically by moving away from the market-profit mindset (IP_MiZ_II).

CONCLUSION

This paper set out to develop a theoretical framework for place-based rural development grounded in the critique of commodification, centralization, and territorialization, and to test its analytical relevance through an empirical study of agritourism initiatives in Albania. The empirical findings both confirm and qualify the theoretical outline presented in the first half of the paper.
First, regarding decommodification, the case studies demonstrate that agritourism can partially decouple rural livelihoods from volatile agricultural commodity markets and standardized tourism chains. All three enterprises—Sabriu Guest House, Kulla Hupi, and Mrizi i Zanave—rely on short supply chains, local labor, and regionally embedded production networks. Food production, accommodation, and service provision are interwoven with neighborhood cooperation, thereby prioritizing use values, trust-based relations, and gradual growth over profit maximization. In this respect, agritourism functions as a counter-practice to commodification. However, the empirical evidence also reveals structural limits: reliance on booking platforms, private ownership, and banking constraints illustrates that these initiatives remain embedded in broader market logics. Decommodification thus appears as a relative and contested process rather than a complete transformation.
Second, concerning decentralization, the cases strongly support the theoretical argument that local agency is decisive. The agritourism projects studied operate as decentralized, network-oriented systems that strengthen local employment, reduce brain drain, and foster collective self-organization. Decision-making and value creation are largely retained within the region. Yet the findings also underscore the importance of supportive infrastructure—roads, communication networks, and access to credit—showing that decentralization requires enabling frameworks rather than merely the withdrawal of the state.
Third, regarding deterritorialization and relational spatiality, the Albanian cases vividly illustrate how rural places function as nodes within translocal networks. Social media, diasporic ties, and cross-border regional cooperation connect peripheral villages to wider tourism circuits without dissolving local embeddedness. These relational configurations confirm the theoretical claim that place-based strategies do not imply isolation but depend on translocal connectivity.

Finally, the empirical material supports the notion of agritourism as a commons-like practice, even under private ownership. Cooperative production networks, shared infrastructures, and collective knowledge-building reflect principles of commoning and municipal self-organization. At the same time, the absence of formal cooperative governance structures indicates that municipalist embedding remains underdeveloped.
Overall, the Albanian cases substantiate the theoretical proposition that rural places can become arenas of emancipatory practice when decentralization, decommodification, and relational connectivity intersect. Agritourism emerges not as a panacea, but as a situated, fragile, and yet promising pathway toward commons-oriented rural transformation.

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IS FERTILITY IN BOSNIA AND HERZEGOVINA NOW DECLINING FASTER THAN IN THE REST OF THE EX-YUGOSLAV AREA?

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ABSTRACT

Bosnia and Herzegovina belonged to the group of republics of the former SFRY, which recorded higher birth rates and a lower mean age at birth of the first child compared to Slovenia, Croatia, and Serbia, thus, experienced "late" fertility transition. However, after independence, although with a quite favorable age structure, population fertility indicators, both absolute and relative, began their decades of marked decline. Using the demographic method, together with general scientific methods and statistical methods, we will analyze the change in birth patterns in Bosnia and Herzegovina with a focus on the last 30 years. This paper shows the change in the age model of fertility in Bosnia and Herzegovina and the consequences that this change had on the level of the total fertility rate. The problem of discontinuity, as well as the methodology of calculating fertility indicators in the inter-census period, forced the authors to use different assessment methods. Bearing in mind the unusually low fertility rate that particularly attracts attention, the paper looks at the problem of estimating the base-line population and calculating relative fertility indicators, especially in the context of the obsolescence of census data. Bosnia and Herzegovina today, in the context of the wider ex-Yugoslav area, occupies a different position when it comes to the age pattern of fertility, making the mentioned area quite homogeneous, but still retaining some peculiarities from the previous period. It is quite certain that the level of the fertility rate, and its age-pattern in Bosnia and Herzegovina do not differ significantly with other ex-Yugoslav countries.

Keywords: total fertility rate, mean age at birth of the first child, SFR Yugoslavia, age-sex structure, estimation.

INTRODUCTION

The long-term decline in fertility in European countries began almost two centuries ago, and in the territory of the former Yugoslavia at the transition from the 19th to the 20th century. Although without essential differences in relation to the broader environment of Southeast Europe, certain differences between the macro units of the former state persisted until the end of the 20th century. In the period between the two world wars, Bosnia and Herzegovina (BiH) was widely underdeveloped agrarian area, most of the population lived in the countryside, and illiteracy was high [5]. The level of overall social and even agricultural underdevelopment was indicated by the fact that on the eve of the Second World War (WW2), most of the land was cultivated with a wooden plow, and

that at the end of 1945 there were only 217 tractors or one plow on three farms [6]. However, after WW2, together with the other republics of the former state, the process of intense deagrarianization began in BiH, which, however, was not initially followed by immediate de-ruralization of the population. This specific form of transition to non-agricultural activities, without significant emigration from the rural area, is confirmed by the fact that only 12% of newly arrived workers in the industry left their place of permanent residence until 1953. BiH society after WW2 was a peasant society in the true sense of the word: most of the population lived in the countryside (83%), only 2% of the population worked in industry, the country was characterized by economic underdevelopment, while 70% of the population was illiterate [6]. This was particularly pronounced among women, where, for example, during the 1950s, the employment rate of the female population was between 2 and 3 percent [5]. In such conditions, BiH met the post-war period with a total fertility rate (TFR) of over five children per woman, twice as much as in SR Croatia, SR Slovenia, and SR Serbia (without the province of Kosovo and Metohija). Childbearing started early, in parallel with early marriage, and lasted long, making the effective fertile period long. Until the end of the 1970s, fertility in BiH was higher than the average for former Yugoslavia. Not only was fertility high after WW2, but the baby-boom period lasted longer than in the most other republics, resulting in a quite favorable population age structure until the end of the 20th century.

A more pronounced decline in fertility occurred during the 1960s, later than in the previously mentioned republics. Although the fertility decline in BiH was faster than the national average (2.19% versus 1.34% per year), the starting point of the fertility decline in BiH was significantly higher, so that the overall national average was only reached at the end of the 1970s. However, what represents the key difference of the fertility transition in BiH compared to low-birth-rate areas (Croatia, Slovenia, Serbia) is that the low-birth-rate areas entered the second demographic transition (fertility transition) ten years earlier than most European countries did, while BiH entered more than ten years later. Namely, the very concept of the Second Demographic Transition (SDT) [12] postulates that in the wider European area, the decline of birth rates to below-replacement level started in mid-1960s, distinguishing three groups of countries whose transition experience was somewhat different. Countries that later enter the long-term fertility decline, often progress faster in that process with the features of the change in the age-pattern of fertility take on the character of the avalanche, once they are activated [13]. Paradoxically, the successor countries of the former SFR Yugoslavia did not manifest the prerequisites for the start of the SDT at all, but it was still happening [7]. Once the traditional patterns of marriage and childbirth in patriarchal societies are disrupted, the decline in fertility becomes precipitous, as confirmed by the contemporary experiences of Iran, Turkey, South Korea, and BiH. The process of modernization of society, although it is often not induced from the inside, but "brought" from the outside, through the expansion of education (especially female) and the transformation of economic activity, affects the decline of fertility as strongly as when it is the authentic outcome of one's own social progress.

This paper will present the most important characteristics of the change in the age model of fertility, primarily as a transformation of cohort and period fertility indicators before the war conflicts in BiH as a starting position, towards those we are witnessing today.

LITERACY AS THE DRIVER OF THE FERTILITY TRANSITION

During the second half of the 20th century, major changes took place in the education and literacy of the female population of BiH. The changes of literacy in BiH after WWII took place in the context of deep social and economic transformations and was marked by continuous improvement. Despite the overall progress, this process was accompanied by pronounced structural inequalities in literacy, especially between men and women, as well as significant differences depending on the age structure and population ethnicity.

According to the 1948 census, 44.9% of the population of BiH was illiterate, with strongly emphasized gender differences (28.7% for men and 59.3% for women). In the wider Yugoslav context, BiH ranked second among socialist republics and autonomous provinces in terms of total illiteracy rates. The highest rate of illiteracy was recorded in the Autonomous Province of Kosovo and Metohija (62%), while high rates of illiteracy were also registered in Macedonia (40.3%) and central Serbia (27.4%). In contrast, the lowest illiteracy rates were recorded in Slovenia (2.4%) and the Autonomous Province of Vojvodina (11.8%) [17]. The results of the same census indicate a marked structural inequality in the level of illiteracy by age cohort. In BiH, among the population 65+ years old, the illiteracy rate was 73.1%, while among women in the same age cohort it reached 92% [28]. In the age group 10-14 years, 34.3% of the population was illiterate, with the illiteracy rate being 44.3% in the female and 28.7% in the male population [28]. This pattern deviates from the expected trend of lower illiteracy in younger cohorts, which has been linked to the disruption and uneven access to education during WWII. Analysis according to ethnicity shows that in 1948, among the population over 10 years of age, illiteracy was 54.4% among Muslims-undeclared, 41.7% among Serbs and 40.3% among Croats [28]. At the state level of Yugoslavia, the illiteracy rate among Muslims-undeclared was 54.3%, while among the female population within this group it reached 70.3% [17].

The 1953 population census indicates a further increase in the level of literacy, whereby the total illiteracy rate in BiH was reduced to 40.2%, while among the females it was 57.1% [18]. According to the results of the 1961 census, this trend continued, and the total illiteracy rate decreased to 32.5%, and among women to 47.8% [19]. The results of the 1971 Census show that in BiH 23.2% of the population was illiterate, with illiteracy being significantly more pronounced among women (35.1%) than among men (10.5%) [20]. In the same census, the share of the population with higher education was only 1.8%. According to the 1981 Census, the illiteracy rate in BiH was reduced to 14.2%, with illiteracy among women at 23.3% and among men at 5.5%. At the same time, the share of the population with completed higher education increased to 4.2%, which indicates considerable progress in the educational structure [21]. Further progress in education was confirmed by the results of the 1991 Census, according to which the share of illiterates decreased to 9.9%. Observed according to gender, illiteracy was 3.4% among men and 16.4% among women, continuing the trend of decreasing overall illiteracy with age and gender differences still present [16]. The share of highly educated population reached 5.5%, with the highest values among people who declared themselves Yugoslavs [10].

The first post-Yugoslav Population Census 2013 showed that the total illiteracy rate in BiH has decreased to 2.8%. Illiteracy was 0.79% for men and 4.76% for women, which confirmed the continuity of gender differences [23]. At the same time, pronounced spatial disparities were identified, with the highest rates of illiteracy registered in municipalities

with an unfavorable age structure, pronounced demographic aging and long-term depopulation processes [11].
Miloš Macura wrote about the influence of literacy on the differentiation of fertility among women in Yugoslavia, pointing, among other things, to the high birth rates in the areas of central Bosnia, which he linked to the high share of illiterate Muslim women [8]. Starting from the fact that the literacy rate in the demographic literature is considered one of the key indicators of reproductive behavior, the decline in fertility in BiH, especially in the period between 1948 and 1971, can be significantly linked to the rapid increase in literacy among the female population. Census data from 1948 show that in the female fertile contingent total illiteracy rate was 56.82% [17]. Illiteracy showed marked age differentiation: it ranged from 35.9% in the 15–19-year-old cohort to 82.5% in the 45–49-year-old cohort [17]. According to ethnicity, the highest rate of illiteracy in the fertile contingent was among women who declared themselves as Muslim-undeclared (69.9%), followed by Serbian (53.9%) and Croatian women (52.14%) [17]. By the census 1971, there was a sharp decrease in illiteracy in the fertile cohort of women, which then amounted to 24.2% [16]. This decline coincides with a pronounced lowering of fertility rates during the 1960s. According to census data from 1971, in the age cohort 10-19 years, illiteracy among women was 6%, while in the cohort from 35-49 years it was 49.7% [16]. In the Census 1991, the total illiteracy of the fertile cohort of women was reduced to 4.3% [16]. The lowest values were recorded in the youngest age group 10-19 years (1.7%), and the highest illiteracy rate registered in the 35–49-year cohort (9.3%) [16].

METHODOLOGY

The subject of research is the pattern of fertility in BiH, both its structural demographic characteristics and the quantity. The change in the birth pattern is reflected in the change in the age at which childbirth occurs, the frequency of births in individual age groups and overall fertility indicators. The transformation of the fertility model during the SDT is changing towards childbirth postponement (a constant increase in the mother's mean age at childbirth (MAB), regardless of parity) and a decline in the fertility level below replacement (approximately 2.1 children per woman). In this sense, the aim of the research is to describe the changes in the birth pattern in Bosnia and Herzegovina since the middle of the 20th century, with a particular focus on the last 30 years.
Regarding the territorial determination of the research framework, the fertility analysis was carried out at the level of BiH as a whole, and certain, smaller, changes in the borders of BiH that existed even immediately after WW2 [6] are not of such a character as to threaten the methodological consistency of the analysis. The timespan can be viewed on several parallel planes. Namely, the fertility analysis itself covers the period 1950-2024 when it comes to period indicators and 1991-2013 in the analysis of cohort fertility indicators[9]. On the other hand, to put the transition of fertility in a specific sociodemographic context, the literacy of the female population was analyzed in the censuses from 1948 to 2013. Such a multidimensional approach to fertility analysis required the use of various data sources, the most important of which are: census books, demographic (vital) statistics, and statistical yearbooks of BiH. In the second part of the fertility analysis, for the purposes of assessing the "real" values of TFR, it was necessary

[9] [1] For a more detailed explanation of the concepts of transferal period and cohort fertility analysis, see "Demography - methods and models", Dušan Breznik, 1972, Institute of Social Sciences, Belgrade.

to assess the annual migration balance after the last population census (in 2013) and to calculate the estimate of the age composition of the fertile contingent in the period 2014-2024, for which alternative sources of data on migration were used, including various studies based on the "mirror statistics" approach, the Migration Profile of BiH, the Migration Profile of the Republic of Serbia, Household Budget Survey in BiH, the Projection of the population of BiH [27] and the age-sex distribution of the migration balance for BiH from the UN World Population Prospects 2022.
The central place is occupied by the demographic method (period and cohort) used in the analysis of fertility, but also general mathematical and statistical methods were used in the assessment of the migration balance, as well as general scientific methods in the description of the sociodemographic context of the epoch during which the fertility transition took place and comparison with the surrounding countries (historical and comparative method).
The complex nature of the fertility transition process has imposed the need to use various sources of demographic data and different methods of population science in parallel to fully understand the transformation of fertility patterns.

RESULTS

The average number of children per woman (TFR) in 1950 was 5.12, that is, fourfold than was recorded in the year of the last population census (2013). Fertility decline started already after WW2, so the TFR decreased approximately by one child per decade. In a certain way, the year 1978 represents a turning point when for the first time TFR was below-replacement (2.012), which can be considered the beginning of the SDT in BiH (Figure 1).

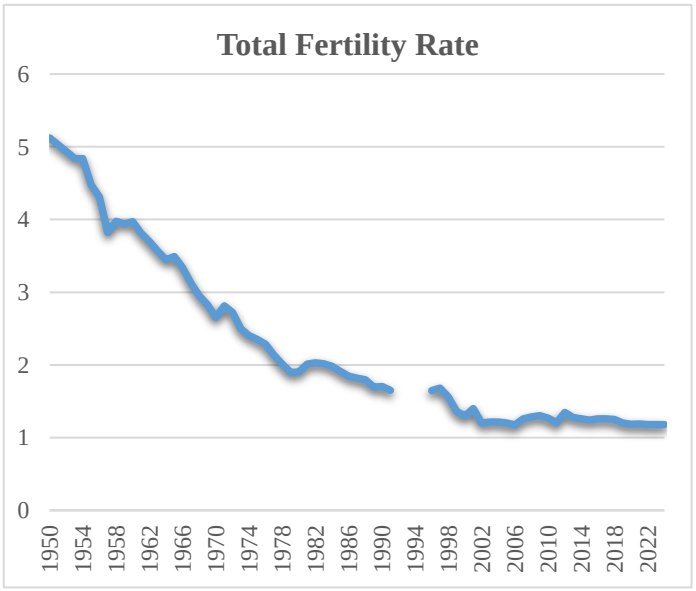


Figure 1. Total fertility rate in the period 1950-2024, Bosnia and Herzegovina

Bearing in mind that the TFR in the methodological sense represents the sum of age-specific fertility rates calculated per one woman (and not per one thousand), it is important to discuss the age-specific birth frequency and cumulative specific fertility rates. Cumulative in this case represents the average number of children born by a woman up to a certain age (Table 1).

Table 1. Age-specific fertility rates

Age-specific fertility rates							
	1965/69	**1975/79**	**1987**	**1997**	**2007**	**2017**	**2024**
15 - 19	0.0490	0.0411	0.0365	0.0361	0.0152	0.0092	0.0071
20 - 24	0.1927	0.1475	0.1323	0.1225	0.0689	0.0539	0.0440
25 - 29	0.1692	0.1219	0.1124	0.0931	0.0834	0.0792	0.0758
30 -34	0.1137	0.0697	0.0555	0.0555	0.0595	0.0722	0.0672
35 - 39	0.0713	0.0342	0.0211	0.0237	0.0208	0.0316	0.0341
40 -44	0.0280	0.0109	0.0055	0.0054	0.0036	0.0054	0.0072
45 - 49	0.0049	0.0011	0.0006	0.0005	0.0003	0.0004	0.0004
Cumulative fertility rates							
15 - 19	0.25	0.21	0.18	0.18	0.08	0.05	0.04
20 - 24	1.21	0.94	0.84	0.79	0.42	0.32	0.26
25 - 29	2.05	1.55	1.41	1.26	0.84	0.71	0.63
30 -34	2.62	1.90	1.68	1.54	1.14	1.07	0.97
35 - 39	2.98	2.07	1.79	1.65	1.24	1.23	1.14
40 -44	3.12	2.13	1.82	1.68	1.26	1.26	1.18
45 - 49	3.14	2.13	1.82	1.68	1.26	1.26	1.18

Source: [15] Statistical Yearbook of the Republic of BiH in 1992; [22] Demography BiH 2024, Agency for Statistics of Bosnia and Herzegovina (2025); and author's calculations.

Obvious changes in the fertility pattern that have occurred in the last 65 years are moving towards childbirth postponement and lowering age-specific fertility rates. However, if we divide the changes into two parts, that is, until 1997 and after 1997 (pre-Yugoslav and post-Yugoslav periods), then the specific characteristics of those changes can be more clearly observed (Figure 2). Namely, most of the decline in Bosnian fertility occurred before the collapse of Yugoslavia, but the transformation of the age model of fertility occurred only after. Thus, from the second half of the 1960s, TFR declined from 3.14 to 1.82 already by 1987 and 1.65 by 1991. In other words, 76% of the total decline in fertility occurred during the first half of the period and only 24% during the second half. On the other hand, if we look at the graphic representation of the rates and their cumulative, we can see that there is no significant change in the age pattern of births in the first half of the period, only a decrease in the frequency. The youngest cohorts (15-19) give birth almost at the same level until the middle of the 1990s, and the peak of fertility even shifts to a lower age in 1997 compared to 1965-1969. However, a more significant transformation of the age pattern of births began only after the collapse of Yugoslavia, and the peak of fertility moves closer to the 30th year of a woman's life. Thus, the cumulative fertility rate shows that not only did the total fertility drop by almost two children, but that more than two-thirds of the increase in the mean age at the birth of the first child (MAB1) occurred right after the independence of BiH.

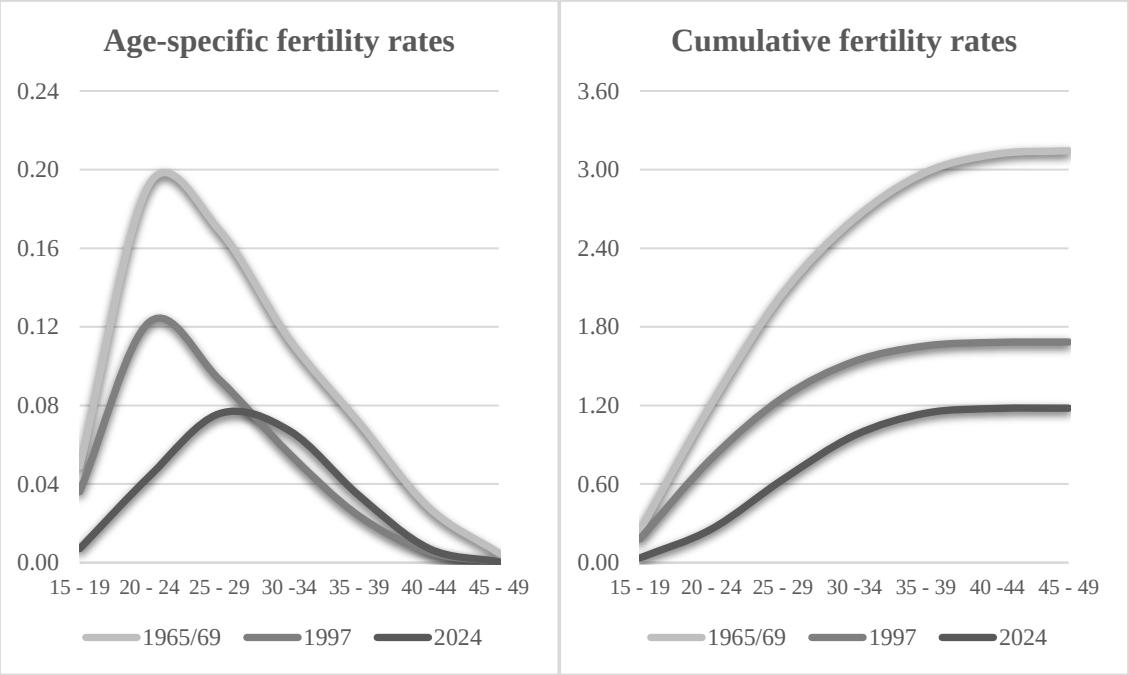


Figure 2. Age-specific fertility rates in BiH, 1965-2024

The previously described changes in birth patterns after independence are also reflected in the increase in MAB, especially in MAB1. The causes of delayed childbearing such as extended schooling, increased participation of women in the labor market and the general trend of later marriages do not distinguish BiH from the wider European environment, and the additional reason of exceptional economic insecurity does not distinguish it from other countries of the ex-Yugoslav area. At the beginning of the 1970s, MAB was 26.8 years, but it declined over the next decade and a half. Not because MAB1 has been lowered, but because fertility has declined due to a serious reduction in the share of higher parities. This significantly shortened the effective fertile period, which must have resulted in a decrease in MAB. For example, in the first half of the 1970s, 12.2% of the total number of births occurred after the age of 35, while only 10 years later this share amounted to only 5.5%, so that MAB dropped to 25.6 years. After the independence of BiH, in 1996, MAB was 26.9 years, but in the following year, due to birth compensation, it dropped to 25.710 years, which was followed by a constant increase. As for MAB1, we only have data from 2004, but based on the ratio between these two indicators, it can be assumed that after the end of the civil war, it was about 23 years, or even slightly less. Figure 3 shows MAB and MAB1 with an estimate for the period 1997-2003. It is certain that over the last 30 years MAB1 has increased by more than five years (Figure 3).

[10] It is assumed that after the end of the war (after November 1995) many women wanted to make up for delayed childbearing, which, along with the average waiting time for conception and pregnancy duration of nine months, resulted in the highest number of births during 1997.

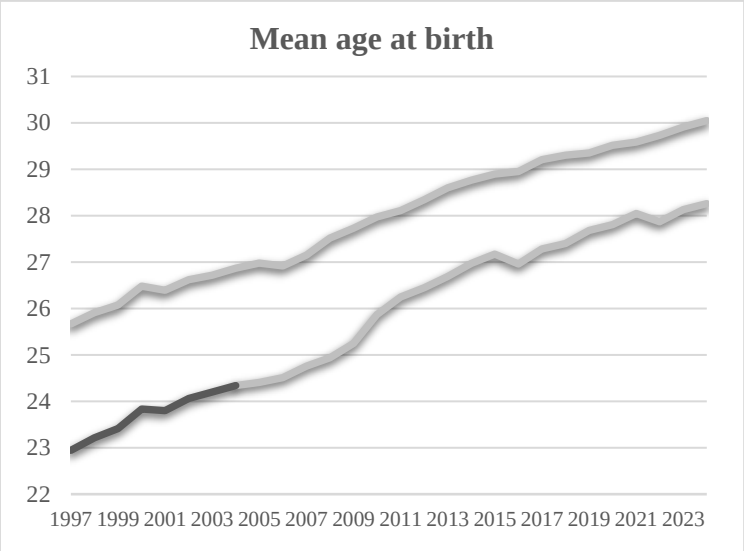


Figure 3. MAB and MAB1 in BiH, 1997-2024

On the other hand, in addition to the period fertility indicators, we also have cohort indicators that more faithfully reflect the actual birth conditions and their age pattern. The description of changes in the age model of fertility in post-Yugoslav BiH can only be complete with a description of the characteristics of the birth pattern that have been recorded immediately before the outbreak of civil war. In this sense, the changes between the 1991 and 2013 censuses were analyzed. In 1991 age-pattern of fertility was already marked by low fertility rates among women up to mid-twenties, and relatively sharply increasing to the mid-thirties. Yet, women achieved up to 70% of total fertility until the end of optimal reproductive age (until 35 years of age), gaining remaining 30% of fertility during advanced maternal ages, and making effective fertile period quite long. Two decades later, in Census 2013, pattern of fertility, although at a lower level, was still quite similar up to the age of 35, but with faster decline in the advanced maternal ages (Figure 4). Completed cohort fertility rate (at ages 45-49) was 2.61 children per woman in 1991, leading to the 23.4% decrease in 2013 (2.00 children per woman). If we reflect on the absolute age-specific changes in fertility, then we can say that fertility fall is relatively constant with age (0.5 children approximately), except for the youngest (smaller) and the oldest (higher) age cohorts.

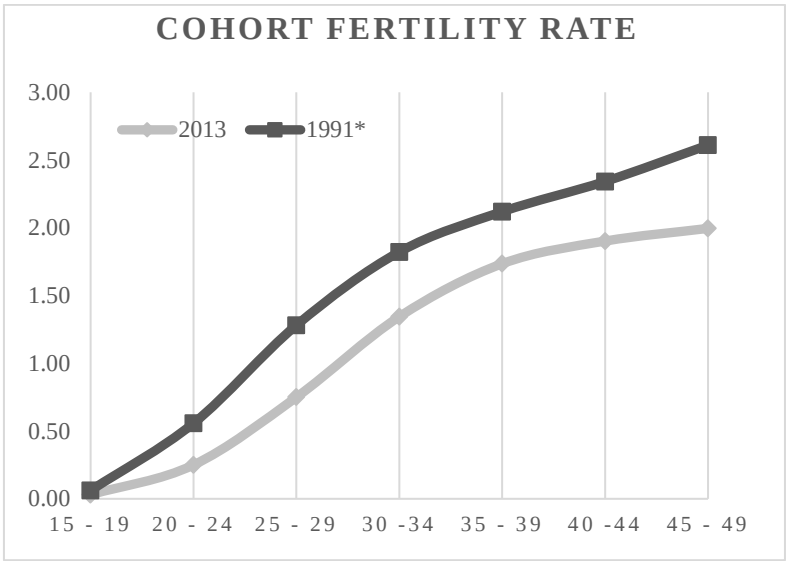


Figure 4. Age-specific cohort fertility rates in BiH, 1991* and 2013

Regarding the proportion of women who gave birth by a certain age, clear changes are visible between the two censuses, especially in women's twenties (Figure 5). Youngest cohort decreased by five percentage points, making up 2% of them participating in reproduction. However, major changes occurred in women of optimal reproductive age (20-34) decreasing by 23, 24, and 12 percentage points in women of 20-24, 25-29, and 30-34 years of age, respectively. At advanced maternal ages, the differences between these two censuses are decreasing with age of women. At the end of the fertile period, women's reproductive participation rate is quite similar in both censuses, 90% and 88% in 1991 and 2013 respectively, indicating relatively low levels of social sterility.

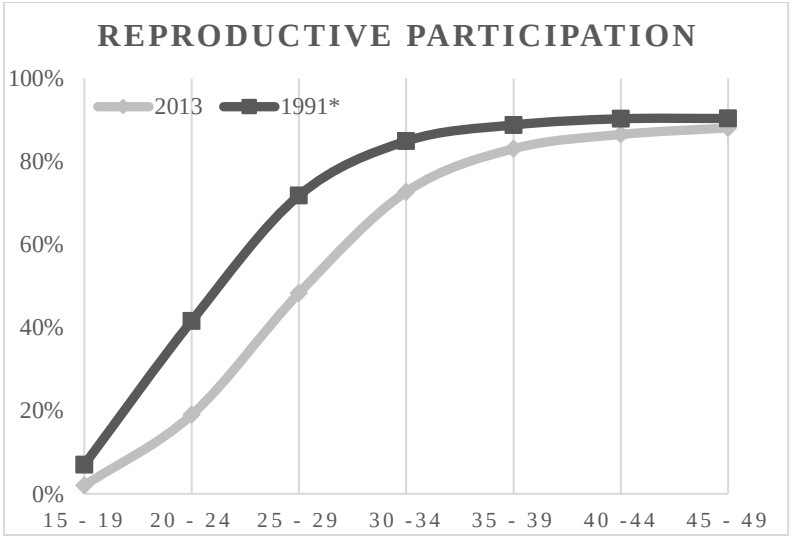


Figure 5. Age-specific reproductive participation rates in BiH, 1991* and 2013

* Analysis of the 1991 Census data in BiH was never finished, and the age and parity specific data were delivered upon request but were not subject of statistical control. The rate does not include all parities because additional data processing showed some illogicalities that were excluded. The first age group refers to fertility up to the fourth child, the second to the fifth child and all others up to the eighth child.

DISCUSSION

Significantly higher fertility in BiH immediately after WWII was inherent to the backward agrarian society of that time, with high fertility rates mostly related to lower levels of education and higher illiteracy compared to other republics, even in urban areas [8].

The high female unemployment and illiteracy of that era were key factors in the high fertility rates. The number of employed women in BiH was only 49 thousand in 1954 [29]. Until the end of the 1970s, the share of the urban population was about one-third, and due to the large demographic losses during WWII (approximately 25% of the total population), the compensation period lasted longer than in other republics [5]. Early childbearing in BiH was so common in the period after the WWII that in analyzes of specific fertility rates, it was observed that only the category of women aged 15 to 19 years did not reduce the level of the rate, more than 30 years after the end of the war [5]. The decline in fertility rates was observed mostly in women aged 25 and over, which indicates the limitation of marital fertility, but with early and almost universal marriage. Until the end of the 1970s, over 80% of women married before the age of 24 [30].

An interesting qualitative explanation of the specific fertility transition in BiH can be found in the study "Man, birth, society" [4]. Based on a survey conducted in 1970 with the aim of determining the social conditioning of changes in fertility in BiH, it was concluded that industrialization and the growth of women's employment affect the decline in fertility rates, but that, due to distinct differences in the speed of economic and regional development in the territory of BiH, in those parts that were affected by economic stagnation, and where the fertility transition has already begun, unfavorable socio-economic conditions further accelerated its decline. Among other things, the research recognizes class affiliation (peasants, workers, officials, experts) as the predominant determinant of the differential fertility of the population of BiH in that period. Thus, the differences between the highest and the lowest class in achieved fertility were 263%, but they decreased in the desired number of children (33%) and were the smallest in the ideal number of children. On the other hand, only the members of the highest-class recorded below-replacement fertility, and at the same time, they were the only ones to record a higher desired fertility than the achieved one, indicating that among all the lower classes there was an unsatisfied need for family planning. In the peasantry, the realized fertility was 1.3 children per woman higher than desired [4].

In the conclusions of the mentioned research, which was carried out in six municipalities of BiH, it was underlined that a further decline in fertility in the class of experts (1.58) and officials and non-production workers (2.66) is not expected, but that the majority of the further decline in fertility could occur in the class of workers (2.55) and peasants (4.15) [4]. Unfortunately, the decline in fertility occurred among all classes, but the decline was more intense among the lower classes. In 1970, this research recorded a total average number of desired children of 2.54, however, regardless of the lack of similar research in the recent period, the research conducted for the purposes of developing the "Demographic Strategy of the City of Banja Luka" recorded the desired number of children of 2.06 [3], indicating that the preferences of the population are shown to be an important limiting factor in the potential rehabilitation of the birth rate in BiH.

The latest, very low, recorded values of the period TFR of 1.18 in 2024, as well as in most years after the 2013 Census, really raise doubts. The shortcomings of period rates in countries where population estimates become outdated as we move away from the census

in time are well known [9]. The biggest shortcoming of such estimates is actually the lack of data on international migration and migration balance, which in highly emigration countries such as BiH usually leads to a greater or lesser overestimation of the resident population in the country. According to World Bank estimates, BiH, with 44.5% of its population abroad, ranks 16th in the world in terms of emigration [14]. Consequently, such an overestimation of the country's population negatively affects the level of the fertility rate. In order to make at least an approximate estimate of the resident population, it is necessary to estimate the international migration balance.

As part of the Study on emigration from BiH [2], based on mirror statistics from the countries of the European Union, the USA and Australia, as well as data from the Migration Profile of BiH, an assessment of the value of emigration until 2018 was carried out. However, the Study itself emphasized that the data do not include emigration to Turkey, the UAE and Serbia, which is an important shortcoming of this assessment considering that Turkey and the UAE are important destinations for emigrants from the Federation of Bosnia and Herzegovina, and Serbia is an important destination for emigration from Republika Srpska. However, as an estimate of emigration, data on the number of persons who were outside the country for 12 months or longer (approximately 58% of the total emigration) was taken from this study, and the linear trend of this number was extrapolated for the years after 2018. To this number, we added 1/3 of persons who took the citizenship of the Republic of Serbia[11] in the corresponding year, thus estimating the annual emigration from BiH.

As far as immigration is concerned, data on immigration to BiH can be considered very reliable, and their monitoring is continuous by the Ministry of Security. For the purposes of assessing the migration balance in this paper, immigration is calculated as the sum of returnees (with the assistance of the IOM and under the Agreement on Readmission) and the number of persons to whom a temporary residence permit was issued. A rate of 0.58 was applied to persons who were issued a temporary residence permit (due to the lack of classification according to the length of stay), which represents the share of those who stay for 12 months or longer, because the same principle is observed among BiH citizens who emigrate. Therefore, the assumption is that as citizens of BiH who emigrate, do so for a period longer than a year with a share of 0.58, foreigners with a temporary residence permit in BiH do the same. Based on the previously described procedure, the values of the annual migration balance were obtained (Table 2).

[11] The Republic of Serbia allows dual citizenship, and those who obtain citizenship do not have to deregister from BiH, so domestic records do not recognize it as emigration. The share of 1/3 was taken as a flat rate i.e. the minimum proportion of those who could leave Bosnia and Herzegovina in the corresponding year.

Table 2. Annual international migration in BiH, 2014-2024

Year	Emigration	Imigration	Migration ballance
2014	16762	7070	-9692
2015	16423	8384	-8039
2016	21816	8418	-13398
2017	26828	7963	-18865
2018	36704	6995	-29708
2019	36726	6541	-30185
2020	34552	5178	-29374
2021	35093	6154	-28939
2022	53226	7342	-45884
2023	58247	8345	-49902
2024	46776	9150	-37626

Source: [2] Study on emigration Bosnia and Herzegovina (2019); [24] The Migration Profile for Bosnia and Herzegovina 2014-2024; [25] The Migration profile of the Republic of Serbia 2014-2024; and author's calculations.

To be distributed according to age and sex, the obtained estimate of the annual values of the migration balance was multiplied by the shares of the female population by age from the empirical migration model applied in the UN World Population Prospects 2022 for BiH [26] (Table 3).

Table 3. Age-specific migration balance for women in BiH, 2014-2024

	15 – 19	20 – 24	25 – 29	30 -34	35 – 39	40 -44	45 – 49
2014	-544	-977	-915	-677	-438	-279	-199
2015	-451	-810	-759	-561	-363	-231	-165
2016	-752	-1351	-1266	-935	-605	-385	-275
2017	-1059	-1902	-1782	-1317	-852	-542	-387
2018	-1668	-2994	-2806	-2074	-1342	-854	-610
2019	-1694	-3043	-2851	-2107	-1364	-868	-620
2020	-1649	-2961	-2775	-2051	-1327	-844	-603
2021	-1625	-2917	-2734	-2021	-1307	-832	-594
2022	-2576	-4625	-4334	-3204	-2073	-1319	-942
2023	-2801	-5030	-4714	-3484	-2254	-1435	-1025
2024	-2112	-3793	-3554	-2627	-1700	-1082	-773

Source: [2] Study on emigration Bosnia and Herzegovina (2019); [24] The Migration Profile for Bosnia and Herzegovina 2014-2024; [25] The Migration profile of the Republic of Serbia 2014-2024; [26] UNWPP 2022; and author's calculations.

Based on the estimated migration balance by sex and age, corrections were made to estimate the size and age composition of the fertile contingent of BiH for the period 2014-2024 and to recalculate age-specific fertility rates (Table 4).

Table 4. Estimated age-specific, and total fertility rate in BiH, 2014-2024

ASFR	15 – 19	20 – 24	25 – 29	30 -34	35 – 39	40 -44	45 – 49	TFR*	TFR
2014	0.0108	0.0491	0.0896	0.0724	0.0270	0.0046	0.0003	**1.269**	1.258
2015	0.0106	0.0475	0.0875	0.0732	0.0276	0.0047	0.0002	**1.256**	1.242
2016	0.0103	0.0503	0.0870	0.0750	0.0294	0.0048	0.0003	**1.285**	1.258
2017	0.0087	0.0495	0.0868	0.0779	0.0321	0.0050	0.0004	**1.302**	1.259
2018	0.0075	0.0515	0.0845	0.0770	0.0328	0.0055	0.0004	**1.296**	1.252
2019	0.0071	0.0514	0.0818	0.0750	0.0335	0.0057	0.0003	**1.274**	1.204
2020	0.0067	0.0479	0.0826	0.0727	0.0341	0.0057	0.0004	**1.251**	1.185
2021	0.0066	0.0470	0.0836	0.0772	0.0335	0.0062	0.0004	**1.272**	1.190
2022	0.0060	0.0442	0.0905	0.0764	0.0353	0.0063	0.0003	**1.295**	1.180
2023	0.0054	0.0429	0.0986	0.0765	0.0365	0.0071	0.0006	**1.338**	1.182
2024	0.0057	0.0425	0.1015	0.0756	0.0381	0.0074	0.0004	**1.356**	1.179

Source: [22] Demography BiH 2024, Agency for Statistics of Bosnia and Herzegovina (2025); and author's calculations.

The deviation of the obtained TFR values compared to the officially recorded ones increased over time and reached 0.18 children per woman in 2024, i.e. 15%. Similar deviations were recorded in Serbia at a slightly lower level, with the highest values recorded in 2021 and amounting to 0.07 children per woman, i.e. 4.6% [9] (Figure 6).

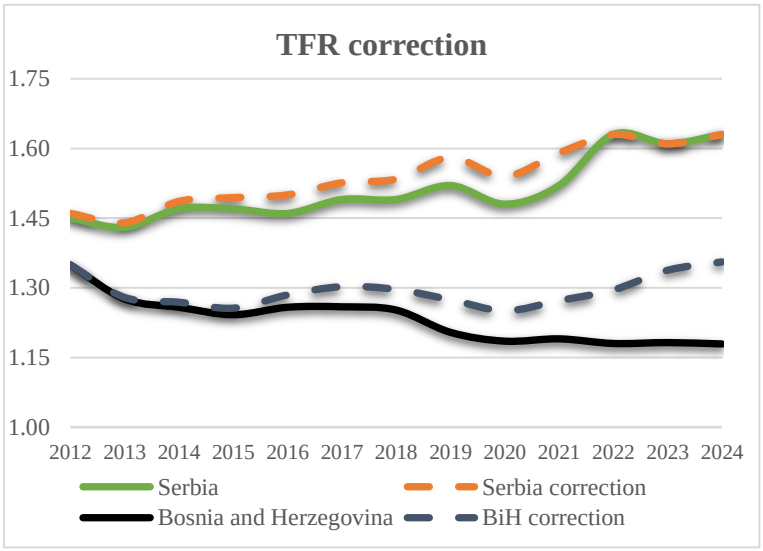


Figure 6. Recorded and corrected TFR in Serbia and Bosnia and Herzegovina, 2012-2024

Regardless of the different values of corrected TFR in Serbia and BiH, a similar pattern, or trend, is easily discernible. In this sense, it is very useful to compare the trend of TFR in all the former Yugoslav republics (Figure 7). The change of corrected TFR values in BiH shows a similar pattern as in Serbia and Montenegro, but, compared to all other former republics, it is at the lowest level. In addition, only these three countries record a full TFR recovery after the shock caused by the COVID-19 pandemic.

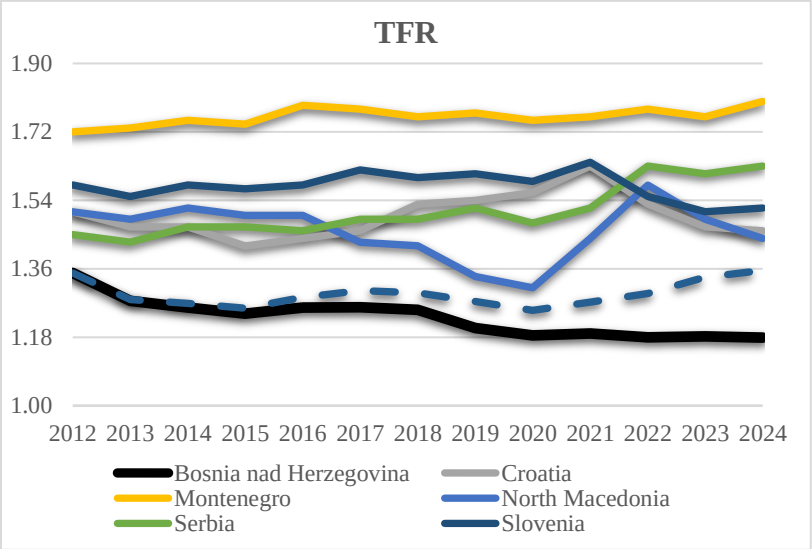


Figure 7. TFR in ex-Yugoslav area, 2012-2024

Apart from the TFR value, an important indicator of fertility transition is the mean age at birth of a child (MAB), which is increasing in all countries of the ex-Yugoslav area. The mean age at the birth of the first child (MAB1) is the highest in Croatia and Slovenia (29.8 and 29.6 respectively), and the lowest in BiH and North Macedonia (28.3 and 28.2 respectively). Considering the pace of growth of MAB1 in BiH, it can be said that BiH is now 10 years behind Croatia and Slovenia. When we look at the total MAB, the differences are similar, and BiH records values like those in North Macedonia. The pace of increase of MAB and MAB1 in BiH does not differ compared to other countries of the ex-Yugoslav area, but the lower values of these indicators are evident (Figure 8).

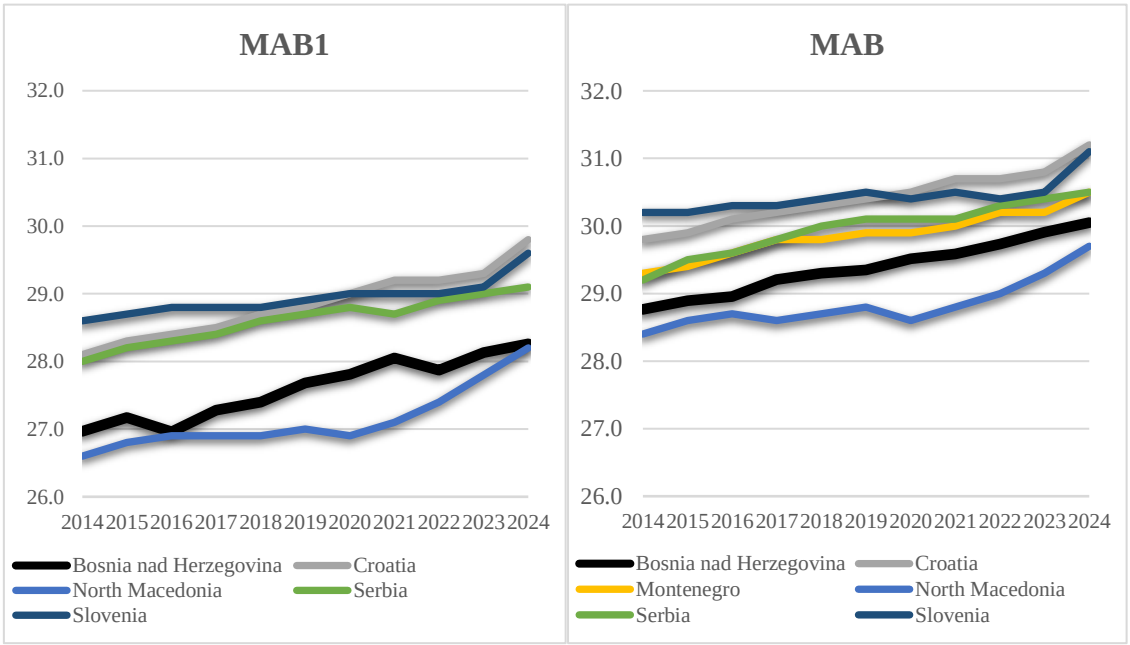


Figure 8. MAB and MAB1 in ex-Yugoslav area, 2014-2024

CONCLUSION

Fertility transition in BiH, although it started later, and with significantly higher TFR compared to the low-fertility part of the former Yugoslavia, during the second half of the 20th century progressed very quickly due to the sharp increase in women's literacy, the improvement of the educational structure and the transition from agriculture to the industrial sector of economic activity. In 1978, TFR fell below replacement for the first time, thus BiH entered the process of the SDT. The continuation of the decline in fertility starting from the early 1980s until today was characterized, at first, by the decline in marital fertility among women aged 25 and more years old, without a significant change in the age pattern of birth, but only by lowering the quantum, and was followed by major changes in the fertility pattern occurred at the turn of the 20th to the 21st century embodied in the postponement of the birth of the first child and further reduction of the quantum of fertility. However, the registered decline of fertility in BiH in the last few years is not as sharp as it seems. Observing the corrected values of TFR (where the strong emigration from BiH after the last population census was considered), it can be said that the population of BiH largely records similar fertility trends as other surrounding countries, and that the model of earlier entry into reproduction is very similar to that of North Macedonia. Although it is at a lower level compared to other countries, fertility in BiH has not been declining faster than in the rest of the ex-Yugoslav area recently because most of the decline in fertility took place before the collapse of Yugoslavia, only the change in the age pattern of fertility took place during the last 2-3 decades. The Ex-Yugoslav area is today, in terms of population fertility, far more homogeneous than it was at the time of the existence of the former SFR Yugoslavia.

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REFINING THE LOCATION OF THE BATTLE OF MOHÁCS FOUGHT 500 YEARS AGO AT THE GATEWAY OF THE BALKANS (USING GEOGRAPHICAL METHODS)

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ABSTRACT

The collapse of the medieval Hungarian Kingdom was caused by the expansion of the Ottoman Empire in Central Europe. The most important and symbolic event in this series of historical events was the Battle of Mohács in 1526. The battlefield was located on the plain near the River Danube and the town of Mohács; however, the exact central location of the battle has not yet been precisely identified and remains the subject of ongoing scholarly debate. We examine the Mohács Plain using GIS software, historical and modern maps, satellite imagery, hydrological data, and digital elevation models. Based on contemporary descriptions and recent literature we identified various landmarks, geographical objects and measured distances from them. Our results indicate that the centre of the battle arena was located south and east of the village of Sátorhely.

Keywords: Battle of Mohács; battlefield geography; environmental reconstruction; GIS

INTRODUCTION AND OBJECTIVES

On 29 August 1526, the armies of the Kingdom of Hungary led by King Louis II suffered a decisive defeat against the Ottoman forces of Sultan Suleiman I on the Mohács Plain. Descriptions of the structure and movements of the opposing armies are more or less known, but the plain is relatively large and the exact location of the battle has not yet been determined. While in the 18th and 19th centuries the battle was still placed near today's Sátorhely (in the middle and eastern part of the plain), in the 20th century a new location emerged, the village of Majs and the foothills bordering the Mohács Plain to the west [1]. On the 500th anniversary of the Battle of Mohács (in 2026), investigations that clarify the location of the fights are of particular importance.
Research objectives:

- We collected numerous contemporary descriptions and documents relating to the battle, which contain information about the geographical environment. We examined maps from the 16th to 20th centuries.
- We familiarized ourselves with the physical geography of the Mohács Plain by studying geographical literature and conducting field surveys.
- We used cartographic and GIS methods to analyze old maps, digital elevation models, aerial photographs, and satellite images.

- We identified the geographical objects mentioned in the descriptions of the battle and used them to determine the more precise location of the Battle of Mohács.

BRIEF HISTORICAL OVERVIEW

On August 29, 1526, the Ottoman army led by Suleiman I destroyed the Christian army of King Louis II and Archbishop Pál Tomori.
During his long reign, Sultan Suleiman I personally led 13 campaigns, seven of which were against Hungary. He achieved his first significant success with the capture of Belgrade in August 1521. His greatest triumph came on August 29, 1526, on the plains of Mohács, when he dealt a decisive defeat to the Christian forces.
Louis II, King of Hungary and Bohemia, was 20 years old in the year of the battle. He fielded the largest army in Central Europe at the time, but even so, it numbered only 30,000 men against the Ottoman forces of approximately 80,000. He fought bravely in the battle, but at the end of the battle, the king and a significant part of the nobility were killed, and the Ottoman troops ravaged Buda and Pest.
According to eyewitnesses, the battle lasted only one and a half or two hours. The Christian army suffered huge losses, with at least 16,000-18,000 soldiers dying on the battlefield. The Ottoman army lost only 300 soldiers on the site and further 1000 in the next 10 days. [2]
The Ottoman victory broke the Kingdom of Hungary. By 1529, Suleiman was already besieging Vienna.

THE LOCATION AND PHYSICAL GEOGRAPHY OF THE MOHÁCS PLAIN

The investigated area – the Mohács Plain microregion – is located in Central Europe, in the Pannonian Basin, on the Great Plain, next to the Danube River. The study area lies mainly in Hungary, but a smaller part extends into Croatia as well.
During our physico-geographical investigations, we mainly focus on this microregion, but this area has been in constant contact with the surrounding microregions. The boundaries of the investigated area are as follows:

- the edge of the Baranya Hills in the north and northwest;
- in the east, the line of the Mohács-Danube and the Mohács Island;
- in the south, the Karasica Stream and the Bán Hills (Baranyahát);
- in the southwest and west, the transition is gradual towards the Lower Drava Plain.

In the Mohács Plain and its immediate environs, four surface levels can be distinguished by elevation. The geomorphological properties are markedly different from each other:

- lower and higher floodplain levels (Fig. 1 number 1);
- flood-free terrace (Fig. 1 number 2);
- the hilly area bordering the Mohács Plain from the north and west (Fig. 1, number 3).

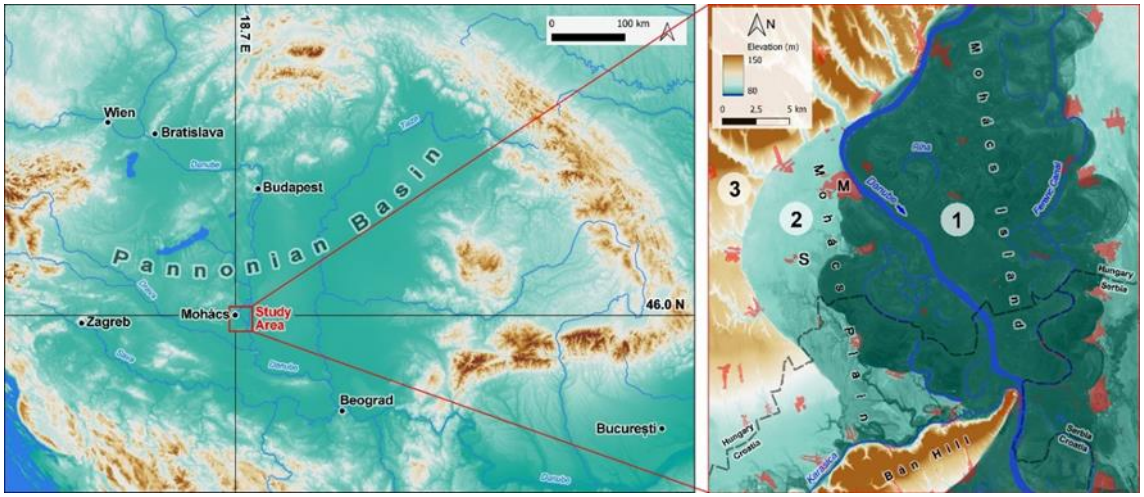


Figure 1. The location of the study area within the Carpathian-Pannonian Basin (A) and its vertical geomorphological levels (B). Legend: 1 = Lower and higher floodplain levels (dark green); 2 = Flood-free terraces (light green); 3 = Hilly areas (brown); M = Mohács; S = Sátorhely

Lower and higher floodplain surfaces

Areas located 5-6 m above the zero level of the Danube (79.195 m above sea level at the Mohács gauge[12]), i.e. at around 84-85 m elevation, are called lower floodplain surfaces. Before river regulations they had been inundated by the Danube even at a slightly higher than mean water level; therefore, they remained dry at low water levels. Such surfaces are of Late Holocene age. Recent backwaters (permanent or temporary oxbow lakes) are characteristic of the surface, which are partly of natural origin and partly formed as a result of river regulations.

From the evidence of the maps drawn in the past centuries, the low floodplain was mostly covered by swamps, waterlogged areas with reed-beds. Fishing and gathering related to the traditional 'notch' economy was typical. The higher ground was used as pasture in the summer. Before the regulations, humans did not settle in these low-lying areas.

The higher floodplain surfaces rise 8-9 m above the 0 zero level of the Danube (i.e. 87-88 m elevation above sea level). Water could only reach them during major floods. The higher floodplain surface can be observed in patches of various size south of Mohács on the inner banks of oxbows, where extensive floodplain forests stand. [3]

The bank stabilization and river regulation works carried out in the 19th century have very significantly transformed the surface of the floodplain. In the area protected by dykes and drainage canals (between the edge of the geomorphological floodplain and the flood-control dykes, in the protected floodplain), since the construction of the protection structures, geomorphic action has been taken over from the river by agrotechnology and today the latter governs landscape evolution.

During our research, we used maps from the 17th and 19th centuries to reconstruct the pre-regulation course of the Danube and other waterways. (Fig. 2A) To reconstruct the course of the Mohács-Danube in 1526 with absolute precision is now almost impossible since fluvial geomorphic action has completely reshaped the floodplain topography since then. Few accurate descriptions and maps of the Danube section between Mohács and Kiskőszeg (Batina) have survived from the period before regulation and flood-control

[12] https://www.vizugy.hu

works. In the course of the research, we performed a comparative investigation of some early map representations in order to locate the course and dimensions of the Mohács Danube around 1685. It can be concluded that the current bed of the Danube between Mohács and Kiskőszeg has little to do with that solely formed by the river before the regulations. When researching the Battle of Mohács, you have to reckon with a narrower, but much longer and more sinuous river bed. [4]

Flood-free terrace

The flood-free terrace is located at an altitude of 90-100 m above sea level, bordered by the floodplain to the east and the hilly area to the west. The flood-free terrace is separated from the floodplain by a steep 4-6 meter high slope on the eastern side. On the western side, a 15-30 meter high steep slope separates it from the hills.

The terrace, covered with fertile soil, is now mainly used for farming. However, we can observe on maps from the previous centuries that in the shallow valleys of the smaller watercourses crossing the loess-mantled terrace, there occurred waterlogged areas, which were predominantly used as pastures. Due to river regulations, the extent of wetlands has been significantly reduced. The major routes ran on the free terrace, such as the thousand-year-old military road along the Danube, on which traffic was only disrupted by streambeds.

Largely due to the work of waters, and to a lesser extent to the wind as geomorphic agents, microforms with a relief of a few meters have been formed on the flood-free terrace. They are either negative or positive features. In its central section the free terrace is ca. 10 km wide, with the Sátorhely ridge in the middle, but other elevations can also be observed in the area.

Today, it is more difficult to detect the differences in microtopography. The excellent, chernozem-type soils formed on the terrace surface are intensively cultivated. As a consequence, the smoothing effect of tillage and rainwater is enhanced. The large-scale field cultivation of the 20th century planated the terrace surface, reducing and eliminating the differences in microtopography, which were extremely important in previous centuries, through tillage operations.

Today the most easily noticeable and most contrasting negative forms can be associated with regulated, channelized streams: the Csele, Jeny, Lánycsók, Lajmér and Borza Streams, which now flow in artificial channels bordered by dykes on the terrace surface. However, their meandering beds active before the regulations can also be observed on contemporary maps or on current satellite images. The beds of the streams crossing the terrace are the widest and deepest along the eastern edge.

Aerial and satellite images taken in times of proper soil moisture content, vegetation cover, and irradiation angle also show microtopography which is hardly noticeable in the field. These include the traces of ancient watercourses, some of which may once drained to the Danube or to other major watercourses. They have been inactive for a long time.

The former, deeper Danube riverbed lying in front of the western hills is also a marshy area. Streams flowing down from the hills have built flat alluvial fans across it. This has transformed it into a series of separate marshy patches of varying sizes, covered with reed vegetation.

We digitized the water levels surfaces? on the Mohács terrace, marshy, wet, inland water areas and wet meadows from maps and satellite images (Fig. 2B). Having surveyed and mapped the swamps, wetlands, and inland water spots, a more differentiated picture of Mohács terrace was achieved. South of Mohács the following areas of larger extension

needed for the Battle of Mohács, and those which remained sufficiently dry even after a prolonged rainy period could be identified at the eastern side of terrace:

- the interfluve between the Bég and Lajmér streams,
- the area east of Sátorhely,
- the area between Udvar and Dályok,
- the area between Izsép and Hercegmárok and
- the area between the Karasica ditch and the Kisfalud (Branjina) Stream.

The western section of the terrace, close to the hills, from Lánycsók to Buziglica, especially the environment of the Majs alluvial fan, was regarded unsuitable for warfare.

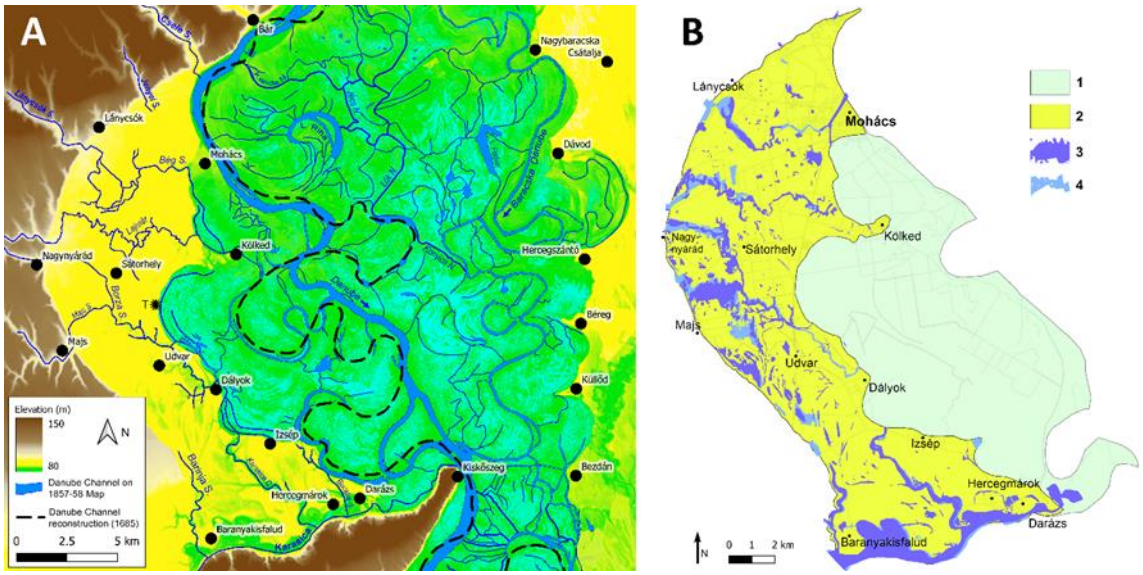


Figure 2. The reconstructed 17th and 19th centuries pre-regulation course of the Danube and other waterways (A). The digitized marshy, wet, inland water areas and meadows from maps and satellite images (B). Legend: C = Canal; N = "Notch"; S = Stream; T = Turkish Hill; 1 = lower and higher floodplain surfaces (in the 16th century mainly swamps); 2 = flood-free terrace; 3 = inland and stagnant water spots, wet areas; 4 = wet meadows

Hilly areas

The hilly area bordering the flood-free terrace to the west and north are genuine hills in the north, while the southern part can be considered more of an alluvial fan plain. This area is covered with thick loess and is mainly used for agriculture. The steep slope between the hilly area and the plains has a height difference of 40 meters in the north and only 10 meters in the south. This steep slope was created by paleo-Danube erosion in the late Pleistocene. Streams flow from the hills to the flood-free terrace, dividing the edge of the hilly area with valleys and forming alluvial fans at the mouths of the valleys. [3]

GEOGRAPHICAL OBJECTS AND SPATIAL DATA THAT ARE IMPORTANT FOR DETERMINING THE LOCATION OF THE BATTLE

The Danube and the transport routes

The main watercourse in the area is the Western or Mohács branch of the Danube. The presence of the watercourse, its water level and its floods have determined the life of Mohács and its surroundings for centuries. The armies marched along the Danube and its floodplains, and the configuration of flood-free and marshy lands, and above all the defensive aspects, were of fundamental significance in their camping. Transport and

warships also used the river. The armies also needed large quantities of drinking water, and the Danube was the best source for this.
In the past, the main branch of the river was the Baracska Danube, which flows along the eastern side of Mohács Island. The eyewitness of the fights, István Brodarics [5] also mentions this in his account of the battle. The Danube splits into two channels just above Báta village. The larger channel splits the Trans-Hungarian region into flat fields, the smaller one washes the banks of Báta and Mohács, and both arms merge below Mohács, forming an island.
The relative dimensions were reversed by the end of the 18th century with the widening of the western branch due to certain tectonic and morphological reasons. The process, which eventually resulted in the Mohács branch becoming wider and the Baracska branch (Ferenc Chanal) narrower, can be traced on maps. During the regulations, the Hungarian section of the Danube downstream Budapest became shorter by more than 100 km (as a result of meander cutoffs). In the study area numerous bends were cut off in the 19th centuries. [6]
Both the Christian and Ottoman armies used the river and the old military route running alongside it for marching and transport.
Suleiman left Constantinople on 23 April. The journey was along the old military route and the troops were accompanied by a considerable flotilla on the Danube after Beograd. The Ottoman army crossed the Karasica Stream, which borders the plain from the south, on August 28, and reached the middle of the Mohács Plain on August 29.
The army of King Louis II left Buda on 20 July 1526 and his troops were stationed in dozens of places before reaching Mohács. The king arrived in Mohács on 25 August. [7]
The Ottoman campaign diary reports several instances of extreme weather conditions (rain, hail) during the journey. Due to the rainy weather, it can be assumed that there were muddy, swampy areas along the streams on the western side of the flood-free terrace. (Fig. 2B) It can be assumed that the Hungarian military leadership therefore designated the eastern side of the flood-free terrace as the battlefield. This choice was reinforced by the military route that had been used here for thousands of years.

Floodplain and swamps along the Danube

South of Mohács, the higher and lower surfaces of the floodplains widen considerably between the Danube and the flood-free terrace. This area was not suitable for battle, but it appears as a landmark in descriptions.
Brodarics described the location of the battle as follows: “As we have said above, this place is a vast, wide plain, not broken by woods, shrubs, water or hills, but on the left, between it and the Danube, there was muddy, marshy water, covered with dense sedge and reeds where many people later perished.” [5]
Miklós Istvánffy called it a swampy lake. [8] A Czech source also reported that a deep swamp lay directly next to the battlefield: *“*Many sank in the swamp, one after the other fell into it.” [9] Among the Ottoman Turkish chroniclers, Kemalpaşazade also notes [10] that the battle took place west of the Danube marshes. Brodarics, the Czech source and Kemalpaşazade all mention that many Christians perished in this swamp after the battle.
These features fit the marshland on the right bank of the Danube, the so-called Vizslak Meadow.
On the western side of the Mohács plain, there are only muddy, waterlogged areas, but there are no deep swamp where many people could have drowned during the battle.

“Large ditch”

The Ottoman Turkish chronicler Lutfi Pasha also reported on a ditch that started from the marsh and crossed the plain: “… a spy has reported that the unbelievers, besides being so numerous, have dug a large ditch, one end of which stretches up to a hill and the other to the Danube, and it is impossible to pass through it.” [11]

Miklós Istvánffy also stressed the importance of the ‘ditch’ or ‘valley’: “Some of our horsemen retreated into the valley between the hill and a nearby marshy lake…” [8]

Using satellite images and free terrain models, we discovered an ancient river valley. This abandoned, now partially buried river valley, as described above, starts at the marsh and crosses the flood-free terrace in a southeast-northwest direction. Our recent studies, based on a digital elevation model derived from LIDAR data and color-infrared (CIR) aerial photographs, have also revealed this landform, as well as other important landmarks (Fig. 3)

The ditch or valley in question is very different from the meandering valleys of the active watercourses of the plain. The former riverbed, which is nearly 5 kilometres long and 50–70 meters wide, runs in gentle curves of a kilometer scale, may have appeared man-made to those observing the site from a distance. Moreover, in its immediate vicinity, Christian armies did carry out earthwork. This is evidenced by the fact that the mass graves excavated in the 1960s and 1970s may originally have been depressions designed for military purposes. Together, these may explain why the scouts believed the ditch to be artificial. The former riverbed is now only 1 meter deep. In our opinion, the level differences have been evened out mainly due to large-scale agricultural cultivation in the 20th and 21st centuries.

The “large ditch” should not be confused with the traces of 20th-century military trenches that can be seen in the area.

On the western side of the Mohács plain, near the village of Majs, there is no large ditch that matches the descriptions.

The Sátorhely Ridge

In his description, István Brodarics mentioned two other important geographical places in connection with the battlefield, a hill and a village: “In front of us there was a long hill, like a stage, behind which there was the camp of the Turkish emperor; at the bottom of the hill, there was a small village with a church, named Földvár. This was where the enemy set up their canons.” [5] The low, curved hill was the Sátorhelyi-hát (Sátorhely Ridge).

The Sátorhely Ridge played an interesting role in the battle. According to Brodarics, an Ottoman cavalry regiment tried to outflank the Christian army from the west: “… the enemy’s armies in the valley that spread out to our right, under the hills, were moving silently, betrayed only by their spearheads.” [5]

He claims that the soldiers themselves could not be seen, the movement of the Ottoman warriors was revealed by the spearheads and the light reflected by them. The regiment moved to the north behind a low elevation. This low hill was the Sátorhely Ridge, which is only a few meters higher than the plain.

We made a visibility analysis using the QGIS software tool. Using modeling, we determined that if the Ottoman cavalry advanced in the Borza stream valley and under the cover of the Sátorhely ridge, only the tips of their spearheads would have been visible, as the terrain provided 3–4 meters of cover. [12]

The hills around the village of Majs correspond in some respects to the eyewitness description, but they do not meet all the criteria.

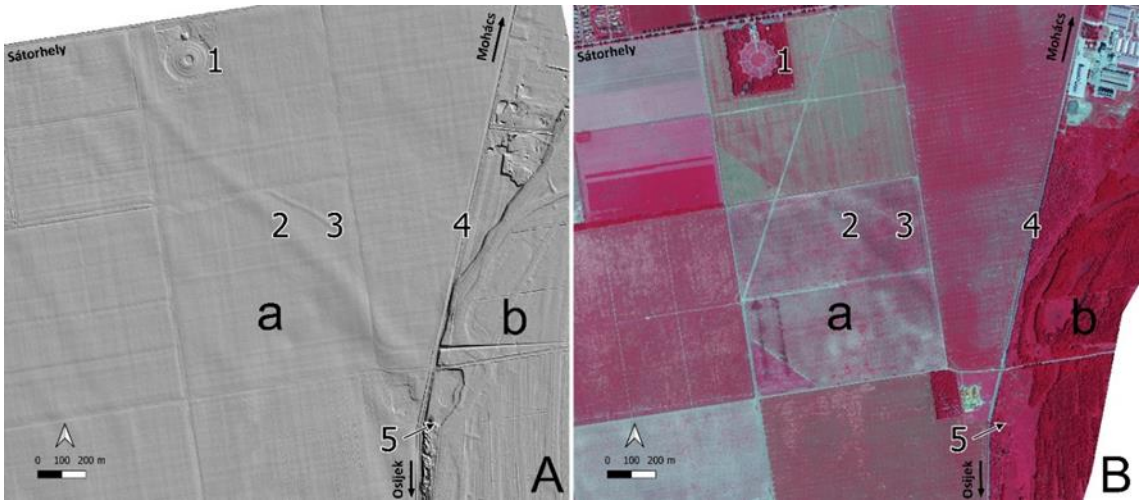


Figure 3. Landmarks located east of the Sátorhely village, as well as their appearance on a digital elevation model created from LIDAR data (A) and a color-infrared aerial photograph (B). Legend: a = Floodplain; b = Flood-free terrace; 1 = Mohács National Memorial; 2 = "Large Ditch"; 3 = 20th-century military trenches; 4 = Former path of the old military route; 5 = Turkish Hill (Törökdomb)

The spatial characteristics of the battlefield, the Christian and the Ottoman camps

On the Hungarian king's orders, the troops were united in a larger camp near Mohács on 27 August. According to contemporary descriptions the Christian military camp situated about half Hungarian mile (ca. 4 km) south of Mohács, in the immediate vicinity of the marshy floodplain below Mohács. Brodarics mentioned: "So the next day, around half a mile below Mohács, our army met theirs…" [5] Brodarics's mile has already been the subject of debate among researchers. We worked with an approximate mileage of 8 kilometres. However, it should be pointed out that Brodarics had neither an instrument, nor an accurate map, so his data can only be considered estimates, with a tolerance of a few hundred metres.

Ursinus Velius wrote: "The location of the royal camp was marked out on the flat and open fields near the marsh." [13]

The bulk of the Ottoman army crossed the Karasica stream, which bordered the plain from the south, on August 28, the day before the battle, and camped near the crossing point near Baranyavár, about two Hungarian miles (about 16 km) from the Christians. [5] On the morning of 29 August, from the camp near Karasica, the Rumalian troops reached the Borza Valley and began to make camp in the early afternoon.

Brodarics reported: "In front of us was a long hill in the shape of a theatre auditorium, beyond which the Turkish emperor was setting up his camp."[5]

Velius' report confirms this: "… The gently rising hill prevented the enemy's camp from being seen. … The camp of the Turks was pitched opposite, at the foot of the Mount." [13] The location of the camp is clearly identifiable as the flat area of the Majs alluvial fan that remained dry in front of the basin margin.

The Hungarian army had time to settle on the chosen battlefield, south of the camp, on August 29th.

According to Brodarics, they moved from the camp to the battlefield, one mile (ca. 8 km) from Mohács, and half a mile from the river. "The place where the army was stationed was a mile from Mohács, and half a mile from the Danube River, which flows by it." [5]

According to Jacomo Zaratino, who served in the regiment of the Croatian ban in the battle, the two armies were positioned about an Italian mile (about 1.6–1.8 kilometers) apart before the battle. “Thus, at the said place, at one o’clock in the afternoon, skirmishes began between armies only an Italian mile apart”. [14]
East of today's Sátorhely village, next to the large ditch, five mass graves were found in 1960, 1975, and 1976, containing the remains of approximately 1,700 dead. These are the most important archaeological remains of the battle. The Mohács National Memorial (or Historical Memorial Park of Mohacs) was established around the mass graves in 1976. [15]

Földvár village

From István Brodarics’ account of the Battle of Mohács, we know that a village called Földvár played an important role in determining the scene of the battle.
Brodarics reported: “In front of us was a long hill in the shape of a theatre auditorium, beyond which the Turkish emperor was camped, and from the hill a small village with a church, called Földvár, descended, and there the enemy guns were positioned.” [5]
The location of the village has been the subject of debate for nearly 100 years. There are several medieval village ruins in the central part of the Mohács Plain. Near the present-day village of Majs (on the western side of the Mohács plain) there is an archaeological site of a medieval village, but based on our research, this is not the remains of the medieval Földvár village, but rather traces of the medieval Nagymajsa village. [16] In our opinion, the archaeological site next to Borza manor is the most likely candidate (but this debate has not yet been definitively settled). An excavation carried out by László Papp in 1967 on a village/settlement remains east of the Borza manor suggests that a settlement existed there in the Middle Ages, the location of which corresponds to the descriptions of Földvár. [17]

Turkish Hill (Törökdomb)

Turkish Hill is a prominent, man-made feature of the military landscape of Mohács and is more than 1,500 years old. During the Roman period, watchtowers (burgi) were erected at selected points along the frontier road to control and supervise traffic along the Danube Limes. The present-day Turkish Hill marks the location of one of these towers. The associated military road (via militaris) continued to be used after the end of Roman rule and remained in operation roughly a thousand years later. In 1526 the Ottoman army led by Suleiman the Magnificent approached the battlefield along this route before the Battle of Mohács.
Local tradition attributes an important role to the hill during the battle. Various legends associated with the site propose different interpretations. According to these accounts, it may have been the place where the sultan prayed for victory, where he pitched his tent, or even a cemetery for Ottoman Muslim soldiers who fell in the battle. However, there is no reliable evidence for these claims, and recent research indicates that the hill could not have functioned either as an Ottoman cemetery or as the site of the sultan’s tent.
In 1630–1631, the governor-general of Buda, Hasan Pasha of Buda, had a well dug on the hill and a wooden structure erected above it. After the reconquest of the region, the building at this commemorative site was converted into a Christian chapel in 1687. It is not known how long the chapel remained in use or what functions it served. Nevertheless, it still appeared on maps from the late eighteenth century, before finally disappearing from cartographic records in the 1780s. [18]

RESULTS AND CONCLUSIONS

We collected and analyzed the most important terrain features and distance data. Based on an analysis of the landscape and a summary of data on landmarks and distances, we have placed the important elements of the battle on the Mohács plain (Fig. 4).

- the flood-free terrace was suitable for battle, while the marshy floodplain was not,
- in rainy weather, there is more waterlogged, muddy terrain on the western side of the flood-free terrace than on the eastern side, so the eastern half is more suitable for a battle fought with heavy cavalry (the location of the battle was chosen by the leaders of the Christian army),
- the ancient military road runs along the eastern edge of the terrace,
- The Christian camp was located about 4 kilometers (half a mile) from Mohács at the time of the battle.
- The Ottoman camp and part of the Ottoman army were hidden from the Christian troops by a low ridge (Sátorhely Ridge).
- on the day of the battle, the Ottoman camp was located between a low ridge and a higher hill,
- the central part of the battlefield was about 8 kilometers (1 mile) from Mohács and about 4 kilometers (half a mile) from the western branch of the Danube,
- there was a deep swamp (Vizslak Meadow) next to the left wing of the Christian army, in which many drowned at the end of the battle,
- there was a large ditch between the Christian army and the battlefield, which we believe to be the remains of an ancient riverbed,
- Before the battle, the two armies lined up about 1.6-1.8 kilometers (1 Italian mile) apart on the northern and southern sides of the battlefield.
- Part of the Ottoman army was located among the houses of the village of Földvár.
- The most important archaeological finds from the battle are the mass graves, which lie east of today's Sátorhely, along the large ditch.
- The most important Ottoman monument of the battle (Törökdomb) lies on the border between the flood-free terrace and the marshy floodplain.

We believe that most of the geographical and historical data does not fit with the western half of the Mohács Plain, around the village of Majs.
In our opinion, the central events of the Battle of Mohács took place east and south of the present-day village of Sátorhely.
Geographical and archaeological research will continue even after the 500th anniversary. We hope that future discoveries and research results will confirm our battle reconstruction.

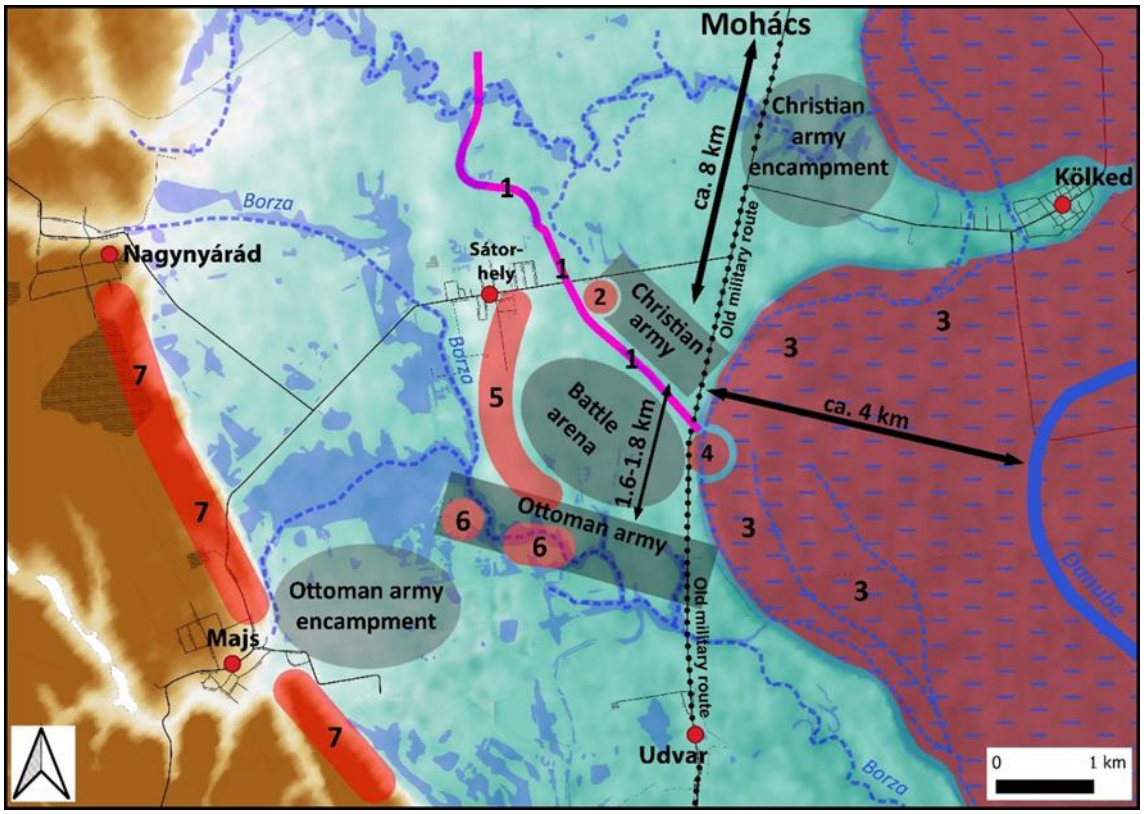


Figure 4. The main scenes of the battle. Legend: 1 = "Large Ditch"; 2 = Massgraves (Mohács National Memorial); 3 = Vizslak Meadow; 4 = Turkish Hill; 5 = Sátorhely Ridge that obscured the Ottoman camp and part of the army from Christian observers; 6 = The remains of the medieval Földvár village; 7 = The "mountain" in front of which the Ottomans set up their camp

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MEASURING THE SPATIAL CONCENTRATION OF HIGHLY EDUCATED POPULATION: THE EXAMPLE OF THE REPUBLIC OF CROATIA

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ABSTRACT

Two key processes are closely connected to highly educated population: continuous growth of their part in the population and the tendency of higher concentration in space. The concentration of human capital is emphasised in the cities which is partially the consequence of the fact that young urban people more frequently decide to take higher education than young people in rural areas. Moreover, people who come to the cities from rural areas for the purpose of further education very frequently become permanent residents (rural 'brain-drain'). The aim of the paper is to research spatial concentration of highly educated population in Croatia using the data from the 2021 Census. Herfindahl-Hirschman index and classical Gini coefficient were used as the measurements for concentration. Furthermore, the paper suggests the use of modified Gini coefficient which compares the spatial distribution of highly educated population with the distribution of total population. The analysis was conducted on the level of municipalities and cities. The results have confirmed the assumption that highly educated people show the higher spatial concentration level in comparison with the less educated population. The concentration level of people with science doctor's degree is especially high. The regional analysis detects the highest degree of concentration in the central part of Croatia (the capital city). Additional analysis according to age groups also shows the differences in the concentration of highly educated people according to age.

Keywords: spatial concentration, human capital, Gini coefficient, Herfindahl-Hirschman index, Croatia

INTRODUCTION

Population spatial deployment is a reflection of protracted economic and demographic processes. Croatia was caught in the global shift from rural-agrarian into urban-industrial concept after the Second World War which led to a disruption of an even distribution of population [20]. At that time, a strong development of urban concentrated secondary and tertiary activities had a migration of population from rural to urban areas as a consequence [25]. The migration which changed the population deployment in the sense of demographic polarization in Croatia culminated in the 1960s and 1970s. Migration currents sometimes sidestepped smaller and mid-sized towns, targeting directly bigger towns [20]. Throughout several decades, polarization processes generated a certain level of population concentration. It markedly concentrated in Zagreb and the surrounding area, as well as in coastal counties [14] which shaped two focal areas of urbanization in Croatia [21]. From the 1980s onwards, the growth of bigger towns has been slowing down due to

the strengthening of sub-urbanization processes marked by dispersion of population into town-surrounding areas [28], [14].

While the researches of population spatial deployment mainly focus on the entire population, in Croatian literature and wider, there is a lack of papers researching the processes of polarization and population deployment based on the level of education. In general, there are not enough papers dealing with the education structure of population in spatial context. Therefore, the aim of this paper is to research spatial concentration of highly educated population in Croatia. The starting assumption is that highly educated population is more distinctly concentrated in space than total population. The research goal is divided into the following tasks:

- establish the degree of spatial concentration of the population at the age of 15 and older, highly educated population and population with academic level of PhD,
- research whether there are differences in spatial concentration of highly educated population regarding age,
- research whether there are differences in spatial concentration of highly educated population among the five regions in Croatia (so-called planning areas),
- single out the towns and municipalities with the highest percentage of highly educated.

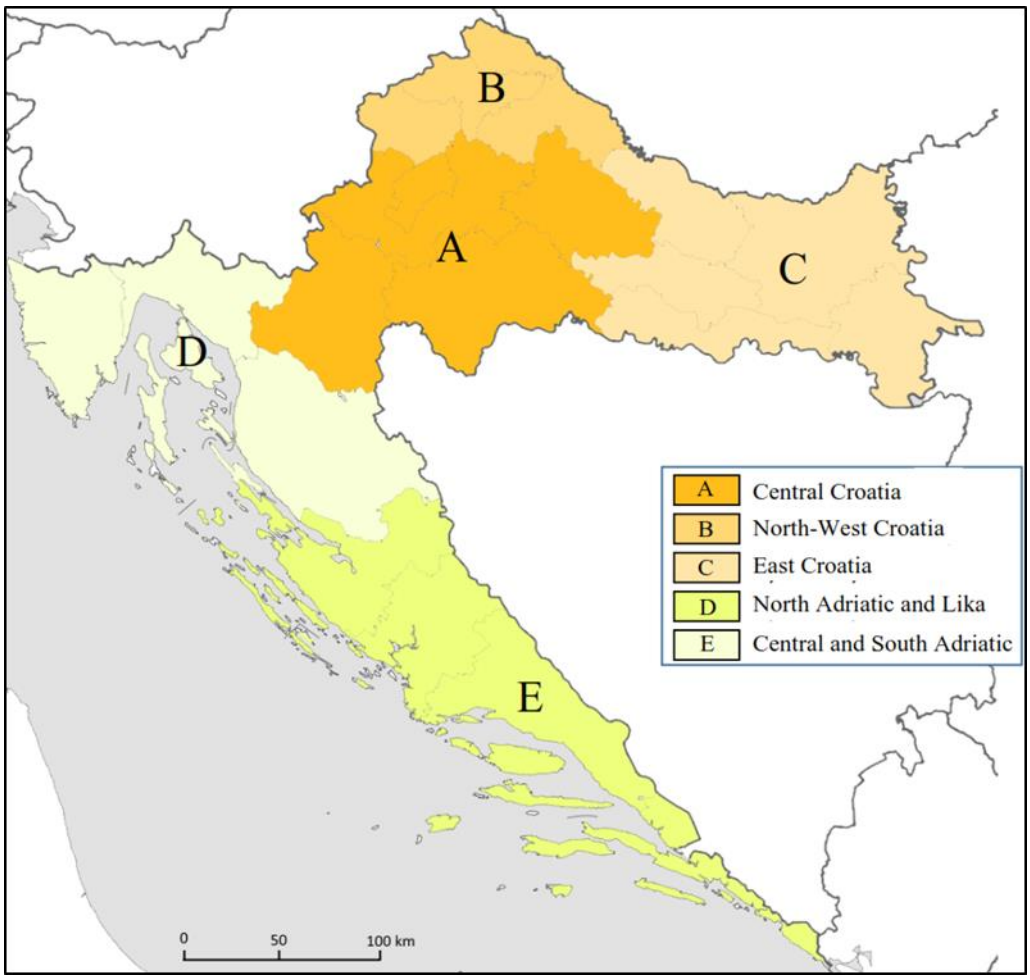


Figure 1. Conceptual division of Croatia in the so-called planning areas Source: [21]

THEORETICAL FRAMEWORK

Two important processes are tied to highly educated population: continuous growth of their participation in total population and a tendency of higher concentration in space. The expansion of the institutions of higher education accompanied by the growth of students in the last decades confirms that many European countries are moving towards the society of knowledge [29]. The number of inhabitants with higher education in Croatia is growing with every census, indicating that every next generation is more educated. For example, in 1971 only 3.6% of population at the age of 15 and more was highly educated (graduating from non-university college at least) [23]. Until 2001, that number grew to 11.9% and in 2001 there was 24.1% of population with higher education level living in Croatia [6], [7]. Despite the fact that the percentage of highly educated people has more than doubled in the last twenty years, Croatia is still below the average level in the European Union.

The other key process is the tendency of spatial concentration of highly educated population. People with a higher level of education are more prone to living in bigger towns [11], which is to say that there is a rather small number of highly educated in rural areas. In fact, there are two main reasons for the deficit of highly educated in the countryside: young people from rural areas decide on higher education at a smaller rate, and those who decide to go to university often continue living in the city after graduating [17]. There are several reasons as to why young people from rural areas decide on higher education compared to urban young people. Most universities and other higher education institutions are located in urban areas, which means that physical distance between the place of living and studying, emotional distance and higher expenses constrain young people from rural areas to enter universities. Furthermore, young rural people have less need for higher education because the local market is dominated by activities demanding less knowledge [29]. Social background plays another important role, e.g. a lot of rural young people do not have highly educated parents [17].

An additional problem for rural areas lies in the fact that those rural young people who decide to go to town for education, do not return to their region after graduating. Initially, young people temporarily migrate from their places of living to the places of studying, only to often make it a permanent place of living after graduating. One of the main reasons why young people do not return to the countryside after graduating from university is the problem of getting a job in their field of training [17]. Unfortunately, unlike students in towns, rural students often have to leave their communities if they want to upgrade their talents. Apart from modest career opportunities, negative perception of rural areas includes fewer possibilities of acquiring high income [26]. Poor infrastructure in such areas, including traffic and municipal infrastructure, also contribute to their negative perception. Certainly, some part of educated young population would continue living in the countryside if commuting to work was improved through better traffic connections [17].

Education and attending universities appear as population migration factors [9], firstly temporary, and later final migrations. As it can be seen, migrations do not influence only the spatial population deployment but can lead to changes in the population structure due to its selective character [24]. Migrations are selective considering the level of education, in which course more educated and more qualified people leave rural areas more often [22], [26]. The mobility of human resources leads to its agglomeration in big towns [8]. This means that at the same time rural ‘brain-drain’ results in creating agglomerations of

high capital in towns and its lack in rural areas. Rural 'brain-drain' represents a serious threat to social and economical vitality of rural areas [1]. Those with relatively lower education, skills and income remain in the countryside [26]. On the other hand, clustering of people with higher education increases the productivity of certain areas and towns, which creates potential for their economic growth [1].

METHODOLOGY

Spatial concentration researches are common in spatial economy and economic-geographical analysis. In order to establish the level of geographic concentration of economical activities (e.g. concentration of employed, companies etc.) different scales of concentration have been developed. Different varieties of the Gini coefficient, Herfindahl-Hirschman index and other scales have found a wide use in those scientific fields. Even though the issues of population concentration and spatial deployment are important in demographic research, studies which would deal with measuring the level of population concentration are rare. For example, some authors dealt with measuring territorial population concentration [3], [2], [10], [19]. For the needs of their research authors mainly 'borrow' scales developed in economic studies and modify and adjust them accordingly.

In order to establish the level of spatial concentration of highly educated population in Croatia, the following indicators were used in this paper: Herfindahl-Hirschman index (HHI), Gini coefficient (G) and locational Gini coefficient (G_l). The analysis are based on the results of Census in 2021 conducted by the Croatian Bureau of Statistics. Data on the number of highly educated people in towns and municipalities were used to calculate the indicators. The results of this research provide the answer to the question whether highly educated population is concentrated in a smaller number of towns and municipalities or it is more equally distributed on national territory.

Herfindahl-Hirschman index (HHI) is one of a very simple and frequently used scales of concentration. It is used in this paper in order to compare spatial distribution of highly educated people with the uniformed population distribution. Gini coefficient (G) represents the most widespread scale of spatial concentration [12]. This coefficient derives from Lorenzo's curve, which means it is defined by the space between the line of uniformed distribution and Lorenzo's curve (the line of real deployment) [13].[13]

Although often used, the drawback of these markers is that they do not take into consideration the differences among regions while measuring the concentration of population (e.g. municipalities differ in area and population) [12]. Therefore, locational Gini coefficient (G_l) was used additionally as a relative indicator which co-relates geographical deployment of highly educated population with the deployment of total population of Croatia. The indicator used in this paper is a modification of location Gini coefficient initially used by P. Krugman whilst working on economic-geographical research [16].

The locational Gini coefficient calculation is based on location quotients which, for the purpose of this article, were calculated as follows:

$$LQ = (P_{Hej} / P_{HeCro}) / (P_j / P_{Cro}) \qquad (1)$$

[13]For the entire calculation procedure of the listed markers consult Braičić & Lončar (2018).

where P_{Hej} represents the number of highly educated in a municipality/town *j*, P_{HeCro} the number of highly educated in Croatia, P_j total number of inhabitants in a municipality/town *j*, P_{Cro} total number of population in Croatia. That way the portion of highly educated in a municipality/town is put into a relation with the portion of the municipality/town in total population of Croatia.
Locational Gini coefficient, modified for the purpose of this paper, was calculated according to this formula (adjusted according to [13], [8]):

$$G_l = 1 - \sum_{k=1}^{n} (x_k - x_{k-1})(y_k + y_{k-1}) \qquad (2)$$

where *k* represents a municipality/town *j* ranked according to location quotient value, x_k cumulative portion of a municipality/town *k* in total population of Croatia, y_k cumulative portion of a municipality/town *k* in total number of highly educated inhabitants of Croatia. If highly educated population was distributed in space proportionally to total population, this index would be 0. This formula was also used to calculate Gini coefficient according to population age groups as well as for certain Croatian regions.

RESULTS AND DISCUSSION

Spatial concentration of highly educated population in the Republic of Croatia

Croatia is not an evenly populated state which is the consequence of geographical, social-economical, political, endogenous demographic factors and inherited settlement structure [20]. According to the last census in 2021, there were 3.3 million inhabitants aged 15 and more. Out of that number, 798,852 were highly educated, while only 16,879 inhabitants had a PhD.
A part of the first research task was to compare the level of population spatial concentration according to the level of education. Table 1 presents the results of the calculation of three relevant indicators of spatial concentration of total and highly educated population. Lower values of Herfindahl-Hirschman index represent more even distribution, while the values approach number one when highly educated population is concentrated in smaller number of towns and municipalities. The situation is similar with Gini coefficient. If the values are closer to zero, population is more evenly distributed in space. Values closer to one indicate more distinct concentration in space. From the results presented in the table it is clear that total population aged 15 and more is not evenly distributed in space and that highly educated population shows even higher level of spatial concentration. When spatial concentration of highly educated is analysed HHI is 0.1105 and Gini coefficient is 0.816. Population with academic PhD is a separate category which is even more concentrated in space - HHI was 0.3009 while Gini coefficient was very close to one (it was 0.9372).

Table 1. Scales of population spatial concentration in Croatia in 2021

Population group	Herfindahl-Hirschman index	Gini coefficient	Locational Gini coefficient
P_{15+}	0.0447	0.6727	-
P_{He}	0.1105	0.816	0.2482
P_{PhD}	0.3009	0.9372	0.5362

Note: P15+ – total population at the age of 15 and more; PHe – highly educated population; PPhD - population with PhD Source: Authors' calulations based on data from CBS, 2021 [7]

Besides the two basic indicators, locational Gini coefficient was calculated, which compared spatial deployment of highly educated with spatial deployment of total population (aged 15 and more). If the value of locational Gini coefficient was 0, it would mean that highly educated population is distributed in space in the same way as total population. Values closer to one mean that spatial distribution of highly educated significantly deviates from the distribution of total population. Obtained values of this coefficient confirm that highly educated population is more concentrated in space (0.2482) that total population. Based on the results of all three indicators it can easily be claimed that more educated population is more concentrated in space than total population, and especially high level of spatial concentration is for the population with PhD. The rest of this research was looking for the answer whether there are differences in spatial concentration of highly educated population regarding age (Tab. 2, Fig. 2). Regardless of the used indicator, Herfindahl-Hirschman index or Gini coefficient, the same conclusions were drawn. Highly educated population, regardless of age, is spatially more concentrated than total population. While the differences in spatial concentration among age groups of total population are very small, they are significantly more distinct when only highly educated population is observed. The lowest values for the two indicators were determined for the youngest highly educated population (aged 20-24), which is also more equally deployed in Croatia. With the rise of age, spatial concentration of highly educated also rises and reaches its peak in the age groups between 40 and 54. Highly educated population of those age groups is the most spatially concentrated. After that age, the level of concentration is dropping so the population at the age from 55 to 74 is again more evenly distributed in Croatia. However, it is impossible not to notice that with the oldest age groups of highly educated (75+) there is another growth of spatial concentration.

Table 2. Spatial concentration of total and highly educated population in Croatia in 2021 by age groups

Age group	Herfindahl-Hirschman index		Gini coefficient		Locational Gini coefficient (P_{He})
	P	P_{He}	P	P_{He}	
20-24	0.0421	0.0565	0.6722	0.7297	0.1258
25-29	0.055	0.096	0.6928	0.775	0.1536
30-34	0.0576	0.1094	0.7013	0.8007	0.1790
35-39	0.0563	0.1172	0.7059	0.8243	0.2092
40-44	0.0558	0.1328	0.701	0.8526	0.2532
45-49	0.0504	0.1364	0.6959	0.8601	0.2896
50-54	0.0439	0.1339	0.6715	0.8512	0.3143
55-59	0.0366	0.1078	0.6508	0.8272	0.3006
60-64	0.0345	0.0932	0.6479	0.8172	0.2871
65-69	0.0364	0.0991	0.6544	0.8264	0.2916
70-74	0.0387	0.0949	0.666	0.8256	0.2681
75+	0.0435	0.1303	0.6641	0.8534	0.3174

Note: P – total population; P_{He} – highly educated population Source: Same as in Table 1.

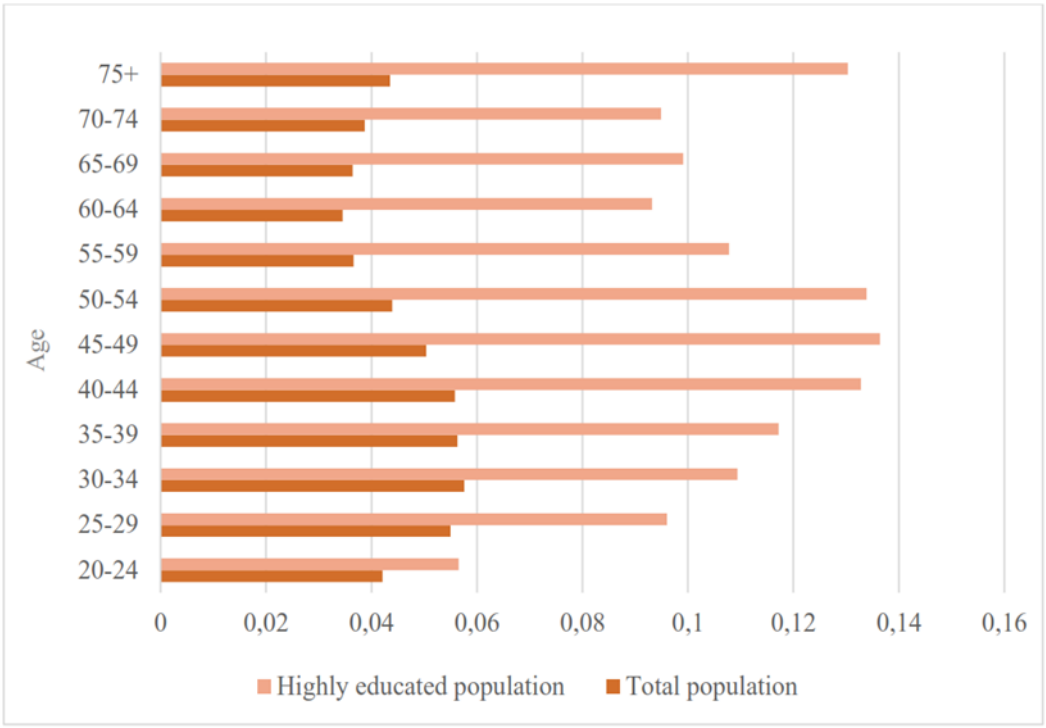


Figure 2. Herfindahl-Hirschman index of population spatial concentration in Croatia (2021) by age groups

Young people who have recently gained higher education are more evenly distributed in space for various reasons. Since they have only recently graduated, they still have not migrated towards larger urban centres. With time, in search for work and career many young people decide to move to larger urban centres. Due to selective migrations of highly educated people towards larger towns, their concentration in space grows with the age of population. Another reason for more even distribution of young highly educated is the fact that more and more rural young people, due to better accessibility of education, gain higher education. It is not only the privilege of urban young people.

The highest level of spatial concentration is with the highly educated population between the age of 40 and 54. Highly educated population at that age is the most work productive and mostly employed in markedly urban centralized activities. Spatial concentration of the population older than 55 lowers because the career pressures diminish [5], so a part of population returns to smaller communities. At the age of 75+, another growth of concentration can be noticed, which means that rural areas have significantly small number of highly educated in the oldest age groups. We are talking about the population mainly born in the 1930s and 1940s when a very small number of young people from rural areas entered universities. Higher education was elite, socially selective and linked to larger towns. Therefore, today's population at the age of 75 and more was extremely concentrated in towns even in their youth.

Locational Gini coefficient indicates the difference between the spatial concentration of highly educated by age groups and the concentration of total population (Fig. 3). At the younger age groups, highly educated population has a very similar spatial deployment to total population. With the rise of age, the differences become bigger, which means that highly educated become more spatially concentrated. At all age groups above 40, the value of locational Gini coefficient goes over 0.25, which indicates that the differences in

spatial concentration of total and highly educated population are more emphasized than with the younger age groups.

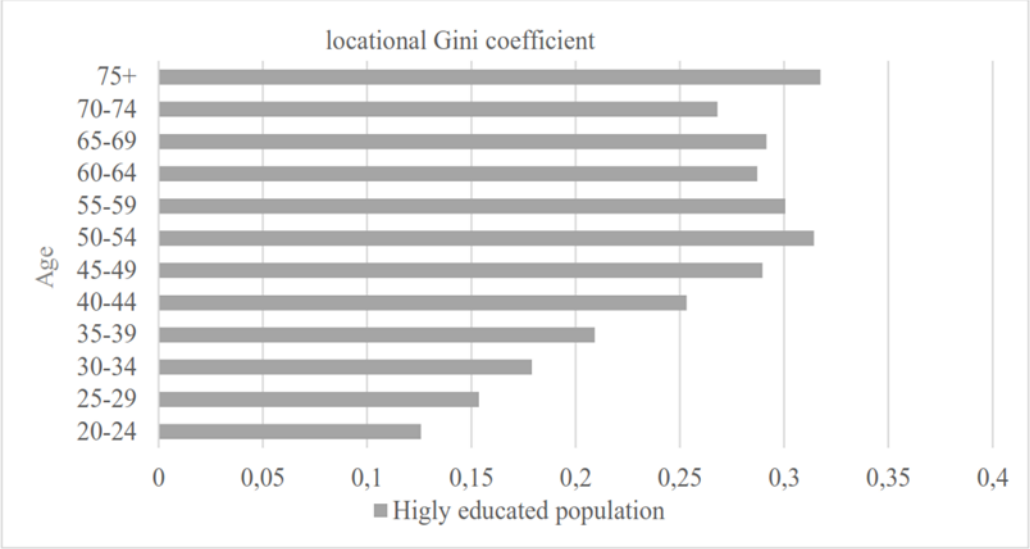


Figure 3. Locational Gini coefficient of spatial concentration of highly educated population in Croatia (2021) by the age groups (referential value = total population of a certain age group)

The research established the differences in spatial concentration of highly educated population among Croatian regions (Tab. 3). For the purpose of spatial analysis Croatia was divided into five so-called planning areas (regions): Central Croatia, East Croatia, North-West Croatia, North Adriatic and Lika and Central and South Adriatic [15]. In all regions highly educated population is more strongly concentrated than total population, and population with PhD even more than that.

The highest spatial concentration of total and highly educated population was established in Central Croatia, which is to be expected since the capital city Zagreb is situated in this area. There is a strong concentration of economic subjects and activity in general, especially tertiary sector [27] which mainly employs highly educated population. The most even population distribution of total and highly educated population is in the area of North-West Croatia. There is no larger macro-regional centre in that region so the population is less concentrated (Fig. 4).

In other plan regions there are larger macro-regional centres: Osijek in East Croatia, Rijeka in North Adriatic and Lika region and Split in Central and South Adriatic region. Even though the level of polarization of total and highly educated population in those regions is roughly equal there are certain differences. For example, total population is somewhat more evenly distributed in the area of East Croatia in regard to two coastal regions (North Adriatic and Lika, Central and South Adriatic). Lowland and agricultural character of East Croatia favours lower polarization of population, and Osijek is a traditionally weaker macro-regional centre than Split or Rijeka. On the other hand, population in coastal regions is mostly concentrated along the Adriatic coast, while the hinterland and islands are less populated [18]. When highly educated population is concerned, it is equally concentrated in those three regions. However, the exception are people with PhD who are more spatially concentrated in East Croatia. The network of higher education institutions is less developed on the territory of this region, and due to this fact almost 70% of all people with PhD in East Croatia live in Osijek, as a large university town. The biggest gap between spatial distribution of total population and

distribution of people with PhD was recorded in East Croatia, confirmed by locational Gini coefficient (0.2664 for highly educated; 0.6402 for PhD). In coastal macro-regional centres (Split, Rijeka) the concentration of people with PhD is not as noticeable as in East (and, of course, Central) Croatia.

Table 3. Spatial concentration of population in Croatia in 2021 in the so-called planning areas

Planning area	Herfindahl-Hirschman index			Gini coefficient			Locational Gini coefficient	
	P_{15+}	P_{He}	P_{PhD}	P_{15+}	P_{HE}	P_{PhD}	P_{He}	P_{PhD}
Central Croatia	0.2954	0.5161	0.7956	0.806	0.9115	0.9732	0.2040	0.3768
North-West Croatia	0.0243	0.0551	0.1137	0.4648	0.6301	0.7959	0.2384	0.4849
East Croatia	0.0381	0.0942	0.428	0.5587	0.7478	0.9241	0.2664	0.6402
North Adriatic and Lika	0.0678	0.1007	0.1941	0.6076	0.6916	0.8016	0.1382	0.3675
Central and South Adriatic	0.0622	0.1091	0.2588	0.6689	0.7657	0.8794	0.1851	0.4499
Republic of Croatia	0.0447	0.1105	0.3009	0.6727	0.816	0.9372	0.2482	0.5362

Note: P15+ – total population at the age of 15 and more; PHe – highly educated population; PPhD – population with PhD Source: Same as in Table 1

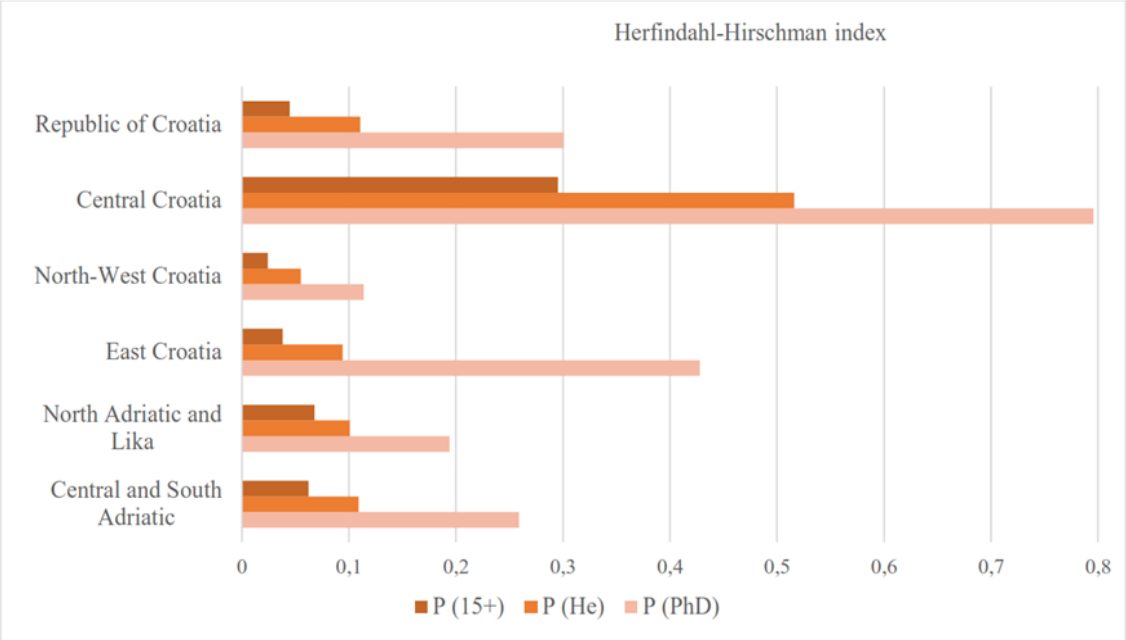


Figure 4. Herfindahl-Hirschman index of population spatial concentration (2021) in the so-called planning areas in Croatia

Patterns of spatial distribution of highly educated in Croatia

So far the analysis has pointed out the level of spatial concentration of highly educated but the used indicators do not reveal the patterns of their spatial distribution. Therefore, the rest of the paper will point out some patterns of distribution of highly educated in the Republic of Croatia.

The beginning of this paper pointed out the distinction between educational behaviour of young people in urban and rural areas. Since the analysis used statistical data at the level of administrative towns and municipalities, in the rest of the text the terms urban and rural will be used for the data which refer to towns and municipalities. The deficit of highly educated in rural areas in Croatia is visible from the information in table 4. Even though there are 28.3% of inhabitants aged 15 and more living in municipalities in the Republic of Croatia, there are only 16% of highly educated living there. Furthermore, there are significant differences among certain Croatian regions. The biggest disproportion between the portion of highly educated in administrative towns and municipalities is in Central Croatia - the region with the largest spatial concentration of highly educated. In Central Croatia 95.1% of highly educated live in towns, while the other 4.9% live in municipalities (rural areas). In most of the other regions - East Croatia, North Adriatic and Lika, Central and South Adriatic - a little over 75% of highly educated live in towns, and 20-25% in municipalities. The exception is North-West Croatia, the region with the most even population deployment, where the difference between the portion of highly educated in towns and municipalities is lower: 63.1% of highly educated in this plan region live in towns, and 36.9% in municipalities.

Table 4. Portions (%) of population aged 15 and more and highly educated population in towns and municipalities in planning areas in Croatia in 2021

Planning area	P_{15+}		P_{He}	
	Towns	Municipalities	Towns	Municipalities
Central Croatia	87.1	12.9	95.1	4.9
North-West Croatia	47.3	52.7	63.1	36.9
East Croatia	58.2	41.8	76.8	23.2
North Adriatic and Lika	70.6	29.4	75.4	24.6
Central and South Adriatic	71.1	28.9	78.8	21.2
Republic of Croatia	71.7	28.3	84.0	16.0

Source: Same as in Table 1

Below are the towns and municipalities with 25% or more of the population aged 15 and over with higher education. These are, in this order:

- in Central Croatia: Zagreb (39.1%), Zaprešić (27.9%) and Samobor (26.1%);
- in Easter Croatia: Osijek (30.2%);
- in North-West Croatia: Varaždin (32.1%), Koprivnica (26.2%) and Čakovec (25.7%);
- in North Adriatic and Lika: Kostrena (40.4%), Opatija (35.3%), Rijeka (32.8%), Kastav (32.7%), Medulin (32.3%), Omišalj (30.5%), Pula (28.6%), Fažana (27.4%), Punat (26.9%), Lovran (26.6%), Crikvenica (26.5%), Rovinj (26.5%), Malinska (26.1%), Kraljevica (26.0%), Viškovo (25.7%), Vrbnik (25.4%), Poreč (25.2%), Pazin (25.0%) and Matulji (25.0%);
- in Central and South Adriatic: Zadar (30.8), Šolta (30.2), Sutivan (28.4), Podstrana (28.3), Korčula (27.4), Bol (26.2), Jelsa (26.2), Janjina (26.1), Gradac (25.9), Vis (25.8), Šibenik (25.7), Makarska (25.7), Okrug (25.3), Orebić (25.2), Hvar (25.2), Župa Dubrovačka (25.1), Konavle (25.1) and Lastovo (25.0).

Space differences in the level of education are emphasized among continental and coastal regions in Croatia. Besides the city of Zagreb, and several other towns in continental part of Croatia, a significant accumulation of highly educated population can be noticed in coastal areas. For example, in Central and South Adriatic region there are more than 25% of highly educated in 21 towns or municipalities, and in East Croatia only in one local unit - the city of Osijek! Such spatial distribution pattern of highly educated is the result of different socio-economical characteristics of continental and coastal part of Croatia, for example the differences in the level of urbanization, differential economical models which do not have the same demand for highly educated and so on.
The concentration of the inhabitants with an academic PhD in urban areas is even more emphasized (Tab. 5). If we compare the towns and municipalities, it results with the fact that 92.6% of people with PhD in Croatia live in towns. That is especially emphasized in Central Croatia where 98.4% of people with PhD live in towns. In fact, more than a half of total number of people with PhD in Croatia is concentrated in the city of Zagreb.

Table 5. Portions (%) of population with academic PhD in towns and municipalities in planning areas in Croatia in 2021

Planning area	**P_{PhD}**	
	Towns	Municipalities
Central Croatia	98,4	1,6
North-West Croatia	73,3	26,7
East Croatia	90,0	10,0
North Adriatic and Lika	79,2	20,8
Central and South Adriatic	86,7	13,3
Republic of Croatia	92,6	7,4

Source: Same as in Table 1

CONCLUSION

The aim of this paper was to research spatial concentration of highly educated population in Croatia. With the continuous growth of highly educated, it was concluded that with every higher level of education the level of population spatial concentration grows as well. In the process, highly educated population shows significantly higher spatial concentration compared to total population, especially population with academic PhD. It is significantly the consequence of agglomeration of people with higher level of education in towns since they rarely find employment in their field of expertise in rural areas. Selective migrations according to the level of education are a threat to social and economic survival and improvement of rural areas.
The research has established the differences in spatial concentration of highly educated regarding age. The youngest highly educated population has a more even distribution in space since they still have not migrated towards larger urban centres. While looking for work many decide to move to larger towns. That results with the highest concentration of highly educated population in the area at the age of most work productivity - between the ages of 40 and 54.
The results of the research indicate that there are differences among Croatian regions in the level of spatial concentration of highly educated population, as well as in their spatial distribution in the state territory. The capital city is in Central Croatia so the highest level of the concentration of human resources was measured there, while in North-West Croatia, the region without larger urban centres, human resources are the least spatially concentrated. When the spatial distribution of human resources is concerned, the city of

Zagreb and its surroundings (and only a few other towns in continental part of Croatia) are standing out with high portions of highly educated in total population, as well as numerous towns and municipalities in the coastal area.
This research is based on the data from the Census in 2021. In order to provide the insight not only into the current state, but also into the direction and the dynamics of concentration processes, future research should include the previous census data as well. Furthermore, this paper emphasizes the measurements of the level of spatial concentration of highly educated population, while its spatial distribution is considered only marginally. Therefore, one of the future research should be directed at a more detailed research of the laws of spatial distribution of highly educated in Croatia.

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TOURIST SATISFACTION AND KEY FACTORS OF ATTRACTIVENESS OF SUMMER DESTINATIONS: A CASE STUDY OF PIERIA, NORTHERN GREECE

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ABSTRACT

The study analyzes the key factors determining tourist satisfaction at Serbian summer coastal destinations in Northern Greece, with a particular focus on the Pieria region. The study is based on contemporary theoretical approaches to tourism, while the empirical part was conducted through a survey among 120 Serbian tourists during the summer tourist season of 2025, aiming to identify respondents' demographic characteristics, travel motives, and satisfaction levels with various elements of the tourist offer. The results indicate that the region predominantly attracts middle-aged and older tourists, highly educated and mostly repeat visitors, with the main motives related to relaxation and recreation, suggesting potential for sustainable and stable tourism development. Using statistical methods, it was found that the gastronomic offer positively affects overall tourist satisfaction, while improvements in environmental standards reduce negative impacts and improve the visitor experience, including their loyalty to the destination. It is concluded that Pieria has favorable conditions for stable and sustainable tourism development, with the need for further enhancement of these aspects. The scientific contribution of the paper lies in the empirical confirmation of the influence of key elements of the destination offer on tourist satisfaction, while the practical contribution provides recommendations for improving destination management to promote sustainability and increase the quality of the tourist offer.

Keywords: tourist satisfaction, coastal tourism, destination loyalty, sustainable tourism development, returning tourists

INTRODUCTION

Tourism represents one of the most important sectors of the global economy, playing a key role in the development of local communities, cultural exchange, and the preservation of natural and cultural resources (UNWTO, 2023; [12], [28]. Among the various forms of tourism, maritime and coastal tourism occupies a special place due to its significant share in international tourist flows, being one of the most important forms of contemporary tourism, particularly in Mediterranean countries [9]. Coastal tourism attracts a large number of tourists during the summer months, offering not only rest and recreation but also the opportunity to experience local culture and traditions. According to [7] the competitive advantage of coastal destinations is further strengthened by a

combination of favorable natural resources, climate, and developed tourism infrastructure.

Greece is recognized as one of the most attractive destinations for summer tourism in Europe, thanks to its rich cultural heritage, favorable climatic conditions, and extensive coastline with numerous islands and coastal regions [13], [15], [19]. Moreover, Greece is renowned as a destination with exceptionally rich mythological heritage, striking natural landscapes, and intensely blue seas, as well as outstanding local hospitality, which leaves a strong impression on visitors despite the continuous growth of domestic and international tourist flows [37].

Coastal regions in northern Greece are particularly interesting, combining natural beauty, cultural heritage, and modern tourism offerings [4]. Studies on regional tourism in Greece indicate that areas such as Pieria are gaining increasing importance, shaped by the perception of the destination's natural, cultural, and recreational resources [35]. Research shows that Mediterranean destinations, like Greece, achieve a high level of tourist loyalty precisely due to the authenticity and diversity of the tourism offer, making them popular destinations for both domestic and international tourists [1].

Motivation for choosing Greece can be explained using the push–pull model of tourist motivation. Push factors, such as the need for rest, relaxation, and a change from everyday life, act as initial drivers, while pull factors, including natural attractions, gastronomy, and cultural offerings, critically influence the final choice of destination [23]. In this context, geographical proximity, cultural affinity, and the perception of good value for money further enhance Greece’s attractiveness among Serbian tourists. Serbian tourists often choose the Pieria region due to its accessibility, quality beaches, wide accommodation options, and authentic Greek atmosphere [38].

Recent research highlights the growing importance of gastronomy as a differentiating factor for summer destinations, with local cuisine becoming a significant element of the overall tourist experience [6]. Furthermore, transport connectivity and destination accessibility are identified as key elements that can significantly influence perceptions of the quality of stay, especially for tourists from neighboring countries [2].

The scientific contribution of this study lies in identifying specific factors that influence tourist satisfaction in Pieria, based on a survey of Serbian tourists. Unlike most domestic studies, which focus on general tourist attractions or services, this study particularly highlights the importance of local hospitality, environmental awareness, affordable prices, and transport connectivity as key factors that can positively or negatively affect overall tourist satisfaction [16], [39]. The research results contribute to a better understanding of the specific elements in the Pieria region that directly shape the tourist experience, providing practical guidance for tourism organizations and local authorities in enhancing the region’s offerings and promotion.

The aim of this research is to examine the level of Serbian tourists’ satisfaction with key elements of the tourism offer in the Pieria region and to identify the factors that most strongly influence their overall satisfaction during their stay. The results aim to provide practical guidance for improving the quality of tourism offerings and the sustainable development of the destination, contributing to a better understanding of the factors that shape tourist satisfaction in coastal summer destinations.

Hypothesis 1: The majority of tourists in Pieria would recommend the destination to others.

Hypothesis 2: Affordable prices have a significant positive impact on overall tourist satisfaction, while tourists are least satisfied with environmental standards.

Hypothesis 3: Satisfaction with the gastronomy offering has the strongest positive impact on overall tourist satisfaction in the Pieria region.
The validity of these hypotheses will be confirmed or refuted through the analysis of the conducted research results, with a clear explanation of the findings.

Literature review

Contemporary literature regards tourist satisfaction as a multidimensional concept that includes both the rational evaluation of service quality and tourists' emotional responses [25]. Overall satisfaction depends on the extent to which the actual experience aligns with expectations. Studies on coastal and Mediterranean tourism highlight that natural resources, cultural heritage, and weather conditions are universally relevant for tourist satisfaction in Mediterranean destinations, yet they alone are insufficient to ensure high levels of tourist contentment. [24] using modern methods such as fsQCA and online review analysis, demonstrate that tourist satisfaction arises from the synergy of multiple factors.
Tourist experiences are significantly shaped by factors such as gastronomy, infrastructure, and hospitality, which influence both the evaluation of the destination and the intention to revisit. In the context of summer destinations, natural and climatic factors are particularly important, while the quality of services and infrastructure often represents a decisive element in forming overall satisfaction [3]. Understanding the interrelationships of these factors enables destinations to improve their offerings and tailor them to the needs of contemporary tourists. Additionally, numerous authors emphasize that tourist satisfaction largely depends on various factors, among which service quality, destination accessibility, gastronomic offerings, cultural attractions, and the sense of safety are particularly significant [34]. As [21] notes, a higher level of satisfaction is one of the key indicators of a successful tourist destination, as it directly affects the intention to revisit and positive word-of-mouth promotion. A survey-based study conducted in Sardinia shows that overall satisfaction and satisfaction with individual elements significantly affect the likelihood of repeat visits, while previous loyalty to the destination is a strong predictor of future behavior. These factors also influence tourists' willingness to recommend the destination to others [17].
Studies in tourism management [29] show that higher service quality and a positive gastronomic experience have a synergistic effect on meeting tourist expectations, indicating the importance of a holistic approach in tourism product development. Li et al. (2023) emphasize that the perception of local hospitality, how tourists experience the behavior and attitude of locals, is not merely a peripheral component of satisfaction but also affects tourists' emotional attachment to the destination, its image, and loyalty. Serbian tourists frequently highlight the positive attitude of local residents as a key component of the tourist experience, representing a stable motivation in destination choice. The high number of Serbian visits to Greece additionally generates a social proof effect, reinforcing the perception of the destination as a reliable and desirable choice [33]. The same authors also stress that, although the local community plays a crucial role in the tourist experience, previous research has insufficiently focused empirically on the interpersonal aspect that shapes tourist perceptions and behavior.
Perceived value that is, the extent to which tourists feel that what they paid corresponds to the quality of the experience is crucial for forming overall satisfaction and future loyalty to the destination, as confirmed by [27]. Local gastronomy represents a key component of overall tourist satisfaction, especially in Mediterranean destinations such

as Greece. [14], [22], highlight that a rich culinary tradition and authentic local offerings strengthen visitors' emotional connection to the destination, enrich the tourist experience, enhance the perceived quality of the destination's offerings, and contribute to the preservation of cultural identity. An international study conducted in Seville (Spain) emphasizes that gastronomy is not merely a physiological need but an integral part of the overall tourist experience, serving as a primary motivation for approximately 15 % of respondents [5].

Environmental aspects of tourism and sustainability are increasingly considered in contemporary studies of tourist satisfaction and destination choice [20], yet their role in shaping overall satisfaction remains non-decisive. [11] present an empirical study conducted in Greece, found that destination ecological standards, while significant from a long-term sustainability perspective, often do not have a decisive effect on tourists' immediate satisfaction. [31] further emphasize that environmental awareness may represent a relevant motivation for destination choice primarily among tourists who are already environmentally conscious, whereas for most tourists, this factor remains secondary to elements such as price, service quality, and overall experience. In this regard, [18] stress that policies aimed at raising ecological awareness and implementing "Green Tourism" programs in the Greek tourism sector are still in the early stages of implementation, and their impact on tourist satisfaction remains limited unless accompanied by broader acceptance by tourists and the local community.

The seasonal concentration of tourists further burdens road networks and local traffic, reducing the overall visitor experience [36]. Accessible transport infrastructure significantly affects tourist satisfaction and destination accessibility, including efficient local transport and ease of movement for people with disabilities [26].

These findings confirm that tourist satisfaction in summer destinations does not arise from individual attributes alone but from their interaction, with the emotional aspects of the experience such as hospitality and gastronomy often proving decisive in forming the overall perception of the destination.

METHODOLOGICAL APPROACH

The research in this study is based on a quantitative research approach, aiming to identify the key factors influencing tourist satisfaction and their perception of the attractiveness of summer destinations in the Pieria region of northern Greece. The empirical part of the study was conducted using a survey method. Participants were selected through a convenience sampling method, and the survey was administered directly at the destination, with voluntary participation and anonymity ensured. A total of 120 tourists from Serbia were surveyed. The use of convenience sampling allows data collection from available respondents but limits the generalizability of the findings to the broader population. The survey was conducted during the summer season (June–September 2025) to cover the main period of tourist traffic and ensure the relevance of the collected data.

The research instrument consisted of a structured questionnaire with 18 questions, combining closed- and open-ended items. The closed-ended questions addressed the socio-demographic characteristics of the respondents (gender, age, education), the purpose of their visit, and their intention to return. The open-ended questions were aimed at assessing satisfaction with specific elements of the tourism offer (cultural heritage, gastronomy, natural resources, environmental standards) using a Likert scale from 1 to 5, where 1 indicated "completely dissatisfied" and 5 "completely satisfied." Prior to the

main survey, the questionnaire was tested on a pilot sample of 15 respondents to verify the clarity and functionality of the questions.

DATA COLLECTION

The collected data were processed using the statistical software package SPSS, employing descriptive statistical methods. For each categorical variable, percentage distributions were calculated, while for questions related to the level of satisfaction with specific factors of the tourism offer, response distributions were analyzed and arithmetic means were calculated. This type of analysis allows for the identification of the highest- and lowest-rated factors of the tourism offer.

To examine the relationship between tourist satisfaction and tourism offer factors, Pearson's correlation analysis was applied, as all variables were quantitative and met the assumption of normal distribution. The strength and direction of the relationships were interpreted based on the correlation coefficient (r): values closer to +1 indicate a strong positive relationship, values near 0 indicate a weak or no relationship, and values closer to -1 indicate a negative correlation. Statistical significance was assessed at the $p < 0.05$ level, with lower p-values indicating a higher likelihood that the observed relationship is not due to chance.

STUDY AREA

The research was conducted in the northern part of Greece, in the Pieria region, along the coast of the Aegean Sea. The study included the following summer tourist destinations: Makrigialos, Paralia, Olympic Beach, Leptokaria, Platamon, and Nei Pori. These destinations are characterized by pronounced seasonality, as the majority of tourist traffic occurs between June and September. Proximity to Serbia, good transport connectivity, affordable accommodation and service prices, as well as a combination of natural and cultural attractions, make these destinations particularly attractive for Serbian tourists. Due to their long-standing popularity among Serbian visitors, the Pieria region was selected as the study area, as it allows for a relevant analysis of tourist satisfaction and the identification of key factors contributing to the appeal of summer destinations.

RESULTS

Based on the analysis of the collected data, the results of the empirical research conducted on a sample of 120 tourists in the Pieria region during the summer tourist season of 2025 are presented. The results pertain to the socio-demographic characteristics of the respondents, their motives for visiting, and their satisfaction with key elements of the tourism offer. The findings are presented using appropriate descriptive and inferential statistical methods, as well as graphical representations.

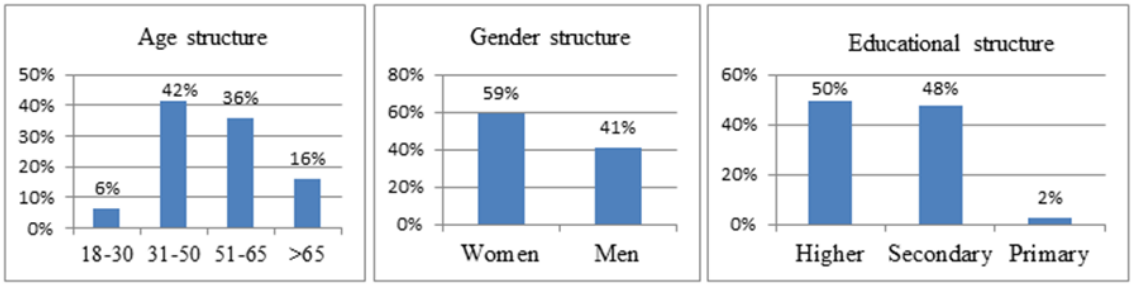


Figure 1. Demographic profile of tourists to summer tourist destinations in the Pieria region, Greece (Source: Authors)

Figure 1. presents the socio-demographic structure of the respondents, showing the percentage distribution by age group, gender, and education level. This analysis provides an overview of the basic characteristics of the sample and serves as a basis for interpreting the research results, given that socio-demographic characteristics can influence tourist motives, perceptions of service quality, and overall destination satisfaction.

The analysis of the respondents' socio-demographic characteristics shows a relatively balanced gender distribution, with a slight predominance of female participants. The sample consists of 59% women and 41% men. The higher representation of women can be explained by their stronger interest in travel, leisure, and tourism activities, which is consistent with findings in tourism and consumer behavior research.

The age structure of the respondents indicates that the studied coastal region is predominantly visited by middle-aged and older adults. The most represented group consists of respondents aged 31 to 50 years (42%), followed by those aged 51 to 65 years (approximately 36%). Respondents over 65 years of age account for 16%, while the youngest age group (18 to 30 years) is the least represented, comprising only 6% of the sample. These results suggest that this coastal region is particularly attractive to the older working population as well as retirees, which has important implications for designing tourism offerings and developing targeted promotional strategies.

The educational profile of the respondents shows that half of the sample (50%) holds a higher education degree or university qualification, while 48% have completed secondary education. Respondents with primary education are negligible, representing only 2% of the sample. This educational structure indicates that the observed coastal region largely attracts visitors with higher levels of educational and cultural capital, contributing to its favorable positioning within coastal summer tourism and providing opportunities for the development of high-value-added tourism offerings.

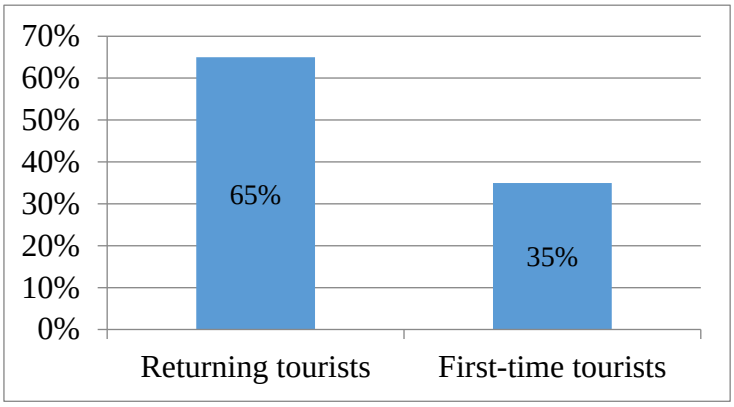


Figure 2. Distribution of tourists according to the frequency of visits to summer tourist destinations in the Pieria region, Greece (Source: Authors)

Figure 2. presents the analysis of respondents based on visit frequency shows that the majority are repeat visitors, accounting for 65% of the sample, while first-time visitors represent 35%. This distribution indicates a high level of tourist loyalty to the destination, as well as a positive cumulative effect of previous experiences on the decision to revisit. The dominant share of repeat visitors can be associated with a high level of overall satisfaction. At the same time, the relatively high proportion of first-time tourists (35%) demonstrates the destination's ongoing ability to attract new visitors, which is an important prerequisite for its long-term development and market sustainability.

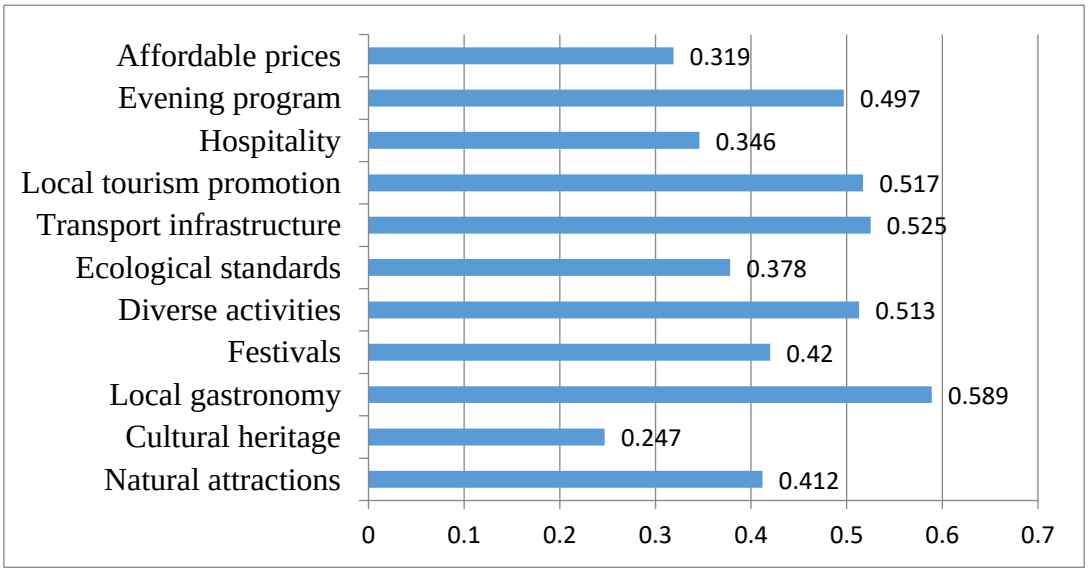


Figure 3. Correlation of supply factors with tourist satisfaction at summer destinations in the Pieria region, Greece (Source: Authors)

Pearson correlation analysis identified a statistically significant positive relationship between specific elements of the tourism offer and overall tourist satisfaction (Figure 3). The strongest correlation was observed for traditional local gastronomy ($r = 0.589$; $p < 0.001$), indicating a moderate-to-strong positive relationship with overall tourist satisfaction. This means that higher levels of satisfaction with gastronomy are associated with higher levels of overall satisfaction with the destination. The weakest, yet still statistically significant, correlation with overall satisfaction was found for cultural

heritage ($r = 0.247$; $p = 0.015$), indicating a weaker association compared to the other analyzed tourism offer factors. All analyzed factors showed statistically significant positive correlations with overall tourist satisfaction ($p < 0.05$), with the strength of the relationships ranging from weak to moderate correlations. These results suggest that elements such as activity diversity, transport infrastructure, and local tourism promotion have a more pronounced association with overall tourist satisfaction compared to other factors. Within the study, respondents rated their satisfaction with various tourism offer factors on a Likert scale from 1 to 5, where 1 indicates "completely dissatisfied" and 5 indicates "very satisfied." The analysis of the average ratings is presented in Table 1.

Table 1. Level of satisfaction with the tourist offerings in the Pieria tourist region, Greece

Tourism supply factors	Average Rating	Standard deviation
AFFORDABLE PRICES	4.62	0.68
HOSPITALITY	4.5	0.76
CULTURAL HERITAGE	4.38	0.93
LOCAL TOURISM PROMOTION	4.38	0.33
LOCAL GASTRONOMY	4.31	0.87
EVENING PROGRAM	4.22	0.96
FESTIVALS	4.18	0.97
NATURAL ATTRACTIONS	4.11	1.06
DIVERSE ACTIVITIES	4.06	1.12
TRANSPORT INFRASTRUCTURE	3.84	1.33
ECOLOGICAL STANDARDS	3.61	1.36

Based on the results presented in Table 1, it can be concluded that respondents generally reported a high level of satisfaction, with average ratings above 4 for almost all variables. The highest ratings were recorded for value for money (4.62) and the behavior of the local population (4.50), confirming that the destination has a stable and long-term recognizable image, based on the hospitality of the local community and affordability relative to respondents' expectations. In contrast, the lowest average ratings were for environmental standards (3.61) and the quality of transport infrastructure (3.84), indicating a need for additional investment in site maintenance, improvement of access roads and supporting services, as well as the implementation of measures aimed at raising ecological awareness.

DISCUSSION AND CONCLUSION

The results of the conducted empirical research provide insight into the structure, motives, and satisfaction patterns of Serbian tourists in the Pieria region, confirming that tourist satisfaction is a multidimensional construct arising from the interaction of economic, social, and experiential factors [21]. The findings indicate a high level of overall satisfaction with the destination, while also revealing differences in the relative importance of individual elements of the tourism offer. This aligns with contemporary theoretical approaches that view the tourist experience as a complex and context-dependent process [25].

The analysis of the respondents' socio-demographic characteristics shows that the Pieria region predominantly attracts middle-aged and older adults, mostly repeat tourists with

higher or secondary education levels. Such a visitor profile suggests a stable demand base and relatively established tourist expectations, which can contribute to a higher level of destination satisfaction. Previous studies confirm that repeat visitors often exhibit greater tolerance toward perceived deficiencies of a destination and a stronger emotional attachment to the place of stay, positively influencing their overall experience evaluation [11]. In this context, the high proportion of repeat visitors in the sample can be interpreted as an indicator of destination loyalty as well as the cumulative effect of prior positive experiences.

Hypothesis H1, which assumes that the majority of tourists in Pieria are repeat visitors willing to recommend the destination to others, is supported by the results. The 65% share of repeat visitors clearly indicates a high level of loyalty, consistent with theoretical models linking destination loyalty to previous satisfaction and positive value perception [8]. These findings further confirm that Pieria functions as a destination with stable tourism potential, particularly in the Serbian market, where decisions on repeat visits are often based on recommendations and personal experience. Results regarding the evaluation of individual elements of the tourism offer indicate that affordable prices were the highest-rated aspect of the stay, supporting Hypothesis H2 regarding the positive impact of price accessibility on overall tourist satisfaction. This finding aligns with studies emphasizing that the perception of value for money is a key determinant of satisfaction and loyalty, especially among tourists from countries with socio-economic characteristics similar to Serbia [27]. Price accessibility, combined with stable service quality, contributes to a sense of a "safe destination," which is particularly important for older and repeat tourists.

In contrast, environmental standards were identified as the lowest-rated element of the tourism offer, further confirming the second part of Hypothesis H2. Although ecological aspects are recognized as important for long-term sustainability, their lower evaluation indicates that they still do not play a decisive role in tourists' immediate satisfaction. These findings are consistent with research conducted in Greece and other Mediterranean destinations, which shows that tourists' environmental awareness often remains secondary to factors such as price, gastronomy, and service quality [11], [31]. However, the literature also warns that neglecting ecological standards may jeopardize the destination's long-term competitiveness, especially in the context of rising expectations among environmentally conscious tourist segments [30]. Correlation analysis indicated that satisfaction with local gastronomy has the strongest positive association with overall tourist satisfaction, thereby clearly confirming Hypothesis H3. The obtained correlation coefficient ($r = 0.589$; $p < 0.001$) reflects a moderate-to-strong relationship, confirming that the gastronomic experience is a central component of the tourist experience in Pieria. These results are consistent with contemporary research highlighting that local gastronomy is not merely an additional attraction but a key element of destination authenticity and tourists' emotional attachment to the place of stay [1]. Similar findings have been observed in other Mediterranean destinations, where the gastronomic experience has been identified as a strong predictor of satisfaction, repeat visits, and positive word-of-mouth promotion [5], [10].

The importance of gastronomy is further enhanced by its interaction with the local population, which was also highly rated in the study. Positive perceptions of local hospitality contribute to the formation of the emotional dimension of the tourist experience, as studies indicate that the quality of interaction between tourists and locals directly affects destination image and loyalty [32]. In Pieria, the combination of

affordable prices, local gastronomy, and hospitality creates a synergistic effect that compensates for observed weaknesses in infrastructure and environmental standards.
Overall, the research results confirm that tourist satisfaction in summer coastal destinations does not stem from isolated attributes but from their interrelation. Economic aspects (prices), experiential elements (gastronomy and hospitality), and functional factors (infrastructure and environmental standards) collectively shape the overall perception of the destination. These findings support multidimensional models of tourist satisfaction and indicate the need for an integrated approach to destination management, in which improvements in individual segments are considered as part of a broader strategy for sustainable development.

Limitations

The study is based on a quantitative approach and correlation analysis of survey data, which allows for the identification of relationships between variables but does not provide deeper insight into the subjective dimensions of the tourist experience. The absence of qualitative methods limits the understanding of tourists' motivations and the emotional aspects of satisfaction. The focus on a single destination and a specific visitor segment reduces the potential for broader comparative interpretation of the findings. Additionally, the cross-sectional nature of the study does not allow for tracking long-term changes in tourists' perceptions. Future research combining different methodological approaches and longitudinal analyses could provide a more comprehensive understanding of tourist satisfaction.

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OLDER PEOPLE'S PERSPECTIVES ON RESIDENTIAL CARE: INSIGHTS FROM THE CITY OF ZAGREB

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ABSTRACT

Croatia ranks among the EU member states with the oldest populations, and ongoing demographic ageing is leading to a growing number of people who require care in later life. However, institutional and community-based care services for older adults in Croatia, including residential care facilities, have been insufficient for decades. Similarly to other European countries, older adults in Croatia typically live in their own homes (ageing in place) for as long as possible. When they begin to require assistance, they most often rely on support from their spouses and children. This study, using the City of Zagreb as a case, examines the attitudes of older adults living in their own homes towards residential care, along with their willingness, motivations, and perceived barriers to moving to a nursing home. It presents the findings of a qualitative research study conducted in the City of Zagreb between December 2022 and January 2023, based on face-to-face semi-structured biographical interviews. The sample consisted of twenty respondents aged 65 and over who live independently in their own home. This study showed that most older adults, regardless of age, education, living arrangement, or health status wish to continue living in their own home for as long as possible. Participants generally view relocation to a nursing home as a strategy for very old age or when they can no longer remain fully independent.

Keywords: City of Zagreb, population ageing, nursing homes, ageing in place

INTRODUCTION

Croatia ranks among the EU member states with the oldest populations, and ongoing population ageing is resulting in a growing number of people who require care in later life [4]. However, institutional and community-based care services for older adults in Croatia, including residential care facilities, have been insufficient for decades. Long-term care presents a particularly significant challenge. The Croatian long-term care system is underfunded and fragmented, with public social support providing lower coverage than in many other EU countries [9].

Most older adults prefer to age in place for as long as they perceive themselves to be relatively healthy and independent, postponing relocation to care homes until health-related crises necessitate such a move [5, 12, 13, 14]. Similarly to other European countries, older adults in Croatia typically live in their own homes (ageing in place) for as long as possible. When they begin to require assistance, they most often rely on support

from their spouses and children [10]. With shrinking household sizes, increased employment of women, and more frequent outmigration of children and relatives, informal care is becoming increasingly challenging, as the pool of potential informal caregivers for older people is being reduced.

In Croatia, approximately 260,000 or 32% of older adults require assistance with at least one activity of daily living or instrumental activity of daily living [9]. This number is expected to increase due to population ageing and the fact that Croatia ranks near the bottom of the European Union in terms of healthy life years at age 65, indicating significantly poorer health outcomes compared to the EU average and most EU countries. In Croatia, healthy life expectancy at age 65 is 5.9 years for women and 6.1 years for men, compared with the EU average of 9.6 years for women and 9.2 years for men [2].

As average life expectancy increases, the proportion of life spent at age 80 and above is growing, a stage of life in which serious illnesses increasingly occur, often significantly limiting the ability to live independently. Mobility issues are very common at this age and may lead to reduced mobility or complete immobility, making additional forms of support necessary for basic daily activities such as personal hygiene, getting dressed etc. In such situations, informal caregivers are often unable to provide adequate care, and if community-based (non-institutional) support services are also insufficient, this usually results in relocation to a nursing home. Due to the urgency of health crises and cognitive decline, older adults are sometimes unable to make decisions about relocation, and the likelihood of involuntary movement from one's own home to a nursing home increase with age and is highest among individuals aged 80 and over [12]. Among part of the population in Croatia, prejudices towards nursing homes are still present, and placing an older person in a nursing home is often perceived as shameful. As of the end of 2022, a total of 10,694 individuals were accommodated in state and county nursing homes in Croatia [7]. Among them, 13.7% were under the age of 75, 40% were between 75 and 84 years old, and 46.3% were aged 85 years and above [7]. In private nursing homes, 7,213 residents were accommodated: 22.8% were aged up to 74, 39.3% were between 75 and 84, and 37.9% were aged 85 or older [7]. Residential care capacities differ considerably across regions, with the largest concentration in the City of Zagreb.

This study, using the City of Zagreb as a case, examines the attitudes of older adults living in their own homes towards residential care, along with their willingness, motivations, and perceived barriers to moving to a nursing home.

DATA AND METHODS

In this study, population census data from 2001, 2011, and 2021 for the City of Zagreb are used to establish the demographic framework of the analysis. The analysis of nursing homes is based on official data on residential care facilities for older persons from Ministry of Labour, Pension System, Family and Social Policy and City of Zagreb.

The paper presents and discusses the findings of the qualitative study, supported by quotations from the interviews. The qualitative research was conducted in the City of Zagreb between December 2022 and January 2023 and was based on face-to-face semi-structured biographical interviews. The sample consisted of twenty respondents aged 65 and over who live independently in their own households, that is, in non-institutional settings. The participants ranged in age from 65 to 86 years, with half of the sample aged 75 or older. There were 7 men and 13 women who participated in the interviews.

Sampling procedure combined the snowball sampling method and the principle of maximum variation [6] which was applied to ensure the inclusion of interviewees with diverse experiences in terms of gender, age, marital status, household size, parental status, and health status. The sample size was determined based on data saturation, which was estimated not only from the interviews conducted but also by considering the results of previous field and desk research. Prior to the interviews, respondents were informed about the main objectives of the study and about their rights, including the right to withdraw from the interview at any time. All participants received and signed an informed consent form before taking part in the study. Interviews were mostly carried out in participants' households and lasted between 30 and 80 minutes. With the participants' consent, they were audio-recorded and subsequently transcribed. The qualitative data were analysed through thematic analysis, facilitated by MAXQDA software. Even though the qualitative approach is flexible, results in in-depth and detailed information, allows the use of multiple data collection methods and minimises the chance of having missing data, its limitations often are referred to researchers' subjectivity, difficulties in sustaining anonymity and limited generalisability of results – especially taking into account that the research includes participants only in a capital city which may have different experiences than people who are living in different settings. Further on, qualitative research involves complex data analysis, makes replication of findings challenging, and the findings may be influenced by the researcher's bias [8].

DEMOGRAPHICS OF THE CITY OF ZAGREB

According to the 2021 Census, Croatia and all of its counties are experiencing depopulation and population ageing, with notable regional differences in the intensity of these processes. The City of Zagreb likewise recorded a population decline in the most recent intercensal period, with the number of inhabitants decreasing from 790,017 in 2011 to 767,131 in 2021, representing a reduction of 2.9%. During this period, the number of young residents remained relatively stable, while the working-age population declined, and older population increased. Although Zagreb has long been the most attractive migration destination in Croatia, unfavourable demographic trends in other parts of the country, together with out-migration after Croatia's accession to the European Union, have contributed to a reduction in migration inflows to the city which has negatively affected demographic processes.

At the same time, population ageing in Zagreb has intensified markedly. Over the past two decades, the number of residents aged 65 and over increased by more than one third, rising from 115,980 in 2001 to 158,773 in 2021, meaning that today one in five Zagreb residents is aged 65 or older (Table 1). The growing share of older people in the city requires significant adjustments of urban spaces, facilities, and services, as well as an expansion of health, social, and care services to meet increasing needs. Particularly strong growth is observed among the oldest-old population (aged 80 and over), whose number more than doubled during the same period, increasing from 18,267 to 40,100. Although this age group is not homogeneous, individuals within it are more likely to experience illness and frailty. This, in turn, implies a growing demand for formal forms of care, long term care services, and residential accommodation in nursing homes for older and dependent persons in Zagreb.

Table 1. Age structure and selected indicators of population ageing in the City of Zagreb 2001-2021

Census	Total population	0-14	15-64	65+	80+	Average age	Ageing index	Total age dependency ratio	Young-age dependency ratio	Old-age dependency ratio
2001*	779,145	122,963	536,981	115,980	18,267	39.7	94.3	44.5	22.9	21.6
	%	15.8	68.9	14.9	2.3					
2011	790,017	116,059	537,188	136,770	31,068	41.6	117.9	47.1	21.6	25.5
	%	14.7	68.0	17.3	3.9					
2021	767,131	116,644	491,714	158,773	40,100	43.0	136.1	56.0	23.7	32.3
	%	15.2	64.1	20.7	5.2					

*2001: 3,221 unknown age

Sources: Census 2001 https://web.dzs.hr/Hrv/censuses/Census2001/Popis/H01_01_02/H01_01_02.html; Census 2011 https://web.dzs.hr/Hrv/censuses/census2011/results/htm/H01_01_03/H01_01_03.html; Census 2021 https://podaci.dzs.hr/media/rqybclnx/popis_2021-stanovnistvo_po_naseljima.xlsx

Another demographic trend observed across Europe, including Croatia, is the continuous increase in the number of single-person households among older persons. In Zagreb, 23.9% of individuals aged 65 and over live in single-person households. Women are considerably more likely to live alone (29.9%) than men (14.7%) in the City of Zagreb, which largely reflects their greater longevity [1]. While some older people live alone by choice, involuntary solitary living may place them in a vulnerable position and increase the need for targeted social protection [16].

RESIDENTIAL CARE FACILITIES IN THE CITY OF ZAGREB

The largest number of decentralised and private nursing homes in Croatia is in Zagreb. However, Zagreb has the largest older population and, therefore, the demand for such services is the highest. According to the 2021 Census, 2.8% of individuals aged 65 and over in Croatia lived in institutions for retired and elderly people. In the City of Zagreb, this proportion was slightly higher, with 3.3% of older adults residing in nursing homes [1]. In the City of Zagreb, there are ten decentralized nursing homes and one established by the City of Zagreb (for the purposes of this text, the term city-owned nursing homes will be used) located across 18 facilities, with a total capacity of 4,024 places. Currently, around 260 places are unoccupied due to the renovation of accommodation units damaged in the 2020 and 2021 earthquakes. It should be emphasised that, in addition to residential care, city-owned nursing homes are connected to a various forms of non-institutional support services for older people living at home, including meal provision, workshops and occupational therapies, and day care programmes, and similar services. Residential care services are also provided by 23 private nursing homes, 22 facilities operated by other legal entities, and 17 family homes, together offering a total of 2,690 places.

Monthly fees in city-owned nursing homes vary depending on the level of care provided (e.g. number of residents per room; residential, semi-residential, or residential-with-care accommodation depending on the level of independence; quality of the facility) and range from 234 to 995 € per month. The most expensive services are intended for functionally dependent residents who, due to dementia, require continuous assistance and supervision from another person to meet all their needs. In contrast to other cities, fees for accommodation in nursing homes in the City of Zagreb have remained unchanged since 2018. Budgetary allocations from the City of Zagreb cover about 50% of nursing homes'

total revenues, with approximately 36.5 million € designated for this purpose in 2026.[14] At the same time, accommodation fees in private nursing homes have been steadily increasing, typically starting at 1,300 € per month and higher. Despite the high costs, there is strong demand for placement in private nursing homes due to the growing number of older adults who, mostly because of illness and disability, cannot live independently and face long waiting times in decentralized public homes.

In the following section, we present the results of a qualitative study conducted with older adults in Zagreb regarding their attitudes towards residential care, as well as their willingness, motivations, and perceived barriers to moving to a nursing home.

CONSIDERATIONS ABOUT MOVING TO A NURSING HOME

How do older adults ageing in place perceive the possibility of transitioning to institutional care? Participants were asked to indicate their preferred mode of living. Whether to remain in their own home or move to a nursing home. For most respondents, both the younger old (65–79) and the oldest old (80+), women and men alike, the first choice was to live independently in their own homes.

"And at home, you see, at home a person is… I've been in this apartment since 1945. I'm used to it. For example, at night if I need to go to the bathroom, I don't even have to turn on the light. I can go because I know every part of this apartment, and I feel comfortable here." (M, 79, widower, three-person household)

"As long as I can walk, as long as I'm on my feet, I won't go anywhere…" (W, 81, widow, living alone)

"As long as a person is mobile and not demented, it is always better to be in their own apartment. That is freedom. It is natural for us to be free, to be able to go out whenever we want and socialize as we wish." (F, 71, living with spouse)

"Well, here I can truly speak from my own experience… at the moment I don't have that need [to go to a nursing home], but from a psychological perspective it is always more comfortable for a person to be in their own home, and no matter how comfortable and wonderful a nursing home may be, it is still better to be in your own apartment." (F, 69, divorced, two-person households)

The capacity for adaptation and resilience to change gradually declines in later life, making familiar routines and physical environments a crucial source of security and a sense of autonomy. Disrupting this sense of security can generate feelings of instability and intensify perceptions of "the end of life," as well as feelings of vulnerability and frailty [3, 15].

"*I don't know, I even think that nursing homes aren't necessarily bad if it's the right kind of home. But maybe there's that feeling that you're at the end of your life, and I think that really affects you. Still, I hear that among those 300 people there, you'll always find three you get along with, with whom you can laugh and take a walk, as long as you can still walk, it's fine. But somehow there's this feeling that your life is over, that you've gone there. Here, you keep going, as long as you can, maintaining your own order, your own rhythm, and your own life*." (F, 73, living with spouse)

The participants in the study were of different ages within later life (the younger old aged 65–79 and the older old aged 80+), with varying levels of physical health and independence, different levels of education, different living arrangements (with a spouse,

[14] https://www.zagreb.info/vijesti/zg-info/u-zagrebackom-domu-za-starije-smjestaj-samo-234-eura-evo-sto-dobijete-za-taj-novac/813626/

with adult children, or alone), and in different types of housing (house or apartment, with differences in the level of amenities). All these factors may, at certain points in the life course, serve as motivations for deciding to move from one's own home to institutional care. Regardless of objective indicators of overall quality of life (the preservation of an individual's health and functional abilities, housing conditions, and the quality and maintenance of social networks), consideration of a potential move to a nursing home is not always aligned with these factors. This is partly the result of traditional expectations among older people that care, when needed, will be provided by informal caregivers (most often spouses or adult children).

"You see, in my family, traditionally, we somehow… we take care of older family members, and there is this idea that one should not go to a nursing home unless it is really necessary. Of course, there are illnesses that simply require it, physically you cannot manage otherwise, but as long as it is possible, that's how it was. Both my grandmother and my mother died at home, calm, and I was calm as well, and somehow I feel much better that way." (F, 69, divorced, living alone)

With increasing age, accompanied by declining health and reduced functional abilities, individuals also experience a shift in their perspective on their own capacities and an increased awareness of the need for support in various areas of life. Thus, one participant who is disabled hopes to move to a nursing home soon, as he believes it will make daily life easier since he won't have to worry about purchasing groceries, cooking, cleaning, or other household tasks.

"So, you see, I even hope that I will go. You know what, it's not any cheaper to live at home either. I still have to take care of everything, today worrying about what will happen tomorrow: what I'll eat, this, that. But there, I say, you pay, and you don't have to worry about anything." (M, 81, widower, living alone)

"…at the moment when a person is no longer mentally capable, when you don't know where you are, when you don't know how to dress yourself, when you don't know anything. That's dementia, Alzheimer's, and I don't know what other terrible illnesses, then a person must be in a nursing home. And that's what I told my husband and children: the moment we can no longer take care of ourselves or manage our own well-being, then a person like that belongs in a care home." (F, 71, living with spouse)

Those with relatively preserved health and independence most often respond to the question, "At what point would you decide to leave your own home for an institution?" as follows:

"And when I assess, if I can actually assess, that I can no longer manage on my own and if something happens… for what actually needs to come." (F, 75, widow, living alone)

The part of the response stating "if I will be able to assess it" is particularly important, yet it does not appear frequently. Most older adults more or less expect that they will be able to judge in time when they need help and care from others. However, a portion of the older population, most often those suffering from certain types of dementia, and usually the oldest old are no longer able to independently assess their situation and decide about moving to an institution. Indeed, illness can blur one's perception of their own level of health and independence. For example, one interviewee with pronounced cognitive decline and visible need for assistance and care absolutely rejects the idea of moving to a nursing home:

"…you see, one lady [went] *to this, this, this home… and she went there and says she's satisfied. And listen, don't get mad at me, how can I say this, listening to all those complaints and I don't know what, from those old people. No, thank you. When I become*

immobile and when it happens, then they can do with me whatever they want." (F, 86, widow, living alone)

It has also been shown that attitudes towards moving to an institution vary depending on an individual's previous life experiences, level of education and living arrangement. In particular, those with higher education, often older adults living alone or only with a partner, as well as childless individuals, are more likely to plan their move to a nursing home in advance.

"Well, I look at others in the homes and see that it is perfectly possible to live there, even to do some activities. You're allowed to have a computer. So, for me, knowing what scouts are, what holiday camps are, what union resorts are, and so on, that environment is familiar and not strange to me, and I can clearly see it in the nursing homes. So, I wouldn't feel like a stranger there." (M, 73, living with spouse)

"You see, it all depends on how you… how you create a vision in your mind. I created a vision for myself that I enjoyed my own apartment, that it was wonderful, beautiful for me, but the time has come when I now need more help from others and that I need this care home. And I no longer focus on what was. What was has passed, and now I need to look towards the future, and I see that future in the nursing home." (F, 79, single, living alone)

APPLICATION FOR ADMISSION TO A NURSING HOME

Participants in the study who have children largely rely on them for assistance when needed. Consequently, some do not apply for placement in a nursing home, as they believe it will not be necessary given that they have family members to provide care.

"No, I didn't apply because my children convinced me that I don't need to, that they will take care of me. They say: when the time comes, if it ever needs to happen, there will be no problem at all, but we believe that for now, no, no." (F, 74, four-person household)

"I haven't because my son said that he doesn't want me to go to a nursing home. He still somehow thinks it would be better for me to stay at home, but, well, if it becomes necessary, I'll go without any problem." (F, 69, divorced, two-person household)

Older adults who are single or in childless couples tend to apply to nursing homes earlier in life.

"Yes, of course I applied, even to two nursing homes. Not only in this city but also in a coastal city where I have friends as well. But of course, I applied immediately when I left my job, that is, when I retired… So, everything is open." (F, 75, widow, living alone)

"I applied to a nursing home, to two homes… you can apply to two, and whichever comes through first. In Maksimir, they told me 12 years. Here at Ibler [square], *10 years. This one now, 10 years… I won't say who's alive and who's dead by then, but who knows if I'll even be ready for a home much sooner*." (M, 73, living with spouse)

When asked whose support they would rely on if they became ill, participants gave varied responses: some were unsure whether their children would be willing to help and care for them, while others did not want to burden them.

"I don't know, because… my daughter works almost all day, my son-in-law is on the road from Monday to Friday almost every week. So, I don't know how it will be from now on…" (M, 79, widower, three-person household)

Some participants recognise that times have changed and although they are close to their children and their children are willing to help, work and family obligations may make it difficult to provide daily care if such assistance becomes necessary.
"This is how I see it: if we are in a very difficult situation, with limited mobility and poor health, absolutely a nursing home. I would never want to be a burden, for example, to my daughter. Never. I wouldn't tie anyone's life down, because caring for older people is very hard, it's really difficult. But if I still had vitality, as much as age allows, I would prefer to stay in my own home until the end." (F, 65, living with spouse)
"I think, if I couldn't manage, the children are working, it's difficult. You simply can't...not that they wouldn't, but they can't. Or hire someone to stay with you at home. An older person alone can't stay, regardless of being male or female. If you are immobile, then it's a different matter. But, we women…this is not just because I'm a woman, but we are more resourceful than men, absolutely." (F, 81, widow, living alone)
Among some participants, a psychological barrier exists even to submitting an application for a senior care home, indicating a general reluctance to consider this option. One respondent, for example explained their decision not to apply by referring to the long waiting lists.
"I haven't, but I keep looking for that application form at home… However, I just can't seem to find it. So, I'll have to request it again. I should apply now, but the waiting time is long." (M, 69, divorced, two-person household).

WAITING LISTS FOR PLACEMENT IN NURSING HOMES

Due to long waiting lists at city-owned nursing homes in Zagreb, it is common practice for potential residents to register well before they actually wish or need to move in.
"I've been waiting for 15 years now. They promised me that when a room becomes available and the first opportunity comes, I'm already next in line…both by age and by everything else, by strength and so on… So, I think I will get into the home this year." (F, 79, single, living alone)
A single participant who has been waiting 12 years for a nursing home placement feels fear about the future due to their unresolved application.
"Then I worry about who will take care of me and whether anyone will actually look after me and you can't just get into a home… I already signed up there. It's been 12 years." (M, 85, divorced, living alone)
Typically, the wait for a place in a municipal home is around ten years, which often discourages many older old adults from applying once they become aware of their own frailty.
"Unfortunately, back when I had the chance to register for a nursing home, I didn't. And now, at 80 years old, it's a bit late to wait another 15 or 20 years just to get my turn to be admitted somewhere." (M, 79, widower, three-person household)
In private homes, the situation differs as long waiting lists generally do not exist. Older adults who choose private care usually do so only after a significant decline in health or loss of independence, when they cannot wait for a place in a municipal home or are not registered for one. However, increasing demand has led to waiting lists in some private homes as well. Nevertheless, older adults still tend to prefer municipal homes, perceiving them to provide better care, more recreational activities, greater social participation, and significantly lower costs.

In Croatia, older adults face a high risk of poverty. Most rely on pensions, which are on average relatively low and often insufficient to independently cover the costs of nursing home care. As a result, in state-owned and decentralised nursing homes, where fees are significantly lower than in private facilities, only 37.6% of residents are able to fully cover accommodation costs on their own. In private nursing homes, this proportion is considerably lower, at just 17.7% [7].

PERCEPTION OF A NURSING HOME

Some participants in the study have experience with nursing homes, most commonly through caring for their parents, other family members or through acquaintances who currently live in a nursing home. Although experiences are generally positive, most participants perceive a nursing home solely as a place to live when a person is seriously ill and no longer independent.

"My mother-in-law recently passed away… she was in her nineties. For the last four years, a full four years, she was in a nursing home. She had waited a full eight years and then finally got a place there in Rijeka and settled in. In the end, she was satisfied, not at the beginning. She was very happy with the food: meals were served regularly, they were good, and the cook was excellent." (F, 65, living with spouse)

"I went to visit her [my aunt]. It was somewhere up near Tuheljske Toplice, but I forgot what the home was called. There were far too many of them in the room because the room was too small. I don't know if it was like this one here, but there were four, maybe five of them inside… about five altogether. You could hardly get through because of the beds. But there was no smell at all, nothing like urine or anything else. She was satisfied, and when she was satisfied, that meant it was good, because she was usually quite sensitive." (F, 81, widow, living alone)

A nursing home is, for some, a place they may wish to go, while still hoping they will not have to leave their own home for an institution. One participant, although single and of advanced age, who has been waiting for a place in a home for over 12 years, explains his mixed feelings:

"I don't know, if I were to go [to a nursing home]*, it wouldn't be for long… I'm afraid, yes. I'm afraid they'll call me tomorrow, and I won't be able… you can't postpone. No, then you lose your place in line, and so on. I don't know… everything is fine as long as I'm on my feet."* (M, 85, divorced, living alone)

Number of social contacts with others generally decreases with age and can lead to social isolation among older adults. Research show that social isolation is a significant risk factor for nursing home placement among older adults [11]. One of the participants visits a nursing home five days a week for lunch and social activities. Based on his experiences so far, he has a positive perception of nursing homes and is open to the possibility of moving into one in the future. He recognizes several advantages, especially fewer household chores and the opportunity for regular companionship.

"I would also have company there. I wouldn't be alone, and I see that it's decent, and the food is good. All the staff, the nurses, everyone is kind and polite, and I would never avoid it. I would come, why wouldn't I? Yes, that's right. Besides, I have a pension, so there's no problem." (M, 81, widower, living alone)

Participants view the advantages of living in a nursing home as not being alone, being relieved of household chores, and having regular meals provided. They also perceive one of the major benefits to be the constant availability of medical care. However, despite

these advantages, the structured way of life is somewhat off-putting to them because it limits their independence and requires giving up certain personal habits.
"The advantages, I think, are that you're not alone. You have company, meals are provided, I don't know, from breakfast to lunch to dinner and so on… You have social interaction of some kind, and there's also the option, if you can afford it, a single room. So that when everything becomes too much, you can retreat to your own room. You can turn on the TV, watch whatever you want, whatever you enjoy. You don't have to watch anything you don't like. If you don't like football, you can watch a series, or vice versa. So that's the advantage. (M, 79, widower, three-person household)
"In a nursing home, there's a certain routine, like in school… breakfast, lunch, social activities, always the same people…you're with them, you can't choose. In that group, you might find someone you get along with, or you might not find anyone at all… On the other hand, you have medical care every day, and it's easier if you have a need. You don't have to worry about meals… And again, if you're mobile, it's nice to be in a nursing home, and it depends on how you make your own social life and work on yourself." (F, 71, living with spouse)

CONCLUSION

Zagreb is experiencing a significant demographic transformation, marked by population decline, population ageing, and a decrease in average household size. An increasing number of older adults, particularly those aged 80 and over is resulting in a growing demand for care in later life. Although the largest number of Croatian institutional and community-based services for older people, including residential care facilities is concentrated in the City of Zagreb, their capacity remains insufficient to meet current needs.
As in numerous previous studies, this one also showed that most older adults, regardless of age, education, living arrangement, or health status wish to continue living in their own home for as long as possible. Home is a space they are accustomed to and where they feel safe. They view living in their own home as a source of freedom and independence. Participants generally view relocation to a nursing home as a strategy for very old age or when they can no longer remain fully independent. No differences were observed between men and women regarding the choice to live at home or move to a nursing home, the decision to relocate, and perceptions of life in such a facility.
This study showed that attitudes towards moving to an institution vary depending on an individual's previous life experiences, level of education and living arrangement. Those with higher education, often older adults living alone or only with a partner, as well as childless individuals, are more likely to plan their move to a nursing home in advance. Participants in the study who have children generally rely on them for support when needed. As a result, many choose not to apply for nursing home placement, believing that their family members will provide the care they need. Moreover, some are discouraged from the idea by their own children.
For some participants, it is evident that psychological barriers toward nursing homes exist, seeing them as places where everything is predetermined, which implies a loss of their independence, and as places associated with the end of life. Objective barriers to moving into a nursing home include very long waiting lists for city-owned facilities as well as low financial resources. Therefore, when discussing potential placement in a

nursing home, participants mainly referred to municipal homes, as private ones are significantly more expensive and financially inaccessible for many.

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WHERE MEMORIES TAKE SHAPE: THE ROLE OF SOUVENIRS IN CREATING UNFORGETTABLE TOURIST EXPERIENCES

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ABSTRACT

Ensuring memorable tourist experiences represents a key factor of competitiveness in tourism. In modern tourism, souvenirs go beyond the role of simple objects and become symbols of personal experience and traveler identity. They serve as material traces of a journey that connect people, places, and memories. Studying the role and significance of souvenirs is highly important for adequate tourism planning and development. From the perspective of tourism demand, tourists' satisfaction with souvenir purchases influences their loyalty to a destination. The research was conducted with the intention of pointing out the role that souvenirs play as a gift, a memory, and tangible evidence of the tourist experience. Accordingly, a survey was designed and carried out among tourists who, within the past year, traveled at least once and purchased a souvenir. The goal is to determine, based on the collected responses and their analysis in the statistical software SPSS, whether souvenirs strengthen tourists' emotional connection to a destination and to what extent their authenticity affects repeat visits.

Keywords: memorable tourism experience, souvenirs, gift, revisit intention, authenticity

INTRODUCTION

The concept of authenticity is widely used to understand tourist motivations and experiences, and can refer to the authenticity of objects, tourist destinations, gastronomic specialties, etc., but also to souvenirs. The value of souvenirs has a huge impact on the tourism industry [24], becoming an integral part of tourist experiences over the years.
The word souvenir comes from the French language, from the verb *se souvenir*, which means "to remember". In its original sense, a souvenir is something that serves as a reminder - of a place, experience or person, while in a broader sense, it refers to a memory. Today, it generally refers to an item brought back from a trip or significant location, which serves as a memento of that experience. They are closely related to specific tourist destinations and often depict local landmarks, cultural symbols or traditional motifs [10]. Authentic souvenirs must integrate culture and history to represent the identity of the destination, be handmade, have a unique, attractive presentation, and require local skills of local craftsmen [24].
However, there are different views on the authenticity of souvenirs. Namely, according to Cohen [5], souvenirs represent an example of commodification of culture, indicating that authenticity in modern society has a "loose" meaning, since it is the result of the process of cultural staging and interaction between hosts and tourists. Bernardo, Sousa & Kastenholz [2] point out that directing attention to the perception of authenticity within

each culture precisely through tourism enables the process of cultural commodification of everyday objects, among which are souvenirs. Consequently, souvenirs should not be viewed exclusively as tangible objects which travelers bring back from their travels or give as gifts to others, but as bearers of more complex cultural meanings. Ivkov-Džigurski, Kovačević & Zakić [37] emphasize that souvenirs are an integral part of the cultural heritage of the local population and that they play a key role in shaping the tourist product.

Certain studies indicate that souvenirs, in addition to their role as material memories of a tourist destination, also have a symbolic function, representing the experience and emotions associated with travel [18], [7]. In fact, Brennan & Savage [3] consider souvenirs to be essential to the tourist experience. This is agreed by Swanson & Horridge [30], as well as Sthapit, Coudounaris & Bjork [27], who state that many tourists feel that their trips would be incomplete if they did not purchase souvenirs. So, the souvenir is an important component of the tourist experience and most tourists bring memories and souvenirs as proof. Wilkins [34] points out that people like to remember special moments in their lives and to keep evidence of those special moments. How important the concept of creating an authentic tourist experience is is also confirmed by the fact that the earliest research pointed out that tourism is aimed at creating experiences which represent the essence of travel, whereby tourist experiences are often perceived as extraordinary and different from everyday routine [4]. This approach is confirmed by Kim & So [11], stating that experiences represent the essence and central aspect of the tourism industry. Tourist experiences are defined as pleasant, memorable and interesting experiences.

A little more than a decade ago, Kim & So [11] introduced the concept of a memorable tourist experience, defined as a tourist experience that is positively remembered and recalled after the end of the tourist trip [8]. Many theoreticians in the field of tourism agree that in modern business conditions, providing an unforgettable tourist experience is of key importance for competitiveness in the tourism industry [36], [26]. Hosany, Sthapit & Björk [8] point out that the study of unforgettable tourist experience is not only theoretically relevant, but also practically useful for the tourism industry. Unforgettable tourist experiences can be a key component of a destination's competitiveness, and tourism service providers can gain numerous advantages if they encourage the creation of such experiences [28].

In the context of tourism, from a dynamic perspective, memory plays a key role in understanding individuals' memories of tourism experiences of personal importance [12]. The memory of tourist experiences is a decisive factor in the future behavior of tourists and decision-making when choosing destinations [12]. An experience which remains in the memory emphasizes its uniqueness. For example, travelers who experience a satisfying and memorable tourist experience at a certain destination are likely to share their impressions and experiences with others [21].

Authentic souvenirs are a type of product of cultural exchange and interaction between producers - local residents and tourists. The more tourists are interested in the host culture, the more likely they are to buy souvenirs [23]. Tourists' satisfaction with souvenir shopping experiences is an important factor of destination loyalty [27], [29]. From the destination side, the souvenir business brings local communities very important additional economic income [9] and provides a way to preserve and develop culture [4].

The goal of the research is to examine the role and importance of souvenirs in the formation of a deeper emotional bond between tourists and the destination, that is, to determine whether and to what extent souvenirs contribute to evoking emotions,

preserving memories and encouraging the intention to visit the destination again. This approach is of particular importance for the carriers of the tourist offer, especially those who are directly involved in the creation and placement of souvenirs, since the paper provides clear guidelines as to which values should be nurtured and how to attract different segments of tourist demand.

LITERATURE REVIEW

Early research, carried out from the 1980s to the beginning of the 21st century, was mainly concerned with explaining the evolution of souvenirs, describing the development of the regional souvenir business, as well as analyzing the interaction between the souvenir business and social, economic and cultural aspects. In this period, the first researches were published that dealt with the typology of souvenirs, as well as their functions, meanings and values.

Since the beginning of the 21st century, there has been an increase in the number of studies which study souvenirs as significant tourist attractions, viewed from different perspectives. Research attention has been directed towards tourists themselves, their attitudes and motives for purchasing souvenirs, but also towards other important tourism issues which are directly related to souvenirs, such as destination revisit intention and place attachment, destination image, rural tourism, the impact of tourism vendors on the cultural tourism experience, as well as the sustainability of the destination economy, culture and environment [23].

Wilkins [34] emphasizes that the motivations for purchasing souvenirs go beyond the purchase of the item itself because souvenirs actually function as material symbols of meaning and memories associated with the tourist experience. He deals with assessments of the behavior of tourists when buying souvenirs, that is, the influence of gender on purchased souvenirs and motivations for their purchase. The research identifies the key importance of souvenirs as proof of experience, as well as their role as gifts and memories of the trip itself.

Sthapit, Coudounaris & Björk [27] indicate that the pleasure and co-creation of experiences during on-site souvenir shopping in a tourist destination create unforgettable experiences and that such memories enhance tourists' sense of attachment to the destination. Speaking about the importance of authenticity, the study of Brennan and Savage [3] is particularly noteworthy, which emphasizes the need to protect the intellectual property rights of indigenous communities, especially in the context of artworks produced for the souvenir industry.

Paraskevaidis & Andriotis [20] show that souvenirs are more than material objects, that they function as social and cultural symbols, satisfying tourists' expectations and connecting the travel experience with meaning, authenticity and memories.

Shen & Lai [23] conducted a systematic review of souvenir literature, from 1981 to 2020, to identify research developments, major themes and existing gaps, and to suggest directions for future research. Based on the search of a large number of papers, they singled out the types of souvenirs which attract the interest of tourists and classified them into the following categories: "handicrafts", "crafts", "textiles", "handcrafts", "tourist art" and "postcards". Based on the available literature, it is noted that souvenirs have been part of tourism studies for almost 50 years, although most publications have been published in the last 20 years [2].

Seočanac et al. [22] indicate that gastronomic products often serve as souvenirs that not only preserve the memory of the experience, but also help tourists express their uniqueness and gain social recognition. This is confirmed by Vujić, T., Cvijanović & Vujić, M. [33], who claim that gastronomy, as a tourist attraction, has the power to attract tourists and make them loyal to it and the destination it is associated with.
Bernardo, Sousa & Kastenholz [2] considered 282 papers dealing with souvenirs. They sorted them into six main research topics: authenticity; shopping; symbolic value; shopping satisfaction; destination image and tourist experience. Souvenirs can be seen as items that provide cultural mediation between hosts and guests. The study conducted by Bernardo, Sousa & Kastenholz [2] is important for the tourism business sector, as it allows its stakeholders to better understand the physical (e.g. material and appearance) and psychological (e.g. meaning and representativeness) attributes of souvenirs, as well as their empirically proven capacity to influence tourists' attitudes and behavior during their visit to a destination, potentially improving destination and service experiences, and leading to increased purchases as well as loyalty.
Sthapit, Björk & Rasoolimanesh [26] conducted a study examining the relationship between memorable souvenir shopping experience, nostalgia, destination attachment and revisit intention.
Morgan & Pritchard [18] point out that souvenirs function as items that mediate tourist experiences through time and space, emphasizing the importance of materiality and memory in shaping tourist identities and performances. Swanson & Horridge [30] analyze how the motivation to travel affects the type of souvenirs which tourists buy, as well as the attributes of the product and the store where the souvenirs are purchased. Wilkins [34] also analyzes the motivations behind the purchase of souvenirs, including their role as records of memories, evidence of experience, and objects to be gifted to others. The same author points out that souvenirs play an important role as gifts for others, which expands the travel experience beyond the tourist himself.
The research conducted by Kumar, Trupp & Pratt [13] emphasizes that souvenirs are carriers of meaning and not just commercial products, because both tourists and sellers associate them with the identity, memory and culture of the destination.
Haldrup [7] shows that souvenirs are not only objects of memory, but also material bearers of affective and emotional relationships which continue to influence the tourist experience outside the destination itself - through everyday life and the emotional bonds they form with their owners.
However, Liu et al. [16] start from the idea that souvenirs are more than material objects - they are "destination echoes" that help tourists reconstruct memories, travel identity and personal experience of a place. These authors introduce the concept of souvenir locality, which implies a connection with the people, place and past of the destination (collective memory).

METHODOLOGY

The aim of the paper is to perform a statistical analysis of the data collected through survey research on the attitudes of tourists towards buying souvenirs and their influence on loyalty to the destination. Data were collected using an online structured questionnaire, using a random sample method. The survey questionnaire is composed of four parts and includes the respondents' demographic characteristics, travel habits, behavior when buying souvenirs and attitudes towards souvenirs measured by a five-point Likert scale

(23 statements). The research was conducted on a sample of 182 respondents, of which 171 respondents were included in the final analysis. Eleven respondents were excluded due to a negative answer to the initial, elimination question about buying souvenirs during the trip.

Data analysis was carried out using statistical software SPSS 26.0. Data processing included descriptive statistics, correlation analysis and one-factor analysis of variance (ANOVA) according to the age structure of the respondents.

In order to achieve the goal of the research, one main and two auxiliary hypotheses were set in the paper.

Main hypothesis (H): *The authenticity of souvenirs strengthens the emotional connection of tourists with the destination.*

Hypothesis H1: *Emotional connection with the destination has a positive effect on the loyalty of tourists (revisit and recommendation).*

Hypothesis H2: *There is a statistically significant difference in the perception of the importance of souvenirs depending on the age of the respondents.*

To test the hypotheses H and H1, a correlation analysis was used to determine the relationship between tourists' emotional connection with the destination and their loyalty, measured through the intention to revisit and the willingness to recommend the destination. Correlation analysis enables the identification of the strength and direction of connections between variables, thus empirically examining whether tourists with a greater emotional connection to the destination are more inclined to loyal behavior. One-factor analysis of variance (ANOVA) was used to examine the existence of statistically significant differences in the souvenir buying behavior among respondents of different age categories.

RESULTS AND DISCUSSION

In the research, female respondents dominate, making up 80.7% of the total sample, while male respondents make up 19.3%. This gender structure is actually common in research related to tourism and souvenir shopping, where women traditionally show a greater interest in this topic. For example, Littrell et al. [17] tried to understand what influences the consumption of authentic handicrafts, concluding that age, travel experience and type of tourism (but not gender) are relevant. Unlike them, Wilkins [34] and Xu & McGehee [35] emphasized gender differences in the shopping behavior of tourists, which includes the purchase of souvenirs and other tourist items, which is also confirmed by this research. The results of the study conducted by Anderson & Littrell [1] are interesting and show that older women who travel with their spouses or friends made planned purchases of authentic souvenirs, while younger and middle-aged women who usually travel with children bought souvenirs unplanned and hastily.

When it comes to the age structure of respondents, the largest percentage of respondents belongs to the age group 26-35 years (34.5%) and 18-25 years (28.7%). Together, these two groups make up 63.2% of the sample, indicating that younger tourists dominate the survey. The youngest respondent is 16, and the oldest is 68. The available literature also indicates that demographic characteristics, especially the age of tourists, have a significant impact on their preferences and behaviors related to the purchase of souvenirs. For example, Tsai & Chen [32] showed that age differences influence preferences for souvenir attributes, such as appearance and price, while Dey [6] identified age as an important demographic factor shaping tourists' intentions to purchase souvenirs.

These findings support our results that older tourists value more the symbolic and authentic component of souvenirs compared to younger respondents (Table 1).

Table 1. One-Way ANOVA, differences in the age structure of respondents regarding their attitudes about souvenirs

Variables	**Young people** (Mean)	**Middle-aged people** (Mean)	**Elderly people** (Mean)	F	P
S7	2.44	2.73	3.67	13.70	0.001
S2	4.29	4.50	4.76	6.71	0.002
S5	2.88	2.85	3.45	5.21	0.006
S15	3.60	3.77	4.22	5.20	0.006
S21	3.31	3.46	3.94	4.84	0.009
S13	4.49	4.69	4.80	3.42	0.035

Legend: According to the age structure, the respondents were divided into three categories: young (≤30), middle-aged (31-45) and elderly (>45).

* S7 - The authenticity of souvenirs affects my overall impression of the destination; S2 - It is important to me that the souvenirs I buy reflect the local culture and tradition; S5 - I don't care if the souvenirs are commercialized; S15 - Souvenirs allow me to share my travel experience with others; S21 - The emotional value of souvenirs makes me want to revisit a certain destination that I visited during the previous year.; S13 - I like buying souvenirs because they remind me of the places I've been.

Analyzing the statements (S) in which there was a statistically significant difference among respondents according to age, it can be seen that older respondents attach much greater importance to the authenticity of souvenirs and their role in the representation of local culture. These findings suggest that with the increase in age, the need for a deeper, authentic tourist experience, which materializes through souvenirs and extends even after the end of the trip, also increases. In addition, they are characterized by a stronger emotional connection with souvenirs and a greater desire to visit the destination again. Based on the obtained results, which determined a statistically significant difference in the attitudes of respondents in relation to age, *hypothesis H2 is accepted*.

It can be concluded that souvenirs for older tourists are not only an object of purchase, but bearers of personal memories and emotional ties with the destination, in contrast to younger respondents, where authenticity is emphasized to a lesser extent, as well as the emotional dimension of souvenirs, which may indicate a more pragmatic approach when buying souvenirs, as well as greater tolerance towards their commercialization. Such results are in line with modern trends in tourist consumption, according to which younger generations often give priority to the functionality, price or visual appeal of a product in relation to its symbolic meaning.

Dey [6], studying souvenir purchase intentions in craft-rich regions, points out that among demographic factors, age and frequency of travel significantly influence souvenir purchase intention, suggesting that different age groups manifest different motives and behaviors related to souvenirs. Similar results were observed in the research of Olalere [19], which indicates that the perception of the importance of certain attributes of souvenirs varies among tourists, with demographic characteristics, including age, influencing motives and preferences when purchasing souvenirs.

When it comes to travel habits, the largest number of respondents (56.1%) travel 2-3 times a year, 36.9% of respondents travel 4 or more times a year, while only 7% of respondents travel only once a year. Most respondents travel within the framework of organized tours (37.4%). Travels with family are represented by 29.8% of respondents, while 28.1% travel with friends. Independent trips are the least represented and make up 4.7% of the total sample.

Considering the main motive of the trip, the respondents first mention rest and recreation (55.6%), followed by business trips (21.6%), while cultural motives and visits to family/friends are less common, with 4.7% each.
Although it was possible to choose several answers to the question about the reasons for buying souvenirs, the two most common and dominant reasons were a gift for others (80.7%) and a personal memory (78.9%). These data indicate that souvenirs have a strong social and emotional function. Authenticity is an important purchasing criterion for 38% of respondents, while aesthetic appeal and proof of visit are less important, with a share of less than 10%. Most respondents (42.7%) buy 2-3 souvenirs per trip. The fact that more than a quarter of respondents (27.5%) buy more than five souvenirs per trip indicates a high level of involvement of respondents in buying souvenirs, which confirms the importance of souvenirs as an integral part of the tourist experience.
In order to gain a deeper understanding of the influence of attitudes about souvenirs on the tourist behavior of respondents, statistically significant correlations between relevant variables were analyzed in the continuation of the paper.

Table 2. Statistically significant correlations between souvenir attitudes and tourist behavior outcomes

Variable 1	Variable 2	r	p
S18	S19	0.784	<0.001
S9	S10	0.755	<0.001
S8	S9	0.701	<0.001
S17	S19	0.659	<0.001
S19	S21	0.618	<0.001
S20	S22	0.546	<0.001

Legend: Only statistically significant correlations ($p < 0.05$) with a correlation coefficient $r > 0.40$ were selected and shown.
S8 - Participating in making souvenirs would make my trip special (eg painting magnets and practical items, participating in preparing local products...); S9 - The souvenir would have a greater emotional value if I participated in making it; S10 - Participating in making souvenirs contributes to making the trip unforgettable; S17 - Souvenirs are a reminder of the accomplished tourist experience; S18 - Souvenirs have a strong emotional and nostalgic value for me; S19 - Souvenirs connect me emotionally with the places I visited; S20 - I would visit again a certain destination that I visited during the previous year; S21- The emotional value of souvenirs makes me want to revisit a certain destination that I visited during the previous year; S22 - Due to the overall impression, I would recommend the visited destination to others

The results of the correlation analysis indicate a strong interconnection of the affective, symbolic and behavioral dimensions of souvenirs, confirming that souvenirs go beyond the function of mere material objects and act as bearers of the destination's meaning and experience. The obtained results are in accordance with the opinion of the authors [16], who point out that souvenirs are not only material objects - they are "echoes of the destination" that encourage tourists to evoke memories and nurture a personal experience of the place.
The strongest correlation was recorded between the emotional value of souvenirs (S18) and emotional connection with places (S19) ($r = 0.784$, $p < 0.001$), which indicates that souvenirs which have a high emotional value significantly contribute to the development of a strong affective connection of tourists with the destination. This finding confirms the theoretical assumptions that souvenirs function as an "emotional bridge" between tourists and places, enabling the extension of the tourist experience even after returning home [26], [15], [16].
High correlations within the souvenir participation and experience dimension (S8, S9, S10) suggest that the perception of souvenirs as "special", "emotionally valuable" and

"unforgettable" is a coherent construct. This indicates that active and personal involvement in souvenir selection is key to its long-term meaning, which is consistent with approaches which emphasize the experiential and narrative value of souvenirs.
The significant correlation between the function of souvenirs as a reminder (S17) and the emotional connection with places (S19) ($r = 0.659$, $p < 0.001$) further confirms the role of souvenirs in preserving memories and reconstructing the meaning of travel. Souvenirs thus become material carriers of the collective and personal memory of the destination.
In order to gain a deeper understanding of the role of individual attitudes in shaping future tourist behavior, an analysis of predictors of the intention to revisit the destination was conducted, and the results are shown in Table 3.

Table 3. Predictors of revisit intention (attitude S20) in relation to other attitudes

Variables	r	p
S22	0.546	<0.001
S21	0.363	<0.001
S13	0.315	<0.001
S19	0.288	<0.001
S15	0.275	<0.001

Legend: S22 - Due to the overall impression, I would recommend the visited destination to others; S21- The emotional value of souvenirs makes me want to revisit a certain destination that I visited during the previous year; S13 - I like to buy souvenirs because they remind me of the places I've been; S19 - Souvenirs connect me emotionally with the places I visited; S15 - Souvenirs allow me to share my travel experience with others.

The analysis of correlations with the outcome variables of loyalty shows that the affective and symbolic dimensions of souvenirs are significantly related to the intention to revisit and recommend the destination. The connection between the emotional connection with the place (S19) and the desire to visit again (S21) ($r = 0.618$, $p < 0.001$) stands out, which indicates that souvenirs indirectly contribute to the loyalty of the destination by strengthening the tourist's emotional connection with the place.
The results also show that destination recommendation (S22) is a strong correlate of revisit intention ($r = 0.546$, $p < 0.001$), suggesting that positive narratives about the experience, fueled by souvenirs, play an important role in spreading word-of-mouth. Although correlations with variables such as experience sharing and recalling places are of moderate intensity, their statistical significance confirms their role in the formation of loyalty. Based on the presented results, the main hypothesis (H): The authenticity of souvenirs strengthens the emotional connection of tourists with the destination *was accepted*, as well as hypothesis H1: Emotional connection with the destination has a positive effect on the loyalty of tourists (revisit and recommendation).
The aim of this research was to determine whether, and to what extent, souvenirs affect the emotional connection of tourists with the destination, as well as whether there is a correlation between the degree of emotional connection with the destination and the willingness of tourists to visit it again or recommend it to others.
In order to understand the relationship between souvenirs, emotions and loyalty, it was of particular importance to test hypothesis H2, which looked at the differences in the perception of the importance of souvenirs among different age groups. Bearing in mind that the results of the research showed that older tourists value the authenticity and symbolism of souvenirs to a greater extent, as well as that younger tourists made up the largest share in the sample, it is necessary to consider the relevant dimensions of souvenirs which can significantly contribute to younger tourists, especially members of generations

Y and Z, being recognized as a target segment in the area of souvenir purchases. Millennials (Generation Y) are often described as the experience generation. They have completely redefined the concept of travel, prioritizing meaningful, personalized experiences over material possessions. On the other hand, tourists belonging to Generation Z often prefer cheaper trips which allow them to explore the world without major financial burdens [14]. Accordingly, the views of the authors Torabian & Arai [31], who found that tourists prefer souvenirs made by local craftsmen from local materials, at an affordable price, are of importance. These authors agree with Cohen [5] that both tourists and souvenir sellers are "active creators of meaning" and that "authenticity" lies in the "eye of the beholder" [2:257]. Namely, considering that generations Y and Z have emerged as the most influential demographic groups in shaping the future of travel, it is necessary to additionally emphasize the possibility of active participation in the creation of souvenirs, that is, in the creation of an unforgettable experience. Consistent with these views, Sthapit, Björk & Rasoolimanesh [26] show that experience co-creation, tourist engagement and shopping satisfaction positively influence the memorability of souvenir shopping experiences. Such experiences, in turn, strengthen feelings of nostalgia, attachment to the destination and the intention to revisit, emphasizing the importance of souvenirs as material symbols of authentic and memorable tourist experiences.

That souvenirs indirectly contribute to the strengthening of loyalty through the creation of an emotional connection with the destination was confirmed based on the conducted statistical analyzes and the acceptance of hypotheses H and H1. Additionally, the importance of souvenirs is confirmed by the highest rated statements related to destination recommendation - "I would recommend the destination to others" (M=4.68) and the nostalgic value of souvenirs - "I like buying souvenirs because they remind me of the places I've been" (M=4.61). The fact that souvenirs can enhance the memorability of the experience and the intention to revisit was also confirmed by Sthapit & Björk [25], who found that the uniqueness and local representativeness of souvenirs are associated with enhanced memory of the trip and the intention to revisit the destination.

However, it should be emphasized that a souvenir, as an item which preserves the memory of a trip, cannot represent the primary goal of a trip, visit or stay. Its role is to contribute to the long-term memory of pleasant travel experiences, while at the same time it has the function of satisfying tourist needs and thus directly affects the increase in tourist consumption. A souvenir should, first of all, be an item that was produced in a given destination, as an authentic and credible symbol of its climate and local environment [37]. The local community, craftsmen and the nurturing of local crafts play a crucial role in strengthening the connection between souvenirs, emotions and loyalty to the destination. Liu et al. [16] point out that souvenirs that carry elements of the destination location help tourists preserve memories and prolong the feeling of satisfaction and well-being after the trip. These objects, through sentimental value and stories about experiences, function as material symbols of an authentic tourist experience and strengthen the emotional connection with the destination. The results of the conducted research confirm how important the authenticity, locality and appearance of souvenirs are. Namely, with the possibility of choosing more than one answer, art items stand out as the most represented type of souvenir (87.1%). In addition, a significant share is occupied by practical items (45%) and gastronomic products (39.2%). Also, the lowest rated statement is "I don't pay too much attention to the appearance of souvenirs, I take the first one I see" (M=1.27). Additionally, Sthapit, Coudounaris & Björk [27] point out that satisfaction and active participation in the very process of buying souvenirs during a stay contribute to the

creation of unforgettable shopping experiences, and that the role of sellers is extremely important in that process. The authors cite implications for souvenir retailing – for example, that retailers should offer a variety of products, improve the quality and appearance of window displays, and encourage interaction with customers to contribute to greater satisfaction and memorability of the experience. A study by Shen & Lai [23] contributes significantly to the creation of these experiences, which provides a good reference for souvenir suppliers, especially artisans, retailers and other micro-entrepreneurs, to understand tourist behavior related to souvenirs. It further helps these stakeholders to understand the importance of the souvenir industry and their work to the destination's economy, society and culture, and then to contribute to sustainability tourism.

CONCLUSION

The findings of this research contribute to the understanding of the role that souvenirs play in the formation of destination loyalty. The central role of emotions was confirmed, i.e. the opinion of the respondents that souvenirs which encourage an emotional connection with the destination significantly contribute to the intention of revisiting and recommending. This is in line with the theory of emotional memory and the concept of nostalgia in tourism.

The identification of participatory experience (co-creation) as a distinct dimension has a special significance. The participation of tourists in the production of souvenirs represents an innovative approach which can significantly contribute to the unforgettable tourist experience and the formation of loyalty. This is of particular importance for attracting dominant demographic groups (Generations Y and Z).

The recommendations that this research provides can be especially useful for destination management and souvenir manufacturers, in the sense that they focus on the emotional value of souvenirs and create souvenirs which encourage nostalgia and emotional connection. Emphasizing authenticity can be of particular importance, especially for a certain segment of demand (older tourists) and the development of participatory programs - workshops for making souvenirs, offering personalization of souvenirs as a tourist product. It is also suggested that the holders of tourism development, as well as the sellers themselves, enrich the offer with creative content and perfect souvenirs as gifts, given that this is the dominant reason for purchase. Understanding the differences in the attitudes of tourists of different age groups can contribute to the adjustment of the souvenir offer, whereby the emphasis on authenticity, local production and emotional value could be particularly effective in attracting older tourists and encouraging their loyalty to the destination, while the concept of co-creation would be used in attracting younger tourists. The above has important implications for market segmentation and the design of souvenirs of a certain tourist destination, but also for strengthening the connection between souvenirs, emotions and loyalty of tourists.

The main limitation of this research relates primarily to the uneven gender structure of the sample (predominance of female respondents), which can limit the applicability of the results, that is, can lead to generalization. Also, for future research, it is necessary to further analyze the characteristics of souvenirs in order to more clearly define what is particularly important to tourists when buying souvenirs. Such an approach would greatly help in the creation of souvenirs that would attract the attention of different segments of tourist demand.

It is necessary to take a deeper look at the attitudes of generations Y and Z, especially when it comes to participation in the creation of souvenirs and unforgettable experiences. These generations increasingly strive for personalized, interactive and experiential forms of consumption, whereby they do not view souvenirs exclusively as material objects, but as part of the overall experience of the destination. Involving younger tourists in the process of creating souvenirs, through the aforementioned workshops, digital tools or direct cooperation with local producers, can contribute to strengthening their emotional connection with the destination and increasing the likelihood of repeat visits or recommendations to others. In this way, souvenirs become a tool for creating authentic and unforgettable experiences, adapted to the expectations of modern tourists.
Future research should include a more representative sample, a longitudinal design to monitor actual behavior (revisit), as well as qualitative methods for a deeper understanding of the emotional connection to souvenirs.

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ENVIRONMENTAL CHALLENGES AND REPRODUCTIVE DECISIONS: A QUALITATIVE STUDY BASED ON FOCUS GROUPS

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ABSTRACT

This study explores how environmental challenges shape reproductive intentions and family-related decision-making in Serbia. Based on five focus groups conducted between November 2025 and January 2026 in environmentally burdened municipalities, the research examines how individuals interpret ecological risks and how these interpretations influence their perceptions of health, safety, and long-term family planning. Participants described severe and worsening environmental conditions, particularly air pollution, which they linked to health problems in children and the need for everyday adaptive strategies. Environmental concerns affected reproductive decisions indirectly, intersecting with economic insecurity, institutional distrust, and mobility strategies aimed at protecting family well-being. While few participants attributed their reproductive choices solely to environmental factors, many viewed pollution as part of a broader context of uncertainty. These qualitative insights complement emerging quantitative evidence on climate-related fertility impacts in Serbia, underscoring the need for integrated policies that connect environmental protection with reproductive health and social support systems.

Keywords: Environmental risks; Reproductive decisions; Air pollution; Perceived health threats; Mobility strategies.

INTRODUCTION

Environmental degradation has been widely recognized as a factor shaping reproductive health and demographic behavior. Environmental risks are increasingly understood as part of broader global syndemics that link climate change, pollution, and population health [7]. Numerous studies demonstrate that exposure to air pollution and other environmental hazards is associated with adverse reproductive outcomes and increased health risks for infants and children [1] [5]. Beyond biological effects, environmental uncertainty increasingly influences how individuals perceive safety, risk, and long-term family planning [9] [3]. Recent research on eco-anxiety shows that environmental concerns have become part of the emotional and moral landscape of reproductive decision-making, particularly among younger generations [2][6]. While the health implications of pollution are well documented, less is known about how individuals interpret these risks and how such interpretations shape reproductive decisions. This study contributes to this growing body of literature by examining how residents of five environmentally burdened Serbian municipalities interpret ecological risks and how these interpretations shape their reproductive intentions and everyday family practices. This study examines subjective experiences of environmental challenges and their perceived influence on family planning. The aim is not to quantify effects, but to understand how

people talk about and make sense of the relationship between environmental conditions and reproductive choices.
As this paper represents the first publication based on the recently completed fieldwork, its aim is to provide an initial overview of key perceptions and emerging patterns identified in the focus groups. The analysis presented here offers foundational insights into how individuals interpret environmental risks in relation to reproductive decisions, while a more comprehensive and systematic examination of the full dataset will be developed in forthcoming project outputs within POPENVIROS.

METHODOLOGY

The study is based on qualitative data collected through 5 focus groups conducted between November 2025 and January 2026 in Serbia. A total of 30 participants took part in the discussions. The groups were intentionally composed to include individuals of different genders, ages, educational backgrounds, and residential settings (urban/rural). Participants were between 20 and approximately 37–38 years old, representing a life stage in which individuals typically consider starting or expanding a family. This age structure was essential for capturing perceptions of environmental risks in relation to reproductive intentions.
Focus groups were conducted in five locations in Serbia, selected due to their distinct environmental profiles and relevance for understanding local variation in exposure and perception:

- Belgrade - an urban environment with high levels of traffic-related and industrial pollution
- Pančevo - an industrial center with long-standing air quality challenges
- Smederevo - a city located near major industrial facilities
- Valjevo - a city with chronically high concentrations of particulate matter and severe winter pollution episodes
- Kosjerić - a smaller community with pronounced local sources of air pollution

The discussions explored participants' perceptions of environmental quality, everyday coping strategies, and reproductive considerations. A thematic approach was used to identify recurring patterns across locations. Given the exploratory nature of the study, the analysis focuses on broad thematic insights rather than detailed coding structures, which will be elaborated in a forthcoming journal article.

RESULTS

Perceived severity of environmental problems

Across all sites, participants described environmental conditions as severe and worsening. Air pollution, especially during winter, was the most salient issue. In Valjevo and Kosjerić, individual heating and topography were central concerns; in Smederevo and Pančevo, industrial emissions dominated local narratives. Many participants emphasized visible pollution, unpleasant odors, and the inability to spend time outdoors.
As one participant noted: "*When I come home, all my clothes smell like smoke*."

Health concerns and everyday adaptations

Parents frequently linked pollution to respiratory illnesses, allergies, and skin problems among children. Many households rely on air purifiers, limit outdoor activities, or travel to rural areas on weekends to "breathe clean air." These adaptations reflect a privatization of environmental risk management, where individuals compensate for institutional shortcomings.

One parent explained: "*As soon as my child comes inside after being outdoors, the coughing starts and lasts for half an hour*."

Environmental concerns and reproductive decisions

Environmental factors influenced reproductive intentions in nuanced ways:

- Some participants delayed or reconsidered having additional children due to fears of pregnancy complications or long-term health effects.
- Others emphasized the importance of relocating to cleaner areas before expanding their families.
- For a minority, environmental degradation contributed to decisions not to have children at all.
- Many participants stressed that environmental concerns intersect with economic and social insecurities, making it difficult to isolate their influence.

As one participant stated: "*I would love to have a third child, but honestly - with this air, I don't dare.*"

Mobility as a protective strategy

Residential mobility emerged as a key response. Families in Smederevo and Valjevo described moving, or planning to move, to less polluted neighborhoods, rural areas, or entirely different municipalities. Migration was often framed as a prerequisite for raising children in healthier conditions.

A participant from Smederevo explained: "*We're building a house in the countryside, on the side of town farthest from the steel plant*."

Distrust in institutions

A pervasive theme across all groups was distrust in local and national institutions. Participants expressed frustration with inadequate environmental monitoring, weak enforcement of regulations, and poor health services. This distrust amplified feelings of vulnerability and shaped perceptions of reproductive risk.

As one participant put it: "*Nothing is being done here - no plan, no will, no trus*t."

CONCLUSION

The findings suggest that environmental degradation influences reproductive decisions indirectly, through its impact on health perceptions, daily routines, and trust in institutions. Rather than acting as a single decisive factor, environmental concerns accumulate alongside economic and social uncertainties, contributing to hesitation, selective mobility, and adaptive parenting practices. The study also highlights the emotional dimension of environmental exposure, fear, frustration, and resignation, which

may shape long-term demographic behavior in ways not captured by quantitative indicators.

These results build on previous research in Serbia showing that climate and environmental changes affect demographic processes and population behavior patterns, including migration, health, and reproductive decisions, as confirmed by recent studies analyzing regional specificities and adaptive responses to environmental stressors [8]. These qualitative insights complement recent quantitative evidence from Serbia showing that climatic stressors can have measurable demographic effects. A recent study analyzing nearly 382,000 births across 25 districts found that exposure to hot days (average temperature >25 °C) leads to a significant decline in birth rates 9–10 months later, followed by a partial rebound [4]. This research demonstrates that environmental conditions influence fertility not only through physiological pathways but also through broader socio-climatic pressures that shape perceptions of security and future planning. Our findings add to this evidence by showing how individuals interpret environmental risks in their everyday lives and how these interpretations inform reproductive hesitation, mobility strategies, and family-building decisions.

Environmental challenges in Serbia's polluted municipalities therefore shape reproductive intentions through complex pathways involving health concerns, institutional distrust, and adaptive strategies. While few participants attributed their reproductive decisions solely to environmental factors, many described pollution as an important part of a broader context of insecurity. Taken together with emerging demographic evidence on climate-related fertility impacts, these findings underscore the need for policies that integrate environmental protection with reproductive health and social support systems. Improving environmental conditions may not only enhance public health but also create a more secure environment for family formation.

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VULNERABILITY OF CULTURAL HERITAGE TO ANTHROPOGENIC IMPACTS: A CASE STUDY OF THE STEĆCI NECROPOLIS IN THE CITY OF EAST SARAJEVO

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ABSTRACT

Stećci are medieval stone tombstones that represent a unique cultural phenomenon in both Europe and the wider world. Dating back to the late Middle Ages, they are distributed across almost the entire territory of Bosnia and Herzegovina. Throughout history, stećci have been exposed to various natural and anthropogenic influences, which have resulted in a gradual decline in their number. Human activities have frequently caused their destruction, most notably during wars, treasure hunting beneath the tombstones, construction activities, and agricultural practices on arable land. Today, stećci are exposed to anthropogenic impacts such as urbanization and unplanned construction, pollution and waste disposal, the construction of road infrastructure, as well as various economic activities. Such treatment of stećci, combined with the negative effects of natural processes, has highlighted the need for serious consideration of their protection and the development of effective preservation models. The most vulnerable necropolises are those located near cities experiencing rapid urbanization. Examples can be found in the area of the city of East Sarajevo. The aim of this paper is to analyze anthropogenic impacts on three stećak necropolises—Crnač, Pavlovac, and Krupac—located in the area of the City of East Sarajevo. The research methodology includes the application of geospatial technologies in the implementation of both direct and indirect research methods. The research results showed that the Pavlovac and Crnač necropolises belong to the category of highly vulnerable sites, while the Krupac necropolis belongs to the category of moderately vulnerable sites.

Keywords: stećci, urbanization, cultural heritage vulnerability, East Sarajevo

INTRODUCTION

Cultural heritage, especially when it is unprotected, is exposed to the negative impact of various natural as well as anthropogenic factors. Human-related processes including technological advances, population growth, pollution, or planned landscape development have massively affected archeological sites, resulting in partial damage or total loss of cultural heritage; additionally, these sites are sometimes affected by management problems, such as lack of financial resources and knowledge and inadequate or absence of site management [1].

Stećci are autochthonous cultural and historical monuments dating from the 12th to the 16th century. They are most commonly found in Bosnia and Herzegovina, and to a lesser extent in Serbia, Montenegro, and Croatia. As a distinctive element of cultural heritage, stećci represent a potential tourist attraction and offer opportunities for the development of cultural tourism. However, not enough has been done to preserve, protect, and promote stećci for tourism in Bosnia and Herzegovina. According to some estimates, nearly 20% of the total number of stećci in Bosnia and Herzegovina has been destroyed, submerged, or lost [2]. Throughout history, anthropogenic pressures have repeatedly led to their destruction, especially in the context of warfare, treasure hunting, infrastructure development, and intensive agricultural practices. In some areas of Bosnia and Herzegovina, complete necropolises were removed and reused as construction material for roads, public facilities, housing, and the restoration of religious buildings.

The spatial framework of the research is the City of East Sarajevo, more precisely the municipality of East Ilidža, one of the six municipalities that constitute the city. In this municipality, three endangered necropolises of stećci have been recorded and are analyzed from the perspective of their vulnerability to anthropogenic influences. These are the stećci necropolises Crnač in Donji Kotorac, Krupac, and Pavlovac. Since stećci originated as a manifestation of the social status and power of the ruling medieval nobility, the necropolises analyzed in the municipality of East Ilidža can be associated with the Pavlović noble family and the territory of the medieval Pavlović Land. Over 340 stećci necropolises have been recorded within the area of the former Pavlović Land [3].

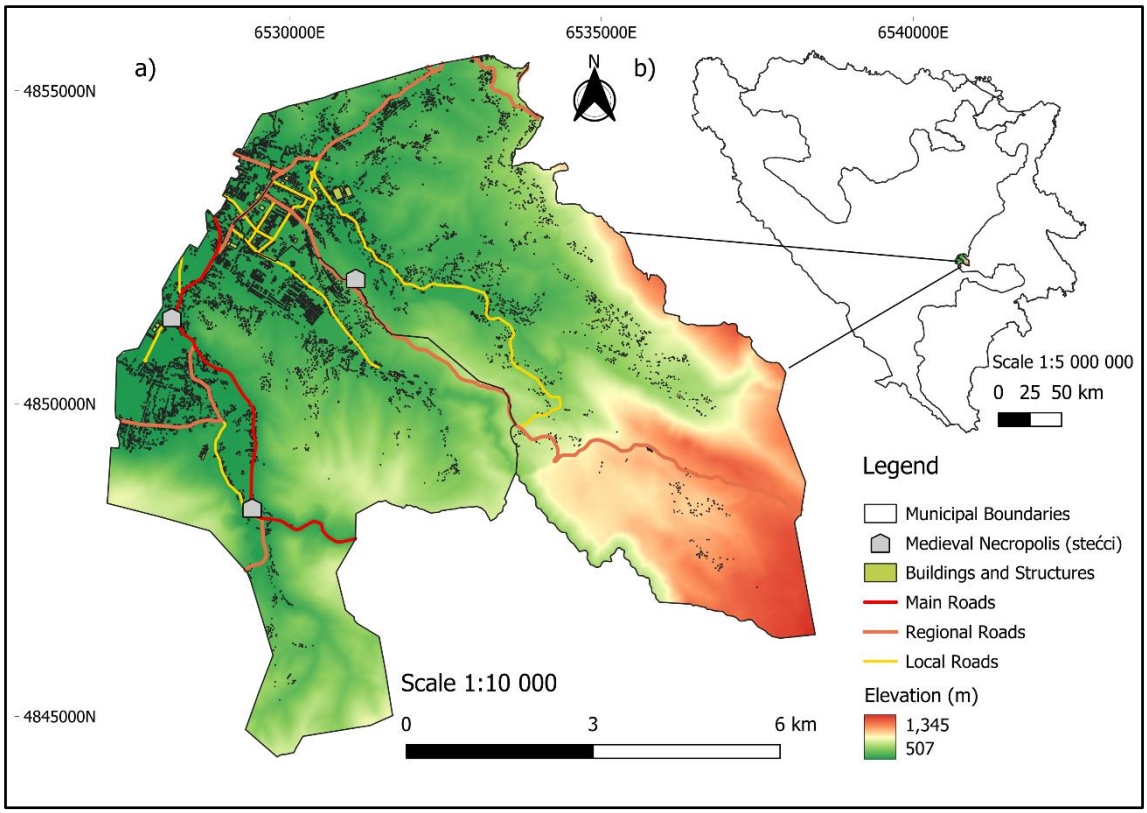


Figure 1. a) Municipalities of East Ilidža and East Novo Sarajevo; b) Location of the municipalities within Republic of Srpska/Bosnia and Herzegovina

Since this study analyzes the vulnerability of cultural heritage to anthropogenic impacts, it is necessary to consider certain socio-geographical processes that are characteristic of the research area. During the inter-census period (1991-2013) the City of East Sarajevo achieved an increase in the number of inhabitants by 12376 (number of inhabitants increased by 26 %). The city recorded positive demographic growth thanks to the positive inter-census change in three municipalities (East Ilidža, East Novo Sarajevo and Pale), which was a consequence of migration, refugees coming back and positive migration balance of internal migrations. It is important to emphasize that from the perspective of population biodynamics, all municipalities have a negative natural increment [4]. According to the estimates of the Statistical Office of the Republic of Srpska, in 2024 the City of East Sarajevo records a slight increase in population. Over an eleven-year period, the population increased by 0.8%, or by 503 inhabitants; thus, in 2024 the city has 60,419 inhabitants [5].

The City of East Sarajevo comprises five urban settlements with a total area of approximately 35 km², accounting for 2.4% of the city's total territory. According to the 2013 Census, 65.4% of the population resides within this area. The highest level of urbanization is recorded in the municipality of East Ilidža, at 93.7%. Specifically, in two settlements out of a total of five, covering approximately 44% of the municipality's territory, 93.7% of the population resides. In the municipality of East Novo Sarajevo, 73% of the population lives in a single settlement occupying 17.9% of the municipality's total area [6], [7].

By analyzing CORINE Land Cover (CLC) data for the area of the City of East Sarajevo in 2018, the urban area covers only 0.91%. If the data from 2000 and 2018 are compared, there was an increase of urban areas in the researched area by 4.7 km², i.e. in 2000 urban area occupied a surface of 8.5 km² and in 2018, it was 13.2 km², which represents an increase of about 55 % compared to 2000. Urban areas were expanding the most in municipalities of East Ilidža and East Novo Sarajevo, while other municipalities recorded just a slight increase. An increase of urban area in municipality of East Ilidža in 2018, compared to 2000, exceeded 400% and in municipality of East Novo Sarajevo 200% [8]. Spatial transformation, the expansion of urban areas, and the construction of urban infrastructure and transport networks exert a negative impact on the environment of this area, as well as on its cultural heritage. Research conducted in the municipalities of East Ilidža and East Novo Sarajevo identified the presence of 29 illegal depots. Most of these depots are located within 2 km of urban settlements, while 60% are situated at less than 100 m from roads and within densely populated areas. Furthermore, approximately 45% of the illegal depots are located within forest belts, and 70% are positioned at less than 50 m from watercourses [9].

East Sarajevo and Sarajevo are situated in the Sarajevsko polje, a basin-type depression enclosed by high mountain massifs. Such a topographic setting, typical of the Dinaric geomorphological system, plays a significant role in shaping local atmospheric dynamics. During the winter months, stable anticyclonic conditions and frequent temperature inversions restrict vertical air circulation, leading to the accumulation of air pollutants. Most local air pollution originates from individual heating systems and road traffic, which further exacerbates the situation during the heating season [10]. Elevated concentrations of air pollutants also negatively affect cultural monuments, including stećci.

METHODS

The analysis of the vulnerability of cultural heritage to anthropogenic impacts in the area of the City of East Sarajevo was based on the application of geospatial technologies in the implementation of both direct and indirect research methods. Direct research methods included fieldwork and the collection of data directly at the sites.

In this study, three stećak necropolises were selected as case studies. Two necropolises, Crnač and Krupac, were chosen because of their significance and level of protection, as they have been proclaimed national monuments of Bosnia and Herzegovina. The third necropolis, the Pavlovac necropolis, was selected due to its specific characteristics: it contains one of the largest stećci in Bosnia and Herzegovina (believed to be the grave of Pavle Radenović) and represents a notable example of the vulnerability and destruction of cultural heritage caused by human activity.

For collecting data on the location and position of the stećak necropolises and mapping the access infrastructure, a GPS device was used. Fieldwork included processes of inventorying, photographing, and assessing the level of vulnerability of the cultural heritage—the stećak necropolises—to anthropogenic impacts.

Table 1. Indicators and scoring scale used for assessing the vulnerability of stećak necropolises to anthropogenic impacts

Indicators / Score	**0**	**0.25**	**0.5**	**0.75**	**1**
Authenticity	Very low authenticity	Low authenticity	Moderate authenticity	High authenticity	Fully preserved authenticity
Level of protection	No protection	Local level	Regional level	National level	International level
Threat from roads/traffic infrastructure	Very high threat	High threat	Moderate threat	Low threat	No threat
Urban-construction pressure[15]	Very high pressure	High pressure	Moderate pressure	Low pressure	No pressure
Threat from landfills	Very high threat	High threat	Moderate threat	Low threat	No threat
Threat from economic and development activities[16]	Very high threat	High threat	Moderate threat	Low threat	No threat
Tourism pressure	Very high pressure	High pressure	Moderate pressure	Low pressure	No pressure
Neglect and lack of maintenance	Very high neglect	High neglect	Moderate neglect	Low neglect	Maintained
Impact of social factors:vandalismtheft	Very high impact	High impact	Moderate impact	Low impact	No impact
Level of awareness of the local community	No awareness	Low awareness	Moderate awareness	High awareness	Very high awareness

[15] Unplanned and excessive construction, infrastructure projects, land-use change, and visual degradation of the cultural landscape

[16] Industrial activities in the vicinity, exploitation of natural resources, and agricultural activities

By analyzing the literature related to the vulnerability of cultural heritage[11], [12] ,[13], [14], the authors proposed ten indicators (Table 1) representing the most common anthropogenic threats to cultural heritage. The vulnerability assessment was carried out by experts (two social geographers, a physical geographer, a GIS analyst, an environmental geographer, a historian, and an archaeologist) who evaluated the listed indicators of anthropogenic impact on the stećak necropolises. Furthermore, following the example of the GAM model [15], [16] specifically one of its segments (VPr – protection level), the above-mentioned indicators were further elaborated and a scoring scale was proposed in which each indicator was evaluated using a normalized scale from 0 to 1, where lower values indicate higher vulnerability and stronger anthropogenic impact, while higher values represent more favorable conditions and lower levels of threat. The overall score of the site was obtained as the arithmetic mean of the listed indicators. Based on the total score, the sites can be classified as: Very high vulnerability (0.0–0.25), High vulnerability (0.25–0.50), Moderate vulnerability (0.50–0.75), Low vulnerability (0.75–1.0), and No vulnerability (1.00).
Data regarding the locations of medieval necropolises, as well as registered illegal landfills, were collected through field research using the All-In-One Offline Maps 3.18 application to determine their latitude and longitude. Furthermore, Geographic Information Systems (QGIS Desktop 3.40.15) were applied to gather data on built structures and the road network within the study area; these data were extracted from Open Street Map using the QuickOSM plugin. GIS was also utilized for creating buffer zones around the necropolises and for cartographic visualization. For the purpose of displaying terrain relief characteristics, a Digital Elevation Model (DEM) (with a spatial resolution of 5 m was employed.

RESULTS AND DISCUSSION

The settlement of Krupac in the municipality of East Ilidža is located in the southeastern part of the Sarajevsko polje, at the point where the Željeznica River emerges from a canyon. The necropolis of stećci is situated next to the Sarajevo–Trnovo main road (Figure 2). The present-day site is not the original location of the necropolis, as it was relocated from its initial site, Kovačevina, due to the opening of a quarry. The original necropolis in Krupac was mentioned by Đuro Basler in 1951, when he recorded 37 stećci [17]. Bešlagić mentions a necropolis with 33 stećci at the Kovačevina site in Krupac; these were undecorated and located next to a modern Orthodox cemetery [18]. In the immediate vicinity of the necropolis there was also an old Muslim cemetery. Until 1977, the entire complex of stećci was located on the western side of the Sarajevo–Trnovo road. This cultural and historical site was threatened by quarrying activities, which continuously expanded toward the necropolis, so that by 1976 the necropolis was located at the edge of a precipice 10–15 m deep [17]. In 1977, the necropolis consisting of 23 stećci and 14 nišans was relocated to a new site on the eastern side of the Sarajevo–Trnovo road, where it remains today. The relocation was carried out by experts from the City Institute for the Protection of Cultural Monuments in Sarajevo.



Figure 2. The Krupac necropolis (photo LukićTanović M.)

This necropolis, under the name "Historic Area – Necropolis with Stećci and Nišans in Krupac", was proclaimed a National Monument of Bosnia and Herzegovina in 2007. The national monument consists of 21 stećci and 12 nišans. A site inspection conducted in 2007 established that the site was not being maintained, that some monuments had cracked due to natural factors, and that traces of repairs were visible on several nišans [17].

The Crnač necropolis is located in the settlement of Donji Kotorac in the municipality of East Ilidža, at a site approximately 100 m from the Sarajevo–Trnovo road. A local road cuts through this necropolis (Figure 3). According to Bešlagić, a necropolis with 59 stećci is situated at the Crnač site, in the immediate vicinity of the former airport on the Butmirsko polje [18]. The monuments are mostly of large dimensions, well carved, but damaged and partly sunken into the ground. [18].

This necropolis, under the name "Historic Area – Necropolis with Stećci at the Crnač Site in Donji Kotorac," was proclaimed a National Monument of Bosnia and Herzegovina in 2012 [19]. According to this decision, 54 graves with stećci were recorded at the Crnač necropolis, of which 51 are chest-shaped and 3 gabled. The graves are arranged in three groups, oriented along the west–east and southwest–northeast axes. The stećci are undecorated but bear inscriptions.



Figure 3. The Crnač-Donji Kotorac necropolis (photo Golijanin J.)

A site inspection conducted in 2012 established that the necropolis area was overgrown with low vegetation, thorny bushes, and grass, and that some of the stećci were partially or completely sunken into the ground. Based on the configuration of the terrain, it can be assumed that their number may be greater. The stećci are exposed to accelerated deterioration due to the lack of regular maintenance. Plant organisms (lichens and moss) are present on the monuments and contribute to the deterioration of the stone structure, while the sunken stećci could not be technically documented. The decision also identifies specific risks, such as the disintegration of the site due to long-term neglect, adverse atmospheric influences, and the spread of spontaneous vegetation [19].

When it comes to the protection of necropolises that have been proclaimed national monuments of Bosnia and Herzegovina, the Government of Republika Srpska is obliged to ensure legal, scientific, technical, administrative, and financial measures for the research, protection, conservation, and presentation of the national monument [17], [19]. At the same time, the Commission to Preserve National Monuments of Bosnia and Herzegovina is responsible for determining the conditions and providing funds for the preparation and installation of an information board containing the basic information about the monument and the decision proclaiming the property a national monument[17], [19].

For the purpose of the permanent protection of the national monument, Level I and Level II protection regimes have been established. Within the Level I protection regime, the prescribed measures include: the prohibition of any construction activities; the enclosure of the national monument with a hedge; the clearing of the parcel of self-grown vegetation; the undertaking of archaeological investigations of the graves; and the implementation of conservation works on any human remains that may be discovered. Furthermore, it is necessary to ensure the preparation and implementation of a programme for the presentation of the national monument. The monument area should remain open and accessible to the public and may be used for educational and cultural purposes. The Level II protection regime applies to the area within a radius of 50 m around the necropolis. Within this zone, it is prohibited to carry out activities that could alter the area or change its ambient character, and the disposal of waste is not permitted [17].

The Pavlovac necropolis is located in the municipality of East Ilidža, on Pavlovac Hill in Kasindo, and represents an example of an urban necropolis that has been almost completely destroyed due to human negligence (Figure 4). The site once contained a necropolis with 28 stećci (22 chest-shaped and 6 gabled monuments) and the monuments were very well carved, although they were damaged, partially sunken into the ground, and overgrown with forest. [18].

The necropolis itself has considerable historical significance because it is associated with the noble Pavlović family, from which the name Pavlovac is derived. Its importance is further emphasized by the assumption that the largest stećak belongs to the nobleman Pavle Radenović, a prince from the Pavlović noble family [18]. It is also important to note that the necropolis is located near a medieval caravan route that led from the Sarajevsko polje along the valley of the Prača River and further through the Drina region toward Dubrovnik, which was the main trading centre of the time.



Figure 4. The Pavlovac necropolis (photo Lukić Tanović M.)

The destruction of the necropolis began in 1980, when it was relocated by the Yugoslav People's Army for the purpose of constructing a military training ground. One part of the stećci was moved to the site of Donje Mladice, while another part was relocated to Krupac. Only the largest stećak, believed to belong to Pavle Radenović, remained at the original site, most likely because its weight made relocation impossible. This stećak has a volume of 11.40 m³ and a weight of 31,920 kg, making it the largest known stećak [18]. The relocation of the stećci was carried out under professional supervision, specifically under the supervision of the then City Institute for the Protection and Use of Cultural-Historical and Natural Heritage. However, the irresponsible attitude toward the relocated stećci, both by the local population and by municipal and city authorities, led to their almost complete destruction. The stećci that had been placed at the secondary site of Donje Mladice were further damaged during the construction of a hotel at that location, after which they were returned to the original site, where they remain today in very poor condition. The results of the analysis of anthropogenic impacts on the three aforementioned necropolises are presented in Table 2.

Table 2. Indicator scores for the assessment of anthropogenic vulnerability of the Pavlovac, Krupac, and Crnač–Donji Kotorac necropolises

Indicator/Site	Pavlovac	Krupac	Crnač – Donji Kotorac
Authenticity	0.25	0.5	0.5
Level of protection	0	0.75	0.75
Threat from roads/traffic infrastructure	0.75	0.25	0.25
Urban-construction pressure	0.5	0.5	0.25
Threat from landfills	0.5	0.5	0.5
Threat from economic and development activities	0.75	0.25	0.25
Tourism pressure	1	1	1
Neglect and lack of maintenance	0	0.5	0
Impact of social factors: vandalism, theft	0.25	1	1
Level of awareness of the local community	0	0.5	0.25
TOTAL SCORE	**0.40**	**0.58**	**0.48**

Based on the overall indicator scores, the Pavlovac and Crnač necropolises are classified as sites with high vulnerability, while the Krupac necropolis falls within the category of moderate vulnerability. Among the analyzed sites, Pavlovac represents the most vulnerable necropolis, with a score of 0.40, whereas Krupac shows the lowest level of vulnerability (0.58), indicating that it is the least affected by anthropogenic impacts. The high vulnerability of the Pavlovac necropolis can be attributed to the fact that the site is unprotected, completely neglected, and poorly maintained. Awareness of the significance of this cultural site among the local community is entirely absent, as the site is frequently used for waste dumping. In addition, the authenticity of the necropolis has been severely compromised due to dislocation, and a high level of vandalism has been recorded. On the positive side, the Pavlovac necropolis is exposed to a low level of threat from economic and development activities, as well as from roads and traffic, due to its location on the outskirts of the city, at the transition to a rural area.

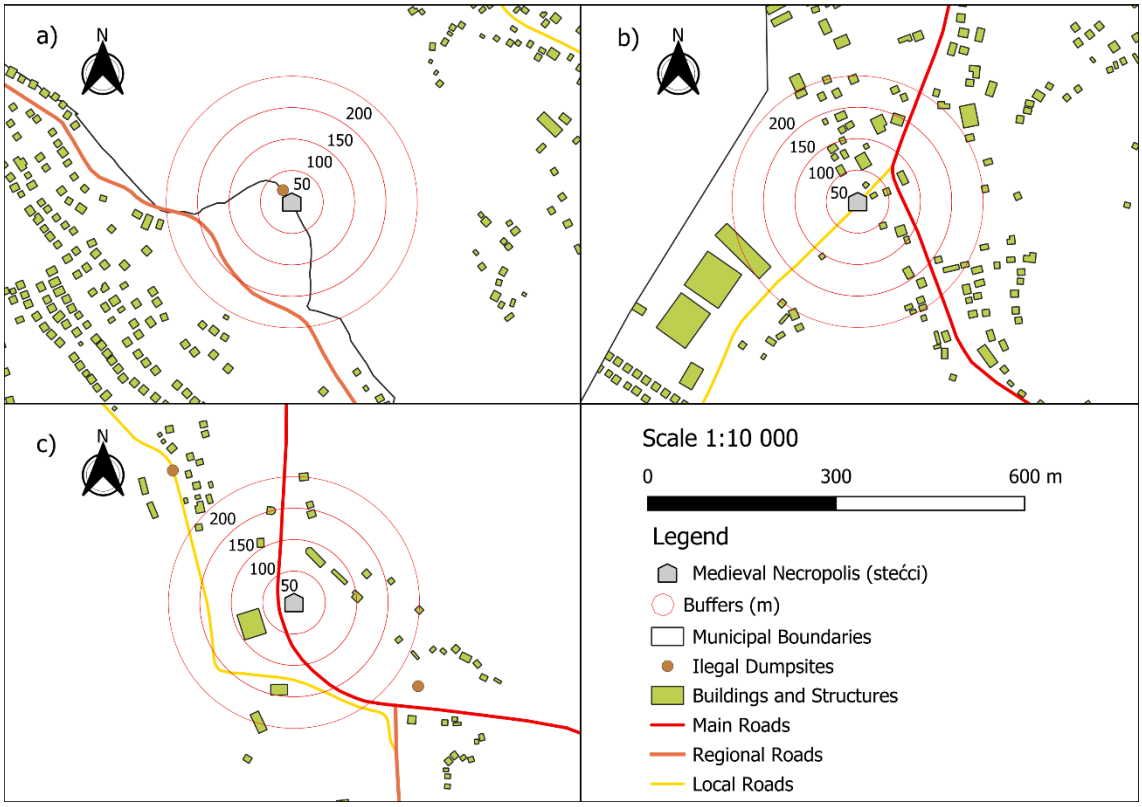


Figure 5. Buffer zones and surrounding anthropogenic features of the stećak necropolises: a) Pavlovac; b) Crnač; c) Krupac.

The Crnač necropolis, classified as high vulnerability, benefits from a high level of protection but is primarily threatened by urbanization. The site is particularly affected by roads, as a local road cuts through the necropolis. In addition, there is substantial urban and construction pressure, and the site is exposed to a high level of threat from economic and development activities. Although the Crnač necropolis is a national monument of Bosnia and Herzegovina, it is completely neglected and poorly maintained, and local community awareness of the significance of this cultural and historical monument is low. The least vulnerable necropolis is Krupac, which, according to the vulnerability indicator scores, falls into the category of moderate vulnerability. Its relatively higher overall score is since the necropolis is better maintained, is not exposed to vandalism or theft,

experiences no tourist pressure, and benefits from a high level of protection as a national monument of Bosnia and Herzegovina. The main threats to this site, however, are its proximity to roads and exposure to economic and development activities.
It is also important to note that none of the three analyzed necropolises have fully preserved their authenticity, primarily due to the dislocations mentioned earlier. Finally, all three necropolises received a score of 1 for the tourist pressure indicator, indicating that they experience no tourist pressure and are therefore not threatened in this regard. This can be seen as a drawback rather than an advantage, since, as part of the cultural heritage, these sites should be incorporated into the tourism offerings of the City of East Sarajevo.

CONCLUSIONS

As indigenous medieval monuments, stećci hold great cultural and historical significance. However, insufficient efforts have been made in Bosnia and Herzegovina to protect and promote stećci for tourism. These cultural monuments are exposed to various natural and anthropogenic impacts. Anthropogenic pressures, such as urbanization, unplanned construction, pollution and waste disposal, road infrastructure development, and economic activities, can negatively affect cultural heritage.
The analysis of the vulnerability of three stećak necropolises in the area of the City of East Sarajevo—Crnač in Donji Kotorac, Krupac, and Pavlovac—revealed a significant degree of vulnerability. According to the research results, the Pavlovac and Crnač necropolises are classified as sites with high vulnerability, while the Krupac necropolis falls into the category of moderate vulnerability. Based on the analysis of indicators measuring anthropogenic impacts—such as exposure to roads, urban and construction pressures, and threat from economic and development activities—the Crnač and Pavlovac necropolises are particularly threatened.
Although formally protected as national cultural monuments, the Crnač necropolis shows clear signs of neglect and poor maintenance. The most vulnerable site is the Pavlovac necropolis, which lacks protection, is almost entirely neglected, and largely devastated. The regular disposal of waste at this location reflects a complete lack of awareness among the local community.
The analysis also showed that all three sites experience no tourist pressure, indicating that they are not utilized as tourist attractions for the development of cultural tourism. In this regard, measures should be undertaken to protect and preserve these necropolises, as they represent significant cultural heritage with considerable tourism potential.

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TRENDS IN TOURISM EMPLOYMENT IN SERBIA – HIGHLIGHTING THE GENDER DIMENSION

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ABSTRACT

Tourism employees face multiple challenges related to job stability, irregular working hours, seasonality, and wage adequacy. Nevertheless, according to the NACE Rev.2 classification, the number and share of persons employed in tourism industries in Serbia have been rising in recent period, except during the COVID-19 pandemic. Given the noticeable gender divide, the aim of this paper is to shed light on tourism employment trends for men and women across different tourism sectors. We use annual data from the Labor Force Survey to assess current trends in tourism employment by sex in Serbia for the period 2010–2024, with particular focus on 2020, which was severely affected by the pandemic. Overall men's participation in tourism employment was almost double that of women during the analyzed period, with the greatest differences observed in land transportation (6 times on average), more than double in case of sports activities, amusement and recreation activities, but also air transport and creative, arts and entertainment activities (1,8 times each). Women represented 1,4 times more employed than men in accommodation, 1,7 times in activities of travel agencies and 1,4 times in libraries, archives, museums and other cultural activities. The similar employment pattern is detected in food and beverage service activities and fairly same number in gambling and betting activities. Employment fell in 2020 for both sexes, but women maintained greater labor engagement, as the number of female employees decreased less during the pandemic. The vulnerability of tourism market employees is multifaceted, and the gender dimension in Serbia highlights that women employed in the tourism sector demonstrated greater resilience in pandemic years.

Keywords: tourism, employment, gender, COVID-19, Serbia

INTRODUCTION

Tourism industry offers versatile possibilities for the employment, not only direct, but also indirect and induced, with varying tourism income multiplier. Researching tourism employment is a difficult task when compared to the other industries because it is characterized by seasonality, unsteady working hours, inadequate pay for family labor and informal or even illegal labor. Additional challenge is related to the rapid turnover of the staff that is closely related to the difficulties in climbing the corporate ladder and getting low pay while working late shifts and/or during weekends and/or holidays [1]. Seasonality can play important part in the decision to stay in tourism industry, as shown in Grobelna and Skrzeszewska [2] who analyzed perceptions of the students engaged in tourism industry and concluded that seasonality may relate to their employment aspiration after graduation. There is another important divide between more or less developed

countries, as tourism is regarded as more luxury associated behavior with expected high-quality products in countries with higher economic power, while in developing countries is more related to the economic development and poverty reduction [3]. Melián-González and Bulchand-Gidumal [4] tried to give an answer to the question whether the tourism development is associated with employment of low quality and concluded that institutional regimes play important role in improving the low quality of tourism occupations. Alongside the mentioned issues, Aynalem, Birhanu and Tesefay [5] also highlight the important factors for greater turnover in tourism employment: low education and training, undemocratic and rigid corporate culture, discrimination, sexual harassment and political instability. When summarizing the literature review on tourism and employment opportunities in developing countries, Mishra and Kaur [6] put emphasis on local residents, lack of training possibilities and need for proper education, but stress that poor pay and gender bias are characteristic for all countries regardless of their economic development.

Supplementary to the "gendered employee" and "gendered power" perspective [7], two important theoretical frameworks describe the female tourism employment, according to Obradić and Marić [8]:

- pyramid shape of female tourism employment, given that women occupy sessional and part-time jobs (bottom of the pyramid), while only few get to the managerial top positions (Richter)
- two-way segregation: horizontal - women occupy less paid jobs as receptionists, waitresses, room attendants, cleaners, travel agency sales persons; and vertical -men occupy key managerial positions while women are prevalent in posts with less influence (Parrett)

It has been documented that such wage discrimination and "occupational crowding" exist in Portugal where tourism employment means low wages, unsteady job and high feminization, followed by weak horizontal and pronounced vertical segmentation [9]. Recent literature review [10] revealed persistence of gender divide in tourism as women are still mostly in frontline service roles and men are mostly in leadership positions, which can be followed in six key themes: leadership barriers, work-life balance constraints, sociocultural norms, gender pay gap, limited career development and ineffective diversity policies. Alacron and Mulor [11] summarized five key issues in the gender analysis of tourism work: informal and precarious work, criteria for the selection of the labor force, wage gap and sexual harassment at work. While women easily enter into tourism labor market, they have harder time in getting in higher responsibility and pay positions, especially if their careers are interrupted by fertility intentions, making it important to create "develop women-friendly" policies [12]. As a consequence, women in tourism are "still underpaid, under-utilized, under-educated, and underrepresented" [13].

The importance of tourism activity is closely related to two Sustainable Development Goals: 5th – "Achieve gender equality and empower all women and girls" and 8th – "Decent work and economic growth" and their mutual relationship can be of utmost importance. Providing "the sustained, inclusive and sustainable economic growth, full and productive employment and decent work" in case is tourism is conceptualized as a Target 8.9 - By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products. The indicator that is used for the assessment of the development is - Indicator 8.9.1 Tourism direct GDP as a proportion of total GDP and in growth rate. This enables the continuity in the statistical monitoring of the tourism development, and as tourism industry is very sensitive activity, it is possible

to document the recent shock induced by the COVID-pandemic. Historically, in 2020 tourism sector was hit with the worst crisis as tourism's contribution to the global economy fell from 3,8% of GDP to only 1,8% in 2020 [14].

Since "there is no role, position, activity or process within tourism system that is immune to specific gender relations" [15], in order to achieve the targeted development in tourism, it is important to include the gender dimension, as tourism employment in heavily dependent on the female labor force. When giving the research context for the women empowerment in tourism work (Global Report on Women in Tourism) [16] discussed low-status jobs, gender stereotyping, informal employment, exploitation and decent work. Second Edition of the report [17] shifted the focus on possibilities and the Sustainable Development Goals, connecting them to the five important domains: employment, entrepreneurship, education and training, leadership, policy and decision making, and community and civil society.

Additionally, many other issues prevail, especially in terms of female entrepreneurship as literature review conducted by Figueroa-Domecq, Jong and Williams [18] showed that researchers are focusing on certain tourism industries, such as hotels and restaurants, compared to technology or management. There is also geographical divide, as more articles were from Global North and rural settlements, suggesting that women are not equally represented in research (and employment) in higher positions, less developed countries and urban areas. Obradić and Marić [8] put stress on Central and Eastern Europe, asking the important question – did tourism play important role in ex-communist societies for women employment, as unemployment rocketed during the transition? The conclusion is that both young and old, single mothers or divorced were able to find employment in tourism sector, a for some even meant starting their own business.

Still, it is an irrefutable fact that gender pay gap exists in the tourism sector [19], given that men would get bigger pay for equivalent work, something that also holds for Serbia as women's earnings as percentage of men's earnings is 94.69% in accommodation and food services [17]. This is to be expected, as Gajić and Ivkov Džigurski [20] showed that gender employee structure in Vojvodina consisted of 68% women and the young, emphasizing pay gradient for different tourism sectors (the biggest wages in airport subsector and the lowest in hotels subsector). Garača et al. [21] concluded that existence of gender inequality exists when it comes to hotel employment in Vojvodina, as 4/5 of their respondent believes that certain jobs are only for men (waiter, carpenter, locksmith, electrician, chauffeur, security), while others are just for women (cook, maid, hotel hostess, cleaning lady, receptionist) stating the reason for such opinion "the nature of business". Still, there is a reason for the optimism, as the recent study revealed the possible cracks in so-called glass ceiling in the hospitality industry in Serbia, Croatia, Montenegro, and Bosnia and Herzegovina [22].

The goal of this paper is to encapsulate the sensitivity of tourism sector by using appropriate gendered tourism statistics in order to shed a light on tourism employment trends, but with special focus on gender dimension in Serbia for period 2014-2024. Since COVID-19 pandemic was great challange not only in medical sence, but also in many societal spheres, one of our research question integrates the severity of flop in employment trends in tourism in 2020 and 2021. In second part of the paper we describe the data sources and internationally comparable data from eurostat database we will be using in our research, and the methodological challanges in defining tourism employment. In third part of the paper, we focus on results from our study, highlighting the gendered tourism statistics in Serbia. In conclusion and disscusion, we focused on

importance of gender in trends of tourism employment and rebounce of women employment after COVID-19.

DATA SOURCES

While trying to define tourism employment, we encounter many obstacles, as it is quite hard to abstract only those employees directly involved in tourism activities. While hotels, restaurants, tour guides, travel agencies, and transportation services are the primary sources of employment in the tourism industry [3] it is hard to statistically capture only those employed in tourism industry. Alongside the challenges that stem from the seasonal variability on the job market, obstacles to define the "tourism employee" is further amplified in the effort to collect timely and high quality statistics of the tourism employment. According to the UNWTO [1], it is possible to overcame this by using one of the three major groups of data sources for (1) measuring labor demand, (2) measuring labor supply or (3) administrative records. For the purpose of our research, we will be consulting widely used and cross-national comparable survey on labor force which is household-based sample survey that falls into second category - Measuring labor supply. Since ILO [23] gave country specific data sources for employment in tourism industries, as recommended in case of Serbia, we are using Labor force survey (LFS) as main data source. The branches of economic activity (industry) at the time of this report was published were presented through NACE, rev. 1 classification. It is important to make a connection between old and new classifications, as nowadays NACE, rev. 2 is in use, we have to "translate" industry groups covered by NACE rev. 1 to NACE rev. 2. This is closely relating to the UNWTO [17, 24] categorization of tourism industries that typically produce characteristic tourism products and activities, and it is equivalent to the more colloquial term 'tourism sector'. Since we need data segregated by gender structure from Labor Force Survey, we will be using certain tourism sector categories more widely, namely:

1. Accommodation for visitors relates to I55
2. Food and beverage serving activities - I56
3. Railway passenger transport - H49
4. Road passenger transport - H49
5. Water passenger transport - H50
6. Air passenger transport - H51
7. Transport equipment rental - N77
8. Travel agencies and other reservation services activities - N79
9. Cultural activities - R90, R91
10. Sports and recreational activities - R92, R93
11. Retail trade of country-specific tourism characteristic goods; and
12. Other country-specific tourism characteristic activities.

For the purpose of this research, we used few data sources in order to answer the research question. The data are characterized by certain inconsistencies that we addressed in discussion. We obtained annual 2010-2024 for men and women in respective tourism sectors from Labor Force Survey [25] as a main source, but also we took data that are not gendered in order to follow the overall trend in tourism employment. These data include employment statistics from UNWTO [26] and Business demography by legal form [27] from Eurostat in order to capture the most direct employment in tourism sectors, as these data offer greater details in terms of classification, but are poor in terms of timeframe.

RESULTS

Depending on the data source, the number of employees in tourism sector varies, as the different subsectors can be viewed as those related to tourism activities. Even though the data for Serbia in UNWTO [26] exist, it is not gendered, making it important only for the overall summation of employment trend in tourism industry. According to this data source, the number of employees in tourism industries (Figure 1) has been on steady upward trend in period 2015-2023. In 2015, contingent of tourism employees encompassed 135 411 workers, and rose to the 178 516 in 2023. The highest relative increase between two years was 7% in 2018/2017, and during the period 2021/2020 there has been the same level of tourism employment in Serbia. Still, the recuperation is evident, as last available data shows 5% increase in 2023/2022.



Figure 1. Employed persons in the tourism industries, Serbia, 2015-2023 Source: UNWTO [26]

The data from business demography statistics from Eurostat (2022) shown in Table 1 reveal through 2-digit classification that tourism employees in Serbia are predominantly engaged in land transport and food and beverage services (around 75 thousand each). It is notable da less tourism employees are engaged in rest subsectors compared to most prominent ones. Around 14 thousand tourism jobs were occupied in accommodation and less than 4 thousand in travel agency and tour operator services. The data are available for only two years, making is hard to spot a trend, but still we can conclude that high steadiness exist between data sources. Unfortunately, these source does not offer data broken down by gender, which limits the analysis. Still, we can conclude that high resemblance of values from both UNWTO and Eurostat for overall tourism employment.

Table 1. Persons employed in selected tourism industries, Serbia, 2021 and 2022, business demography

	2021	2022
Land transport and transport via pipelines	75390	74991
Water transport	1071	1010
Air transport	1489	1618
Accommodation	14063	14340
Food and beverage service activities	75857	74328
Rental and leasing activities	2773	2897
Travel agency, tour operator and other reservation service and related activities	3975	3755
Total	174618	172939

Source: Eurostat [27]

Even though the more detailed data are from Labor Force Survey [25] depicted on Figure 2. showing the number of employees in various tourism subsectors, there is no classification beyond the 2 digits NACE rev. 2, so we are unable to get the most accurate picture. This means that used data source includes some of the employees that are not directly connected to the tourism sector, even though most of them work in service industries. The biggest subsector in terms of employment is Land transport and transport via pipelines, with a bit more that 100 thousand in 2024. By comparing these data with previously analyzed trends from Eurostat [27], we conclude that ¼ more employees from this subsector encompassed through household based labor survey than business demography source. This gives us corrective factor, which is important to adequate conclusions. Before the COVID-19 pandemic, there has been steady rise in number of employees in land transport (except for 2015/2014), but after the pandemic and 2020/2019 fall, we can observe the notable rise in 2021/2020 and then 2-year falling. Only the last available data show that in 2024 compared to 2023, we are witnessing greater employment. When we consult the data on employees in different transportation means, we conclude that land transportation succeeds by far in terms of number, as there is only around 3 thousand employees in water transport and 6 thousand in air transport on average in period 2010-2024. Both are characterized by pronounced fluctuations in terms of labor participation, which can be also seen in pandemic period.

The second largest subsector is reserved for Food and beverage service activities, as last available data shows that around 80 thousand people are engaged in this subsector, and when we compare with number we already encounter in Table 1 for years 2021 and 2022, the values are almost exact match. Unlike the land transportation subsector, the food and beverages services is much more sensitive to the economic turbulence, as the number in this subsector fell in the period after the world economic crisis in 2008. Biggest rise was in 2015, when 27% more employees were recorded compared to previous year. On the other hand, COVID-19 pandemic had tremendous impact on this food and beverage subsector, as the number of employees fell for 11,2% in 2020 compared to 2019. The employment in this subsector remain in this "pandemic number" of around the 75 thousand, and just in 2024 rose for 5% compared to previous years.

In the Accommodation subsector there is also great accordance in the numbers of employees from different sources, as they are quite close. This subsector seems to be the most sensitive to external factors, as it shows greater fluctuations than previous two analyzed. After three years of similar employment, in 2013 it is recorded the great fall for 40% and then year after that great rise of 30%. Even more drastic situation happed in next years, with constant variations, with interesting fact that even though in first pandemic

year the number of employees fell for 16,5%, this is not the greatest difference between years in whole time series. Still, the biggest rise was recorded between 2021 and 2022 (40%).

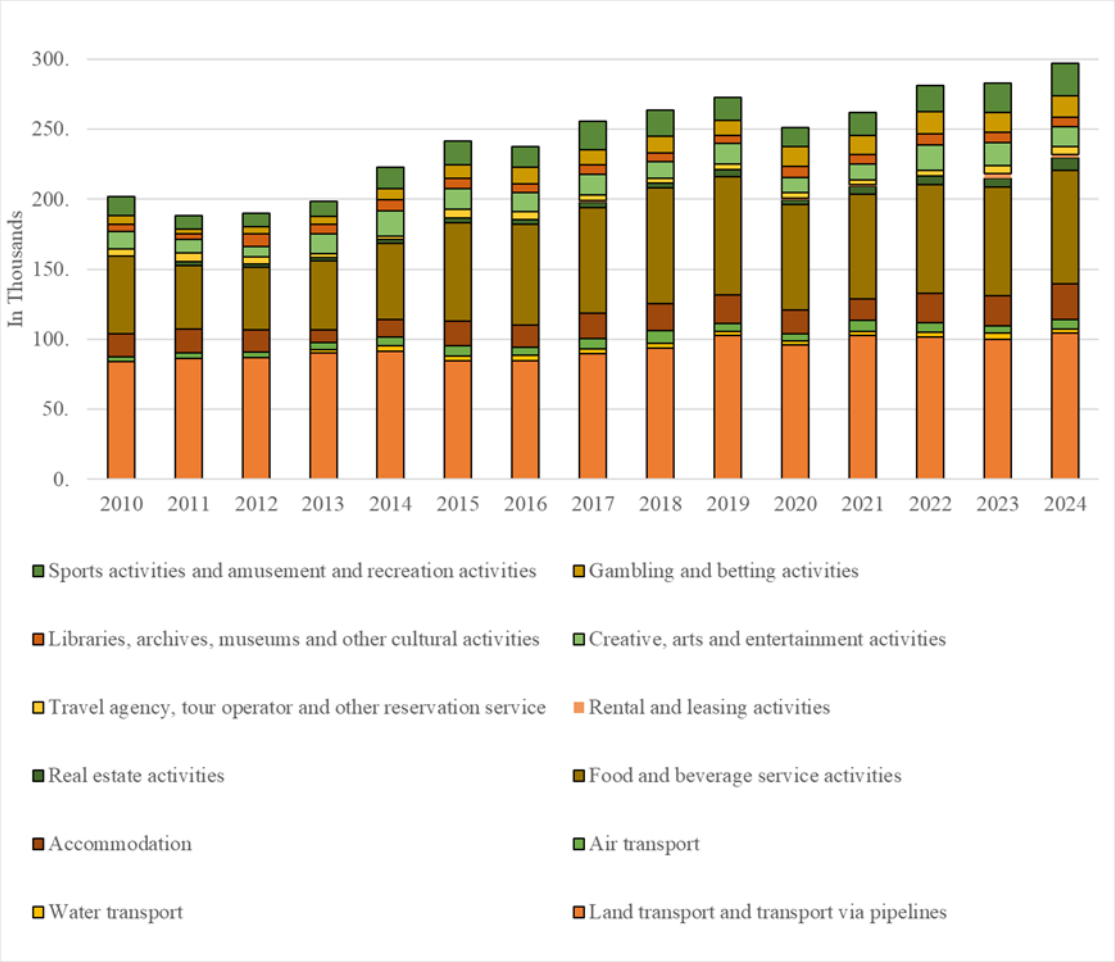


Figure 2. Employed persons in the tourism industries by subsectors, Serbia, 2010-2024 Source: LFS [25]

When it comes to the travel agency employment, the average number in period 2010-2015 was 4,7 thousand, but with quite pronounced fluctuations that are not following simple trajectory. The same situation is for subsectors connected to the culture and art related employment, where on average worked 13,5 thousand employees in Creative, arts and entertainment activities and 6,8 thousand in Libraries, archives, museums and other cultural activities. On the other hand, in the tourism activities close to sports, there are 16 thousand employees on average in Sports activities and amusement and recreation activities and 10 thousand Gambling and betting activities. The greatest relative increase in found in Gambling and betting activities between 2010 and 2024, with more than doubling the number of those engages in this subsector (139% increase).

In order to dive deeper into gender perspective in tourism employment in Serbia, the visual inspection of Figure 3. gives us an adequate glimpse. It is important to add that in case of some subsectors (water transport, real estate and rental and leasing activities) we don't have continuity in gender statistics, so we omitted them from the analysis. There is a pronounced difference in number of males and females engaged in tourism industry in Serbia, but with great differences between various subsectors. The greatest one is spotted

in land transportation, as more than six times higher male employment was recorded on average for period 2010-2024. This is main reason for overall difference in gender employment, because the other subsectors have much more balances ratios. The other subsectors characterized by predominance of males are air transport and creative, arts and entertainment activities (1,8 times each) and more than double in case of sports activities and amusement and recreation activities. On the other hand, there is 1,4 times more employed women than men in accommodation, 1,7 times in activities of travel agencies, 1,4 times in libraries, archives, museums and other cultural activities. The similar number are seen in food and beverage service activities, with a bit more males included in this subsector and fairly same number in gambling and betting activities.

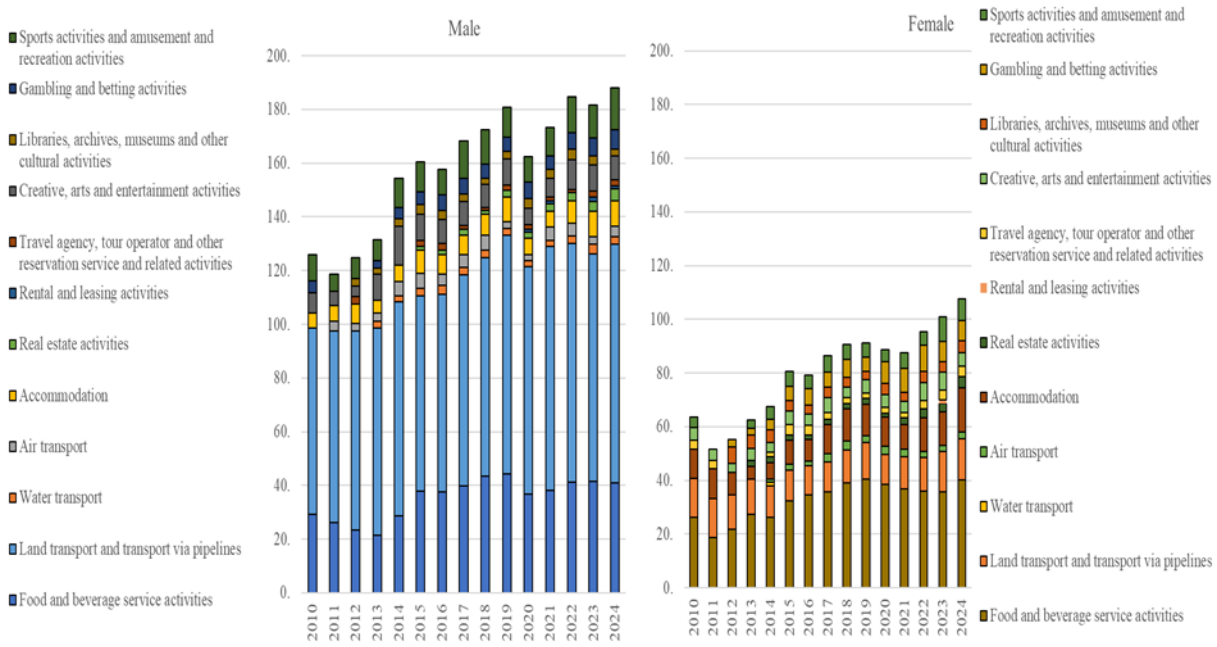


Figure 3. Employed persons in the tourism industries by subsectors by sex, Serbia, 2010-2024
Source: LFS [25]

There is an absolute difference in number of employees by gender in different subsectors, but land transportation had stunning divide, as average number in 2010-2024 for men are 80 thousand and for women 12,8 thousand. For air transport, there is on average 4 thousand man and 2,5 thousand women employed in this industry. In sports activities and amusement and recreation activities, there is pronounced gender divide, as around 10,8 thousand men and 5,5 thousand women work in this subsector. Similar is in creative, arts and entertainment activities with involved 8,7 thousand men and 4,8 thousand women. On the other hand, there is more women employed in accommodation subsector compared to men (10,3:7,3), travel agencies (2,9:1,8) and cultural posts (4,1:3,0). Vaguely the same numbers exist in food and beverage services, around 35 thousand men and 32.6 thousand women, gambling and betting services (5,3 thousand man and 6,1 thousand women).

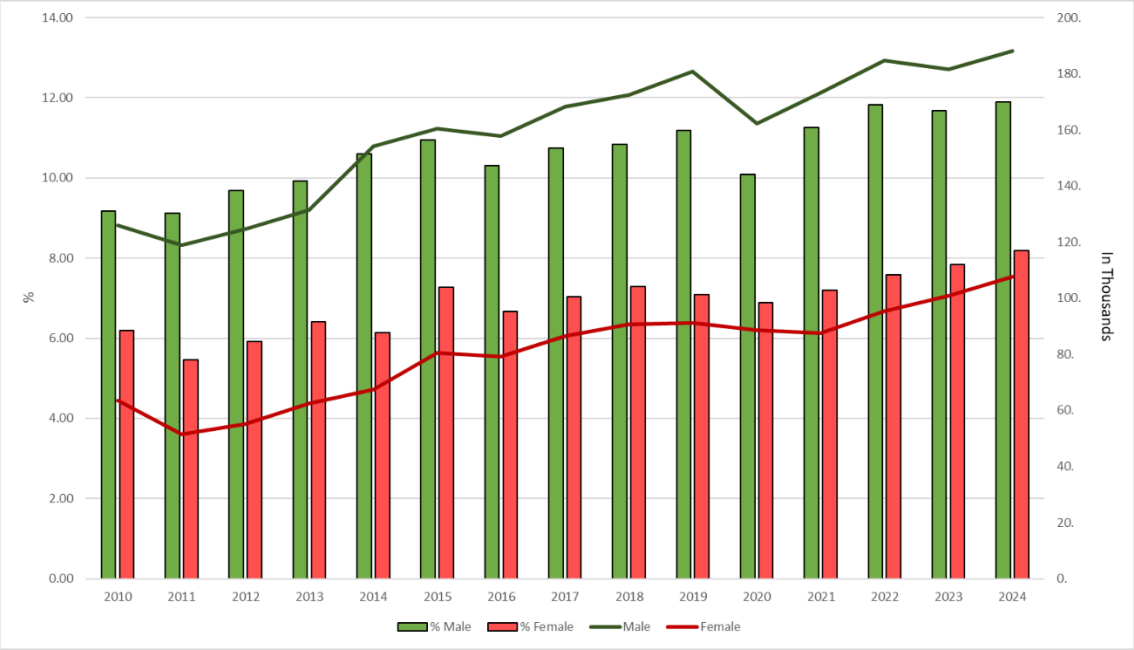


Figure 4. Number and share of employed persons in the tourism industries by sex, Serbia, 2010-2024
Source: LFS [25]

In order to capture the different employment vulnerability in tourism sector in term of gender during the COVID-19 pandemic, we will consult the data on overall male and female tourism employment, but also the shares of tourism employment in total number of employees of different gender. It is evident (Figure 4) that there is greater number of men engaged in tourism activities as we have already states, but it is interesting to stress that number and share of men employed in tourism experienced much more pronounced fall during the COVID-19 compared to women. While number of men employed in tourism industry decreased from 180 thousand in 2019 (11,2%) to 162 thousand in 2020 (10%), in case of women we have much steadier situation, as number fell from 91 thousand in 2019 (7%) to 88,6 thousand in 2020 (6,9%).

DISSCUSION AND CONCLUSION

The foundation for the gender research in tourism were set few decades ago, as Byrne Swain [28] stated in 1995 that "gender, as ideology and as relationships between the sexes, is a primary factor in human interactions, and is thus an important aspect of future tourism social science". Following rich literature in this topic, our objective was to give overview of tourism employment trends and to put into perspective gender structure of tourism employes in Serbia, using national statistics that can be comparable between countries. The findings from UNWTO [17] reveal that out of all tourism employees, 54% are women compared to 39% in broader economy. In case of Serbia, we are encountering different situation as, 2/3 of tourism employees are men, while in broader economy we have much more balanced shares (56% men and 44% women). This is showing that country specific situation exists, and thus calling for further future investigation. Given that women are predominately in lower pay and subordinated jobs as theory suggest, it is intriguing thought whether women in Serbia on purpose avoid tourism related jobs.

Importance of female engagement in tourism industries is closely related to many demographic aspects since fertility decision often make career gaps that puts women in unequal position. Also, education can play crucial role in preparation of future employees in tourism, and since more girls are involved in tourism studies, it is important to distinguish how this translate to less numbers of female tourism employees in Serbia. Still, it is important to stress that tourism plays great role in process of women empowerment, but we have to have in mind that women are "often concentrated in low-skilled or informal work, which affords them less access to social protection and puts them in a precarious position during a global pandemic" [29]. Tourism was one of the most heavily affected of all sectors [14] so the paper also places special emphasis on the significant health and economic shock caused by COVID-19, which had a disproportionate impact on the labor force by gender because women suffered smaller "employment shock" in Serbia.

When analyzing the gender "divide" in tourism industries, we found that jobs related to the traditional household maintenance are those where more women are employed, as suggested by Alarcón & Mullor [11]. There are more women employed compared to men in accommodation, travel agencies and libraries, archives, museums and other cultural activities. On the other hand, traditional male occupations are reinforced also in tourism sector, such as drivers, pilots and those jobs related to sport. The equality in tourism employment by gender is found in food and beverage service activities, which partially deviates from the theoretical expectations. Still, the traditional gender roles that persist in household division of work, namely outside the employment sphere, seems to have penetrated into the employment patterns in tourism sector in Serbia.

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FROM DIVERSITY TO HOMOGENIZATION - THE RISE AND DECLINE OF ETHNIC FRACTIONALIZATION IN SERBIA

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ABSTRACT

Research on the ethnic composition of population is gaining increasing importance in many countries, particularly in the context of immigration countries that often receive ethnically diverse populations. In contrast, countries facing negative demographic trends, such as emigration, low fertility rates, and advanced population ageing, frequently experience a decline in ethnic diversity and a shift toward ethnic homogenization. The analysis is based on census data used to calculate the Ethnic Fractionalization Index to identify current trends in ethnic diversity in Serbia. The results indicate that the population of Serbia is undergoing a reduction in ethnic diversity, reflecting a deepening process of ethnic homogenization due to unfavorable demographic processes. The significance of this study lies in its relevance for minority policy development and for a broader understanding of the position of minority communities within society, particularly in the context of long-term demographic change.

Keywords: Ethnic fractionalization, ethnic diversity, Serbia, homogenization, ethnic fractionalization index

INTRODUCTION

Although many scientists once assumed that the question of ethnicity in contemporary societies would become obsolete, recent trends suggest the opposite. The analysis and collection of data on ethnic affiliation remain a central feature of many societies of the world and support for this hypothesis has become increasingly prevalent in recent literature [1], [2]. Ethnic structure represents a key dimension of social heterogeneity. Ethnically diverse societies often face significant challenges in fostering social cohesion among different ethnic groups, as well as concerns regarding whether such diversity may contribute to broader social and political instability. In addition to managing interethnic relations, ethnically diverse states also confront issues of economic cohesion, especially in relation to the social position of ethnic communities, the presence of discrimination or inequality, which is important for formulation of minority and other public policies.
Most contemporary research examines ethnic diversification from the perspective of developed countries, particularly those characterized by high levels of immigration [3], [4], [5], [6], [7], [8]. A dominant focus of this literature is the impact of ethnic diversity on the socio-economic development of states [10], [4], [9], [11]. In addition, a substantial body of research addresses the relationship between ethnic diversity and political processes, including democratic stability [12], [13], [14]. Only a limited number of studies examine the role of ethnic diversity in less developed or developing regions [15],

[16], [10], [17]. The smallest share of research focuses on regions characterized by emigration processes and persistently negative demographic trends. This gap is particularly evident in the Balkans, where research on ethnic diversification and its dynamics remains scarce [18]. This issue is especially relevant in the context of Serbia, a country marked by long-term negative demographic trends and a declining population over recent decades due to low fertility rates, negative natural increase, sustained emigration, and deepening population ageing [19]. In addition, it is important to note that Serbia is a multi-ethnic, multi-confessional and multilingual country. Overall, this raises an important question: how do negative demographic trends affect general ethnic diversity in the country? Given the region's complex historical heritage, this question is of particular significance.

Ethnic fractionalization, which lies at the core of this study, is most measured using census data. However, the use of census statistics entails significant methodological limitations, including frequent changes in classification and nomenclature on national affiliation, shifts in ethnic categories, variations in self-declared ethnic affiliation, and overall data volatility, both statistically and in terms of the inclusion or exclusion of specific categories across census rounds [20], [21], [22]. These factors reduce the reliability of ethno-statistical data and require caution in their application. This is especially important given that ethno-statistics constitute the primary quantitative basis for the formulation of minority policies [22].

The main objective of this paper is to analyze long-term trends in the ethnic fractionalization index, which represents one of the most widely used measures of ethnic diversity [23], [24], in Serbia from 1948 to 2022. In addition to analyzing changes in ethnic fractionalization across successive censuses, the study explores the underlying drivers of these transformations and identifies the key demographic and socio-political factors that may have influenced them. In this way, the paper contributes to a deeper understanding of the complex processes shaping the decline of ethnic diversity in this region, particularly within developing regions characterized by adverse demographic trends, that have remained underrepresented in the existing literature. Beyond its academic contribution, the findings of this study also have practical relevance, as they may serve as a foundation for the more informed design and implementation of minority policies.

LITERATURE REVIEW

As previously noted, ethnic diversity represents a highly dynamic component of population dynamics, with a major methodological challenge arising from the definition and categorization of ethnic or, in some cases, racial affiliation, depending on the focus of the research. It is widely recognized that no universal definition of ethnicity exists, resulting in clear limitations in its conceptualization and in the interpretation of related data. Ethnic affiliation is therefore most understood through its multidimensional nature, as it does not constitute a static attribute but rather forms part of an individual's broader identity [25], which is very important for implication of understanding ethnic diversity.

As a result, a central question in many studies of diversity concerns the impact of ethnic fractionalization and ethnic polarization on a country's overall development, as well as the conceptual distinction between these two phenomena and the appropriate methods for measuring diversity. The Ethnic Fractionalization Index captures the degree of "fragmentation" within a system, whereas polarization indices measure the distance

between two distinct groups, often conceptualized as opposing extremes, within that system. In recent years, increasingly sophisticated measures of ethnic diversity have emerged that move beyond these two traditional approaches [26], [27], [27], [28].

Apart from papers which are focused on measuring diversity, a substantial body of research has focused on examining how ethnic fractionalization and polarization affect economic development. Empirical findings usually suggest a positive correlation between higher levels of ethnic fractionalization and slower economic growth. According to these studies, more ethnically fragmented states tend to exhibit lower GDP per capita and weaker overall economic performance, largely due to reduced social cohesion arising from many ethnic groups in the country [29]. This erosion of social cohesion negatively affects the functioning of state institutions. Ethnically heterogeneous societies more frequently face lower-quality public goods and services, often as a result of institutional distrust, inadequate integration frameworks, segregation, and high levels of discrimination. Consequently, the adverse economic effects of ethnically fragmented societies are most manifested through the insufficient performance of institutions and their limited capacity to respond to the needs of ethnically diverse populations [10], [4], [5], [30].

More recent studies increasingly emphasize a positive relationship between ethnically diverse societies and economic development, particularly in the context of ethnic fractionalization. Ethnic diversity is progressively viewed as a potential resource, as heterogeneous societies may foster innovation and strengthen market dynamics. This perspective is especially relevant for enhancing institutional capacity in ethnically diverse environments. Some studies conclude that such societies increase the adaptive capacity of their economies and contribute to long-term economic sustainability. In contrast, ethnic polarization is more frequently identified as a dimension of diversity that negatively affects economic development [9], [7], [11], [31]. An important conclusion emerging from this literature is that ethnic diversity per se does not constitute a developmental obstacle, rather, its economic effects are contingent upon the political system. Democratic regimes tend to be more successful in channeling ethnic heterogeneity in productive ways, whereas authoritarian systems often experience increased corruption in the presence of diversity and ethnic fractionalization [32].

In addition to economic outcomes, a recurring theme in the literature concerns the impact of ethnic diversity on political stability. A common hypothesis suggests that ethnically fractionalized societies are more prone to ethnic conflict and to racial, religious, or ethnic intolerance between groups. Many studies find that higher levels of ethnic fractionalization are positively correlated with increased political fragmentation. At the same time, the effects of ethnic diversity on democratic systems are multidimensional and cannot be readily characterized as inherently positive or negative. Moreover, numerous studies emphasize that linguistic, ethnic, and religious diversity may exert distinct influences, resulting in different democratic outcomes. A large portion of the literature suggests that where adequate democratic mechanisms are in place, stability can be maintained even in diverse societies, whereas weak institutional responses to pluralism constitute a major impediment. Thus, in highly democratic societies, diversity does not necessarily hinder development and may even reinforce democratic stability, however, deep societal polarization remains a key destabilizing factor [12], [13], [33], [34].

A number of studies focusing on less developed or developing regions conclude that high levels of ethno-linguistic diversity negatively affect socio-economic and political development [17], [35]. More recent research, however, challenges this interpretation,

arguing that the root causes of conflict and civil war in such regions are more often linked to unstable political systems, underdeveloped economies, and weak institutions rather than to ethnic or linguistic heterogeneity itself [16], [36]. Accordingly, ethnically diverse societies can achieve substantial economic progress under appropriate socio-economic and politically stable conditions [37], [38], [39].

As previously highlighted, a significant research gap remains regarding the study of ethnic diversity and ethnic fractionalization, particularly in the context of multiethnic regions such as the Balkans. This indicates considerable scope for expanding the discussion on ethnic fractionalization in regions characterized by demographic stagnation and decreasing diversity. One of the studies concludes that there is no direct correlation between the number of ethnic groups, the degree of societal fractionalization, and either economic or democratic stability, instead, the decisive factor lies in the capacity of political institutions to adapt to the specific organizational patterns of heterogeneous societies [40]. Similarly, research on the Western Balkans points to the absence of a clear and direct relationship between ethnic diversity and economic performance, suggesting that ethnic heterogeneity does not automatically result in poorer economic outcomes [41]. As follows, relatively few studies focus on demographically stagnant regions that are transitioning from ethnically heterogeneous to more homogeneous societies [18], while the majority of existing research concentrates on highly immigration-driven countries, where rising diversity is primarily shaped by the inflow of ethnically diverse migrant populations.

METHODOLOGY

The Ethnic Fractionalization Index, as a measure of ethnic diversity, originated in the early 1960s in the Soviet Union and was published in the Atlas Narodov Mira in 1964. It was conceptualized as an ethnolinguistic variable, calculated as one minus the Herfindahl–Hirschman Index of the shares of ethnolinguistic groups. This index represents the probability that two randomly selected individuals from a population belong to different ethnic groups [23], [24]. It is important to emphasize that such measures of ethnic diversity have inherent limitations, primarily because they often treat ethnic affiliation as a static component and fail to account for the fluidity of ethnic identity. As a result, they tend to overlook changes in ethnic modalities or in the classifications of national affiliation and consequently, data variability [42].

In this study, the ethnic fractionalization method is used through the calculation of the Ethnic Fractionalization Index, which indicates the degree of population homogenization or heterogenization by ethnic affiliation. The index is based on the population share of each ethnic group within the country and relies as previously mentioned on the Herfindahl–Hirschman concentration index (HHI), widely applied in economics. The Ethnic Fractionalization Index is calculated as follows:

$$EF_{ct} = 1 - \sum_{i=1}^{n} S_i^2$$

Where EF_{ct} denotes the level of ethnic fractionalization in country c at time t, and S_i represents the share of the population in unit c belonging to ethnic group i $(i = 1, \dots, n)$ at time t. The values of Ethnic Fractionalization Index ranges from 0 to 1. If the index is closer to 1, it indicates a more ethnically heterogeneous population, or contrariwise, if the

index is closer to 0, it indicates a more ethnically homogeneous population of a country. The period analyzed in this study covers Ethnic Fractionalization Index levels from 1948 to 2022, based on census statistics for the entire territory of Serbia.

The reliance on subjective self-identification of nationality in population censuses has become an important source of methodological constraints. This approach has resulted in shifts in ethnic classification frameworks and the emergence of phenomena such as ethnic mimicry, ethnic concealment, and so-called "floating ethnic groups," referring to individuals who repeatedly alter their declared national affiliation [42]. Such dynamics further complicate the analysis of demographic processes and the consistent classification of minority populations. Consequently, certain ethnic communities exhibit reduced data reliability due to pronounced variability in census reporting [20], [21], [22]. Census data therefore frequently reveals inconsistencies between self-declared ethnic identity and officially recorded classifications, representing a substantial challenge for the advancement of ethno-demographic research. This paper includes all ethnic communities (along with their respective shares of the total population) for which data was published in official census statistics.

RESULTS

The most dominant trend observed throughout the entire intercensal period is the almost continuous increase in the share of Serbs within the total population. Following an initial decline during the 1980s, the proportion of Serbs recorded a sharp increase up to the 2011 census. The most recent census, however, indicates a slight decrease in their overall share. Many ethnic communities exhibit a continuous decline in their population shares, including Bulgarians, Bunjevci, Hungarians, Romanians, Ruthenians, Slovaks, Slovenes, and Croats. In contrast, Bosniaks and Goranci represent the only two ethnic groups that recorded a consistent increase over time.

The most pronounced decline was observed among Albanians, whose share of the total population decreased by nearly 13% between 1981 and 1991. The latest census, however, suggests a very modest revitalization of their population share. The peak of Yugoslav identification occurred during the 1980s, reflecting the period of strongest identification with the former state, during which the number of individuals declaring themselves as Yugoslavs reached its highest level. The subsequent weakening and dissolution of Yugoslavia were indirectly reflected in changes in national self-identification, leading to a sharp decline in the share of Yugoslavs.

Similar to Yugoslavs, the shares of Montenegrins and Macedonians followed a comparable trajectory, increasing up to the censuses of the 1980s and 1990s, after which followed a decline. Particularly non-specific patterns of population dynamics are observed among Roma and Vlachs, who are often characterized as "floating ethnic groups" [42], as they frequently change their declared national affiliation between censuses. This results in highly variable data that are often difficult to interpret from a demographic perspective, making it challenging to identify clear and consistent demographic trends.

These dynamics inevitably influenced the trajectory of the Ethnic Fractionalization Index, which increased until 1981, indicating a rise in the level of ethnic heterogeneity in Serbia. This was followed by a sharp decline in the index, after a period marked by substantial political and historical transformations, as well as civil war, culminating in the dissolution of Yugoslavia. That suggested the onset of ethnic homogenization in Serbia. The most

recent census recorded a slight increase in the Ethnic Fractionalization Index. It is important to note that several factors contributed to these observed trends.

Table 1. Percentage share (%) of each ethnic group in the total population according to the censuses from 1948-2022

	1948	1953	1961	1971	1981	1991	2002	2011	2022
Serbs	73.89	73.83	74.65	71.23	66.38	79.93	82.86	83.32	80.64
Albanians	8.15	8.1	9.16	11.66	13.99	1	0.82	0.08	0.93
Bosniaks	0	0	0	0	0	0	1.81	2.02	2.31
Bulgarians	0.91	0.86	0.77	0.64	0.36	0.34	0.27	0.26	0.19
Bunjevci	0	0	0	0	0	0.27	0.27	0.23	0.17
Vlachs	1.43	0.4	0.02	0.17	0.27	0.23	0.53	0.49	0.32
Goranci	0	0	0	0	0	0	0.06	0.11	0.12
Yugoslavs	0	0	0.26	1.47	4.75	4.09	1.08	0.32	0.41
Hungarians	6.64	6.33	5.88	5.09	4.19	4.39	3.91	3.53	2.77
Macedonians	0.27	0.39	0.47	0.51	0.53	0.58	0.34	0.32	0.22
Muslims	0.27	1.16	1.22	1.83	2.31	2.3	0.26	0.31	0.2
Germans	0.64	0.66	0.19	0.11	0.06	0.07	0.05	0.06	0.04
Roma	0.8	0.84	0.13	0.59	1.19	1.21	1.44	2.05	1.98
Romanians	0.97	0.86	0.78	0.68	0.58	0.54	0.46	0.41	0.35
Russians	0.2	0.11	0.09	0.06	0.03	0.03	0.03	0.05	0.16
Ruthenians	0.35	0.34	0.34	0.24	0.21	0.23	0.21	0.2	0.17
Slovaks	1.12	1.08	1.02	0.91	0.79	0.85	0.79	0.73	0.63
Slovenians	0.32	0.3	0.26	0.19	0.13	0.1	0.07	0.06	0.04
Turks	0.03	0.78	0.58	0.22	0.15	0.01	0.01	0.01	0.01
Ukranians	0	0	0	0.07	0.06	0.06	0.07	0.07	0.06
Croats	2.6	2.48	2.57	2.19	1.6	1.24	0.94	0.81	0.59
Montenegrins	1.15	1.23	1.37	1.48	1.58	1.52	0.92	0.54	0.3

Source: SORS (1948-2022). Census statistics, National affiliation

The most dominant factor underlying the reduction in ethnic heterogeneity is demographic in nature, particularly the impact of unfavorable demographic processes such as persistently low fertility rates, long-term outmigration, and pronounced population ageing. Numerous ethnic communities have experienced sustained negative demographic trends and an overall decline in population size, while only a very limited number of ethnic groups recorded population growth.

In addition to demographic factors, political and ideological influences have played a significant role, most notably reflected in the sharp rise and subsequent rapid decline. One of the examples is the rapid rise and decline in the share of individuals identifying as Yugoslavs following the emergence and then dissolution of Yugoslavia. The abrupt decline of the German population was likewise the result of their politically driven emigration from Yugoslavia, particularly from the territory of Vojvodina after the Second World War [43]. Furthermore, the significant decrease in the Turkish population resulted from interstate agreements between Yugoslavia, Greece, and Turkey, which facilitated intensified emigration flows until the 1970s. These movements predominantly involved the emigration of the Turkish population, as well as members of other national communities of Islamic faith from Yugoslavia [44].

The sharp decline in the Albanian population share is attributable to a specific political context, rendering census data increasingly limited after the 1991 census. The Statistical Office of the Republic of Serbia was unable to conduct population censuses in Kosovo and Metohija in 2002, 2011, and 2022, while a substantial proportion of the Albanian population boycotted the 1991 census. A similar issue is observed in the municipalities of southern Serbia (Bujanovac and Preševo), where census data from 1991 and 2011 remain incomplete due to census boycotts by the Albanian population [45].
Finally, the methodological limitations previously discussed significantly constrain the accurate assessment of the population shares of Roma and Vlachs, due to pronounced fluctuations in their population dynamics.

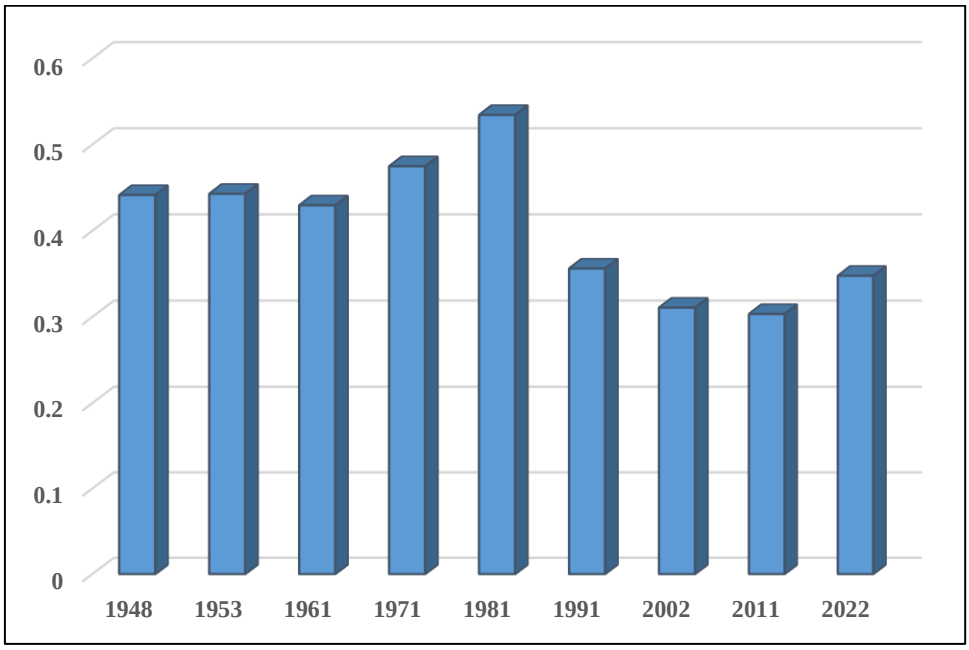


Figure 1. Changes in the level of Ethnic Fractionalization Index, 1948-2022

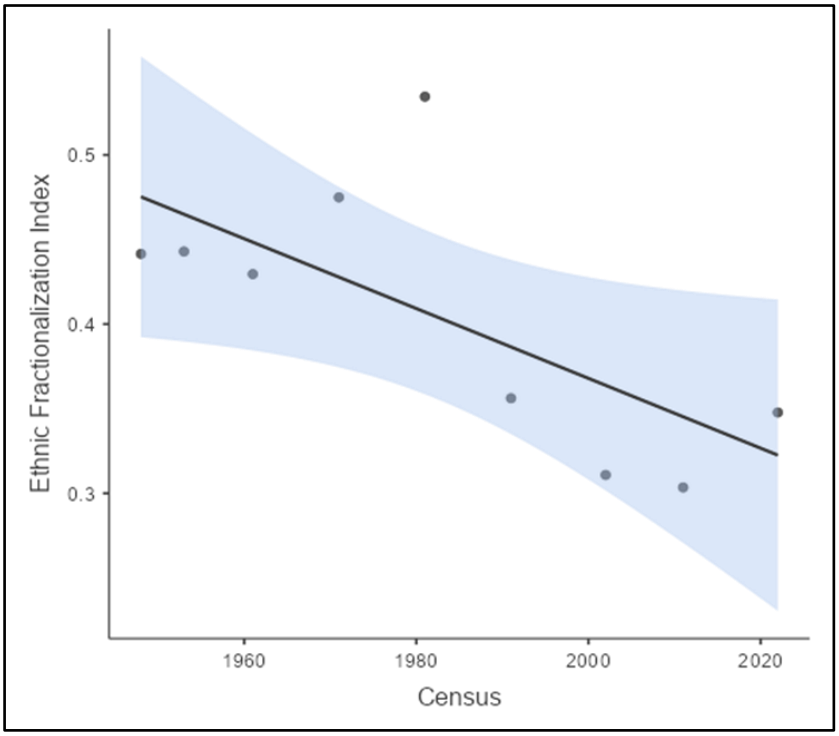


Figure 2. Scatterplot with linear regression showing an overall decrease in Ethnic Fractionalization Index

It is particularly noteworthy that the number of recorded ethnic communities increased continuously from census to census, reaching 44 identified ethnic groups in the 2022 census. However, despite this growing numerical diversity, the population shares of many ethnic groups either stagnated or declined over time. As a result, overall ethnic diversity first stabilized and subsequently decreased, leading to a further intensification of ethnic homogenization within the country due to the influence of demographic and socio-political factors.

DISCUSSION AND CONCLUSION

This study demonstrates that the Ethnic Fractionalization Index in Serbia has undergone substantial changes over time, highlighting once again the dynamic nature of ethnic diversity. Ethnic structure is not a one-dimensional phenomenon, rather, it is shaped by the interaction of demographic, socio-political, and other contextual factors. After a nearly continuous increase up to 1981, the index experienced a pronounced decline, indicating a shift from ethnic heterogeneity toward increasing ethnic homogenization of the population. The transformation of the Ethnic Fractionalization Index over the period from 1948 to 2022 can, on the one hand, be attributed to genuine demographic processes. Many ethnic communities recorded a persistent decline in their population shares, primarily because of long-term low fertility rates, low or negative natural increase, sustained emigration, and pronounced population ageing.

On the other hand, for certain ethnic groups, the observed changes were also influenced by factors of a methodological or political nature, including frequent shifts in self-declared national affiliation and changes in census classifications and methodologies. Although not the central focus of this paper, it is important to note that some ethnic communities exhibited high variability in their population size across censuses, characterized by unstable population trends and abrupt fluctuations that lack clear

demographic explanations. This is particularly relevant in the context of so-called "floating ethnic groups" and phenomena of ethnic mimicry. Such sudden changes in population dynamic, sharp increases or declines in the population shares of specific groups, can substantially affect the values of the Ethnic Fractionalization Index. Consequently, the results derived from this index must be interpreted with caution, considering its sensitivity to underlying methodological issues.

While previous studies have primarily focused on the outcomes and consequences of ethnic diversity, this research contributes to literature by critically examining the temporal stability and data quality underlying measures of ethnic fractionalization. Changes in ethnic fractionalization may reflect not only genuine demographic transformations but also shifts in classification practices and patterns of self-identification. The findings indicate that ethnic categories are not necessarily stable over time, a tendency that is particularly pronounced in post-conflict and post-socialist societies. This instability limits the explanatory and analytical utility of ethnic fractionalization measures and calls for caution in their application and interpretation.

Furthermore, any analysis of these results must acknowledge the significant methodological constraints involved in constructing and interpreting the Ethnic Fractionalization Index for Serbia, including data variability, incomplete statistical coverage, and inconsistencies in census data. Overall, this study demonstrates that ethnic fractionalization is not a purely statistical construct, but a composite outcome shaped by census methodology, socio-political situations, self-identification dynamics, data quality, and specific demographic processes. Consequently, the interpretation of long-term trends in ethnic diversity requires a context-sensitive and cautious approach, particularly when such indices are employed in broader socio-economic and political analyses. Finally, the findings underscore the need for further research focusing on societies experiencing prolonged demographic decline and transformation from ethnically heterogeneous to increasingly ethnically homogeneous spaces.

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CERTIFIED BUT UNSEEN: GUEST AWARENESS OF SUSTAINABILITY INITIATIVES IN EUROPEAN HOTEL REVIEWS

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ABSTRACT

This study investigates the prevalence of environmental sustainability certifications among European hotels and examines how guests perceive these initiatives in online reviews. Such certifications are formal, third-party acknowledgments of a hotel's adherence to established sustainable operating standards. While acquiring these credentials can be costly and time-intensive, they offer hotels a potential competitive advantage by providing verifiable proof of their environmental commitment to increasingly conscientious travelers. Our research addresses three core questions: How does the rate of certification vary across European regions? What themes emerge in guest reviews of certified hotels, and to what extent do guests demonstrate awareness of sustainability practices? Does recognition of these practices correlate with higher ratings? Methodologically, we analyzed hotels listed on Booking.com across four European regions (North, East, South, and West/Central). Findings reveal that only 11.60% of listed hotels hold a sustainability certification, with stark regional disparities: Northern Europe leads (20.86%), while Eastern Europe has the lowest rate (2.90%). Next, we selected 16 hotels—four per region—from the country with the highest number of certified hotels in each area, choosing a mix of high- and low-rated properties with various certifications. From a sample of 50,387 reviews for these hotels, a mere 289 (0.57%) explicitly or implicitly mentioned environmental practices. This indicates minimal guest awareness or commentary on sustainability. Moreover, a significant portion of these mentions were negative, suggesting that certification does not automatically translate into positive guest recognition or higher ratings in reviews. The discussion contextualizes these results within existing literature and explores practical implications for hoteliers seeking to leverage sustainability credentials effectively.

Keywords: sustainability certifications, Europe, hotels, hotel reviews, guest awareness.

INTRODUCTION

In recent years, significant changes in the global environment and resource over-consumption have heightened the urgency for sustainable development [38]. The global tourism industry, while a vital engine of economic development, has increasingly come under scrutiny for its substantial environmental footprint [1]. Hotels are primary contributors within this sector, characterized as one of the most energy-intensive, water-consuming, and waste-producing subsectors [20]. Their operations consume vast natural resources and generate significant carbon emissions and solid waste [4] [38]. Consequently, the hospitality sector faces a dual imperative: to reduce its ecological

impact while maintaining financial viability [38], a challenge driven by strong competition, exigent customer demand, and reputation management concerns [32].

This imperative is reinforced by a significant shift in consumer behavior. Travelers have become increasingly environmentally conscious, seeking more sustainable, "green" accommodation options when planning trips [25]. Having realized the negative environmental effects of hotel operations, such as water consumption and CO2 emissions, many travelers now prefer eco-friendly accommodations, a trend amplified in the post-pandemic era [26] [38; citing GSTC Council, 2021]. Customers increasingly want to minimize their footprint and signal their environmental concern through their consumption choices [4].

In response, hotels are showing increasing concern for managing their environmental and social impact [29] [32] and are making efforts to implement green practices and sustainable guidelines [4]. These practices often focus on energy conservation, waste reduction, and water conservation [29]. Such initiatives are implemented not only to "do the right thing" but also to respond to customer requests and improve customer perceptions of quality and satisfaction regarding environmental expectations [10] [29].

To institutionalize these efforts and credibly communicate them to the market, third-party environmental or green certifications have emerged as essential and influential tools [11] [30] [35]. These certifications provide a structured framework for hotels to reduce their environmental footprint [36]. They offer standardized benchmarks, enabling hotels to credibly signal their environmental commitments [38] while also allowing customers to signal their own values through their stay, thereby enhancing engagement and consumption intention [4]. As a result, certifications have become strategic assets for market competitiveness [38], and the global hotel industry has seen many properties earn certification for "green" operation [10]. These certifications can be regional, national, or international, and may cover a single product, service, or group of services [7].

Online travel platforms are increasingly spotlighting certified properties by displaying sustainable badges to communicate these efforts to guests [19] [38]. However, a crucial and underexplored question remains: How do these sustainability signals translate into online reputation—a central determinant of digital visibility and consumer trust? Unlike traditional reputation, online reputation is fluid, algorithmically ranked, and driven by user-generated content like reviews and ratings [23]. While the use of sustainable badges may increase the visibility of eco-friendly hotels and aid informed decisions, there is often an attitude-behavior gap [19]. Guests' positive attitudes may not translate into booking intentions or actual behavior, and consumer awareness of sustainability in tourism remains under-researched [19] [31]. Therefore, it is unclear if these labels actually influence guests' choices or if the perceived reputational returns from certifications materialize [19] [38].

Our research addresses three core questions: How does the rate of certification vary across European regions? What themes emerge in guest reviews of certified hotels, and to what extent do guests demonstrate awareness of sustainability practices? And, finally, does recognition of these practices correlate with higher ratings?

The paper begins with a literature review and a description of the methodology. It then presents the empirical findings, followed by a discussion of their implications, practical applications, and the study's limitations.

LITERATURE REVIEW

An environmental certification refers to a “voluntary procedure that sets, assesses, monitors, and gives written assurance that a business, product, process, service, or management system conforms to a specific requirement,” and is often accompanied by a marketable logo or ecolabel (Black and Crabtree, 2007, p. 20; cited in [18]). For hotels, green certification is one approach to put sustainability into practice, representing a third-party organization’s acknowledgment that a company abides by a set of environmental standards and continually strives to have a positive environmental impact [9].

These certifications serve a critical function in the marketplace as tangible evidence that helps counteract potential "greenwashing" accusations by providing external validation of a hotel’s commitment [5] [18]. Consequently, hotels may adopt these awards to distinguish themselves and signal accountability to customers [9]. Although the process is typically time-consuming and expensive, it aims to address customers' environmental consciousness and enhance the hotel's perceived green value and brand image [9].

The business rationale for pursuing certification is compelling. A primary objective is to provide guests with accurate information about a hotel's environmental performance during booking [18]. Hotels expect certification to boost perception, loyalty, and visitation, ultimately translating into higher bookings and revenue [6] [9] [32]. Certifications can serve as a crucial signal, decreasing a tourist's perceived risk and increasing trust in the hotel’s claims [41]. Furthermore, the process often leads to more mature environmental management, which can enhance performance and lead to operational cost reductions [9] [18]. This operational advantage can translate into financial benefits, with some findings indicating a positive effect on market value, revenue efficiency, and competitive advantage [3] [5].

However, the path from certification to commercial success is fraught with complications. A significant challenge is the proliferation and inconsistency of certification schemes themselves. With over 140 different eco-labels in sustainable tourism, each with its own standards, the landscape is complex and can confuse rather than reassure consumers [28] [34]. Guests are generally not sufficiently aware of the different systems and do not understand the variety of hotel eco-labels [24]. This lack of consumer recognition is a likely factor in the low global adoption rates among hotels [28], a pattern evident in specific region like Africa (where less than 3.4% of hotels are certified) [34].

This confusion directly impacts consumer behavior, leading to a well-documented "green gap" where positive intent does not translate into action [10]. A consistent finding is that for most tourists, core factors like location, price, and quality take precedence over a sustainability label when booking [4] [18]. While a niche market of older, more educated travelers actively seeks certifications [21], the majority are not significantly influenced by them. Consequently, empirical results on financial performance are mixed, with some studies finding no significant impact on revenue or market performance [10] [39].

This gap underscores the critical role of communication and execution. Research suggests that the mere possession of a certificate is insufficient [29]. Hotels must explicitly and effectively communicate their initiatives. Experimental studies show that prominently displayed sustainability badges on booking platforms can positively influence attitudes and booking intention [19], and tailored messaging (e.g., highlighting certificates vs. ongoing efforts) can improve appeal to different traveler segments [39]. Positive guest

recognition of specific practices in reviews, such as linen reuse, is correlated with higher ratings [8].

Yet, the central question remains: How often do guests actually notice and value these practices in their post-stay evaluations? Existing evidence points to a stark disconnect. Studies analyzing online reviews find that even at certified hotels, guest discourse is overwhelmingly dominated by traditional themes like service and amenities, with eco-concerns being rarely mentioned [29]. This suggests a significant gap between the hotel's sustainable actions and active guest perception, indicating that certification does not automatically shape guest attitudes or review content.

It is within this context of low adoption, consumer confusion, and a glaring perception gap that the present study is situated. While the literature establishes the theoretical value and operational benefits of certification, and highlights the challenges in communication, there is a need for large-scale, regional analysis of actual guest discourse in Europe. This study directly addresses this by investigating: the prevalence of certification across European regions, the themes in guest reviews of certified hotels, the extent of guest awareness of sustainability practices, and whether such recognition correlates with higher ratings. The findings aim to move beyond stated intentions to examine the tangible, visible impact of certifications in the digital word-of-mouth that increasingly drives hotel choice.

DATA AND METHODOLOGY

The methodology involved a two-stage data collection process. On 1 November 2025, a search was conducted on Booking.com for hotel accommodation for two people from 17–20 March 2026 (three nights). This period was selected as it falls on weekdays and does not coincide with Easter or other major European holidays.

All European countries available on the platform (excluding Russia and Belarus) were queried. Using the platform's filter options, results were restricted to hotels holding recognized sustainability certifications.

The search results were compiled into a table and then visualized geographically using Mapchart.net. Europe was divided into four major regions for analysis: North, East, South, and West. From each region, the country with the highest number of certified hotels was selected: **Sweden** (North), **Poland** (East), **Spain** (South), and **France** (West). For each of these four countries, four hotels were selected for further analysis: two from the **highest-rated** properties and two from the **lowest-rated** properties. Selection criteria prioritized hotels with a higher volume of reviews, while also aiming for diversity in star ratings (from one to five stars) and types of sustainability certification.

Subsequently, we analyzed guest reviews for all sixteen hotels to identify comments pertaining to their environmental practices. Online reviews, a form of user-generated content (UGC), are the cornerstone of electronic word-of-mouth (eWOM) in the travel industry [13] [14] [15] [16] [17] [40]. With the development of Web 2.0 platforms, consumers have taken a more active role in sharing opinions [27]. This eWOM has revolutionized travel planning, empowering independent travelers to select destinations and book accommodations by using advice shared by fellow travelers online [22] [37].

Compared to classical word-of-mouth, eWOM possesses distinct advantages that make it a powerful marketing tool [33]. It has a vastly greater reach, is permanent, and is easy for consumers to understand [42]. In the hospitality sector—where evaluating service quality

in advance is difficult—online reviews play a particularly influential role [38], creating a critical online reputation [23] [38].
Crucially, online reviews from peers are generally perceived as more reliable and trustworthy than marketing materials provided by service providers themselves [2]. This makes UGC an essential tool for attracting tourists and marketing tourism products [12].
As manually reading all reviews was not feasible, we employed keyword analysis. Using terms such as "sustainable," "green," "energy," "water," "recycling," "waste," and "plastic," we screened each identified review to confirm its relevance to the hotels' environmental practices—or lack thereof.
Some socio-demographic and travel behavior data of reviewers are available from the platform, along with individual hotel experience ratings. This quantitative data was first examined using descriptive statistics.
Subsequently, a sentiment analysis was performed to evaluate the textual content of the reviews. This process determines the emotional tone of the text, classifying the writer's attitude toward the hotel as positive or negative.
Finally, a qualitative content analysis was conducted to identify key themes and patterns. An initial set of dimensions and codes, derived from the existing literature, was applied to the text. Through an iterative process, certain themes were consolidated or refined, while others were eliminated. Representative quotations from the reviews were then selected to illustrate the findings.

ANALYSIS OF RESULTS

A total of 83,629 European hotels had availability for the queried period. Of these, 9,699 were certified for sustainability practices, representing 11.6% of the total (table 1).
Northern Europe leads the continent in environmentally friendly practices, with 20.86% of its hotels certified. In contrast, Eastern Europe lags well behind, with only 2.9% certified (table 1).

Table 1. Number and percentage of hotels with sustainability certification in Europe

Region of Europe	Country	Total hotels	Hotels with Sustainability Certification	% hotels with sustainability certification
North	Iceland	227	17	7.45
	Norway	786	109	13.87
	Sweden	1310	319	24.35
	Finland	652	202	30.98
	Denmark	645	188	29.15
	Estonia	200	36	18.00
	Latvia	224	20	8.93
	Lithuania	252	7	2.78
Total North		**4296**	**896**	**20.86**
West	The Netherlands	2091	436	20.85
	Belgium	1136	182	16.02
	Luxembourg	129	15	11.63
	Germany	14,117	1636	11.58
	Switzerland	2458	166	6.75
	Austria	3213	323	10.05
	Liechtenstein	19	2	10.53
	UK	8699	1153	13.25
	Ireland	666	116	17.42
	France	12,160	1974	16.23
Total West		**44,868**	**6003**	**13.38**
East	Poland	2737	138	5.04
	Czechia	1985	47	2.37
	Slovakia	519	5	0.96
	Hungary	924	42	4.55
	Romania	1269	35	2.76
	Bulgaria	966	8	0.83
	Moldova	106	0	0
	North Macedonia	163	1	0.61
	Serbia	433	5	1.15
	Bosnia-Herzegovina	268	1	0.37
	Croatia	403	26	6.45
	Slovenia	335	71	21.19
	Kosovo	154	0	0
	Montenegro	209	11	5.26
	Albania	1077	2	0.19
	Ukraine	1007	13	1.29
	Georgia	1266	9	0.71
	Azerbaijan	370	7	1.89
	Armenia	455	4	0.88
Total East		**14,646**	**425**	**2.90**
South	Andorra	125	9	7.20
	Spain	7367	1421	19.29
	Portugal	1992	465	23.34
	Italy	10,076	457	4.54
	San Marino	16	0	0
	Monaco	9	6	66.67
	Malta	234	17	7.36
Total South		**19,819**	**2375**	**11.98**
Total Europe		**83,629**	**9699**	**11.60**

At the country level, Finland (31% of hotels certified), Denmark (29%), and Sweden (nearly 25%) are the most advanced (table 1; figure 1). In Western Europe, only the Netherlands exceeds a 20% certification rate. In Southern Europe, Portugal (over 23%) and Spain (nearly 20%) are at the forefront of the green hotel movement. One notable exception is Monaco, where two-thirds of hotels are certified; however, this figure is based on only nine hotels in the sample.

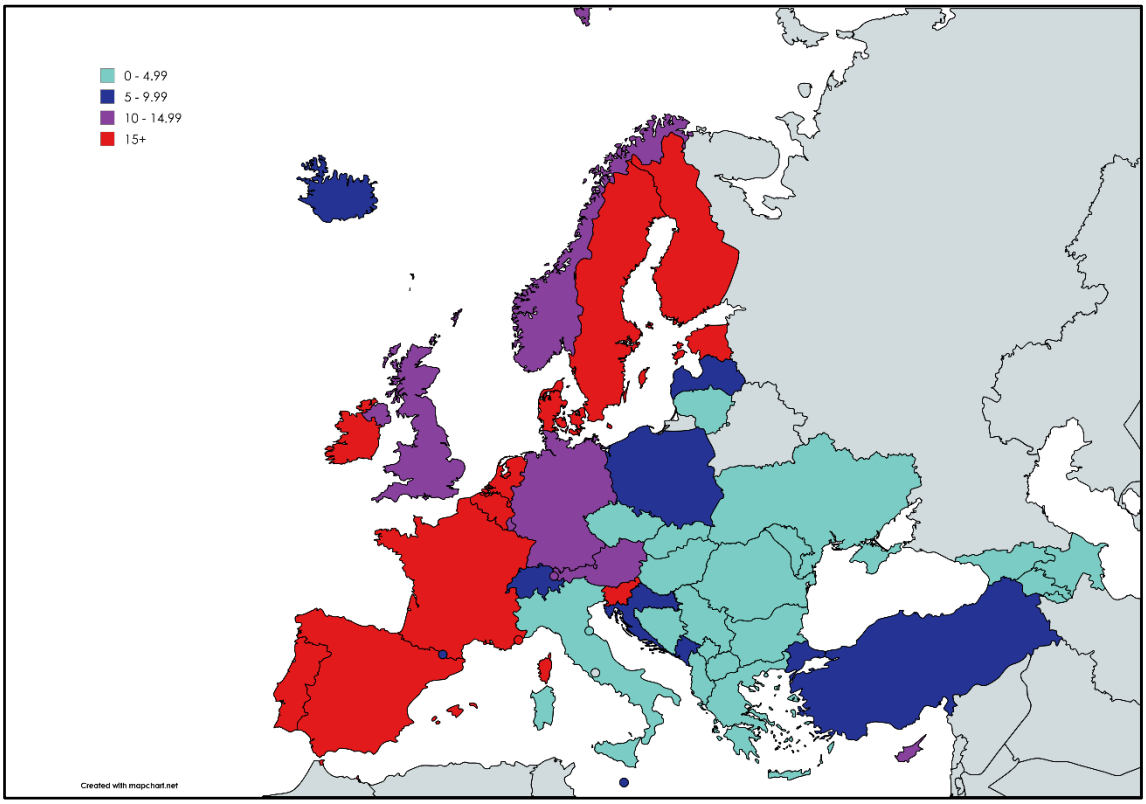


Figure 1. Rate of hotels with sustainability certifications

In Eastern Europe, Slovenia is a standout, with a certification rate exceeding 21%. Elsewhere in the region, percentages are very low, culminating in Moldova and Kosovo, where none of the hotels were certified (table 1; figure 1).

For the second part of the analysis, 16 hotels were selected from four countries based on criteria outlined in the methodology chapter. These hotels are detailed in Table 2 below.

Table 2. Hotels included in this study

Region - Country	Name of hotel	Location of hotel	Hotel categ.	Average review score	Certification Type	Total # of reviews	# of reviews mentioning env. practices
North - Sweden	Hotell St. Clemens	Visby	***	9.9	Nordic Swan Ecolable	581	8
	Hotel Royal	Gothenburg	***	9.1	Green Key (FEE)	4677	12
	Sure Hotel Studio by Best Western	Bromma (Stockholm)	***	6.6	Green Key (FEE)	434	3
	Scandic Stortorget	Malmö	****	7.1	Nordic Swan Ecolabel	1453	3
	Total Sweden			8.61		7145	26
East - Poland	Raffles Europejski	Warsaw	*****	9.6	Green Globe	1038	1
	PURO Centrum	Łódź	****	9.5	LEED	5219	10
	Ibis Styles	Bielsko-Biała	***	7.5	Green Key (FEE)	471	2
	Ibis Budget Warszawa West Station	Warsaw	*	7.9	Green Key (FEE)	11,991	7
	Total Poland			8.43		18,719	20
South - Spain	Seda Club Hotel	Granada	*****	9.6	Ecostars	707	8
	ARTIEM	Madrid	****	9.5	Ecostars	2021	52
	Eurostars Central	Madrid	****	8.4	Bioscore	4652	86
	Negresco Princess	Barcelona	****	8.4	Biosphere Certification	4918	26
	Total Spain			8.65		12,298	172
West - France	Hotel Leonor	Strasbourg	****	9.3	Green Key (FEE)	4711	22
	Château Hôtel Grand Barrail	Saint Emilion, Bordeaux	*****	9.2	EU Ecolabel	1137	12
	Best Western Hotel Opera Drouot	Paris	***	8.1	Green Key (FEE)	1454	10
	MOB Hotel Lyon Confluence	Lyon	***	8.1	Green Key (FEE)	5151	27
	Total France			8.65		12,453	71
Europe	Total			8.56		50,615	289

In total, guests left over 50,000 reviews for the 16 hotels studied. Among these, only 289—a mere 0.57%—contained any explicit or implicit references to the hotels' environmental practices (table 2). Significant regional disparities exist within this low overall figure. The rate was lowest in Poland (Eastern Europe) at just 0.11%, followed by Sweden (Northern Europe) at 0.36%. Guests in France (Western Europe) mentioned environmental practices at a rate (0.57%) matching the overall European average. The highest awareness was observed in Spain (Southern Europe), where the rate reached 1.40%—though this figure remains still notably low.
As shown in Table 3, most reviews referencing environmental practices were submitted by couples who stayed at the hotel for one to two nights, typically in 2023 or 2024.

Table 3. Socio-demographic and travel attributes of reviewers

Attribute		Frequency	% of total
Travel companionship	Solo	66	22.83
	Couple	151	52.25
	Family	38	13.15
	Group	34	11.76
Nights spent	1	91	31.49
	2	88	30.45
	3	64	22.14
	4+	25	8.65
Year of staying at the hotel	2022	7	2.42
	2023	107	37.02
	2024	110	38.06
	2025	65	22.49

They rated their hotel experience an average of 7.94, which is considerably lower than the overall average rating of 8.56 for all reviews of the 16 hotels (Table 2). This indicates that when mentioning environmental practices, guests at these certified hotels expressed lower satisfaction than when evaluating other features. This pattern is corroborated by the sentiment analysis (Figure 2), which shows that nearly two-thirds of comments specifically about hotels' environmental practices were negative.

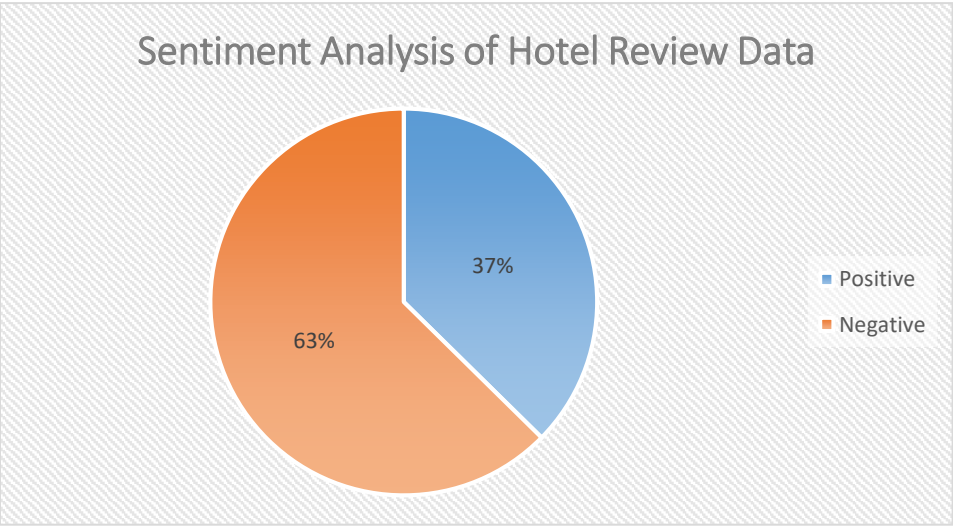


Figure 2. Sentiment analysis of hotel review data

Quantitative and qualitative analysis of reviews

Next, we analyzed the review texts to identify recurring themes and sub-themes. This analysis revealed five major themes (or dimensions) and 14 sub-themes (or codes), which are presented in Table 4.

Table 4. The main themes and subthemes resulting from the qualitative analysis of reviews

Dimension	Frequency	% of total	Codes
Water	69	23.88	Shower
			Leakage
			Towel reuse
Energy	149	51.56	Heating
			Cooling
			Lighting
Waste reduction & separation	14	4.84	Refill
			Recycling
Food origin	40	13.84	Organic
			Local
General practices	36	12.46	Environment
			Sustainable/-bility
			Green
			Eco-friendly

Theme 1: Energy Consumption

More than half of all comments referencing hotel environmental practices concerned energy consumption (Table 4), with a majority of these assessments being negative.

The primary complaint centered on the inability to adjust room temperatures. In Spanish hotels, an energy-saving policy kept the cooling system off during winter, leaving only heating active. This created a "greenhouse effect" in sun-exposed rooms, causing them to become excessively hot—a problem that persisted through the night. Ironically, guests reported being forced to open windows to sleep, negating the intended energy savings (e.g., cases 166, 168, 244). Numerous other reviews cited non-adjustable heating (e.g., cases 113, 114, 116, 118, 127, 129, 135, etc.) and non-functional air conditioning (e.g., cases 87, 89, 90, 91, 94, 98, 101, 108, 110, 119, 120, 122, 123, 124, 128, etc.), highlighting a widespread issue with climate control.

One guest left the following comment regarding the excessive heating in the room:

"The room was boiling hot—so hot that, ironically in the middle of winter, we had to sleep with the window open. The heating could not be turned off or lowered. We asked at reception, but no solution was offered."

Another disgruntled guest left a lengthy comment from which we are reproducing only a few fragments (case 115):

"I had an awful stay at [Hotel Name]. The heating was broken, so it was blasting at full power the entire time. My room felt like a sauna. I contacted the front desk, and someone came to try to help. He advised me that the system was broken and he couldn't log in to change anything due to a system issue. His solution was to give me a bottle of water. I had the windows wide open all night, but as it was very mild outside, it made no difference. I had a terrible night overall. In the morning, I spoke to the manager and explained that the uncontrollable heating had led to a miserable night. […] Later, I received a reply stating that the heating system wasn't broken—it was simply on because it was winter. I countered by pointing out that hotel staff had told me it was broken, and

that individual room controls should still be available, citing regulations that confirm this. I received no further response. Overall, I was very unimpressed. I will never stay here again. The customer service was terrible, showing a complete lack of care or consideration for guests and for the environment. Heating an enormous hotel when it's 15 degrees Celsius outside, without giving guests the option to turn it off, is absolutely appalling for both customer comfort and the current climate emergency."

In other instances, the reported problem was the opposite: some hotels, in an effort to conserve energy, provided insufficient heating, leaving rooms uncomfortably cold. For example, one guest remarked (case 242):

"Although the outside temperature was 13 degrees Celsius in the mornings and evenings, the heating was off and the room was cold. We complained, and a staff member explained that 'it is the system.' It has nothing to do with the system, but is simply a way to reduce energy costs at the expense of our comfort. They later brought in a small electric heater to warm the room."

This approach sometimes led to undesirable consequences, as noted by a guest at the same French hotel (case 252): *"It was so cold in our room the first night that I got sick."*

These were not isolated incidents, with similar complaints noted in several other reviews (e.g., cases 93, 95, 99, 113, 228, 259, 260).

Of course, not all comments were negative. A number of guests provided positive feedback, noting that the air conditioning functioned properly (e.g., cases 96, 100, 261) and that room temperatures were adjustable (e.g., cases 11, 56).

Another energy-related issue noted in guest reviews was the lighting system. The primary problem was not inadequate lighting, though a few guests mentioned malfunctioning (case 218) or poor lighting (cases 54, 278). Instead, the chief complaint centered on the automated technology controlling the lights—and in some instances, the heating and television. This system's complexity frustrated many guests who could not determine how to operate it (e.g., cases 27, 31, 34, 48, 52, 54), although a minority found it innovative and exciting (case 33).

This frustration is exemplified by one guest's remarks (case 34):

"The lighting system is a joke—and torture. A simple light switch would be a perfect solution, but apparently, that's too straightforward for this hotel. It would take multiple paragraphs to describe the idiocy of this system and how it deprived me of sleep, so I will just say it sucks and should be ripped out and replaced with a few working light switches. PS: If you book this hotel, plan on staying at least three nights—that's how long it will take you to figure out the lighting."

Theme 2: Water saving

Most comments in this section dealt with shower pressure, water leakage and towel reuse. Guest feedback on shower pressure was predominantly positive, with many praising its strength (e.g., cases 15, 47, 56, 58, 60, 63, 102, 184, 187, 193–196). While some noted low pressure (e.g., cases 14, 186, 197, 263), the prevailing sentiment aligns with sustainability goals, as higher pressure can reduce overall water usage. One guest's enthusiasm was captured in the remark: *"Water pressure in the shower is the best I've ever experienced anywhere in the world"* (case 59).

Several water-related inefficiencies were noted in guest reviews. These included leaking fixtures, particularly from shower heads (e.g., cases 39, 61, 185, 192, 221), with one guest specifying: *"Shower head broken spreading water in every direction."* Guests also

reported long wait times for hot water, resulting in significant waste (e.g., cases 16, 107, 112).

Despite these issues, some guests positively acknowledged the hotels' sustainability efforts regarding water conservation, as illustrated by one review: *"Loved the sustainability push at the hotel with a focus on reusing and not wasting water"* (case 64).

One of the most common "green" initiatives in hotels worldwide is encouraging guests to reuse towels, a simple measure that conserves water and energy. However, guest reviews reveal significant inconsistencies in the execution of this policy.

Many guests reported that their towels were changed daily against their wishes, undermining the sustainability intent. For example, one noted, *"Replaced towels daily even though we hung them up"* (case 203), while others cited similar experiences (e.g., cases 42, 211). Some expressed frustration that staff did not follow the hotel's own guidelines: *"Only towels on the floor were supposed to be removed and washed, yet all of my towels were taken for no reason. Don't pretend to be 'green'!"* (case 34).

Conversely, other guests experienced the opposite problem: towels were not changed even after multiple days, leading to complaints about hygiene and convenience (e.g., cases 22, 23, 43, 201, 202, 205, 206, 207, 214, 208, 256). One guest explained a confusing interaction: *"We didn't ask for the towels to be changed for 2 days, and on the 3rd day we put them on the floor... and they picked them up and hung them back up for us"* (case 209).

This inconsistency was summarized by one reviewer, who observed, "*Some rooms offer replacement of towels, others do not"* (case 286). Despite these operational flaws, the policy itself received praise from guests who valued its environmental purpose, with one stating, *"I also think it's excellent and progressive that the towels are only replaced if you explicitly request it!!!"* (case 215).

Theme 3: Food and beverage origin

Guest feedback on the hotels' food and beverage sustainability practices reveals a spectrum of awareness and appreciation. Many guests were pleased with the emphasis on local sourcing, particularly at breakfast (e.g., cases 1, 2, 5, 7, 26, 233, 240) and lunch (case 51), recognizing it as a key sustainable practice. One guest noted, *"We love that breakfast buffet comes with local products only as we believe in supporting the local community whenever this is possible"* (case 236).

However, the execution was sometimes inconsistent. Some guests observed that staff did not actively promote local options, as one review pointed out: *"The wine bar waiter seemed to know nothing about local wine and kept pushing New Zealand Sauvignon"* (case 241). Others were indifferent or dissatisfied with the local focus, preferring more international offerings: *"Unfortunately, breakfast isn't very international, with too many local dishes"* (case 36).

Feedback on organic products was similarly mixed. Several guests positively noted the use of organic food (cases 19, 240) and bathroom amenities (case 266). One comprehensive review praised, "*Fantastic organic breakfast… [and] the use of organic shampoos and soaps"* while suggesting further amenities like guest bicycles (case 18). Conversely, others criticized the lack of visible organic or ethical options, with one guest stating, *"For a hotel that's supposed to offer organic, ethical, local options… I saw absolutely none of that"* (case 279).

Theme 4: Waste reduction and separation

Several guests acknowledged and appreciated specific hotel initiatives to reduce waste and promote recycling. Positive feedback highlighted conscious efforts to minimize food waste. Guests approved of replacing buffet service with à la carte menus, with one noting, *"Liked ordering from menu. Dislike the waste of food on big buffets"* (case 53). Others supported smaller buffet selections designed to avoid excess, though some felt pricing should reflect the scaled-back offering: *"I'm totally OK with a smaller array of food to avoid waste, but it should be priced accordingly"* (case 289).
The provision of refillable amenities was also well-received. Guests valued water refill stations to avoid single-use plastic bottles (e.g., cases 103–105) and praised the use of refillable soap dispensers (case 21).
Opinions on recycling programs were divided. Some guests were impressed by innovative commitments, such as one who remarked, *"Impressed with their commitment to recycle, especially the cool glasses that are made out of their wine bottles"* (case 216). However, others experienced practical failures in execution, as illustrated by a guest who was prevented from using indoor recycling bins: *"I tried to recycle paper, plastic bottles and aluminum cans into the bin in front of the elevator but the receptionist didn't let me and indicated to me to put them into the bin outside ([which was] not for recycling)"* (case 46).

Theme 5: Overall evaluation of "green" practices

Overall, a number of reviews show that some guests acknowledge and approve of hotels' commitments to environmentally friendly practices (e.g., cases 9, 10, 44, 64, 71, 80–82, 85), particularly when these initiatives do not compromise comfort (e.g., cases 65, 78).
However, others felt that certain hotels took the concept to an extreme, leading to perceptions of inconvenience or poor value (e.g., cases 68, 281). One critical review encapsulates this sentiment:
"The eco-concept taken to the extreme... sometimes ridiculous (no TV, instead 2 meager books in the rooms.) a library decor of books in the living room, but inaccessible behind a fence. A breakfast that was way too expensive... despite the variety of products on offer. Pay attention to quality more than to decor.... Orange juice of dubious quality despite its presentation in a lemonade bottle, watered-down and flavorless coffee: offer real espressos, etc." (case 281)

DISCUSSION AND CONCLUSIONS

This study set out to map the landscape of environmental sustainability certifications among European hotels and to understand the extent and nature of guest awareness and valuation of these practices as expressed in online reviews. The findings paint a complex and somewhat contradictory picture, revealing a significant gap between the strategic adoption of certifications by hoteliers and their operational execution and subsequent recognition by guests.
The pronounced regional disparity in certification prevalence—from over 20% in Northern Europe to under 3% in Eastern Europe—confirms that sustainability is not a uniformly integrated priority across the continent. This pattern aligns with broader socio-economic and policy landscapes, where Northern and Western European nations often exhibit stronger environmental governance and consumer awareness. The leading

positions of countries like Finland, Denmark, Sweden, the Netherlands, and Portugal suggest that certification uptake is influenced by a combination of regulatory pressure, market demand, and industry leadership. Conversely, the exceptionally low rates in much of Eastern Europe highlight a significant area for development, though the standout case of Slovenia demonstrates that progress is possible within the region. These disparities present a challenge for platforms and travelers seeking consistent sustainable options across Europe and underscore the need for targeted support and incentives in lagging regions.

The most striking finding is the profound disconnect between hotel certification and guest discourse. With only 0.57% of over 50,000 reviews containing any reference to environmental practices, it is evident that sustainability credentials are not a primary driver of online review content for the vast majority of guests. This suggests that, for most travelers, such certifications either go unnoticed, are considered a basic expectation, or are simply less salient than core experiential factors like service, location, cleanliness, and comfort. This is consistent with earlier findings by [29] [18] [4]. The low mention rate challenges the assumption that certification automatically translates into enhanced brand communication through user-generated content. It indicates that while a segment of "conscious travelers" exists, they constitute a vocal minority in the review ecosystem.

Perhaps more consequential than the low volume of mentions is their predominantly negative sentiment. The finding that mentions of environmental practices correlate with a significantly lower average rating (7.94 vs. 8.56) is critical. It reveals that when sustainability initiatives *are* noticed, they are often perceived as detracting from the guest experience. The thematic analysis provides a clear explanation: guests become aware of sustainability primarily when it causes inconvenience or perceived discomfort.

The dominant theme of problematic energy conservation—specifically, non-adjustable climate control leading to rooms that are excessively hot or cold—turns a well-intentioned practice into a major source of dissatisfaction. This frustration is exacerbated by poor communication and inflexible systems, as vividly detailed in the review excerpts. Similarly, inconsistent towel reuse policies and overly complex automated systems generate guest irritation by creating confusion and a sense of lost autonomy. These findings underscore a crucial principle: **operational implementation is as important as strategic intent**. A certification standard may mandate energy-saving systems, but if their deployment disregards fundamental guest comfort and control, it risks backfiring, creating negative associations with the hotel's "green" identity.

Positive recognition does occur, but it is more nuanced and often tied to initiatives that enhance the experience or align with guest values without imposing sacrifices. Guests appreciate tangible quality and ethical benefits, such as strong water pressure (which aligns with efficiency), high-quality local and organic food, and thoughtful waste-reduction measures like refillable amenities. These practices are perceived as adding value rather than restricting it. This distinction highlights a pathway for effective communication: hotels should emphasize sustainability initiatives that have a clear, positive guest-facing benefit.

Theoretical Implications

This research contributes to the literature on sustainable tourism and service management by empirically demonstrating the weak link between formal environmental certification and guest-generated electronic Word-of-Mouth (eWOM). It challenges the simplistic assumption that "green" credentials directly yield positive online reputation. Instead, it

supports a more complex model where guest awareness is low and sentiment is contingent on the seamless integration of sustainable practices into the service experience. The study highlights the role of online reviews as a rich, unsolicited data source for auditing the real-world, guest-perceived effectiveness of sustainability policies.

Practical Implications for Hoteliers

1. Certification should not be an end in itself. Hotel managers must rigorously evaluate how mandated practices affect the guest experience. Climate control systems must retain reasonable guest autonomy. Sustainability policies, like towel reuse, require consistent staff training and execution to avoid perceived hypocrisy.
2. The negative sentiment often stemmed from confusion and frustration. Hotels must clearly explain the *purpose and benefit* of any practice that might alter the traditional guest experience. Empowering front-line staff to explain and, where possible, offer solutions or compromises is essential.
3. Marketing and branding efforts should foreground sustainability measures that guests inherently appreciate, such as locally sourced gourmet food, high-efficiency showers, or refillable premium amenities. These are more likely to generate positive reviews and enhance the brand's value proposition.
4. If certain sustainable choices involve a trade-off (e.g., a smaller breakfast buffet to reduce waste), this should be communicated clearly, and pricing should be perceived as fair.

Limitations and Future Research

This study has limitations. The analysis was confined to reviews on a single platform (Booking.com) and to a select sample of hotels within leading countries. The manual text-mining approach, while efficient, may have missed extremely implicit references to sustainability. Future research could expand the geographic and platform scope, employ in-depth interviews to understand guest perceptions beyond reviews, and conduct longitudinal studies to track changes in awareness and sentiment.

CONCLUSION

In conclusion, this study reveals that environmental sustainability certification among European hotels remains uneven and that its impact on the guest experience, as reflected in online reviews, is minimal and often counterproductive. While a certification may serve as a valuable internal management framework and a signal to a segment of the market, it does not guarantee positive guest recognition or competitive advantage in the digital reputation sphere. The low awareness suggests that certifications alone are not powerful differentiators in the crowded online marketplace. More critically, the prevalence of negative mentions serves as a stark warning: poorly implemented sustainability measures can actively damage guest satisfaction and online ratings. Therefore, the key to leveraging sustainability credentials effectively lies not merely in acquiring them, but in implementing them with unwavering attention to guest comfort, clear communication, and operational consistency. For the European hotel industry, the journey towards sustainability must be one that guests are willing to take—and enjoy—not one they are forced to endure.

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SECTION

CARTOGRAPHY, GIS

& SPATIAL PLANNING

LAND SUITABILITY CLASSIFICATION FOR SUSTAINABLE AGRICULTURAL PRODUCTION AND CLIMATE CHANGE ADAPTATION IN SLOVENIA

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ABSTRACT

Project RajonSI is developing a national methodology for agricultural land-suitability classification in Slovenia to support sustainable land use, risk reduction, and the adaptation of agricultural production to climate change. The technical framework and pilot models were established in 2025 by harmonising multi-source spatial datasets representing relevant factors for agricultural production and implementing them in a GIS-based multi-criteria evaluation. All input layers are prepared as rasters at a target resolution of 10 m. Natural factors include soil properties (texture parameters, skeletal content, depth, pH, organic matter, plant-available P_2O_5 and K_2O), climate indicators (T_{min}, T_{max}; derived indices such as the number of days with $T_{max} > 30/35$ °C and $T_{min} \leq -1$ °C in the growing season, precipitation totals, evapotranspiration, and drought indices), topography (slope, elevation, aspect, topographic wetness index), and other environmental and spatial data (flood areas, water protection areas, land use map). Suitability (*S*) is computed using the Weighted Linear Combination method. Suitability maps were created for arable land, permanent grassland, intensive orchards, general viticulture, and key crops (maize, cereals – wheat and barley, potatoes, apples/pears, strawberries, American blueberries, pasture-cut grassland, and pasture grassland). The approach is designed to run under multiple climate scenarios (EURO-CORDEX RCP 2.6/4.5/8.5) to assess future suitability envelopes. Output maps will serve decision-makers (MAFF) and practitioners and will be available via a web GIS viewer and open-data services.

Keywords: Agricultural zoning; land suitability; GIS; WLC; climate change adaptation

INTRODUCTION

Agricultural zoning classifies land according to its suitability for specific agricultural uses by integrating natural and management constraints [1,2]. It is based on a detailed analysis of natural factors such as soil, climate, altitude, topography, water resources and other environmental factors together with technological and economic parameters that influence agricultural production [3].
For the implementation of land-suitability classification, reliable and sufficiently precise spatial data are essential. These include data on the chemical and physical properties and

potentials of agricultural soils, soil-degradation processes, soil-management technologies, on macro- and micro-climatic conditions, agrometeorological indicators and relief characteristics, as well as data on agricultural plant species adapted to climate change, alongside various additional datasets [4]. In Slovenia, the increasing frequency of droughts, heatwaves and floods underscores the need for spatially explicit guidance to support sustainable land use, reduce environmental and economic risks, and inform adaptation to climate change.

The three-year RajonSI research project (2024–2027) aims to: (i) compile and harmonise national spatial datasets relevant to agricultural suitability; (ii) design a transparent multi-criteria evaluation (MCE) based on the Weighted Linear Combination (WLC) approach; (iii) define sector- and crop-specific criteria; and (iv) deliver zoning maps and a web-based GIS viewer for policymakers and farmers.

MATERIALS AND METHODS

Data and GIS standards

All factors are presented as spatial input layers and prepared as raster GeoTIFFs in the national coordinate system (D96/TM, EPSG:3794) with a target resolution of 10 m (tested at 20–100 m). Factors are grouped into soil, climate, topography, and other spatial factors. Some factors are used as constraints to limit suitability (e.g. built-up areas, water bodies, floodplains, water protection areas).

Soil factors and derivation

Soil attributes were derived from the geometry of the national soil map PK25 [5] using three complementary approaches:

(1) polygon-level attribution from soil samplings of national soil-monitoring programs stored in the Agriculture Institute of Slovenia soil database "eTLA"(values calculated as median per polygon);

(2) aggregation of soil parameters from "eTLA" to soil-mapping units (PKE); and

(3) soil data from representative soil profiles [6], aggregated to soil typological units (PSE) and interpolated to the soil map using weighted averages based on PSE shares in soil-mapping units (SMU).

Target attributes include pH ($CaCl_2$), organic matter, plant-available P_2O_5 and K_2O, texture fractions (sand, silt, clay), and skeletal content.

Climate datasets and indicators

EURO-CORDEX regional climate simulations created by Slovenian Environment Agency (ARSO) were used for a reference period (1981–2010) and near-future period (2011–2040) under RCP2.6, RCP4.5, and RCP8.5 [7]. Derived indicators include the number of days above T_{max} thresholds (25 °C, 30 °C, 35 °C), frost or near-frost days in the growing season ($T_{min} \leq -1$ °C), seasonal precipitation and temperature means, evapotranspiration and water-balance indices, and drought indices (SPI, EDDI, SWD).

Topographic derivatives

From the LiDAR-based DEM (aggregated to 10 × 10 m), slope, aspect, elevation, and topographic wetness index (TWI) were computed to support mechanisation feasibility, erosion risk and wetness-related constraints.

Standardisation

Before conducting the multi-criteria evaluation, factor standardisation was required. For each factor and agricultural production type, experts converted the original values into standardised scores from 0 to 100, where 0 indicates unsuitable and 100 indicates most suitable. Standardisation methods included:

(i) continuous membership functions for numerical variables;
(ii) class lookup tables for categorical variables;
(iii) binary constraints $C_j \in \{0,1\}$ for limiting conditions (e.g., flood zone, water body).

Multi-criteria evaluation

Suitability (S) is calculated using the Weighted Linear Combination (WLC):

$$S = \Sigma(w_i X_i) \times \Pi(C_j),$$

where X_i are standardised factor scores (0,100). Weights w_i reflect factor importance and sum to 1 within each model. Standardisation and weighting follow best practice in raster-based MCE [8].

Sector- and crop-specific models

General land-use models include arable land, permanent grassland (cut/pasture variants), intensive orchards and general viticulture. Crop-specific models include maize, cereals (wheat and barley), potato, apple/pear, strawberry, American blueberry, pasture-cut grassland and pasture grassland. For improved classification, arable fields were categorised following Land Capability Classification(LCC) principles [9,10]. Each model defines its own factor set, membership functions, and weights, focusing on natural factors while excluding management-dependent good-practice variables at this stage (Figure 1).



Figure 1. Workflow of the *RajonSI* methodology

RESULTS AND DISCUSSION

In 2025, the factor catalogue (61 candidate variables) and harmonised raster layers for soils, climate indicators and topography were compiled. Draft suitability maps were generated for selected sectors and crops, revealing clear gradients controlled by elevation, slope and thermal regimes, and highlighting flood-prone and frost-prone constraints (Figure 2). Weighting schemes for permanent grassland (mowing vs. pasture) prioritise texture and soil type, followed by precipitation and elevation; mechanisation-related slope thresholds distinguish feasible management zones.

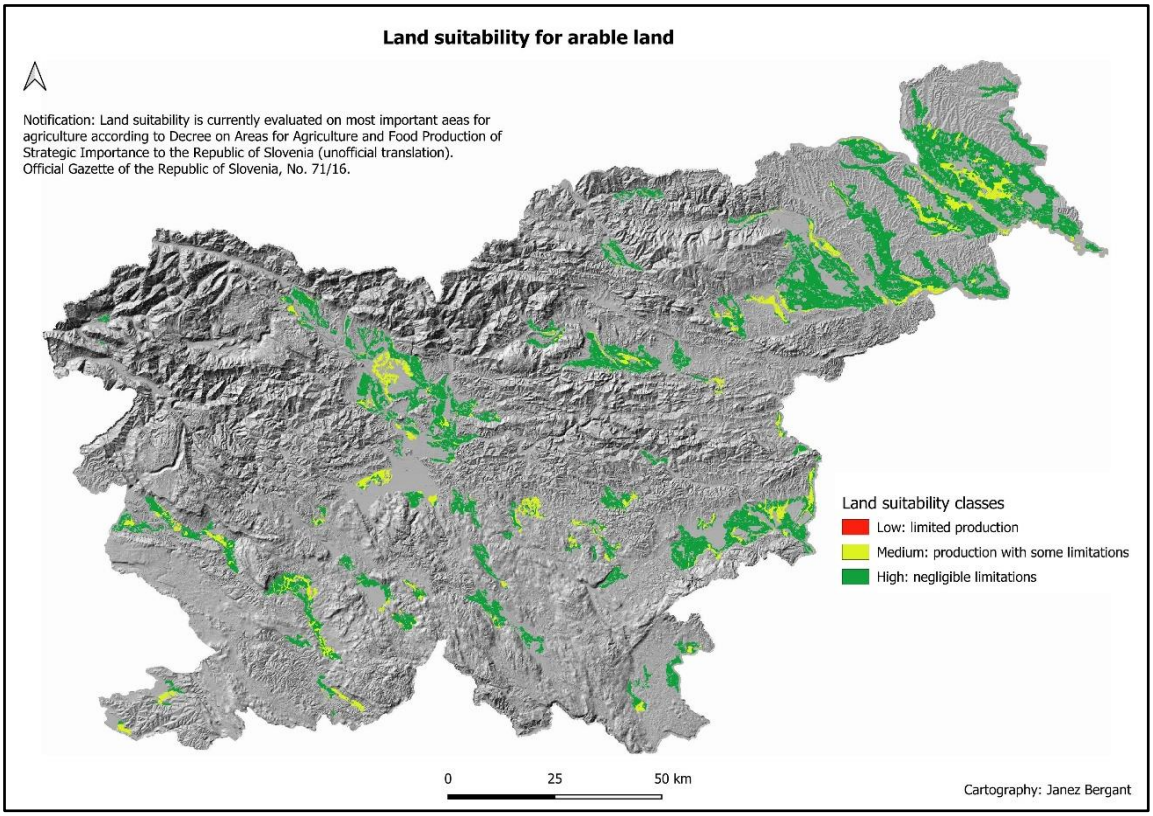


Figure 2. Draft land suitability map for arable land.

The spatial analysis indicates a predominance of areas classified as highly suitable for arable land, accounting for 84% of the evaluated agricultural area (171,243 ha) (Figure 3). These areas are characterised by negligible limitations to crop production and form the core of Slovenia's strategically important land for food production. Their spatial distribution largely follows lowland plains, valley bottoms and gently undulating terrain, where favourable soil properties, topography and accessibility support stable and intensive agricultural use.

Low-suitability areas represent 16% of the assessed area (33,416 ha) (Figure 3). These zones are spatially fragmented and primarily associated with more complex terrain, transitional relief or locally unfavourable soil conditions. Limitations in these areas are likely linked to factors such as slope, shallow or heterogeneous soils, drainage constraints or increased erosion risk, which restrict productive arable use and increase management requirements.

The strong dominance of highly suitable land highlights the overall favourable natural conditions for arable agriculture within the designated strategic areas. At the same time, the presence of low-suitability zones underscores the need for site-specific land management, where alternative land uses, reduced cropping intensity or targeted soil-conservation measures may be more appropriate. From a planning and policy perspective, the results support prioritising the protection of high-suitability land, while recognising low-suitability areas as more vulnerable and need of careful management to prevent land degradation.

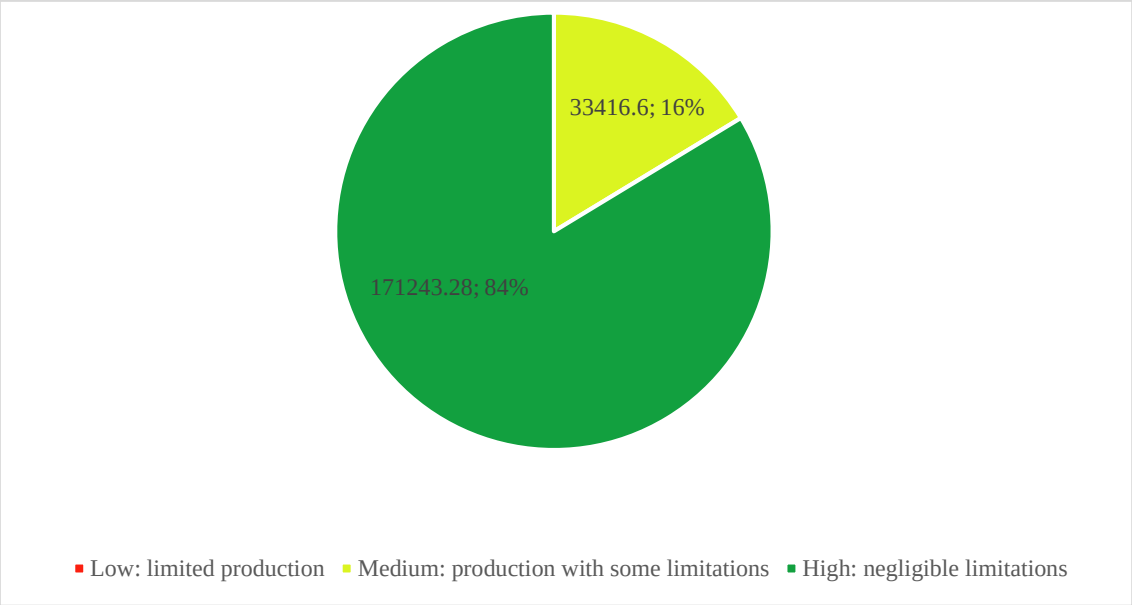


Figure 3. Distribution of land suitability classes.

CONCLUSION

Project RajonSI establishes a reproducible, transparent GIS framework for producing crop-specific land-suitability maps and creating agricultural zones in Slovenia. The harmonised data stack and WLC-based models enable cross-sector suitability assessments under current and future climates. Next steps include accessing land-suitability maps for future climate scenarios using EURO-CORDEX climate data, model calibration with expert knowledge, refinement of membership functions and weights, publication of national suitability layers, and deployment via a web GIS viewer to support Ministry of Agriculture, Forestry and Food (MAFF) and farm-level decisions.

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IDENTIFICATION OF POTENTIAL GEOHAZARD AREAS IN WESTERN MACEDONIA BASED ON SEISMIC DATA

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ABSTRACT

Western Macedonia is located within a seismically active zone of the Balkan Peninsula, characterized by complex geological, tectonic and seismotectonic area of active intra-plate tectonics and history of moderate to strong earthquakes.
The identification of potential areas prone to geohazards is therefore essential for seismic hazard assessment, land-use planning, and risk mitigation. This study uses seismic data to delineate potential geohazard areas through spatial and statistical analysis.

Keywords: seismic data, GIS, geohazard ś

INTRODUCTION

Geohazards associated with seismic activity represents a significant threat to population, infrastructure, and economic development. Earthquakes may lead not only to direct ground shaking damage but also to secondary effects such as surface faulting, landslides, and ground deformation. Identifying areas with elevated geohazard potential is therefore a critical step toward effective risk mitigation, urban planning, and the implementation of appropriate building regulations [3]. In regions such as Western Macedonia, where settlements and critical infrastructure are often located near active tectonic structures, this need is particularly pronounced.
Seismic data constitute a fundamental source of information for investigating seismotectonic processes and assessing geohazard potential. Earthquake catalogs provide detailed records of event location, magnitude, depth, and temporal occurrence, allowing

for the analysis of spatial and temporal seismicity patterns. Statistical analysis of seismicity, including frequency–magnitude relationships and spatial density methods, can reveal zones of increased stress accumulation and enhanced seismic activity [15]. When combined with spatial analysis tools, these methods enable the delineation of areas that may be more susceptible to future seismic events [10].

The aim of this study is to identify and delineate potential geohazard areas in Western Macedonia based on the systematic analysis of seismic data. By applying spatial density analysis using Kernel Density Estimation (KDE), statistical seismicity parameters, and Geographic Information System (GIS) techniques, this research seeks to identify areas of increased geohazard potential.

STUDY AREA

The western part of the Republic of North Macedonia, which is defined as the West Macedonian tectonic zone, is an internal massif located in the northeastern part of the Dinaric-Hellenides. To the west it borders the Mirdita zone (on the territory of Albania), it also partially borders the Cukali zone (in the Debar region). Its eastern border, towards the Pelagonia massif, is a regional fault zone [7].

The region is characterized by a complex geological and tectonic setting resulting from the interaction of the Eurasian and African plates with numerous active and potentially active faults. Western Macedonia encompasses several major tectonic units [9], including grabens, horsts, and fault-bounded basins, which contribute to its heightened seismic activity.

The seismotectonic framework of the region is further constrained using the receiver function method, revealing significant lateral variations in crustal thickness and internal structure [12, 13].

The region is intersected by numerous faults, but some of them have high seismicity defining them as active faults: Sharplanina, Elbasan-Debar, Pelister and Peshtansko-Petrinski, Figure 1.

These faults are predominantly of the normal slip type, which reflects the extensional regime of the area. They also represent seismic sources with clearly expressed temporal and spatial continuous seismicity [8]. The geological base consists of a combination of metamorphic, sedimentary and volcanic units, with localized zones of weak sediments in basins that can intensify ground shaking during seismic events [2]. Since the concentration of earthquakes is in the entire region under consideration, we say that it has the characteristics of a true seismic zone.

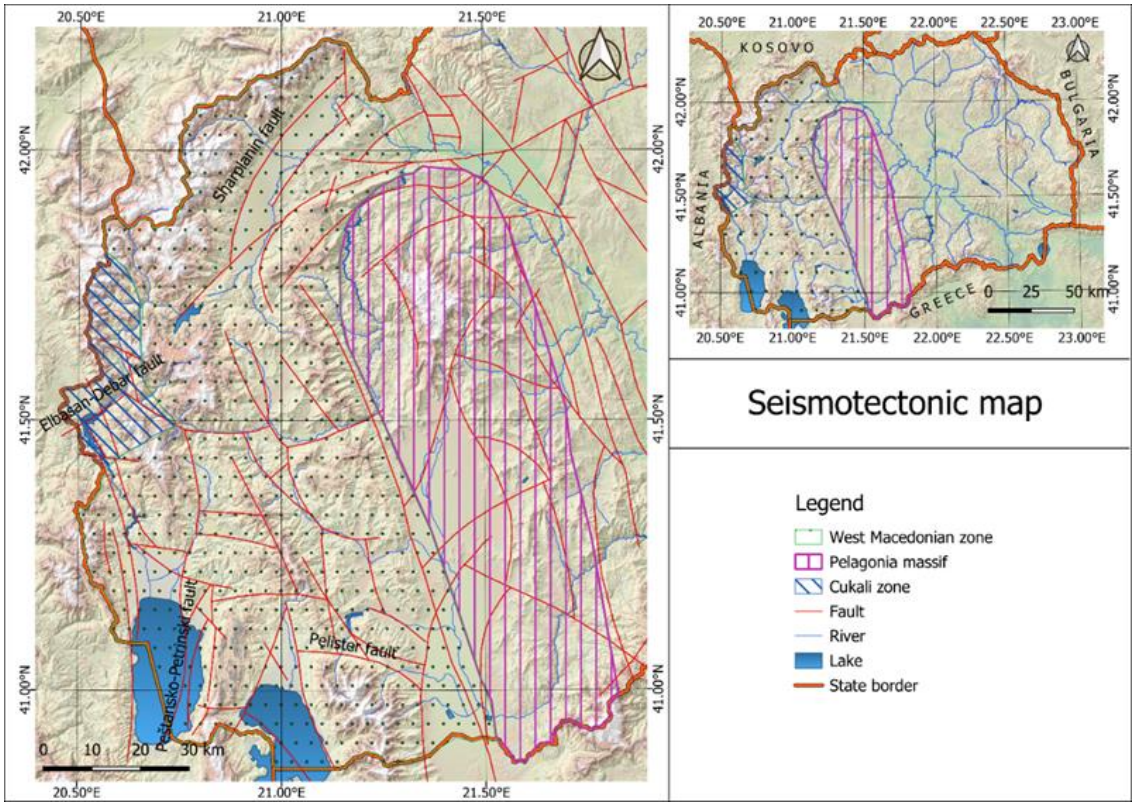


Figure 1. Seismotectonic map of the study region

HISTORICAL AND INSTRUMENTAL SEISMICITY

Seismicity defines the spatial distribution of historical and contemporary earthquakes in a given area over time. The integration of historical and contemporary earthquake data is essential for seismological research. Historical records document catastrophic earthquakes, while modern data provide continuous seismic records and enable precise analyses. This connection facilitates a more comprehensive understanding of the recurrence of strong earthquakes, the identification of active faults, as well as the mapping of areas exposed to seismogeological effects.

The territory of Western Macedonia is characterized by a complex tectonic structure. The interaction of block structures results in pronounced seismicity, manifested through very weak to strong earthquakes, with magnitudes ranging in the interval $0.1 \leq Mw \leq 6.7$. Earthquakes with epicenters located in Western Macedonia are grouped into several epicentral areas, which spatially belong to the Western or Drim, seismogenic zone [4, 9]. Most of them are located entirely on the territory of Western Macedonia, while some extend partially across its borders (they represent border epicentral areas). Epicentral areas with high seismic activity include Debar, Peshtani–Ohrid–Struga and Bitola regions, where the recurrence of earthquakes that produce seismogeological effects is observed. The remaining areas are characterized by moderate to low seismic activity, Figure 2.

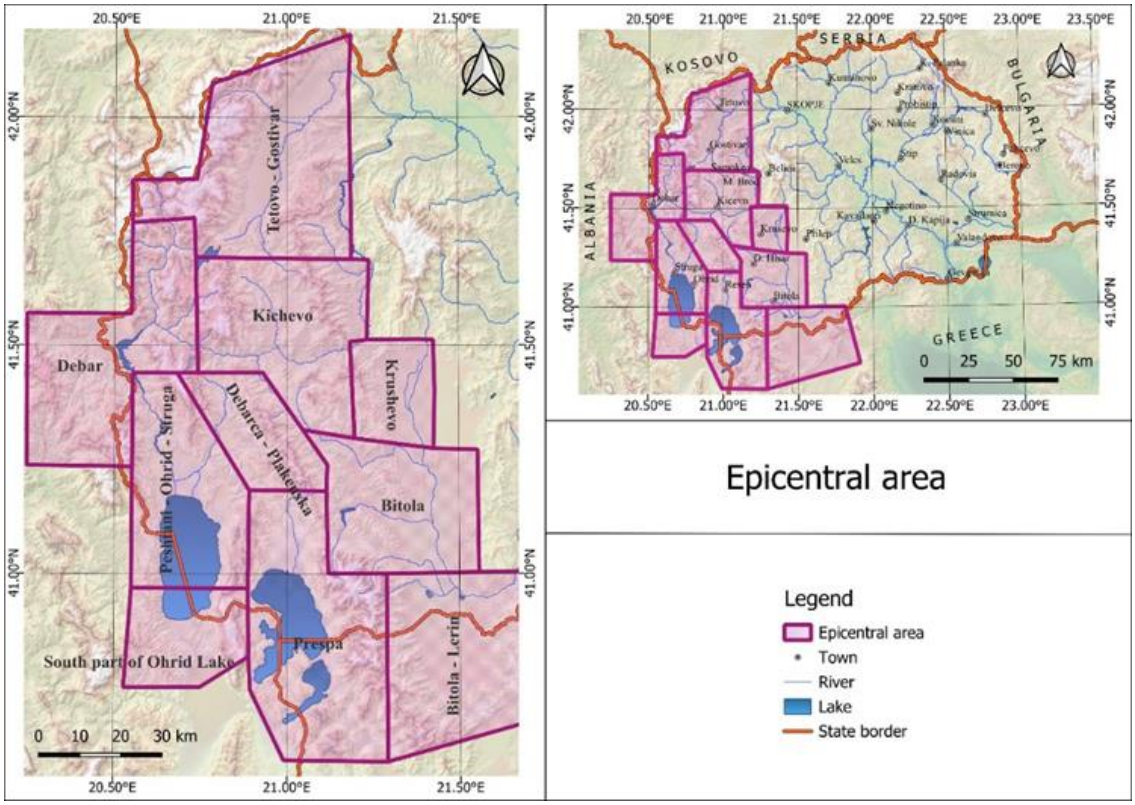


Figure 2. Epicentral areas in Western Macedonia

Faults responsible for seismic activity with magnitudes ML ≥ 5.0 (or moment magnitudes Mw ≥ 5.0), classified as active and representative faults for the epicentral areas to which they spatially belong, include the Shar Planina Fault, the Elbasan–Debar Fault, the Peshtani–Petrino Fault system, and the Pelister Fault [4].

Considering both historical and contemporary seismicity, it is evident that epicentral areas with increased seismic activity are most often associated with earthquakes capable of generating pronounced seismogeological effects. For example, in the epicentral area Peshtani–Ohrid–Struga, significant events include the historical earthquake of 527, as well as more recent earthquakes in 1911 and 2017. Similarly, in the epicentral area Debar, notable earthquakes occurred in 1967 and 2020. In the epicentral area Bitola, the historical earthquake of 1858 and the event of 1994 are particularly significant.

Historical seismicity for the period 525–1900 is characterized by seven earthquakes, all with magnitudes Mm ≥ 5.0 (Mm—magnitude determined from macroseismic data), while contemporary seismicity covering the period 1901–2023, includes a total of 12 736 earthquakes with magnitudes ranging from 0.1 ≤ Mw ≤ 6.7. Spatial distribution of seismicity for the period 1901-2023 are presented in Figure 3.

Figure 4, illustrates the number of earthquakes with magnitude intervals of one unit each.

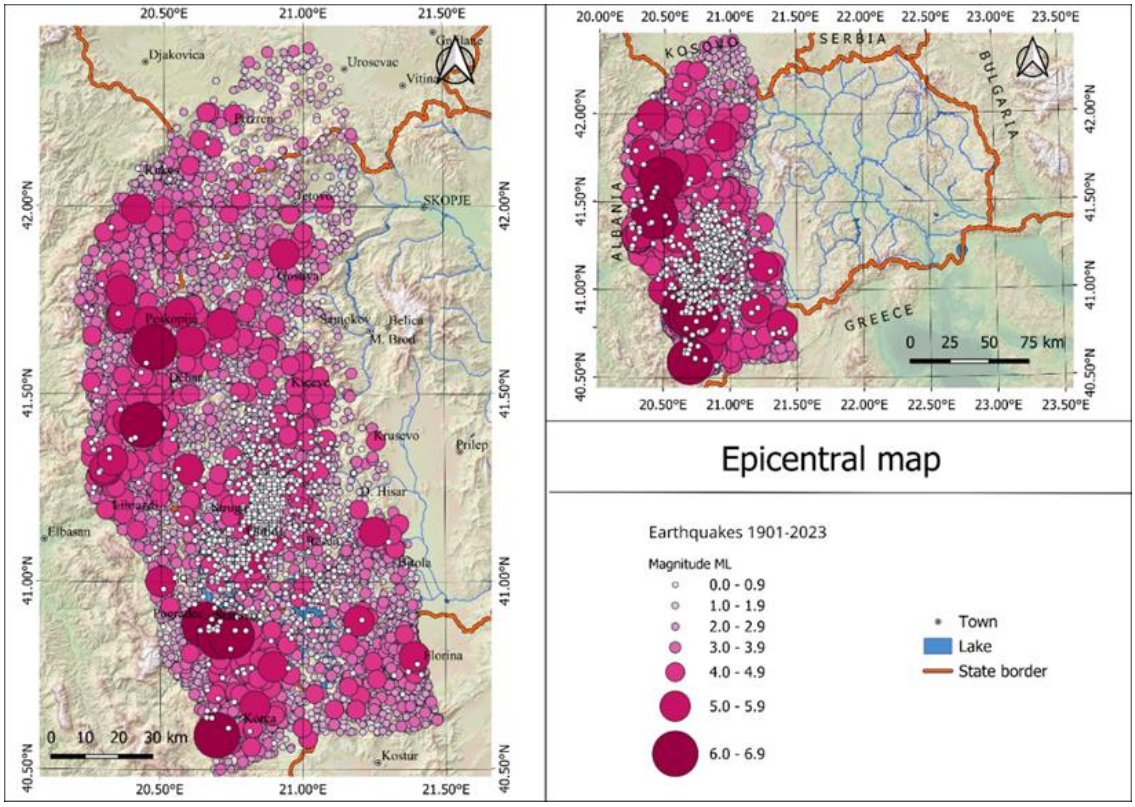


Figure 3. Epicentral map of the study region

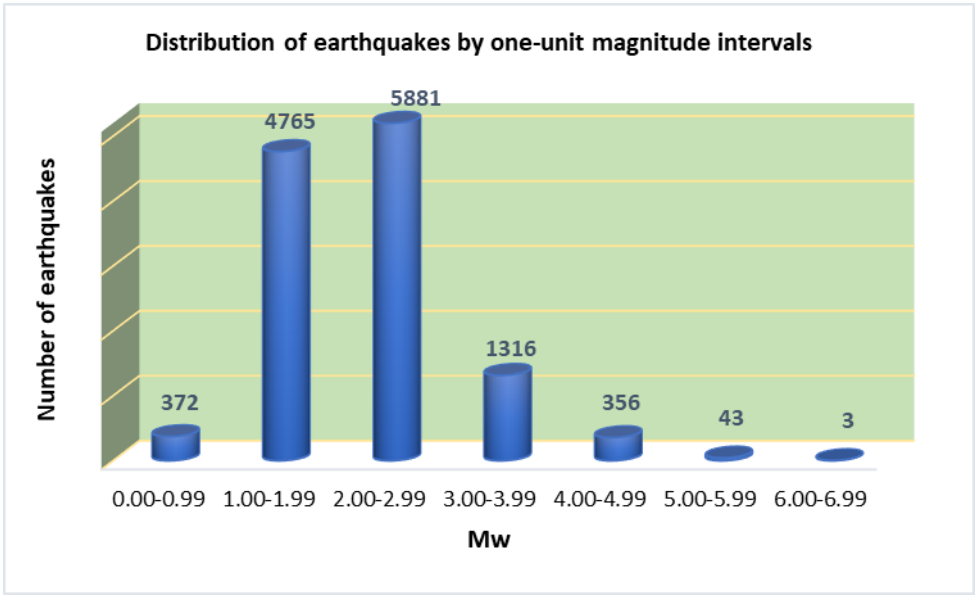


Figure 4. Distribution of earthquakes by one-unit magnitude intervals

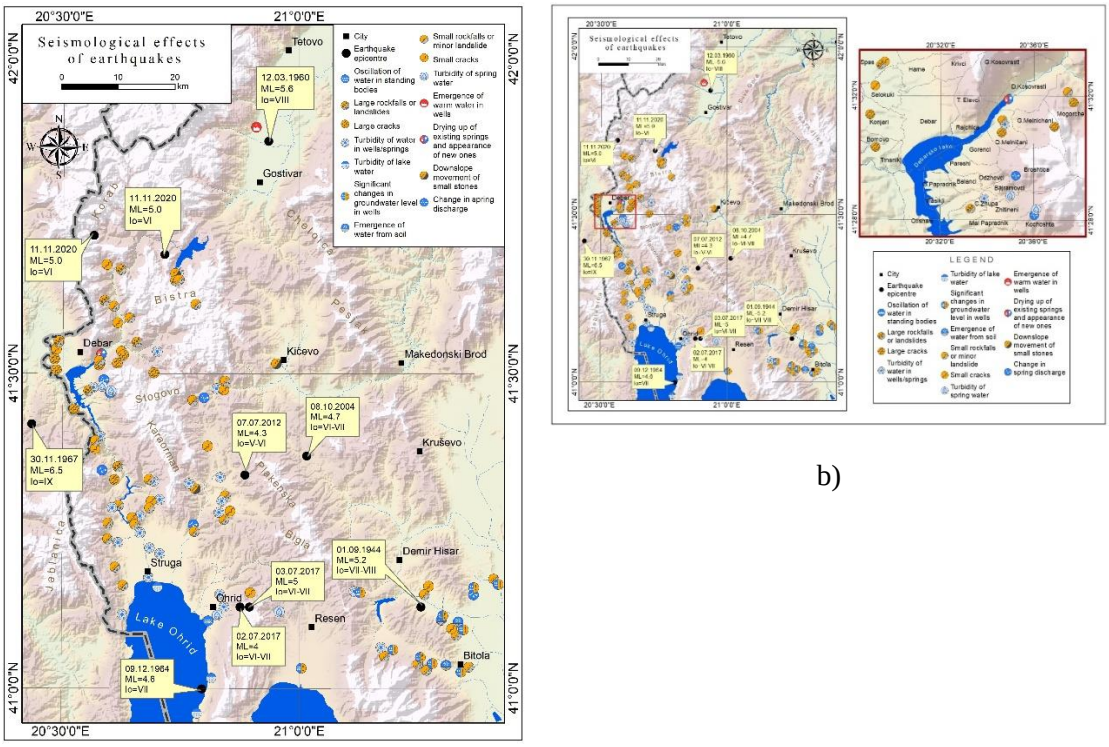
METHODOLOGY

The assessment of seismic geohazards in the study area was carried out using an integrated methodological approach that combines seismological, geological, and spatial analyses. The analysis is based on the application of the frequency-magnitude relationship, spatial density analysis and multi-criteria evaluation in GIS.

Seismological data includes analysis of an earthquake catalog covering the period 1901–2023 [5], contains historical and contemporary (instrumental) events. Based on this dataset, the Gutenberg–Richter relationship [6] was applied to estimate the parameters a and b, as well as the maximum expected magnitude (Mmax), [14]. The b-value was calculated using the maximum likelihood method, proposed by [1], considering only events above the magnitude of completeness (Mc), in order to ensure the reliability of the frequency–magnitude distribution. The spatial variation of b-values was subsequently interpreted as an indicator of relative stress accumulation within the crust.

To estimate the spatial distribution of seismogeological environmental effects caused by earthquakes, a Kernel density estimation (KDE) approach was applied using data on documented seismogeological effects. These include surface ruptures, landslides, liquefaction, and other ground deformation phenomena associated with earthquakes. KDE was used to transform the observed effects into a continuous density surface, highlighting areas with a higher concentration of such effects. The resulting map represents the spatial probability of seismogeological effects from observed seismicity [15, 16]. The final phase of the analysis involved the integration of several thematic layers within the GIS: (i) spatial distribution of densities obtained from KDE, (ii) geological features of the terrain, (iii) isoseismic patterns and their sensitivity, and (iv) distribution of seismically sensitive soils. By overlapping and combining these layers, it was possible to identify areas with different levels of seismic geohazard. As a result, the study area was classified into three categories: high, moderate, and low seismic geohazard.

The analyzed earthquakes with seismogeological effects are presented in Figure 5 (a and b).



a) b)

Figure 5. Earthquakes with seismogeological effects of nature. a) Seismogeological effects of Western Macedonia (left figure); b) Seismogeological effects of the strongest earthquake in Western Macedonia, Debar 1967 (right figure)

RESULTS

This section presents the results of the analysis of macroseismic data with seismogeological effects, and earthquake epicenter distributions for the purpose of identifying geohazard prone areas in Western Macedonia.

It can be observed that the entire study area is characterized by a widespread distribution of earthquake epicenters, indicating that seismic events of different magnitudes—from minor to strong—have occurred throughout the analyzed period, Figure 3. This pattern reflects a persistently high level of seismic activity, confirming that the area can be classified as highly seismically active.

This spatial pattern is consistent with the results obtained from the Kernel Density Estimation (KDE), which highlights zones of increased concentration of seismic activity. The Kernel Density Estimation (KDE) analysis revealed a non-uniform spatial distribution of seismogeological effects, with clearly defined zones of increased density. The highest density values are concentrated in specific areas, indicating spatial clustering of earthquake-induced environmental effects. These zones correspond to areas with repeated occurrence of seismogeological effects and represent the most affected parts of the study area, Figure 7.

Furthermore, the relatively low b-value ($b = 0.62 \pm 0.01$) shows us that earthquakes of higher magnitude dominate in these areas, indicating increased stress accumulation conditions in the crust, Figure 6.

The combined interpretation of the distribution of seismogeological effects, KDE results, and b-value analysis confirm that the identified areas in Western Macedonia show a high level of seismic activity and represent a region with significant potential for seismic geohazards.

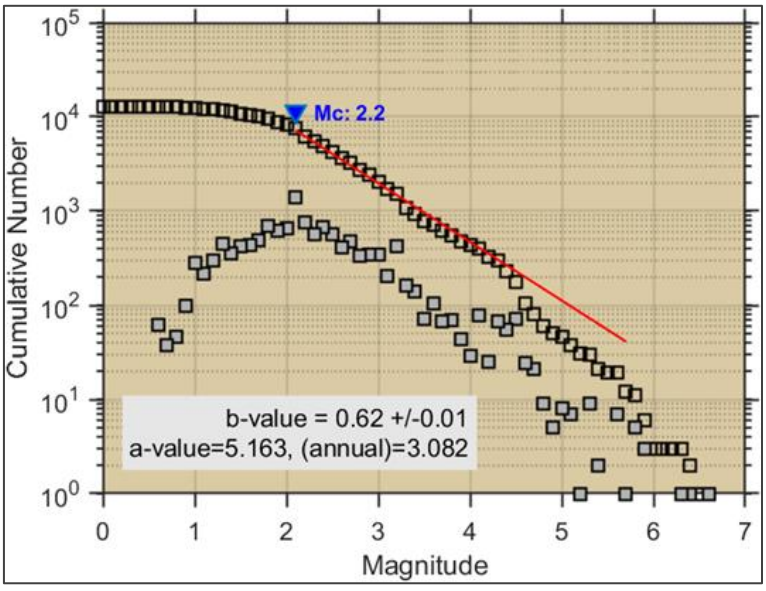


Figure 6. Frequency–Magnitude distribution

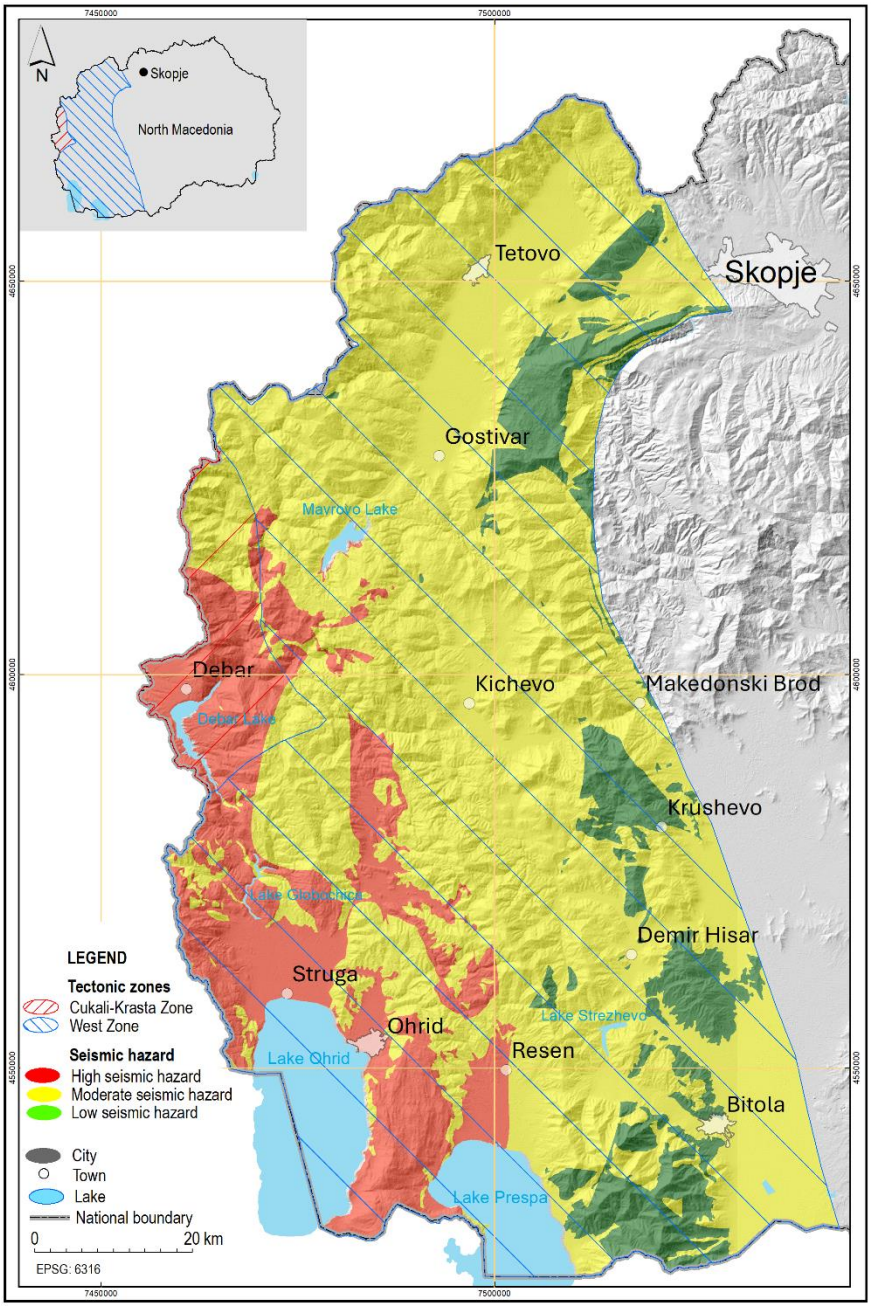


Figure 7. Identification of potential geohazard areas in Western Macedonia based on seismic data

DISCUSSION

The spatial distribution of earthquake epicenters throughout the region confirms a continuously active seismic regime, with events of different magnitude.

This model is further supported by the spatial clustering of seismological effects, identified through the Kernel Density Estimation (KDE), which highlights the different zones of concentrated seismic effects caused by earthquakes.

The obtained b-value ($b = 0.62 \pm 0.01$) indicates relatively high stress conditions in the crust, which is usually associated with the dominance of seismic events of higher

magnitude followed by seismogeological effects. It follows that, a low b-value depicts the region as a potential zone of future strong seismic activity [11].
The result is strongly supported by the global trend of decreasing b-value with depth in the continental crust and subduction zones.
This is confirmed by the analysis of the seismicity of Western Macedonia, which indicates that the hypocenters of earthquakes are generally located at depths of up to 30 km.
The Geographic Information System (GIS) enabled the identification and classification of geohazard areas.
The results show a strong spatial correlation between the identified areas of high geological risk, areas of increased seismic activity (Fig. 3) and the main active fault structures (Fig. 1), strengthening the reliability of the applied methodological framework. From this correlation, the areas colored in red (Fig. 7) are exposed to a high seismic risk from earthquakes with seismogeological effects. Based on the observed seismicity and seismotectonic characteristics of the region, these areas have historically been affected by strong earthquakes (Fig. 5b), associated with significant seismogeological effects and therefore it is considered that these areas are likely to experience future strong earthquakes capable of generating significant seismogeological effects. Areas colored yellow is exposed to moderate earthquakes, without pronounced effects on the natural environment. Areas exposed to very weak earthquakes with seismogeological effects are colored green. The proposed methodology provides reliable identification and classification of seismic geohazard zones.

CONCLUSSION

This study presents methodological framework for identifying, assessing and spatially delineating areas of seismic geohazard by combining seismicity analysis, Kernel Density Estimation (KDE), F -M distribution, and geological-tectonic data within the Geographic Information System (GIS).
In this way, areas exposed to seismological effects of earthquakes in Western Macedonia were identified.
Identification of high geohazard zones show a strong correlation with active fault structures, high seismic density, and KDE values, while low geohazard zones are characterized by lower seismic activity and more stable geological conditions.
The proposed methodology provides a scientifically sound and spatially explicit framework for assessing seismic geological risk. It is suitable not only for academic research, but also for practical applications in spatial planning, seismic risk management and disaster mitigation strategies

ACKNOWLEDGEMENTS

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INTERDIURNAL THERMAL ANALYSES OF INNER COURTYARDS BY MEANS OF AIRBORNE REMOTE SENSING

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UDC: 528.8.044.8:551.584.5-026.65(436)

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ABSTRACT

Urban areas are heavily modified in terms of surface temperatures (UHI: Urban Heat Island) relative to their rural environment. By means of airborne or satellite-based Earth observation, it is possible to find out changes in radiation and energy flux densities in the mesoclimate of the city. Land cover utilization and sealing aspects play a significant role in the modification of surface temperatures in a city. In the present work, the surface temperature data, derived from the thermal scanner surveys of the years 1986, 2004, 2011 and 2021 as well as the degree of sealing, the land use, the land cover and the climatopes, were summarized in a geodatabase. With this GIS-based information, it is possible to analyze the thermal behavior of different inner courtyards according to their underlying surfaces as well as their size. In addition to the description of the climatological features of the Graz urban area, a part of the paper is dedicated to the data preparation and methodology development, following by the analysis of results based primarily on statistical evaluations. After successful creation of the database, the results indicate a strong correlation between sealing degree and thermal behavior of inner courtyards. The temperature increases with higher sealing degrees whereas the opposite greener areas – lower temperature was recognized as well. Additionally, thermal characteristics vary depending on their location within the city according to climate conditions. Almost no strong correlation referring to their size was identified.

Keywords: Thermal Remote Sensing, Surface Temperature, Inner Court Yards, Urban Climate

INTRODUCTION

According to the United Nations, in 1950 less than 30% of the world's population was resident in urban Areas, at the end of the second century the number grew up to 50%. Already 2015 the number increased to 70% [1]. Although urban areas cover only 0.2% of the earth's surface, they contain most of the world's population, why a future-oriented, sustainable city development is unalterable [2]. In the last years (decades), satellite, as well as airborne remote sensing techniques, got recognized as a handy tool for analyzing urban structures.

Urban areas change the earth's surface, the atmosphere above, compared to their surrounding they have a strongly modified climate because of a different urban-type settlement with an increased number of housings, transportation and so on. They have a stronger intensity of development, a much higher degree of sealing and a lack of green areas and vegetation [3]. Thereby the city climate differs to their surrounding in several

conditions. An increased surface and air temperature, which often leads to the development of a heat island can be observed and the wind can be strongly modified [4]. All this leads to an anthropogenic caused climate modification, changing the climate and air conditions in the city environment [5]. It concerns not only metropolis regions with millions of inhabitants but also the climate conditions of small cities like Graz with about 300.000 inhabitants are already different. Remote sensing can provide answers about the complexity in varying degrees of detail and from different backgrounds. Fully comprehensive data collection enables the quantitative description of the earth surface, its parameters, and dynamics. Remote sensing developed to an ancillary discipline within city climate and plenty of other disciplines [4].
The comprehensive data collection of airborne thermal scanner flights makes the map and monitor process of the different physical properties of structures and forms used in the city environment possible [6]. In urban areas thermal Remote Sensing is defined as the measurement of the surface temperature and their properties, which correspond to the land use and land cover. Those datasets are available in different spatial and temporal resolutions [7]. The urbanization process has a strong influence on the earth surface and the land use change. The advantage of the thermal Remote Sensing technologies, compared with in-situ temperature measurement on the ground is the delivery of surface temperature information's [8]. Those are comprehensive and simultaneous records taken by airplanes or satellites, which are of primary importance for detailed investigations. They make a further survey of the Land Surface Temperature (LST) or the Urban Heat Island (UHI) or other phenomena in the city possible. Additionally, a temperature analysis of the close urban-rural space is practicable, whereas further statements for the city climate can be made [9]. In-Situ measurement methods are because of different interpolations in comparison error prone. To compare the thermal behavior of inner courtyards of the foundation period (Figure 1) through data taken by airborne thermal scanner flights, the use of statistical parameters like the mean value and standard deviation, can be helpful. The area density describes the center of a distribution, while the standard deviation makes a more precise quantification of the amount of variation of the available data set possible [10], [11].

STUDY AREA, DATA AND METHODOLOGY

Study Area

In this paragraph, an overview of the location as well as the climatological features for the investigation area Graz, the capital of the province of Styria in Austria, will be described. For a consistent size of the study area and the used data sets, the city boundary with an area of 12.756 hectares was used. Graz has a river called "Mur" flowing through and splitting the city up into two parts. One is on the left bank in the "Riedelland" while the right bank has the "Plabutsch-Buckhogel" range with 763 m above sea level. The climate character can be described continental with a strong influence on the precipitation, having a small amount of snow during winter, while in summer the thunderstorms frequency is high. Situated in a valley basin with asymmetry and its location southeast of the Alpine ridge, the city is recording a low amount of wind, which increases especially during winter, the possibility of inversions and fog. This causes many disadvantageous for air pollutant and forces four local wind circulations differing during the day [12], [13], [14], [15], [16].

Regarding the temperature, there are different patterns within the city. The tributary valleys in the east show the highest variations in daily temperature differences, the Grazer Feld (in the south) has very moderate temperature and records much fog. The city center is warmer because of the densely built-up area also resulting in a heat island. Two different types of heat islands with different structures, depending on the Murvalley wind system can be formed. A very balanced climate can be found on higher parts of the crests that are called “Riedel” because of the existing inversions in this area [17], [18].

Data and Methodology

In this analysis, the land surface temperatures derived from the airborne thermal scanner flights of the years 1986, 2004, 2011 and 2021and the respective data for the land cover, the land use, the predefined climatopes and the sealing degree of each year of the city of Graz were used to identify modification of the land surface temperature of the inner courtyards [10].

The land use is divided into several different land use categories and was used for the extraction of the foundation structure. This dataset contains 30 different land use structures appearing in the urban area of Graz and were predefined in [12], [16], [17]. For example, the agricultural areas like vineyards or forest and artificial surfaces like industrial or commercial units or green urban areas were distinguished. It also contains the layer foundation structure, which is essential for the underlying work and did almost not change over the years what makes sense, as it is an old structure from the 19th century. The slight change from 1986 to 2011 concerns around 2.5 hectares, which results in a decrease of the area from 274 to 271 hectares and is influenced only by the data collection and not an underlying change itself. Also, the other datasets, like the sealing degree, the land cover and the climatopes were predefined [15], [19], [20]. One challenge of this work was moreover to merge the big datasets to extract several layers in one with a uniform reference system. Figure 1 represents the spatial contribution of analyzed court yards in Graz.

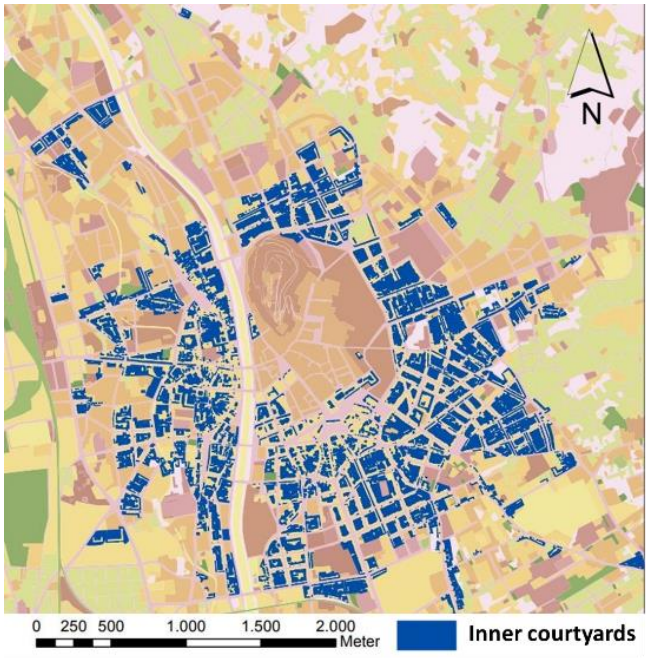


Figure 11. The location of the selected inner courtyards in Graz.

Because of the different sensors, different pre-processing steps and diverse data formats used for collecting the surface temperature and the other information, some additional pre-processing steps were necessary to homogenize the data before importing all into one geodatabase. Through an intersection, it was possible to keep the spatial reference of the data and thereby manage, save, reprocess, and analyze them.
Figure 2 shows examples of used data (LC/LU, Image representation and thermal coloured information). As seen in Figure 3 an overview of the workflow is depicted before the data was finally transformed into vector data.

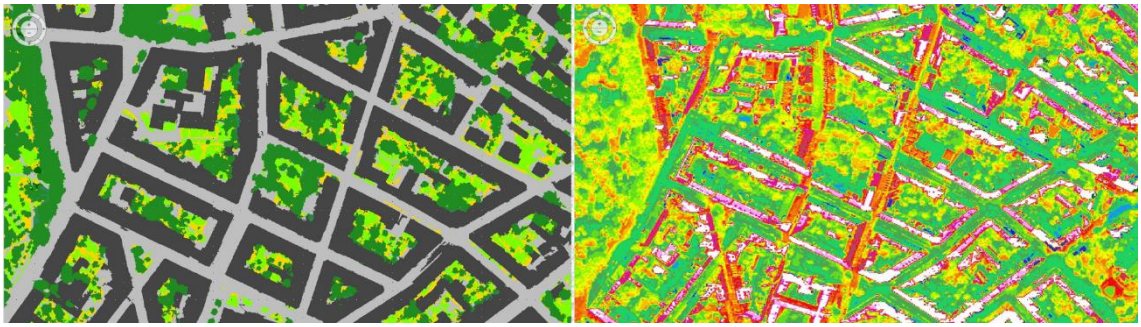


Figure 12. Landcover structure left (black: buildings, grey: sealed areas, dark green: trees and bushes, light green: grass) and thermal image representing the surface temperature right (2021 midday) of the foundation area in Graz.

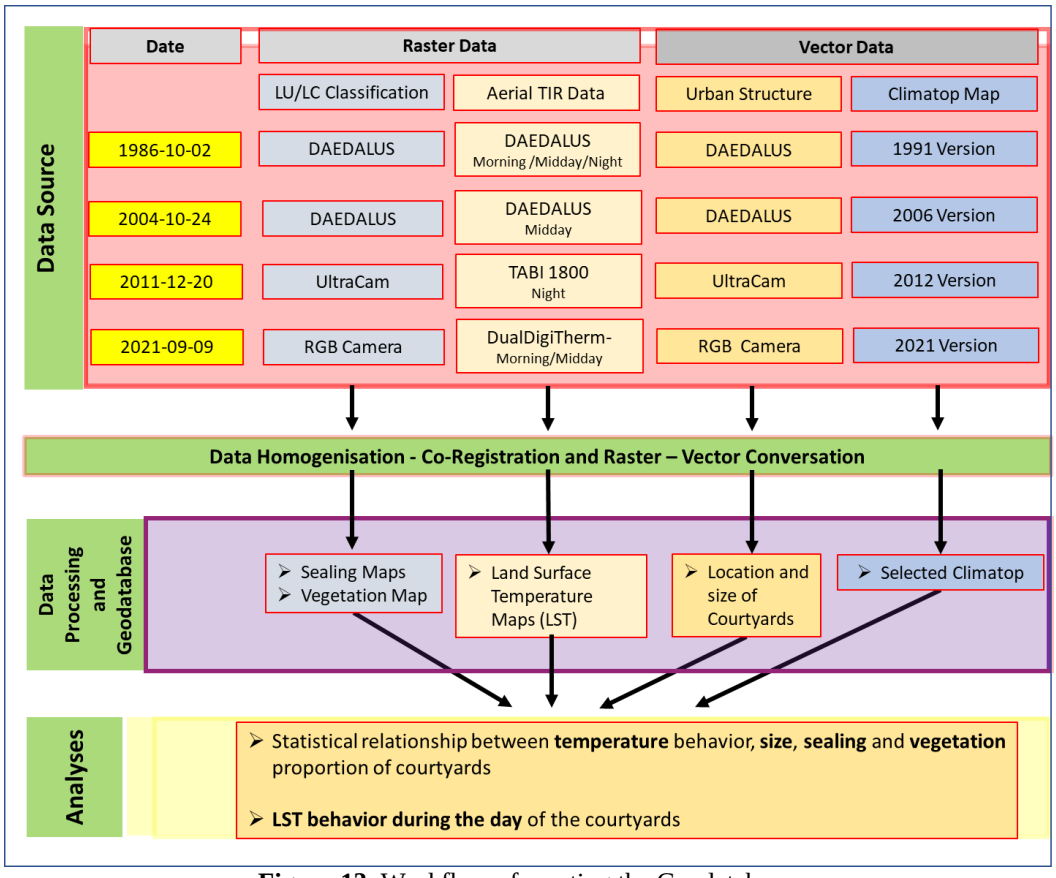


Figure 13. Workflow of creating the Geodatabase.

The surface temperatures were delivered in a format of different bit depths. 1986 had 8 bit, 2004 and 2011 had 32 bits. In order to homogenize the data, the data of the flights of 2004 and 2011 were rounded to integers of 8 bit. The comparison was easier having all the data in 8 bits, the data loss was reasonable, especially considering the already achieved file size of 16 gigabytes. Otherwise, the computing time, which already demanded several hours at each step, would have been considerably longer. In the last step, before transforming into vector graphics the thermal scanner flights from 2004 and 2011 were split into four and 16 parts to avoid an exceeding the two-gigabyte limit of the shapefile type. If the size limit is crossed the output file is empty after the process. Then the data was combined in several consecutive steps starting to merge all data without the surface temperature, which was added at the end.
After successful creation of the database, including now the degree of sealing, the land use category for the foundation structure, the surface temperatures and the climatopes, one for every year, the weighted average and the standard deviation were calculated and exported for every polygon. This made a further calculation of different statistics possible to determine correlations between the surface temperature and either the size or its sealing degree.

RESULTS

According to [13], [14], [21] the climate of inner courtyards is determined mainly through ventilation conditions which in order are primarily influenced by the size and the number of floors. It is being evaluated if, based on the available data, a relation between thermal behavior of inner courtyards and their size as well as their sealing degree can be identified. Not discussed in this context will be the influence of the number of floors.

Distribution of inner court yards

The area of the inner courtyards has reduced by the value of three hectares over time, which can be neglected and has been regarded as constant over the years. The degree of sealing increased in Graz by 5%. Against the general trend, the inner courtyards registered a decrease of sealing degree of 12%. As seen later, a lower density has a strong effect on thermal behavior leading to lower temperatures.
In Figure 4 the inner courtyards of 1986 were categorized into classes of 0,1 hectares, showing for each class the number of inner courtyards and their relative occurrence. Because of the constancy of this structure type within the city area over the years, there is no need for further consideration of the following years. Thirty-nine inner courtyards between 0,3-0,4 hectares cover 11,2% of the foundation area. Following that, 19 inner courtyards with the class size 0,6-0,7 hectares are covering 10,2% of the area. The biggest one has 2,6 hectares and represents 2,2% of the area.
As shown in Figure 5, the inner courtyards have according to their location in the city very different structures in terms of size and shape. It is a result of historical development due to different reasons. The ones located on the right part of the river “Mur” (Figure 5 left) are disrupted, have small houses or other barriers in between and no permanent open space at all. Those on the left side (Figure 5 right) are very homogenous and well defined. While analyzing the influence of the size of the inner courtyards on their temperature behavior, those circumstances need to be considered to get meaningful results. Consequently, just the coherent inner courtyards of the left side of the river were taken into consideration.

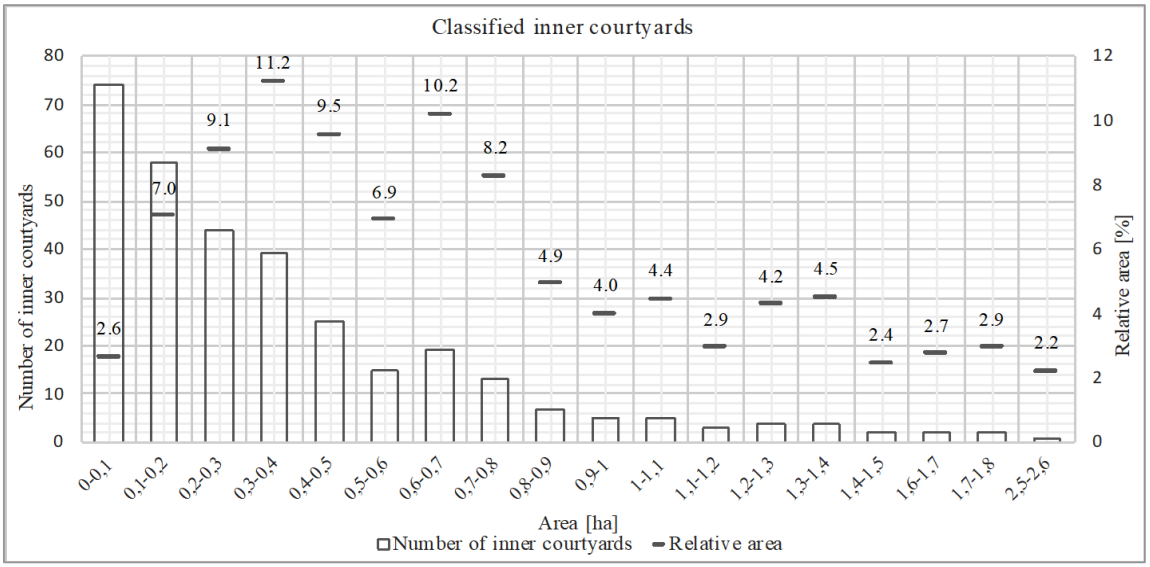


Figure 14. Area of inner courtyards of the foundation structure classified in ha of 0,1 and their corresponding number and relative area in % - 1986.

Temperature versus size of inner court yards

To validate a possibly existing correlation of the parameters, namely the size of inner courtyards and their temperature, the area was categorized into classes of intervals of 0,1 hectares. Subsequently, the area-weighted average of the classes was applied, and a linear regression was calculated. Through a linear regression, the trend of a possible correlation between parameters can be evaluated. In this work, for assessing the strength of an underlying correlation, the valuations were applied as seen in the Figures 6 - 11 the strongest correlation between the parameters can be seen at midday of 1986 with a coefficient of determination (R2) of 0,61. The data of the flight of December 2011 reveals a coefficient of R2 = 0,52. A weaker correlation can be seen in the night of 1986 with R2 = 0,44, and 2021 with R2=38., respectively at midday 2021 with the lowest value 0.00024. During the flights at midday 2004 as well as in the night of 1986 and 2021 no linear correlation between the characteristics can be seen. Because of the large temperature ranges of the individual flights a uniform y-axis was renounced.

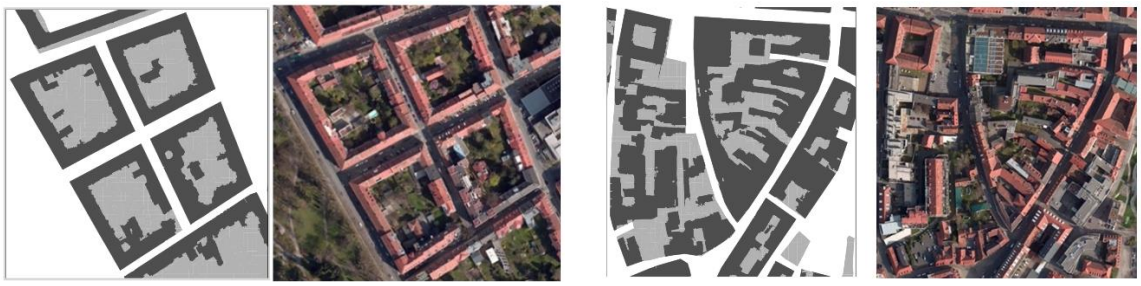
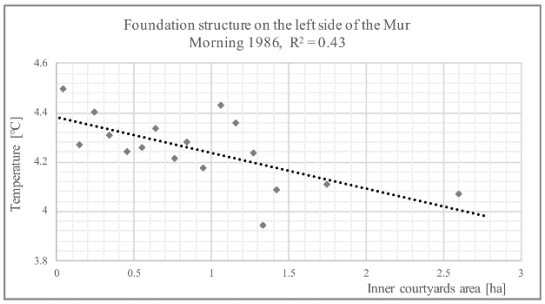


Figure 15. Inner courtyard of the foundation structure
(Dark grey: Building; Light grey: Inner courtyard, UltraCam 2015).



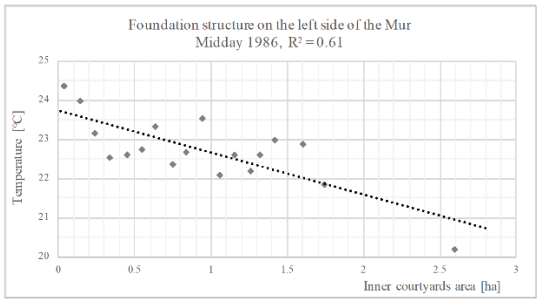
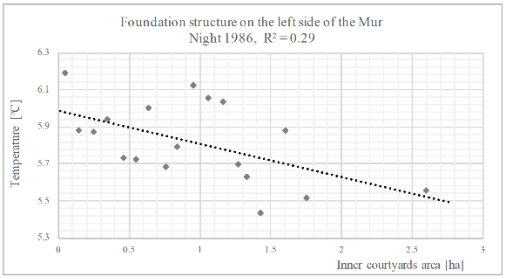


Figure 16 (left). Area of inner courtyards classified in ha of 0,1 vs. temperature in °C. The courtyards are located in the foundation structure of the left side of the Mur – Morning 1986.
Figure 17 (right). Area of inner courtyards classified in ha of 0,1 vs. temperature in °C. The courtyards are located in the foundation structure of the left side of the Mur – Midday 1986.



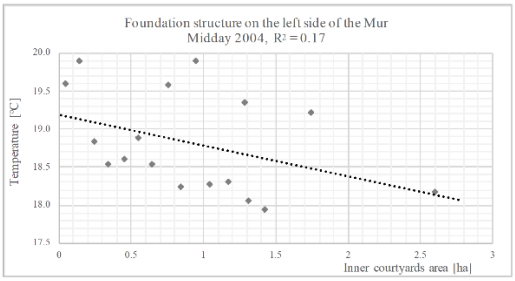
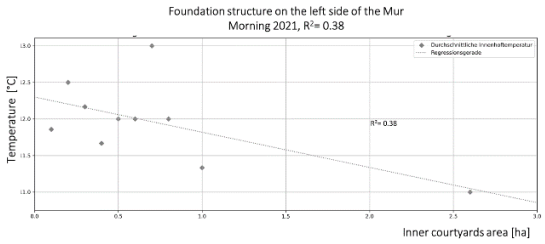


Figure 18 (left). Area of inner courtyards classified in ha of 0,1 vs. temperature in °C The courtyards are located in the foundation structure of the left side of the Mur – Night 1986.
Figure 19 (right). Area of inner courtyards classified in ha of 0,1 vs. temperature in °C. The courtyards are located in the foundation structure of the left side of the Mur – Midday 2004.



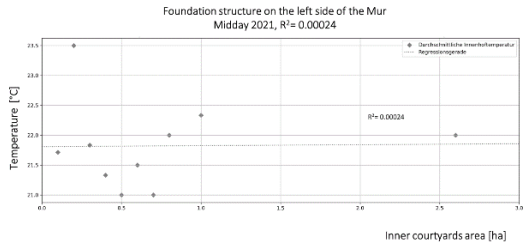
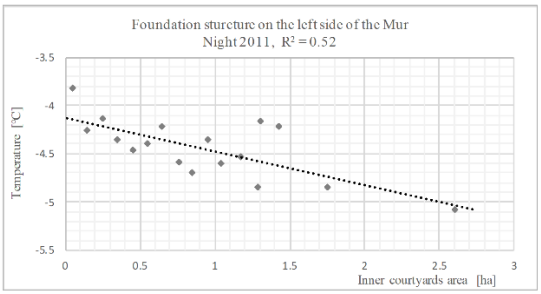


Figure 20 (left). Area of inner courtyards classified in ha of 0,1 vs. temperature in °C The courtyards are located in the foundation structure of the left side of the Mur – Morning 2021.
Figure 21 (right). Area of inner courtyards classified in ha of 0,1 vs. temperature in °C. The courtyards are located in the foundation structure of the left side of the Mur – Midday 2021.

Temperature versus degree of sealing

The sealing is an impermeable surface such as asphalt or concrete used for streets, pavements, parking and so on. As already remarked in the works of [4], [9], [22] those materials are changing and reducing processes and functions irreversibly within the landscape ecosystem. The degree of sealing describes the relations between the sealed areas compared to the whole investigation area. According to [23], the number of sealed areas is one of several micro- and mesoscale variables causing and influencing the city climate. Depending on the material of the sealed areas, they lead to a change of the thermic and hydrological properties and additionally to a decrease of vegetation.
Compared to humidity saving materials, dry asphalt or any other impervious surfaces heat up much more due to the lack of evaporation, for which an enormous amount of energy is needed. As a result, the additional, available energy is transformed into the long-wave range radiation as well as turbulent fluxes of the ground- and air heat capacity – which

leads to a warming of the atmosphere [23]. The evaporation process removes heat; this is why more continuous green cover areas like grasslands, forest or wetlands appear in thermal scanner flights as much cooler. Depending on the spatial extent and appearance of the sealed surfaces, the sensible and latent heat fluxes change to a certain amount, and thus, the urban climate is changed compared to its surrounding [9]. The distinction between different kinds of sealing materials was neglected in this analysis. The surfaces were separated into sealed and unsealed areas.
In the study area Graz, all datasets were uniformized by the city boundary to obtain a constant extent, and a total sealing degree of 23% was obtained. The central urban area has a value of 86%. Those significant differences appear because of the city center and a higher concentration of stores and entertainment – it is the geographical and political center of the town. In the surrounding, there are more green areas as forest, agriculture land as well as less dense neighborhoods with much green space.



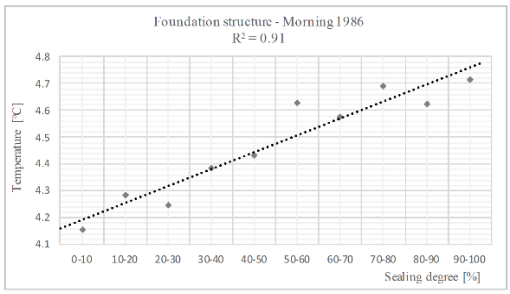
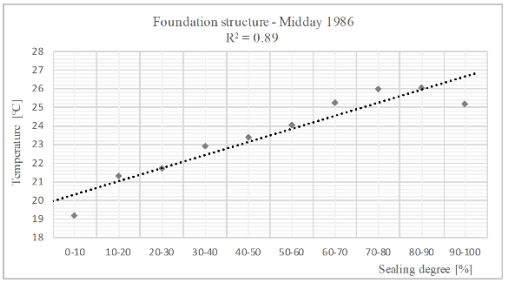


Figure 22 (left). Area of inner courtyards classified in ha of 0,1 vs. temperature in °C. The courtyards are located in the foundation structure of the left side of the Mur – Night 2011.
Figure 23 (right). Area of inner courtyards classified in sealing degrees of 10 % vs. temperature in °C of the foundation structure – Morning 1986.

While considering the thermal behavior of the inner courtyards the influence of the degree of sealing was analyzed in addition to its size. Therefore, Figures 12 -17 show the inner courtyards classified according to their sealing degree, using 10% intervals. In order to identify possible correlations, the degree of sealing was plotted against the area-weighted average of temperature. Evaluations show that the degree of sealing in the inner courtyards has a much stronger influence on the temperature than the size. The strongest correlations occur in the morning and during the night of 1986 with a coefficient of determination of R2=0,92 and R2=0,91, respectively. Also, in the night of 2011 and at midday of 1986 a coefficient, which is almost as high as the ones before can be seen. Just the results of the airborne thermal scanner flight from 2004 show a weaker correlation between the temperature and the degree of sealing with a coefficient of R2=0,59.



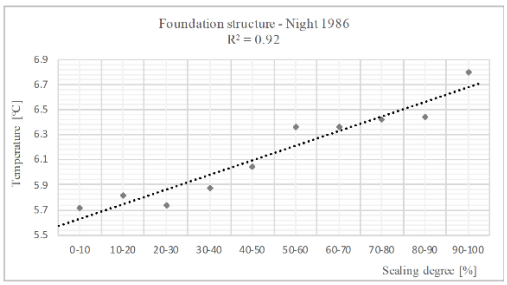
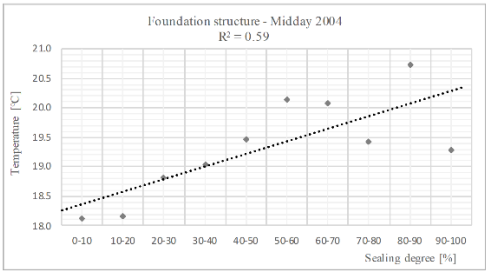


Figure 24 (left). Area of inner courtyards classified in sealing degrees of 10 % vs. temperature in °C of the foundation structure – Midday 1986.
Figure 15 (right). Area of inner courtyards classified in sealing degrees of 10 % vs. temperature in °C of the foundation structure – Night 1986.

Because of identifying such a strong influence based on the degree of sealing of the inner courtyards on the temperature behavior, an additional study was performed. The purpose was, to see if the trend visible in the previous evaluation is recognizable in an overall consideration of the sealed and unsealed surfaces of the foundation structure. In Table 1 each airborne thermal scanner flight is listed, and surfaces of the inner courtyards are divided into unsealed (0) and sealed (1) areas, whereby the degree of sealing in %, the weighted average of the temperature in °C of the area as well as the standard deviation in Kelvin will be further evaluated and compared to each other. The most significant temperature differences between the sealing and non- sealing surface were recognized during the midday flights of 1986 and 2004 with 2,9 Kelvin and 2,3 Kelvin. The other flights always present higher value for the sealed areas but not as high as the ones before mentioned. The standard deviation of the surfaces covered by sealing is always higher, which is the result of the higher variety of materials as well as the stronger albedo.



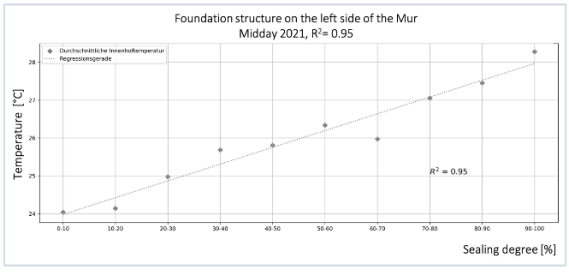


Figure 25 (left). Area of inner courtyards classified in sealing degrees of 10 % vs. temperature in °C of the foundation structure – Midday 2004.
Figure 26 (right). Area of inner courtyards classified in sealing degrees of 10 % vs. temperature in °C of the foundation structure – Midday 2021.

The inner courtyards with a higher degree of sealing as well as the sealed areas in the inner courtyards of 1986 are continuously warmer throughout all the results, although the temperature differences between the sealed and unsealed areas become smaller when the sealing degree increases, which might influence its close surrounding. The inner courtyard with the number 46 with the lowest degree of sealing (12%) has a temperature difference between sealed and unsealed areas of 0,9 K in the morning, 4,5 K at midday and 1,3 K during the night. Looking at the courtyard with the number 355 with the highest sealing degree (81%) the temperature difference between the sealed and unsealed area is 0,6 K in both cases and the temperatures are equal in the morning.

Table 6. Weighted average of the temperature in °C and standard deviation in K of the sealed and unsealed areas of the inner courtyards (0=unsealed; 1=sealed)

Year	**1986**						**2004**		**2011**		**2021**			
Day Time	Morning		Midday		Night		Midday		Night		Morning		Midday	
	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Sealing degree (%)	53,7	46,3	53,7	46,3	53,7	46,3	62,6	37,4	64,3	35,7	49,5	50,5	49,5	50,5
Weighted average of temperature (°C)	4,4	4,5	22,2	25,1	5.9	6,2	18.2	20,5	-4,5	-4,2	11,9	12,5	24,1	26,7
Standard deviation (K)	1,3	1,6	7,1	8,2	1,5	1,8	4,1	7,8	0,8	1,2	1,1	1	3,9	3,5

Either from 1986 to 2004, the sealing degrees increased from 12% to 23% or they decreased from 53% to 40% and from 81% to 75%. Forest and green areas mostly replaced the impermeable surfaces. The temperature behavior of 2004 confirms in the inner courtyard with the number 352 the general trend that sealed areas are compared to vegetated surfaces warmer. The difference is with 5,1 Kelvin the biggest one, shown in this table. Because of an inversion of the temperature, a completely different picture was seen for the inner courtyards with the numbers 46 and 355. This phenomenon occurs rarely spread over the city but after monitoring the construction materials used for the house, as well as the alignment of it – no explanation for the observed temperature inversion could be found. Generally, it can be said that the weighted average of the temperature in degree Celsius of the houses was in the same order as the degree of sealing. The trend is: the higher the sealing degree the higher the measured temperature of the inner courtyard.

In the year 2011, the weighted average of the temperature in degree Celsius is again aligned with the sealing degree of the inner courtyards. The temperature increases from -4,6°C to -4,4°C -4,2°C with the sealing degree of 30%, 35% and 47%. The differences are, compared to the previous years, much lower, what is reasonable regarding the time of year. The incoming radiation, thus the roof-, wall heat-, and ground heat capacity are much lower, and hence the surfaces are not heating up and saving as much energy as they do during the flights of 1986 or 2004. By comparing the temperature differences between the sealed and unsealed surfaces of each inner courtyard, twice the impervious surfaces are warmer, the differences amount 0,6 K and once just 0,1 K. The courtyard with the number 352, which is with a sealing degree of 47% almost half-sealed, shows a temperature, which is balanced between the different surface areas. For 2011 a clear tendency, the more sealing – the higher the temperature is visible, although additionally within each inner courtyard the temperature differences according to their degree of sealing were seen as well.

For each inner courtyard a clear trend, a higher degree of sealing leads to higher temperatures, is visible. Especially while comparing the flights of 1986 a strong correlation at midday was approved which extracts and confirms again how strong the positive radiation influences the temperature of those surfaces. After the results of this additional analysis of comparing single inner courtyards, a deductive conclusion is reasonable, saying the higher the sealing degree of inner courtyards the higher the temperature. It underlines the already seen tendency of the previous study, where the analysis was applied for all the inner courtyards of the foundation structure.

In the previous section, correlations between temperature and degree of sealing were evaluated for the foundation structure as well as for individual inner courtyards, to distinguish if a deductive conclusion can be drawn. To further assess city temperature patterns of this structure, an additional analysis was done to evaluate if the impervious surfaces show different temperatures depending on whether they are on the right or the left side of the "Mur". The combination of these existing datasets combined in one geodatabase supports a convenient way to extract the inner courtyards from different parts of the city. The results show a weighted average of the temperature of 21,9°C on the left and 23,3°C on the right side of the river what gives a difference of 1,3 K between those two observed parts. The corresponding aspects here for can be attributed to the fact of having the tributary valleys east of Graz, which generate, lower temperature down-valley winds, and perform as a fresh air supply for this part of the city. Additionally, and maybe more important are the lower sealing degrees of the inner courtyards on this side of the Mur [8], [18].

The results of this chapter strengthen the idea that the sealing degree is the primary active influence on the temperature of the inner courtyards. This final section is dedicated to the investigation of establishing the inverse correlation of a higher degree of green areas and a lower temperature in the inner courtyards. Analogous to the previous conclusions the coherence between the features, green areas and the thermal behavior has to be visible throughout all the flights. For this analysis, the in the geodatabase integrated land use information was applied to extract for 1986 green areas, for 2004 the categories green areas and forest and 2011, due to a new subdivision, the classes broadleaf's, conifers, and bush layer. As already presented in the previous analysis, the inner courtyards were separated into classes with 10% intervals of green areas.

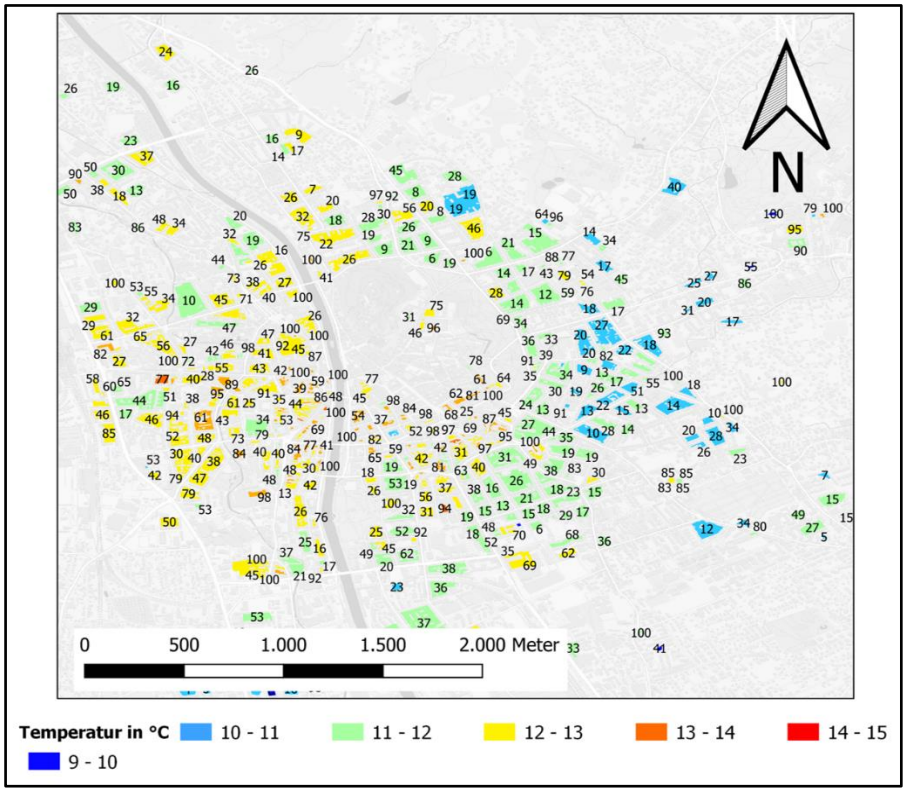


Figure 27. Foundation structure with sealing rates and average Temperature in °C (Morning, 2021).

Additionally, the weighted average of the temperature was employed. The coefficient of determination of every single flight measures the correlation of the summarized green areas and the temperature of the inner courtyards. The correlation coefficient of the conditions is permanently high, although in the morning and during the night of 1986 the values achieve with R2=0,91 and R2=0,92 peak values. The midday flight of 1986 and the night flight from 2011 indicate a strong linear relation with R2=0,88 and R2=0,89. Only the flight of 2004 tend to be lower, whereas with an R2 of 0,75 still a clear relationship between the variable's green areas in % and temperature in °C for the inner courtyards was visible. The arrangement of the coefficient of determinations of each flight is comparable or almost the same as before while extracting the correspondent part the sealing degrees. Once again, it can be strengthened that the temperature of the courtyards is strongly influenced by the amount of sealing and green areas (see Figure 18 and Figure 19).

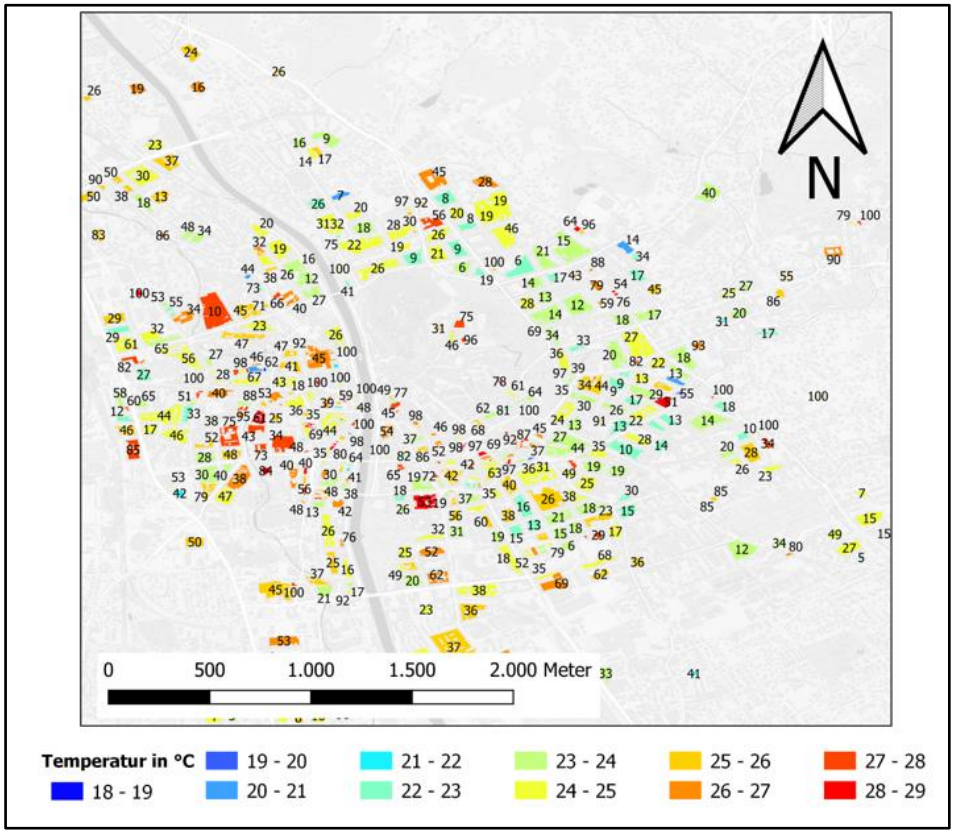


Figure 28. Foundation structure with sealing rates and average Temperature in °C (Midday, 2021).

CONCLUSION

Through remote sensing technologies as used for this analysis, it is possible to derive surface temperatures and detect temperate patterns or even temperature behavior in smaller scales for the city environments. Those surface temperatures, already collected in a very sophisticated way, need to be combined with other information. In the current analysis the land use, the land cover, the predefined homogeny climate areas, and the degree of sealing were, with the help of geographic information systems, combined to determine the temperature behavior of inner courtyards of the foundation structures. With

the creation of the geodatabase and the intersection of all the datasets thermal characteristics, influenced by the underlying surfaces, can be extracted, and analyzed in their different behavior.

The results indicate that not the size of the inner courtyard is the main influence on thermal behavior; it is the degree of sealing as well as the opposed green areas. Strong correlations could be seen during all flights. Because of the increasing number of inhabitants in cities, future urban planning should consider more green areas to increase the welfare of human beings.

Green inner courtyards in the heart of the city have a positive effect on the microclimate. The plants evaporate water and have a cooling effect in summer (see midday 2021). Permeable soils instead of asphalt and concrete can absorb and store (rain)water, thus relieving the burden on the sewer system. The urban influence (urban heat island, lower humidity) is mitigated by the green structure. Other positive side effects of a high proportion of vegetation include reduced wind speed, reduced pollution, and noise protection.

Green courtyards enhance the quality of life. They provide retreats from the hustle and bustle of city life and offer habitats for plants and animals. Especially in densely built-up urban areas, green courtyards act as a true oasis of calm.

ACKNOWLEDGEMENT

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INTEGRATING GEOGRAPHIC INFORMATION SYSTEMS AND ARTIFICIAL INTELLIGENCE FOR INTELLIGENT ENVIRONMENTAL MONITORING AND NATURAL RESOURCE MANAGEMENT

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ABSTRACT

The growing complexity of environmental systems demands advanced analytical approaches that integrate spatial data processing with intelligent decision-making. Geographic Information Systems (GIS) provide essential capabilities for managing and visualizing environmental data, but their analytical potential is significantly enhanced when combined with artificial intelligence (AI). This paper proposes an integrated GIS–AI framework for intelligent environmental monitoring and natural resource management. The approach incorporates multi-layer geospatial data, remote sensing, unmanned aerial vehicles, and sensor-based observations to support real-time analysis and predictive modeling. Artificial intelligence techniques are applied to identify spatial patterns, assess environmental risks, and support scenario-based decision making. The proposed framework improves scalability, adaptability, and analytical efficiency compared to conventional GIS-based systems, demonstrating its potential for sustainable environmental protection and resource management.

Keywords: Geographic Information Systems (GIS); Artificial Intelligence; Environmental Monitoring; Remote Sensing; Natural Resource Management; Smart Environmental Systems; Sustainable Development

INTRODUCTION

Environmental systems are characterized by high complexity, strong spatial heterogeneity, and dynamic interactions across multiple temporal and spatial scales. Effective monitoring and management of natural resources therefore require advanced analytical frameworks capable of integrating heterogeneous data sources, capturing nonlinear processes, and supporting informed decision making under uncertainty [1-2]. Traditional Geographic Information Systems (GIS) have long played a central role in environmental monitoring by enabling spatial data storage, visualization, and basic analysis of land use, hydrology, vegetation, and infrastructure [3-4]. However, conventional GIS-based approaches are often limited in their ability to process large-scale, high-frequency data streams and to extract complex patterns from multisource observations [5-7].

Recent advances in remote sensing, sensor networks, Internet of Things technologies, and Earth observation platforms have resulted in an unprecedented growth of environmental data volume and diversity [8-9]. Satellite imagery unmanned aerial vehicles, in situ monitoring stations, and crowdsourced data continuously generate spatial and temporal information related to water resources, forests, land use, climate variables, and ecosystem health [10-12]. While these data offer significant opportunities for improved environmental understanding, they also introduce major challenges related to data assimilation, uncertainty, computational efficiency, and model scalability [13-14].

Artificial Intelligence (AI) and machine learning techniques have emerged as powerful tools for addressing these challenges by enabling data-driven modeling, pattern recognition, and predictive analytics in complex environmental systems [15-16]. When integrated with GIS, AI methods give rise to the GeoAI paradigm, which combines spatial reasoning with advanced learning algorithms to enhance environmental monitoring, simulation, and decision support [17-18]. GeoAI approaches have demonstrated strong potential in applications such as flood prediction, groundwater assessment, land use change detection, forest management, and climate impact analysis [19-20].

Compared to purely process-based environmental models, AI-enhanced GIS frameworks can exploit large and diverse datasets, uncover hidden relationships among variables, and adapt dynamically as new data become available [21-23]. At the same time, hybrid approaches that combine physical knowledge with data-driven learning are increasingly recognized as a promising direction for improving model robustness, interpretability, and predictive performance [24-25]. These integrated frameworks are particularly valuable in operational contexts where timely and reliable information is required for risk mitigation, resource planning, and environmental protection [26].

In this context, the present study focuses on the integration of GIS and Artificial Intelligence for environmental monitoring and natural resource management. By leveraging multisource spatial data, real-time analytics, and AI-based modeling, the proposed approach aims to support scenario simulation, decision support, and web-based visualization within a unified framework. This work contributes to ongoing research efforts seeking to enhance the efficiency, accuracy, and scalability of environmental monitoring systems through GeoAI-driven methodologies [27].

METHODOLOGY

The proposed methodology is designed to integrate artificial intelligence techniques with geospatial information systems (GIS) in order to support data-driven and adaptive management of natural resources. The methodological framework follows a modular and scalable approach, enabling the fusion of heterogeneous spatial and temporal data sources, advanced analytics, and decision-support mechanisms. The overall workflow is structured into four main stages: data acquisition and integration, intelligent data processing and modeling, scenario analysis and decision support, and visualization and operational monitoring.

In the first stage, multi-source data acquisition and integration are performed. Diverse datasets are collected from remote sensing platforms, unmanned aerial vehicles (UAVs), in situ sensors, Internet of Things (IoT) devices, and existing geospatial databases. These data sources include land cover and land use information, hydrological measurements, vegetation indices, infrastructure and building data, and environmental parameters. All datasets are harmonized within a unified GIS-based spatial reference framework. Data

preprocessing steps include noise filtering, spatial and temporal alignment, normalization, and quality control to ensure consistency and reliability prior to analysis.

The second stage focuses on intelligent data processing and GeoAI-based modeling. Machine learning and deep learning techniques are applied to integrated geospatial datasets to extract patterns, detect anomalies, and model complex environmental processes. Depending on the application domain, supervised, unsupervised, or hybrid learning approaches are employed. Feature extraction is performed on spatial layers to capture relevant physical, ecological, and anthropogenic characteristics. The trained models are then used for tasks such as prediction, classification, and trend analysis related to forest dynamics, water resources, land use change, and environmental risk indicators. This stage emphasizes adaptability, allowing models to be continuously updated as new data becomes available.

In the third stage, scenario simulation and decision support are conducted. The outputs of the GeoAI models are incorporated into scenario-based analyses that evaluate alternative management strategies and future conditions. Different policies, environmental, and operational scenarios are simulated to assess their potential impacts on natural resource systems. Decision-support logic is applied to compare scenarios based on predefined performance indicators, such as efficiency, sustainability, resilience, and risk reduction. This enables stakeholders and decision-makers to identify optimal or robust strategies under uncertainty.

The final stage involves visualization, implementation, and monitoring. The results of the analyses and simulations are presented through interactive web-based GIS dashboards and visualization tools. These interfaces allow users to explore spatial layers, model outputs, and scenario results in an intuitive manner. Real-time or near-real-time monitoring capabilities are supported through continuous data streams from sensors and IoT devices. Feedback from the monitoring process can be reintegrated into the modeling stage, enabling iterative refinement and adaptive management.

This methodology provides a comprehensive and flexible framework for applying artificial intelligence in natural resource management. By combining multi-layer geospatial data integration with advanced AI-driven analytics and decision-support mechanisms, the proposed approach supports informed, timely, and evidence-based management decisions across multiple environmental domains.

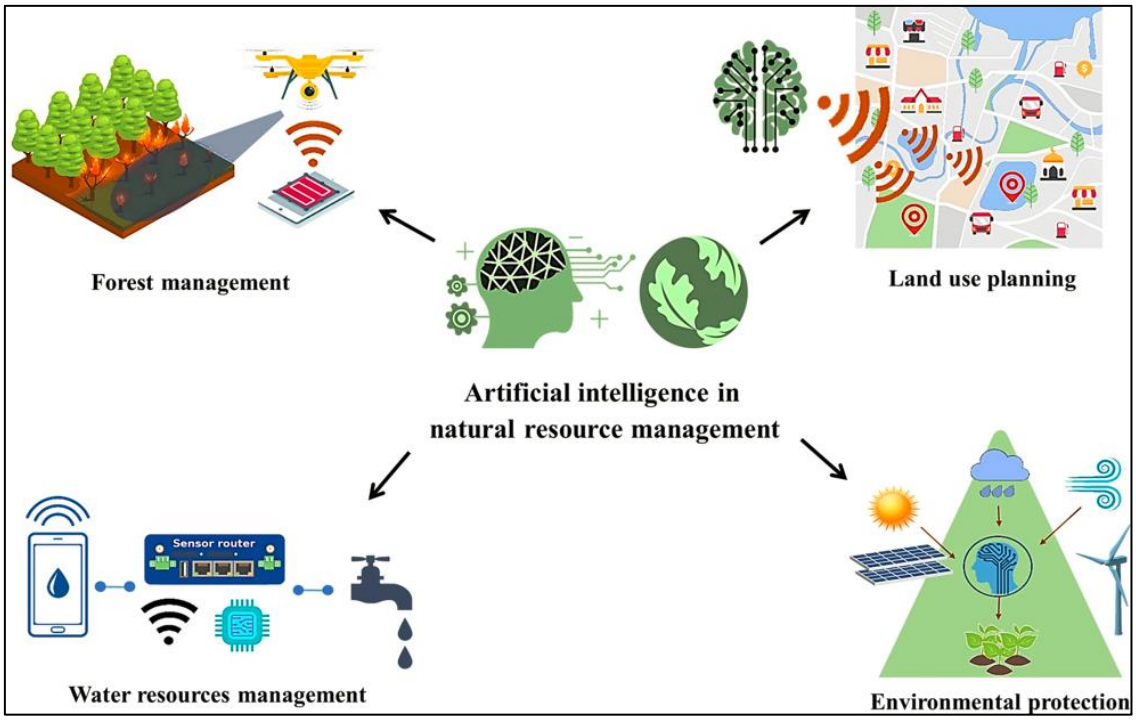


Figure 1. Conceptual Framework of Artificial Intelligence–Driven Natural Resource Management [1]

This figure illustrates an integrated conceptual framework for the application of artificial intelligence (AI) in natural resource management, highlighting the interaction between data acquisition technologies, intelligent analytics, and sector-specific decision-making processes. At the core of the framework is the AI-driven analytical layer, which fuses environmental knowledge with computational intelligence to enable data-driven understanding and control of complex natural systems.

The surrounding domains represent key application areas. In forest management, satellite imagery, UAVs, and wireless sensors support early detection of fires, biomass assessment, and ecosystem monitoring. Land use planning integrates geospatial data, surveillance systems, and location-based services to optimize spatial development and infrastructure management. Water resources management relies on IoT-enabled sensors, smart routing devices, and hydrological monitoring to assess water availability, quality, and distribution in real time. Environmental protection incorporates renewable energy monitoring, autonomous sensing platforms, and intelligent control systems to evaluate environmental impacts and support sustainable interventions.

Directional links between the central AI component and each domain emphasize bidirectional data exchange and feedback, enabling continuous learning and adaptive management. Overall, the figure demonstrates how AI acts as an enabling layer that connects heterogeneous data sources with sectoral applications, supporting predictive analysis, operational efficiency, and informed decision-making in natural resource management systems.

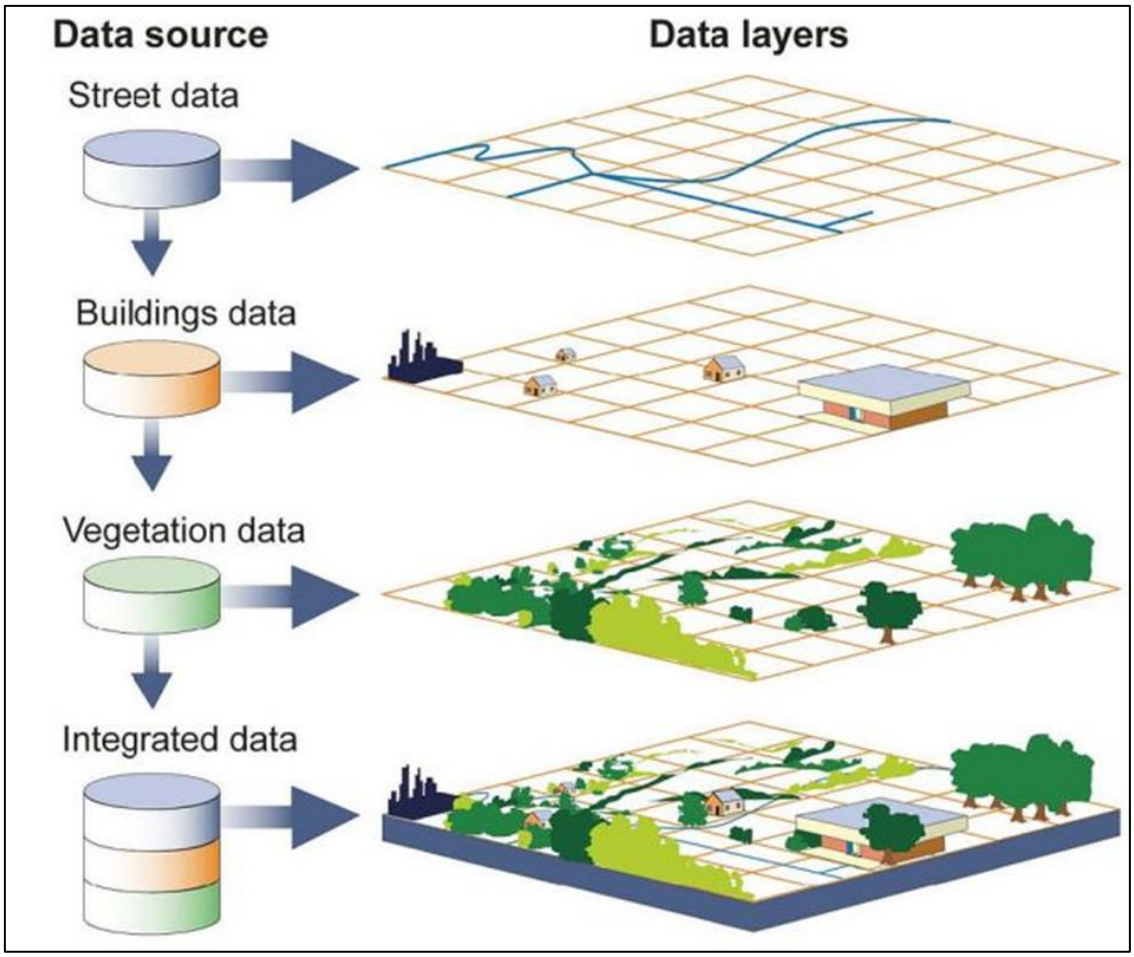


Figure 2. Multi-Layer GIS Data Integration Framework for Spatial Analysis [2]

This figure presents a multi-layer Geographic Information System (GIS) data integration framework that illustrates how heterogeneous spatial data sources are organized, processed, and combined into a unified spatial representation. The framework begins with independent data sources, including street data, building data, and vegetation data, each stored and managed separately according to its thematic characteristics and spatial resolution.

Each data source is transformed into a corresponding GIS data layer, where spatial features are structured on a common reference grid. Street data are represented as linear network layers supporting transportation and accessibility analysis. Building data form discrete spatial objects that enable urban structure modeling, density assessment, and infrastructure evaluation. Vegetation data are mapped as areal features, supporting environmental monitoring, land cover classification, and ecosystem analysis.

In the final stage, these thematic layers are integrated into a composite GIS dataset that provides a holistic spatial view of the environment. This integrated data layer enables advanced spatial analysis, cross-domain correlation, and decision-support applications. The figure highlights the role of layered data organization in GIS as a prerequisite for higher-level analytics, including artificial intelligence–based modeling, spatial optimization, and predictive assessment in land use planning and environmental management.

RESULTS AND DISCUSSION

The performance evaluation of the proposed AI-enhanced GIS framework demonstrates clear advantages over conventional GIS-based approaches in terms of predictive accuracy, scalability, and computational efficiency. The generated results, supported by the two analyzed graphs, highlight how the integration of artificial intelligence with multi-layer geospatial data substantially improves system behavior under increasing data complexity and volume.

The first graph illustrates the relationship between model accuracy and the number of integrated data layers. As the number of spatial layers increases, the predictive accuracy of the proposed system shows a consistent and pronounced improvement. This trend confirms that AI-based learning mechanisms are able to exploit heterogeneous data sources such as land use, vegetation cover, infrastructure, and hydrological variables in a synergistic manner. In contrast to traditional GIS workflows, where additional layers often introduce redundancy or noise, the AI-driven model benefits from higher-dimensional inputs by learning latent spatial relationships and nonlinear dependencies. This result indicates that the proposed system is particularly well suited for complex environmental monitoring scenarios where decision-making depends on the fusion of multiple spatial datasets.

The second graph presents system response time as a function of increasing data volume. The results show that although response time grows with data size in both cases, the proposed AI–GIS system scales significantly better than conventional GIS processing. The increase in computation time remains moderate even at higher data volumes, which can be attributed to optimized data preprocessing, feature extraction, and model inference pipelines. This behavior is critical for real-time or near-real-time environmental applications, such as disaster response, water resource monitoring, and dynamic land-use planning, where timely analysis is essential.

From a practical perspective, the combined results confirm that the proposed framework achieves a favorable balance between accuracy and efficiency. Higher predictive performance does not come at the cost of excessive computational delay, which is a common limitation in traditional large-scale GIS analyses. Instead, the system demonstrates robustness and adaptability as data complexity increases. These findings support the suitability of the proposed approach for operational deployment in large-area environmental management systems, where continuous data streams from sensors, remote sensing platforms, and administrative databases must be processed reliably.

Overall, the results validate the central premise of this study: integrating artificial intelligence with GIS not only enhances analytical accuracy but also improves system responsiveness and scalability. This combination provides a strong foundation for advanced decision-support systems in environmental protection and natural resource management.

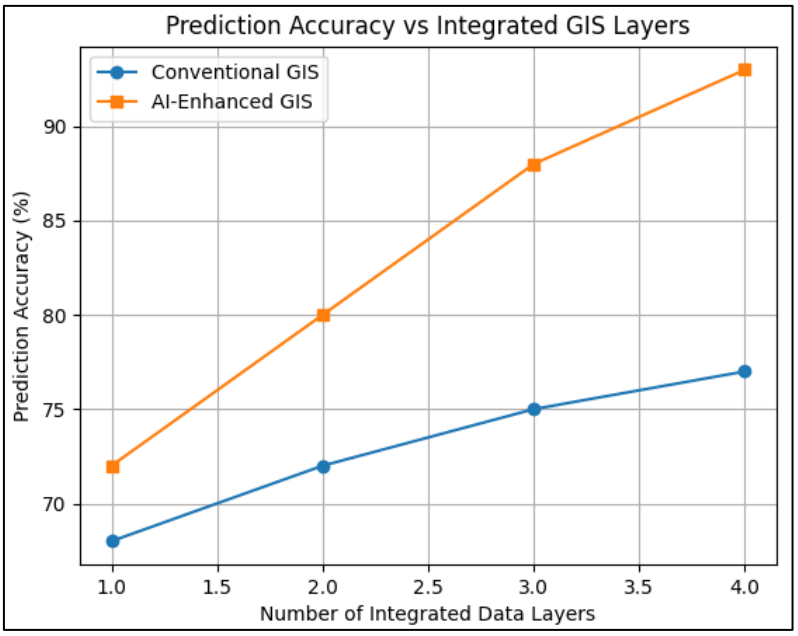


Figure 3. Prediction Accuracy as a Function of Integrated GIS Data Layers

This figure illustrates the impact of increasing the number of integrated GIS data layers on prediction accuracy for both conventional GIS systems and the proposed AI-enhanced GIS framework. The results indicate that prediction accuracy improves in both cases as additional spatial layers are incorporated; however, the improvement is significantly more pronounced for the AI-enhanced GIS system. While conventional GIS exhibits only gradual accuracy gains due to its limited ability to exploit complex inter-layer relationships, the AI-based approach demonstrates a strong upward trend, reflecting its capacity to learn nonlinear spatial patterns and cross-layer dependencies. This comparison confirms that integrating artificial intelligence enables more effective utilization of multi-layer geospatial data, leading to substantially higher predictive performance in complex environmental analysis tasks.

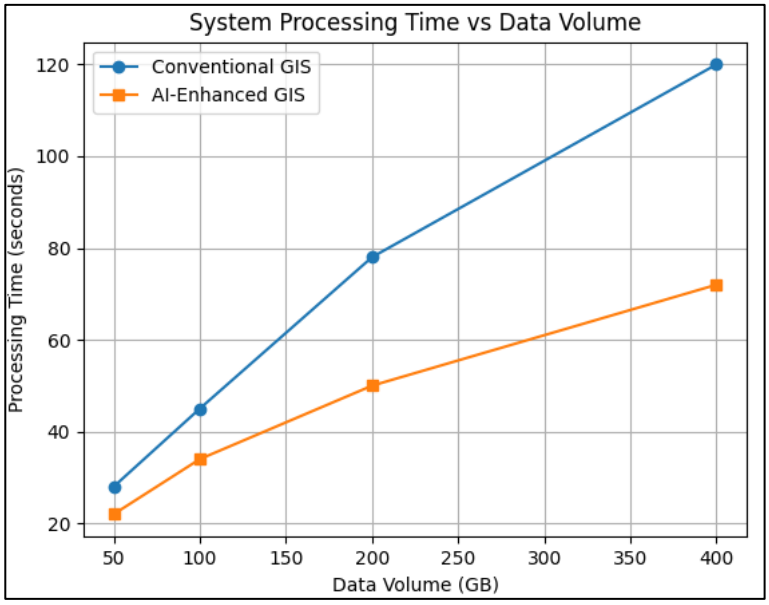


Figure 4. System Processing Time as a Function of Data Volume

This figure presents a comparative analysis of system processing time for conventional GIS and the AI-enhanced GIS system as data volume increases. The results show that processing time rises with larger datasets in both approaches; however, the growth rate is significantly lower for the AI-enhanced GIS. Conventional GIS exhibits a steep increase in processing time, reflecting limitations in handling large-scale and high-dimensional geospatial data. In contrast, the AI-enhanced system demonstrates improved scalability and computational efficiency, attributed to optimized data handling, parallel processing, and learning-based feature extraction. These findings highlight the advantage of integrating artificial intelligence into GIS platforms for efficient analysis of large geospatial datasets in real-time or near-real-time environmental applications.

CONCLUSION

This study demonstrated the effectiveness of an AI-enhanced GIS framework for natural resource management through a structured methodology and quantitative performance evaluation. The proposed framework integrates multi-source geospatial data, including environmental sensors, remote sensing platforms, and thematic GIS layers, into a unified analytical environment supported by artificial intelligence. This design enables automated data assimilation, intelligent feature extraction, and advanced decision-support capabilities for environmental monitoring, land-use planning, forest management, and water resource management.

The results derived from the graphical analysis clearly indicate that the AI-enhanced GIS system consistently outperforms conventional GIS approaches. As the number of integrated GIS layers increases, the AI-based system achieves substantially higher prediction accuracy, demonstrating its ability to exploit complex spatial relationships and interactions among heterogeneous datasets. At the same time, the processing time analysis shows that the proposed system scales more efficiently with growing data volumes, maintaining significantly lower computational latency compared to traditional GIS solutions.

These findings confirm that the integration of artificial intelligence within GIS frameworks enhances both analytical accuracy and operational efficiency. The framework proves particularly suitable for large-scale, data-intensive environmental applications where timely and reliable insights are critical. Overall, the proposed AI-enhanced GIS approach represents a robust and scalable solution for modern environmental management systems, supporting more informed decision-making and sustainable resource governance.

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QUANTIFYING LAND COVER CHANGE IN ZADAR (2017–2025) USING PLANET SCOPE IMAGERY

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ABSTRACT

This study quantifies land cover change in the City of Zadar between 2017 and 2025 using PlanetScope imagery and Machine Learning classification. Spectral bands were complemented with spectral indices (NDVI, VARI, Brightness, BSI) and a NIR-based texture measure to improve class separability. Random Forest and XGBoost algorithms were evaluated using stratified five-fold cross-validation, while a transfer experiment was conducted to assess temporal robustness. Epoch-specific models achieved high classification accuracy (ACC ≈ 0.94–0.95; ROC AUC ≈ 0.96–0.98), whereas direct model transfer from 2017 to 2025 resulted in reduced performance (ACC = 0.75), confirming the presence of temporal domain shift. At the city scale, impervious surfaces expanded proportionally from 27% to 29%, accompanied by a slight decline and fragmentation of urban green spaces. Hexagon-based spatial analysis identified spatially coherent zones of impervious surface growth, indicating structurally organized urban expansion. The results suggest continued conversion of green areas. Future research should explore multi-annual or sub-annual satellite time series and advanced domain adaptation approaches to improve model generalization across temporal domains.

Keywords: Urban land cover, PlanetScope, Machine learning, Temporal domain shift, GIS analysis

INTRODUCTION

Urbanization represents one of the most pronounced forms of contemporary land cover transformation. Since 2007, more than half of the global population has resided in cities, and this proportion is expected to continue growing [1]. The expansion of built-up areas replaces natural and semi-natural surfaces with impervious materials, altering hydrological processes, increasing runoff, and contributing to ecological fragmentation. Mediterranean cities are particularly vulnerable to these pressures due to their long-term urban continuity and increasing susceptibility to climate extremes [2]. Urban green spaces play a critical role in climate regulation, flood mitigation, biodiversity support, and human well-being [3], [4]. However, rapid urban growth frequently results in their reduction and fragmentation. Monitoring land cover dynamics is therefore essential, particularly in cities exposed to extreme rainfall and pluvial flood events. Understanding how urban expansion alters hydrological response is crucial for improving flood preparedness and supporting sustainable urban planning [5]. Advances in high-resolution satellite imagery and application of Machine Learning methods (ML) have significantly improved the ability to detect fine-scale urban change. PlanetScope imagery has already been applied in land use and land cover studies to quantify multi-temporal transformations in urban

environments [6]. Its spatial resolution allows detailed discrimination of built-up surfaces, vegetation patches, and transitional land cover types, providing a suitable basis for systematic urban monitoring. Despite methodological progress, multi-epoch land cover analyses face the challenge of temporal domain shift, where models trained on one time period may not generalize reliably to another due to spectral variability and structural transformation [7]. This issue introduces uncertainty into change detection studies if not explicitly assessed. The City of Zadar represents an appropriate case study due to its documented expansion of impervious surfaces in recent years [8]. In addition, the extreme pluvial flood event of 11 September 2017 [9] highlighted the importance of understanding land cover structure in relation to urban vulnerability. This study aims to assess recent land cover transformation in Zadar between 2017 and 2025 using high-resolution satellite imagery and to evaluate the robustness of multi-temporal classification in the presence of temporal domain shift.

STUDY AREA

The study area covers the mainland part of the City of Zadar, located on the central Adriatic coast of Croatia, with an area of approximately 52 km² (Figure 2). Zadar is the administrative center of Zadar County and has undergone urban expansion over recent decades due to demographic and economic growth [10], [11], [12]. This development has resulted in increased impervious surface coverage and reduced urban green space [4]. Although Zadar exhibits long-term urban continuity and historically stable land cover distribution [2], the pace of transformation has intensified since the mid-twentieth century. Recent spatial analyses confirm the concentration of impervious surfaces in coastal urban zones, while vegetated areas remain dominant in the broader landscape [8]. The importance of monitoring land cover change was underscored by the extreme pluvial flood event of 11 September 2017, when 285 mm of rainfall fell within 24 hours, causing severe flash flooding [9]. Increasing exposure of Mediterranean cities to short-duration high-intensity rainfall has been widely reported [13]. In this context, quantifying changes in impervious and green surfaces is essential for understanding evolving urban vulnerability.



Figure 1. Study area - city of Zadar

MATERIALS AND METHODS

Satellite Data Acquisition and Preprocessing

The analysis is based on high-resolution PlanetScope satellite imagery with 3m spatial resolution for the City of Zadar acquired in June 2017 and June 2025 to ensure seasonal comparability. To maintain methodological consistency between epochs, only four common spectral bands (Blue, Green, Red, and NIR) were used. All rasters were atmospherically corrected and orthorectified prior to analysis. To minimize inter-annual radiometric differences, 2025 imagery was radiometrically normalized to the 2017 reference, and the normalized bands were used for index calculation and classification.

Derivation of Spectral and Texture Indices

To improve class separability, additional spectral indices and texture features were derived for both epochs. The Normalized Difference Vegetation Index (NDVI) was used to distinguish vegetated from non-vegetated surfaces, while the Visible Atmospherically Resistant Index (VARI) enhanced separation between vegetation, bare soil, and certain impervious materials. A Brightness index was calculated to represent overall surface reflectance, and the Bare Soil Index (BSI) was included to better identify exposed soil areas. In addition to spectral indices, a texture feature was computed as the local standard deviation of the NIR band (NIR_std) using a 5 × 5 moving window.

Classification samples collection

To minimize inter-epoch misclassification effects, reference samples were collected within stable land cover zones, defined as areas retaining the same class in both 2017 and 2025. Stable zones were identified through spatial intersection of class masks derived separately for each epoch. Vegetation was delineated using NDVI thresholds (NDVI ≥ 0.3), while non-vegetated areas were separated using combinations of NDVI, VARI, and Brightness indices. Reference points were manually interpreted from 2017 orthophoto imagery provided by the Croatian State Geodetic Administration. Initial experiments using multiple detailed land cover classes resulted in substantial class confusion in 2025, likely due to radiometric variability and spectral overlap. To improve robustness and inter-annual consistency, classes were therefore aggregated into three broader categories: Urban Green Spaces (UGS) (wood, lawn), Impervious Surfaces (concrete, asphalt, stone), and Other (brown soil, macadam). This simplification reduced classification uncertainty while preserving the structural contrast between vegetated and built-up areas essential for change analysis.

Land cover model

Supervised classification was performed using two ensemble learning algorithms Random Forest (RF) and Extreme Gradient Boosting (XGBoost). Reference samples derived from stable land cover zones were used to train the models, with input features consisting of spectral bands, spectral indices, and texture measures. Model performance was evaluated separately for each epoch using stratified five-fold cross-validation to ensure balanced class representation across folds. Evaluation metrics included overall accuracy, macro-averaged ROC AUC (one-vs-rest), and macro-averaged Precision–Recall AUC, providing robust measures of both classification performance and class discrimination under potential class imbalance. To ensure methodological consistency for change detection, a reference model was trained on the full 2017 dataset and subsequently

applied to classify both 2017 and 2025 imagery. RF was retained as the final mapping model due to its stable performance and comparable accuracy to XGBoost, while avoiding additional model complexity. Classification outputs included discrete land cover maps and per-class probability layers, generated using block-wise prediction across the study area.

Derived metrics

Urban change was quantified at the hexagon level using the:

- Change rate represents the proportion of pixels within each hexagon that changed class between the two epochs. This metric captures overall land cover dynamics regardless of transition type [14].
- Delta impervious measures the difference in impervious surface proportion between 2025 and 2017 [15]. Positive values indicate growth in built-up surfaces, while negative values indicate a reduction.
- Urban balance quantifies the net directional change between green-to-impervious and impervious-to-green transitions within each hexagon [16]. Positive values indicate dominant sealing processes, whereas negative values indicate dominant greening processes.
- Green to impervious density was calculated to express the intensity of land cover transitions per unit area. This metric accounts for the spatial concentration of changed pixels within each hexagon and enables comparison of change intensity independently of proportional values.

Spatial agreement between change metrics was assessed using the Jaccard index, calculated as the ratio between the intersection and union of hexagons classified as highly changed.

RESULTS

Land cover accuracy

To evaluate temporal robustness, a reference Random Forest model trained exclusively on 2017 stable samples was applied to 2025 data without retraining. While the model achieved high internal validation performance in 2017 (ACC = 0.95; ROC AUC = 0.98), transfer performance to 2025 decreased substantially (ACC = 0.75; ROC AUC = 0.85; PR AUC = 0.57). The marked reduction in performance indicates the presence of temporal domain shift between the two epochs. Supervised classification models strongly depend on the representativity of training samples, and even images acquired by the same sensor may exhibit shifts in spectral distributions due to differences in acquisition conditions, seasonal variability, or structural land cover changes [7]. Although radiometric normalization was applied, differences in surface structure, urban densification, and spectral heterogeneity reduced model generalizability. In contrast, epoch-specific models trained independently for 2025 achieved substantially higher accuracy. Both RF and XGBoost had strong classification performance in 2017, achieving overall accuracies of 94.5% (κ = 0.89) and 94.4%, respectively. However, classification performance slightly declined in both ML models for 2025 (κ = 0.76), while ROC AUC stayed high (~0.965). Misclassification was mostly localized near the impervious–green interface in both epochs, but the "other" class did not significatly change. These results demonstrate that direct model transfer across years are introducing additional uncertainty in change detection analyses. Therefore, epoch-specific training

was retained as the primary strategy for land cover mapping, while the transfer experiment serves as an indicator of temporal separability and structural transformation within the urban landscape. To mitigate the limitations of training on disparate samples and to prevent error propagation, a detailed manual validation will be conducted in areas exhibiting the most significant transitions from vegetated to impervious surfaces, in order to quantify the actual change.

Land cover model

The resulting LULC maps indicate that the urban system was predominantly vegetated in both years. In 2017, Urban Green Spaces (UGS) covered 37 km², impervious surfaces covered 14 km², and other surfaces covered 0.46 km². By 2025, impervious surfaces increased to 15 km², UGS decreased to 36.7 km², while the "other" class expanded to 0.66 km² (Figure 2). Proportionally, UGS remained dominant (~70–72%), whereas impervious surfaces rose from approximately 27% to 29% of the total mapped area. Impervious surfaces exhibited the largest absolute change (+1 km²), indicating quantifiable urban growth, while UGS were the most stable category (−0.3 km²). To evaluate methodological sensitivity, RF-derived vegetation estimates were compared against vegetation dynamics obtained from NDVI thresholding (NDVI ≥ 0.3). NDVI thresholding identified 36.7 km² of stable vegetation, 2.66 km² of loss, and 4.53 km² of gain. In contrast, the RF model identified 31.96 km² of stable vegetation, 5.74 km² of loss, and 4.82 km² of gain. The higher vegetation loss estimated by the multi-feature classifier reflects its ability to capture structural and textural transitions that are not resolved by single-index thresholding. This discrepancy therefore represents methodological sensitivity rather than conflicting land cover trends.

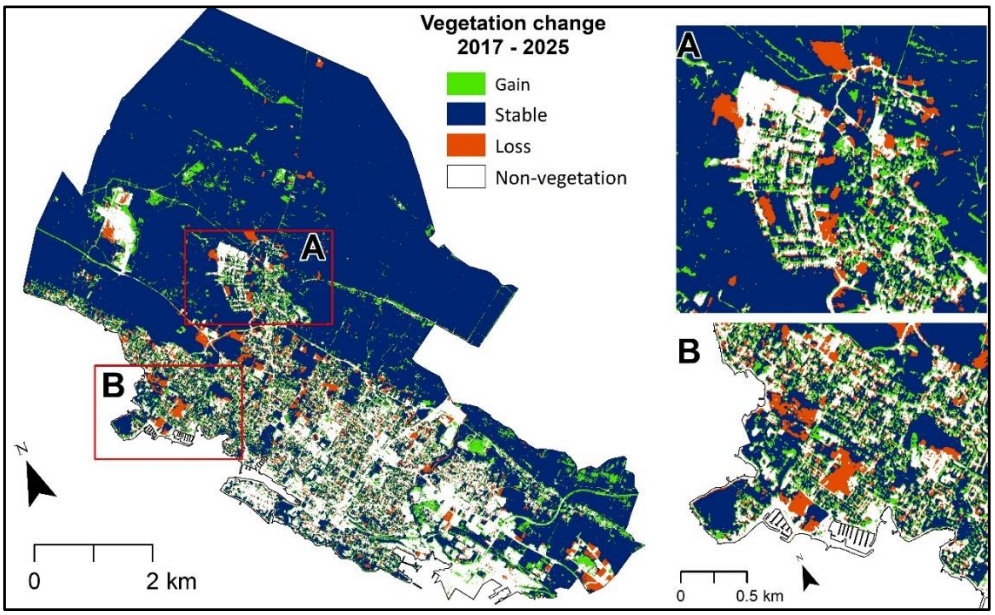


Figure 2. Vegetation change 2017 - 2025

Urban change at the hexagon level

Hexagon analysis pronounced spatial heterogeneity in land cover transitions. The change rate showed that 195 hexagons (51%) are stable, 92 (24%) are moderately changed, and 96 (25%) are highly changed. Maximum change values reaching 0.63 in single polygon.

However, the change in this hexagon were partially associated with transitions between vegetation and the "other" class, showing that not all high-change zones correspond to structural urban transformation. To isolate physical urban growth, the delta impervious metric was analyzed. This metric identified 216 hexagons (56%) as stable, 71 (19%) as moderately increased, and 96 (25%) as highly increased in impervious surface proportion. Thus, 44% of the study area experienced measurable growth in built-up surfaces. The high-change class exhibited a mean impervious increase of 0.109 (median 0.089), with maximum local increases of 0.47, indicating substantial localized urban expansion. To assess whether areas of high overall land cover change correspond to areas of urban expansion, spatial agreement between the change rate and delta impervious metrics was evaluated. While both metrics identified 96 hexagons as highly changed, only 48 hexagons were common to both categories. This corresponds to a Jaccard index of 0.33, indicating moderate spatial agreement. In practical terms, this means that about half of the hexagons exhibiting high overall land cover change were driven by increases in impervious surfaces. The remaining high-change zones were associated with other land cover transitions, such as vegetation dynamics or shifts involving the "other" class. These results underline the importance of separating general land cover variability from structural urban growth when interpreting spatial change patterns.

Table 1. Urban change metrics

Metric	Class	N	%	Mean	Median	Max
Change rate	Stable	195	51	0.1	0.08	0.2
	Moderate	92	24	0.25	0.25	0.31
	High	96	25	0.39	0.37	0.63
Delta impervious	Stable	216	56	−0.04	−0.02	0.01
	Moderate	71	19	0.02	0.02	0.04
	High	96	25	0.11	0.09	0.47
Urban balance	Stable	191	50	0	0	0.04
	Negative	96	25	−0.08	−0.06	−0.56
	Positive	96	25	0.11	0.09	0.47

The urban balance was used to assess the net direction of change, defined as the difference among green to impervious and impervious to green transitions per hexagon. A total of 191 hexagons (50%) were classified as stable, while 96 (25%) negative balance (dominant impervious to green transitions) and 96 (25%) positive balance (dominant green to impervious transitions) (Figure 3). Although the number of positive and negative hexagons was identical, their magnitudes differed. The positive class showed a higher mean intensity compared to the negative class, with maximum values reaching 0.47 and −0.56, respectively (Table 1). Together, these metrics indicate that, despite localized greening processes, the intensity of green-to-impervious transitions exceeded the reverse process.

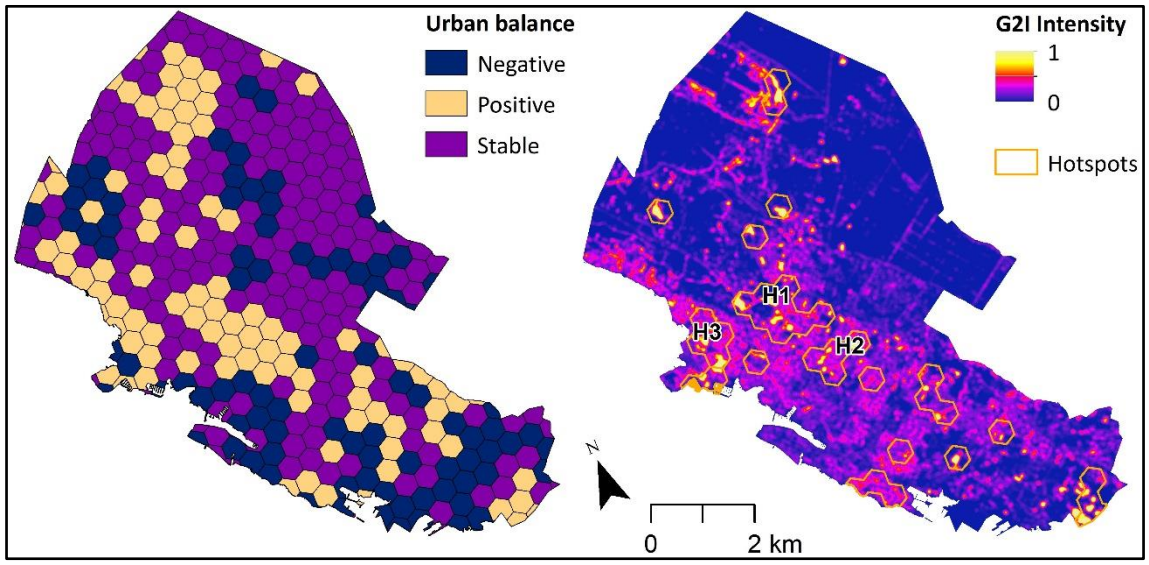


Figure 3. Urban balance (left) and Green to Imprevioss change intensity hotspots (right)

The kernel density map of high delta impervious hexagons (G2Intensity) highlights clear spatial clustering of urban growth rather than a uniform distribution across the study area (Figure 3). High-density zones are predominantly concentrated in central and transitional urban sectors, with secondary clusters emerging along peripheral development corridors. In contrast, northern and outer areas exhibit substantially lower change intensity, indicating spatially uneven urban dynamics. The identified hotspots represent areas where high-intensity impervious surface expansion is spatially aggregated, suggesting coherent development processes rather than isolated local transitions. Based on the density surface, three compact and spatially contiguous hotspot polygons were delineated. These zones correspond to the most concentrated areas of impervious surface growth and reflect structurally coherent urban expansion patterns (Figure 4).

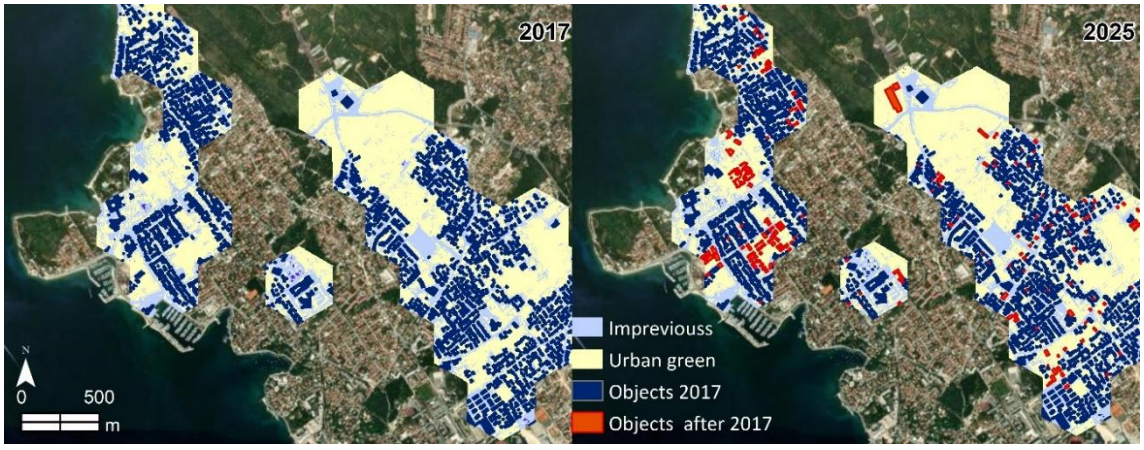


Figure 4. Hotspots of urban change

CONCLUSION

The results confirm that multi-temporal urban mapping is strongly affected by temporal domain shift, as models trained on one epoch do not necessarily generalize reliably to

subsequent acquisitions. Even after radiometric normalization, structural transformation and evolving spectral heterogeneity reduced model transferability, emphasizing the importance of epoch-specific training for robust change detection. Spatial aggregation at the hexagon level revealed concentrated zones of impervious surface expansion, indicating spatially uneven urban transformation rather than uniform growth. Comparison between multi-feature classification and NDVI thresholding further demonstrated methodological sensitivity in vegetation change estimation, highlighting the added value of integrating spectral, index-based, and textural features for detecting structural transitions. Future research should focus on integrating multi-annual or sub-annual satellite time series to better capture temporal trajectories of urban change and distinguish gradual from abrupt transformations. Expanding thematic detail beyond aggregated classes and exploring adaptive or transfer-learning approaches may further improve model generalization across temporal domains. In addition, coupling high-resolution remote sensing with urban planning indicators and hydrological parameters could provide a stronger basis for assessing urban resilience and supporting evidence-based spatial management in rapidly transforming Mediterranean cities.

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SYNERGY OF AR AND GIS DATASETS TO IMPROVE SPATIAL REASONING AND NAVIGATION INTELLIGENCE

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ABSTRACT

Augmented Reality (AR) has become a pivotal technology for advancing spatial cognition and navigation, enabling the seamless integration of digital information into real-world environments. When used with Geographic Information Systems (GIS), AR provides a powerful framework for context-aware visualization and interaction with geospatial data. This paper explores intelligent navigation systems that integrate AR interfaces with GIS databases, supported by artificial intelligence algorithms for adaptive decision-making. The proposed approach emphasizes methodological rigor by integrating spatial data processing, dynamic route optimization, and interactive overlays of geoinformation through smart AR glasses. Such integration reduces cognitive load, enhances situational awareness, and facilitates efficient orientation in complex spatial contexts. Potential applications include urban mobility, cultural heritage interpretation, tourism, and emergency response, where real-time geospatial guidance is critical. The synergy of AR, GIS, and AI technologies significantly improves navigation accuracy and user experience compared to conventional systems. By situating AR within the broader geospatial analytical framework, this study contributes to the development of next-generation intelligent navigation tools and highlights the role of integrated geoinformation technologies in shaping smart environments and spatial decision support systems.

Keywords: Augmented Reality (AR), Geographic Information Systems (GIS), Artificial Intelligence (AI)

INTRODUCTION

Advances in geospatial technologies have changed human concepts of perceiving, interpreting, and interacting with space. GIS has long formed the backbone of spatial analysis, providing structured datasets that allow accurate modelling, visualization, and decision-making [1] [2]. Meanwhile, AR has emerged as a potent medium to enhance human spatial cognition by superimposing digital information on real-world environments [3] [4].

Convergence of the AR and GIS datasets is a significant stride towards improvement of spatial reasoning and navigation intelligence. While bringing the analytical depth of GIS, AR adds the immersive capability, which allows users to experience geoinformation more intuitively and interactively. This synergy strengthens cognitive mapping and situational

awareness and points to new pathways for applications in urban mobility, crisis management, tourism, and smart city development.
By embedding spatial data into everyday environments, AR-GIS integration transforms geoinformation science from a specialist tool into a medium accessible to wider audiences. Particularly for the Balkan region, with its diverse landscapes and complex urban topography, AR-GIS integration contributes to academic and practical value in new opportunities for enhancing spatial literacy, optimizing navigation systems, and supporting decision-making procedures on everything from everyday mobility to emergency response.
This paper explores the theoretical foundations, methodological approaches, and practical applications of AR-GIS synergy, aiming to demonstrate how such integration can advance spatial reasoning and foster intelligent navigation solutions for contemporary geoinformation science. In doing so, it seeks to bridge the gap between abstract geospatial analysis and lived urban experience, offering insights relevant both to global smart city initiatives and to regional challenges.

GIS DATASETS AS THE FOUNDATION OF SPATIAL INTELLIGENCE

GIS datasets form the foundation of spatial intelligence by enabling capturing, structuring, analysis, and visualization of geospatial data, transforming raw location information into meaningful spatial insights for decision-making. GIS integrates diverse data types to reveal spatial patterns and relationships that support planning, resource management, and analytical reasoning across disciplines, extending GIS beyond simple cartography into a holistic spatial intelligence framework [1] [5].
Points of interest (POIs) represent the most direct connection between spatial data and everyday human activity. They may include landmarks, museums, stadiums, cultural sites, and exhibition venues. Within GIS datasets, POIs are described through structured information such as precise geographic coordinates, descriptive attributes (including type, opening hours, accessibility, and popularity), and connectivity data that show transport links, pedestrian routes, and proximity to other attractions [6] [7]. By organizing POIs in this way, GIS enables planners and developers to design applications that support visitor navigation, optimize travel routes, and draw attention to lesser-known locations [7].
Augmented reality adds a new experiential layer to GIS datasets by transforming spatial information into interactive content. Research on the integration of GIS and AR shows that spatial datasets provide the geometric and semantic foundation required to anchor digital content accurately in real-world environments [3]. When AR is integrated with POI data, users can explore tourism destinations through historical reconstructions and multimedia guides layered onto real-world views [8]. In sports environments, AR enhances the spectator experience by providing live statistics, seat navigation, and interactive fan zones within stadiums. Similarly, exhibitions can be reimagined through AR by enriching displays with 3D models, multilingual explanations, and engaging forms of digital storytelling [8].

The combination of GIS datasets and AR creates a dynamic form of spatial intelligence that evolves through user interaction. In tourism, GIS supports smart platforms that recommend attractions based on visitor preferences, crowd levels, or thematic routes, while AR delivers immersive and personalized guidance [9]. In sports venues, GIS assists in crowd management, safety planning, and fan engagement, with AR offering real-time

overlays of match information and navigation support [10]. Exhibition organizers rely on GIS to map indoor spaces, monitor visitor movement, and optimize booth placement, while AR transforms static exhibits into interactive and educational experiences [11].
Overall, GIS datasets form the foundation of spatial intelligence by turning raw location data into meaningful insights and engaging digital experiences. When combined with augmented reality, they redefine how people interact with tourism destinations, sports facilities, and exhibitions. This integration not only increases user engagement but also establishes new standards for cultural, recreational, and educational experiences in the digital age [1] [12].

AR TECHNOLOGIES IN SPATIAL REASONING

AR technologies have become central to the evolution of spatial reasoning. By projecting geoinformation into real-world environments, AR reduces the abstraction traditionally associated with maps and GIS interfaces. Users no longer interpret symbols on a flat surface alone; instead, they interact with spatial data in situ, experiencing it as part of their immediate surroundings [13] [14]. This shift is more than technical - it represents a cognitive transformation in how spatial relationships are understood and applied.
Spatial reasoning depends on the human ability to form cognitive maps - mental models of spatial relationships that guide orientation and movement. AR strengthens this process by embedding geospatial cues directly into the user's field of vision. A short walk through a city, for example, can be enhanced with AR overlays that highlight landmarks, suggest thematic routes, or provide real-time orientation support. The immediacy of these cues reduces cognitive load and improves accuracy in navigation decisions [15].
In professional contexts, such as logistics or urban planning, this capability translates into more efficient workflows. Planners can visualize proposed infrastructure directly on site, while logistics managers can optimize routes with live AR guidance. These examples illustrate how AR transforms cognitive mapping from a mental exercise into an embodied experience.
AR's contribution to situational awareness is equally significant. In emergency response, responders equipped with AR can see hazard zones, evacuation routes, or sensor data overlaid on the environment. This immediate visualization supports rapid decision-making when time is critical [16] [17]. Smart city applications extend this principle further. Traffic flows, crowd densities, and infrastructure conditions can be visualized in real time, allowing city managers to anticipate problems before they escalate. Here, AR does not replace GIS analysis but amplifies it, turning complex datasets into actionable insights visible at a glance.
Spatial literacy - the ability to understand and apply spatial concepts is often difficult to teach because it requires abstract reasoning. AR reduces this barrier by making geoinformation interactive. Students can explore terrain models, climate data, or urban layouts through AR applications that project these datasets into their immediate environment. This experiential learning fosters deeper comprehension and retention of spatial concepts [18]. A short case example: in geography classes across Europe, AR-based fieldwork has been used to overlay historical maps onto current landscapes, helping students grasp both spatial change and continuity [19]. Such applications demonstrate AR's pedagogical potential.
Tourism and cultural heritage provide fertile ground for AR's role in spatial reasoning. Visitors navigating complex urban landscapes or heritage sites benefit from AR overlays

that combine navigation with contextual storytelling [20] [21]. A thematic route through Belgrade's fortress, for instance, could be enriched with AR projections of historical events, guiding visitors while simultaneously deepening their cultural understanding. This dual function: navigation plus interpretation illustrates how AR extends spatial reasoning into cultural and experiential domains.

Finally, AR technologies point toward new paradigms in intelligent navigation and smart city development. By merging GIS datasets with immersive visualization, urban mobility systems can deliver personalized, context-aware guidance that adapts to real-time conditions. Citizens might receive dynamic rerouting instructions based on traffic congestion or environmental hazards, while planners could use AR to visualize infrastructure projects within their actual surroundings. This trajectory suggests that AR is not merely an accessory to GIS but a transformative technology that redefines how spatial reasoning is practiced in both everyday life and professional domains.

SYNERGY OF AR AND GIS DATASETS

The integration of AR and GIS (Figure 1) represents a powerful synergy that is reshaping how spatial data is perceived, analysed, and applied. GIS provides the analytical backbone, offering structured, multi-scale datasets that capture the complexity of physical and built environments. AR delivers immersive visualisation, placing this information directly into the user's context. Together, they transform abstract geospatial data into actionable, intuitive experiences that support decision-making across diverse domains [22] [23]

For example, it is already used in underground maintenance, water and sewer systems, urban planning, indoor environments, and increasingly in tourism. Each of these applications depends on specific types of data. Underground utilities require detailed georeferenced maps of pipelines, cables, and subsurface structures [24]. Water, sewer, oil, and gas networks rely on condition monitoring data, flow measurements, and routing information with meter level accuracy [25]. Urban planning and cadastre demand 3D city models, parcel boundaries, zoning maps, and infrastructure datasets that can be visualized at street level. Indoor environments need positioning data from Bluetooth Low Energy (BLE) beacons, Ultra Wideband (UWB) sensors, or Pedestrian Dead Reckoning (PDR) algorithms, combined with facility management records and asset inventories.

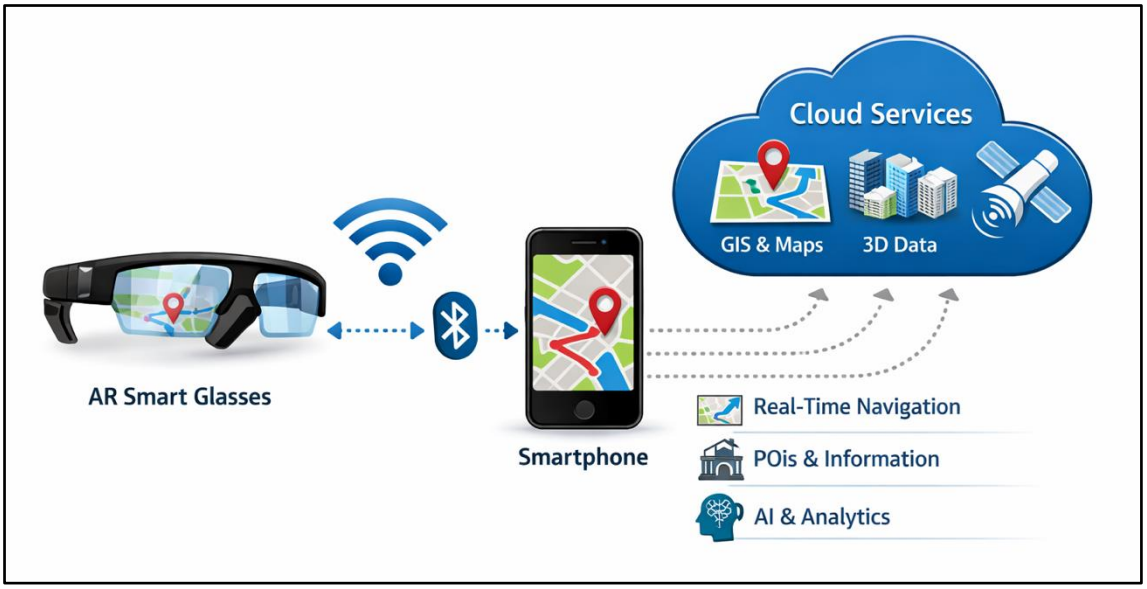


Figure 1. Example of AR and GIS integration, source: authors

Beyond these technical domains, AR-GIS is also finding a role in public engagement and tourism. By overlaying cultural heritage information, landscape changes, or thematic routes onto real environments, AR makes complex geoinformation accessible to visitors. When combined with AR glasses, this potential expands further: visitors could see parcel data, historical maps, or curated city models projected seamlessly into their surroundings. The datasets most relevant for such applications include 3D city models, cadastral maps, cultural heritage archives, and real-time mobility data, which together create immersive and informative experiences [26] [5]. This sets the stage for a deeper exploration of how AR glasses can transform tourism in urban environments.

NAVIGATION INTELLIGENCE IN URBAN SCENARIOS

Navigation in complex urban environments requires more than simple wayfinding; it demands contextual intelligence that adapts to the user's location, interests, and situational needs. This ability is provided by the combination of AR and GIS, which turns navigation into an engaging, educational, and customised experience. AR glasses, equipped with dedicated applications and real-time data streams, represent the next step in urban navigation intelligence.

In practice, AR glasses function as wearable navigation platforms. They have sensors for orientation and positioning, a transparent display built into the lenses, and an application that links to GIS datasets and urban information systems. Visual cues, such as contextual icons indicating points of interest, highlighted landmarks, or arrows guiding the path, are projected directly into the user's field of vision by the display. This method, in contrast to conventional smartphone maps, removes the need for users to look down at a screen, enabling them to stay completely focused on their environment.

Consider a visitor navigating the Belgrade Fortress, a site that combines historical significance with modern urban life. The AR glasses activate the navigation app and overlay a path through the fortress grounds as the visitor starts to walk. The glasses display visual cues at each turn, such as a highlighted outline of the fortress walls or a glowing arrow pointing to the next gate. The glasses include brief historical notes about

the building of the Roman castrum, the mediaeval fortifications, and the Ottoman and Austrian influences that influenced the location. The visitor can learn about history without interfering with the flow of movement thanks to these notes, which show up as subtle text or audio cues. The glasses could display reconstructions of previous conflicts at strategic points or architectural phases, blending cultural heritage with spatial orientation. AI algorithms process the visitor's preferences and movement patterns in real time, ensuring that the guidance adapts dynamically to their pace and interests. AI also filters and prioritizes the most relevant datasets whether historical notes, nearby cafés, or cultural events so that the user receives context-aware information without distraction.

Navigation intelligence extends beyond history. As the visitor approaches the central promenade, the glasses highlight nearby cafés and restaurants, drawing on urban GIS datasets of food and beverage locations. Recommendations are personalized: a symbol for the best local coffee, a marker for traditional Serbian cuisine, or a prompt for vegetarian and vegan options. Even crowd density could be indicated by real-time data, indicating less crowded dining areas or quieter routes.

The system integrates multiple datasets such as cultural heritage archives for historical overlays, tourism and hospitality databases for food, coffee, and leisure recommendations, mobility and transport feeds for guiding visitors to bus stops or parking areas and environmental monitoring data (air quality, noise levels) for optimizing comfort. By combining these layers, AR glasses transform navigation into a holistic urban experience, where movement is seamlessly linked with knowledge, culture, and leisure.

The most important feature of navigation intelligence is adaptability. If the visitor deviates from the suggested path, the glasses instantly recalculate the route, projecting new cues without interruption. If the user expresses interest in a particular topic the app adjusts its overlays, prioritizing relevant information. This personalization ensures that navigation is not only efficient but also meaningful.

If we assume that the city of Belgrade (Table 1) has 1.4 million tourists annually and adoption rate for a similar system using AR and GIS of 7% this translates to approximate 1350 tourists on a peak day citywide, and around 470 peak-day AR-GIS tourists at a single "top hotspot" like the Belgrade fortress. This assumes 35% share concentrated at a top attraction like the fortress [27].

Table 1. Baseline Parameters and Assumptions for AR–GIS Tourist Demand Estimates in Belgrade

Parameter	Value	Units	Notes
Annual tourists	1,400,000	people/year	Belgrade total tourists (assumption)
Adoption rate (low)	5.00%	%	Conservative lower bound
Adoption rate (mid)	6.00%	%	Midpoint scenario
Adoption rate (high)	7.00%	%	Conservative upper bound
Average trip length	2.50	days	Assumption (e.g., city-break duration)
Peak factor	2.00	x	Multiplier to approximate peak-day vs average-day demand
Hotspot share	35.00%	%	Share of AR tourists concentrated at a top attraction (e.g., Fortress)
Interactions per tourist-day	30	events/day	AR actions (POI views, routing recalculations, translations, etc.)

Source: [27]

This example illustrates how AR-GIS synergy can redefine navigation in urban scenarios. It moves beyond simple wayfinding to create immersive journeys, where every step is enriched with context. For tourists, this means deeper engagement with cultural heritage.

For residents, it offers practical guidance in daily mobility, from locating services to avoiding congestion. For city managers, it provides a platform to communicate urban change directly to citizens.

CONCLUSION

Advances in geospatial technologies have fundamentally changed how people understand and interact with space. One of the most significant developments in this field is the integration of AR and GIS. By combining the analytical strength of GIS with the immersive and visual nature of AR, this integration introduces new ways of thinking about space, navigation, and decision-making. Spatial data is no longer limited to abstract maps or databases; instead, it becomes intuitive, interactive, and directly connected to the user's real-world surroundings, improving spatial awareness and cognitive understanding.

Across many application areas, the potential of AR-GIS integration is already evident. In underground utilities and infrastructure management, AR can project subsurface networks directly into the user's field of view, improving safety and reducing errors during maintenance work. In water, sewer, oil, and gas systems, this technology supports condition monitoring and route planning with meter-level accuracy, helping organizations save both time and resources. Urban planning and cadastral management benefit from mobile AR combined with 3D city models, allowing planners, professionals, and citizens to visualize parcel boundaries, zoning regulations, and proposed changes directly at street level. Beyond technical and professional use, AR-GIS also plays an important role in public engagement, making cultural heritage, landscape evolution, and emergency training more accessible to non-experts through realistic and interactive visualizations.

An example of this concept can be seen in the case of navigation intelligence at Kalemegdan Fortress in Belgrade. Using AR glasses, visitors can explore the area through overlaid routes, historical information, and contextual recommendations for food, coffee, or leisure activities. This approach transforms simple navigation into a richer urban and cultural experience. Supporting such applications requires diverse datasets, including historical archives, 3D city models, cadastral data, mobility information, and environmental monitoring, highlighting the complexity and breadth of data behind intelligent urban navigation systems.

Despite these promising developments, several challenges remain. Accurate tracking and georeferencing at the scale of entire cities, efficient rendering of large and complex 3D models on mobile devices, and seamless interoperability between AR platforms and GIS backends are still active research topics. Overcoming these limitations is crucial for moving AR-GIS solutions from experimental pilots to widely adopted, real-world systems.

In conclusion, the integration of AR and GIS represents more than a technical upgrade, it marks a shift in how geospatial data is produced, communicated, and experienced. By uniting analytical precision with immersive visualization, AR-GIS opens new opportunities in urban mobility, tourism, crisis management, and smart city development. As research continues to refine technical challenges and broaden application areas, AR-GIS integration is set to become a pillar of modern geospatial science, reshaping how people engage with space in the digital age.

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SECTION

TEACHING & EDUCATIONAL GEOGRAPHY

PRIOR KNOWLEDGE AND MISCONCEPTIONS ABOUT THE PHYSICAL-GEOGRAPHICAL CHARACTERISTICS OF ASIA AMONG PRIMARY SCHOOL PUPILS

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ABSTRACT

An important prerequisite for effective learning and conceptual understanding of geography is the early identification of misconceptions among pupils in primary education. This paper aims to examine pupils' prior knowledge and to identify misconceptions related to the physical-geographical characteristics of Asia among Grade VII primary school pupils, prior to the formal instruction of the curricular content. The study is based on the assumption that pupils possess general knowledge about the topic acquired through prior learning, media exposure, personal experiences, and other sources, which may include persistent and incorrect conceptions. The research employs a four-tier diagnostic pre-test that enables an examination of response accuracy, pupils' confidence levels, and the reasoning underlying their choices. The testing was conducted before the instruction of the curricular content related to Asia, with the aim of determining what pupils know and identifying the content areas in which misconceptions are most pronounced. The reliability of the diagnostic test was verified, and the main research was conducted in accordance with statistical standards. The sample included Grade VII pupils from different regions, representing both urban and rural environments. The data analysis revealed the presence of numerous and stable misconceptions. A significant proportion of pupils demonstrated misconceptions related to climatic diversity, the spatial distribution of natural phenomena, and the tectonic activity of Asia. In the second phase of the research, a post-test is planned following the implementation of the curricular content on Asia, to determine whether the identified misconceptions have been resolved or continue to persist among pupils. The results of this study indicate the need for systematic diagnosis of pupils' prior knowledge and its active integration into the planning and implementation of geography instruction, as well as the creation of conditions for more effective remediation of misconceptions and the enhancement of teaching quality.

Keywords: diagnostic testing, prior knowledge, misconceptions, primary education, geography of Asia

INTRODUCTION

A highly significant direction in contemporary geography education is the early identification of misconceptions. For this purpose, it is necessary to distinguish between preconceptions, misconceptions and errors. A preconception is defined as an incomplete or naive representation that a pupil possesses before formal learning of the teaching content, while a misconception is an incorrectly formed mental construction that occurs after exposure to a scientific model or theory. On the other hand, an error refers to an answer that is scientifically considered incorrect [4]. Pupils often come to class with their own prior knowledge and beliefs about scientific phenomena. These understandings, which do not coincide with scientifically accepted explanations, are designated as alternative conceptions or misconceptions and can be integrated into the cognitive structure of the pupil, thereby hindering further learning [23]. According to Guerra-Reyes et al. [12], misconceptions can arise from misinterpretation of everyday experiences, inaccurate information obtained through informal media or cultural traditions. Passive receipt of knowledge from traditional teaching, lack of connection of teaching content with real life, use of inappropriate teaching methods can contribute to the formation of misconceptions among pupils. Before studying the teaching content, pupils already have previously formed concepts related to the topic, but they do not always coincide with scientific understanding. Pupils develop intuitive explanations ("naïve theories") from an early age to understand natural phenomena, but these explanations often lead to the formation of misconceptions [11]. As Treagust and Duit [24] point out, such prior knowledge is deeply rooted in pupils and is often resistant to change. Therefore, the early diagnosis of misconceptions prior to formal instruction is of great importance for teachers, as it enables them to effectively plan their teaching. According to Novak [19], the first and necessary step towards overcoming misconceptions is their identification. Diagnostic tests are particularly useful for detecting misconceptions, but also for pupils' scientific knowledge and ignorance.

In geography education, misconceptions arise among pupils due to the abstract nature of certain geographic concepts and processes, as well as a lack of practical examples that would facilitate their understanding. Numerous authors point out that in geography education, misconceptions occur in several thematic areas – cartography, geomorphology, climatology, and regional geography ([18]; [13]; [1]; [7]; [5]; [15]; [25]; [2]).

Within the framework of the study of the teaching content on the natural- geographic characteristics of Asia, specific and measurable phenomena (relief, mountains, rivers, climate) are covered, where pupils can more easily connect them with physical experiences and previous knowledge. This research is designed in two phases. The first phase includes the identification of misconceptions before the formal study of the teaching content on Asia by applying a diagnostic pre-test with four tiers. The second phase will be conducted after the study of the teaching content by applying a diagnostic post-test with four tiers.

The purpose of this paper is to examine the prior knowledge and identify misconceptions related to the natural-geographic characteristics of Asia among seventh-grade pupils in primary education, before the formal study of the teaching content by applying a diagnostic pre-test with four tiers in order to overcome them.

METHODS

The research was conducted in primary schools in seven municipalities in the Republic of North Macedonia on seventh-grade pupils. A total of 339 pupils were tested, of which 162 (47.8%) were male and 177 (52.2%) were female. In terms of territorial distribution, the most pupils were tested from the municipality of Prilep – about 21.2%, while the least were tested from the municipality of Chair – about 4.4% (Table 1). The number of pupils by municipality is not the same, but it does not affect the results obtained. According to official data from the State Statistical Office, the total number of enrolled seventh-grade pupils in the 2024/2025 school year is 20,116[17] pupils, with the tested sample falling within the statistical representative sample.

Table 1. Sample Structure (N=339)

Feature	Category	n	%
Gender	Male	162	47.8
	Female	177	52.2
	Total	**339**	**100**
Municipality	Gazi Baba	63	18.6
	Chair	15	4.4
	Aerodrom	48	14.2
	Dojran	32	9.4
	Prilep	72	21.2
	Radovish	50	14.7
	Gostivar	59	17.4
	Total	**339**	**100**

For the purposes of this research, a diagnostic pre-test with four tiers was designed. Diagnostic tests for the identification of misconceptions in the natural sciences were established by Treagust [22], who developed the methodology of the two-tiers diagnostic test. The first tier tests the pupil's content knowledge, while the second tier requires an explanation of the answer. Later, these tests are upgraded, where Hasan, Bagayoko and Kelley [14] introduce the index of certainty of the answers, while Caleon & Subramaniam, [3] introduce the four-tier diagnostic test, where both the answer and the reason are followed by a measurement of the degree of certainty. The test contains 10 questions that cover key natural-geographic topics: geographical location, tectonic activity, mountains, rivers, lakes, deserts and climatic diversity. Each question is structured in four tiers: the first tier contains content answers with four offered distractors, the second tier measures the confidence of the answer through three levels - I am not sure, I am somewhat sure and I am very sure. The third tier requires an explanation of the reason with four offered alternatives, while the fourth tier measures the confidence in the given reason. This structure allows for a precise distinction between: scientific understanding (correct answer, correct reason and high certainty), superficial knowledge (correct answer or correct reason with inconsistent certainty), strong misconception (incorrect answer with incorrect reason, but with high certainty), weak misconception (incorrect answer and incorrect reason, but the certainty is high only at one tier) and ignorance (incorrect answer and incorrect reason, followed by a low level of certainty).

[17] State Statistical Office (2025). Primary and secondary schools in the Republic of Macedonia, 2024/2025. Available at: https://www.stat.gov.mk/pdf/2025/2.1.25.07_mk.pdf [20]

The testing was conducted before the formal study of the teaching content of Asia. The test questions are based on the content of the geography textbook for seventh-grade by prof. dr. Blagoja Markoski [17], which is in official use in primary schools in the Republic of North Macedonia.

Before the main testing, a pilot study was conducted on a smaller number of pupils, in order to check the functionality and understandability of the test. The analysis was performed only on the first tier of all 10 questions, i.e. on the content accuracy of the answers. The results showed that the coefficient of internal consistency, Cronbach's Alpha (α) is 0.600, which indicates an acceptable level of reliability of the test. The test was also checked by experts in the field of geography teaching methodology. Cronbach's alpha was used to assess the internal consistency reliability of the test. Cronbach's alpha measures the extent to which items in a test measure the same construct and its values range from 0 to 1 [21]. According to George and Mallery [9], they propose the following interpretation rule: $\alpha \geq .9$ – Excellent, $\alpha \geq .8$ – Good, $\alpha \geq .7$ – Acceptable, $\alpha \geq .6$ – Minimally acceptable, $\alpha \geq .5$ – Poor, $\alpha < .5$ – Unacceptable.

The testing was conducted in December, before studying the curriculum content for Asia. Pupils solved the test in writing during geography class for 15 minutes. The testing was anonymous. Before conducting the main statistical analysis, the internal consistency of the test was checked, which was good (Cronbach's $\alpha = 0.735$; $N = 339$; 10 items).

The test responses were entered into an Excel database and then statistically processed in the statistical package SPSS (Statistical Package for the Social Science). The responses were categorized into five groups: scientific understanding, superficial knowledge, strong misconception, weak misconception and ignorance. Scientific understanding, misconception and ignorance indices were determined, as well as the mean value (M) and standard deviation (SD) for each question separately. The normality of the data distribution was checked with the Shapiro–Wilk test. The Shapiro–Wilk test indicated a statistically significant deviation from normality ($p < .001$). However, for large sample sizes, even small deviations from normality may lead to significant results without substantially affecting parametric statistical tests [10]. Homogeneity of variances across groups was examined using Levene's test, a classical procedure for testing the equality of variances [8]. The results indicated that the assumption of equal variances was not violated ($p = .326$). An independent samples t-test and Chi-square test were used to analyze gender differences. One-Way ANOVA with Tukey HSD post-hoc test was used for analysis by municipality.

RESULTS

This section presents the results obtained from the diagnostic pre-test for determining misconceptions among seventh-grade pupils.

Table 2 shows the percentage representation of the three categories: scientific understanding, misconceptions and ignorance separately for each question**.**

Table 2. Distribution of categories by question

Question	Topic	Scientific understanding %	Misconceptions %	Ignorance%
Q1	Climatic diversity of Asia	25.4	40.1	29.2
Q2	Position of the con. Asia	32.7	42.4	21.2
Q3	Europe-Asia border (Ural)	**55.2**	23.9	16.2
Q4	Highest mountain	20.6	**58.7**	13.0
Q5	Causes of climate diversity	**47.8**	22.7	21.5
Q6	Gobi Desert	4.1	**53.1**	**41.3**
Q7	The longest river	20.9	**53.7**	14.7
Q8	Tectonic activity	38.1	31.6	23.9
Q9	Lake Baikal	4.4	**49.0**	**43.7**
Q10	Natural features of Asia	30.1	30.4	33.0

According to the results shown in Table 2, it can be concluded that the highest percentage of scientific understanding was registered in the question about the natural border of Europe and Asia (55.2%), which indicates understanding of this geographical concept. The highest percentage of misconceptions was recorded in the questions about the highest mountain (58.7%), the longest river Yangtze River (53.7%) and the Gobi Desert (53.1%), which indicates that pupils have significant misconceptions about certain teaching contents. Meanwhile, the highest percentage of ignorance was recorded in the question about the deepest freshwater lake - Lake Baikal (43.7%).

For a more detailed view of the results for the different categories of responses among pupils, figure 1 shows the mean value (M) and standard deviation (SD) for the indices of scientific understanding, misconceptions and ignorance.

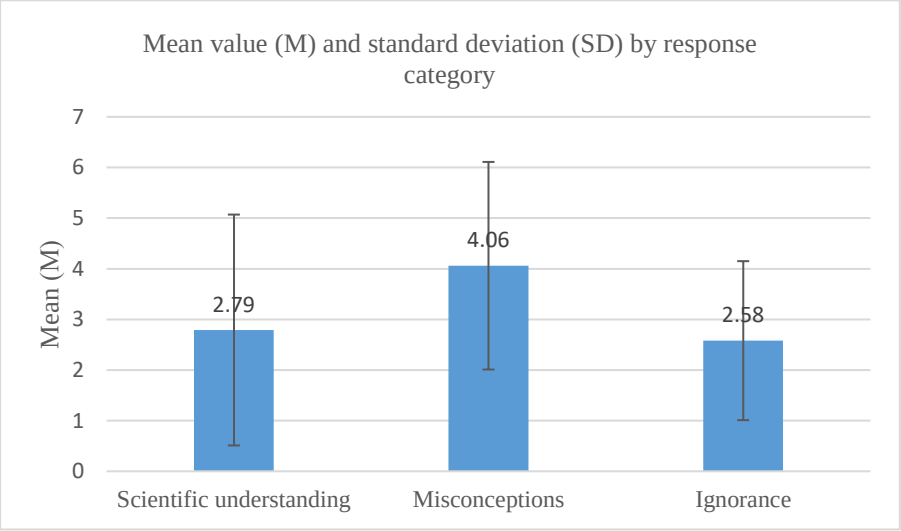


Figure 1. Mean value (M) and standard deviation (SD) for the indices of scientific understanding, misconceptions, and ignorance.

From the presented results, it can be noted that the highest average value was registered for the misconception index (M=4.06), which indicates that conceptual misconceptions are present and expressed among pupils. Meanwhile, the average value for the scientific understanding index is (M=2.79), and for the ignorance index (M=2.58). These results show that conceptual misconceptions among pupils are more often present than scientifically correct answers. The greatest variability of pupils' answers was observed for the scientific understanding index (SD=2.28), then for the misconception index (SD=2.05), and the smallest for the ignorance index (SD= 1.57).
In order to determine possible differences by gender, an analysis of the mean value (M) and standard deviation (SD) of the scientific understanding, misconceptions, and ignorance indices was performed.

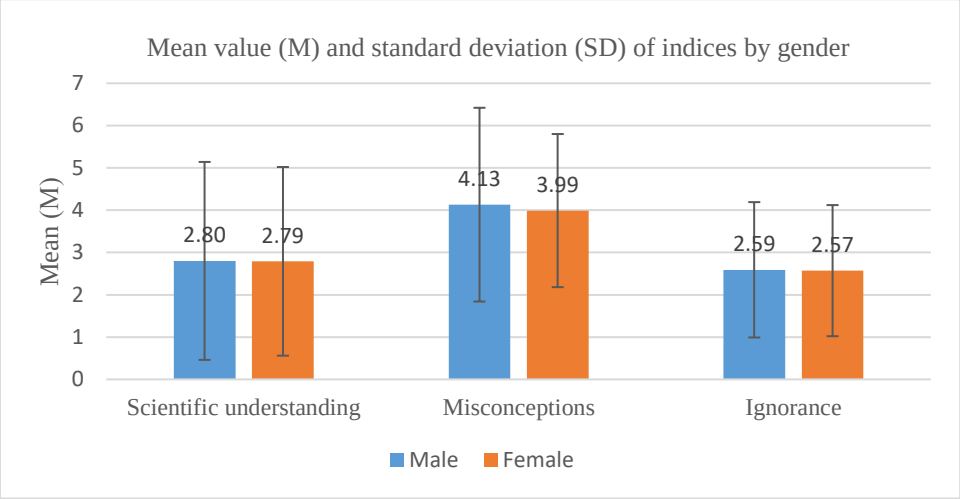


Figure 2. Mean value (M) and standard deviation (SD) of the indices of scientific understanding, misconceptions and ignorance by gender

From the figure, it can be observed that the differences according to gender are minimal. In the indices of scientific understanding and ignorance, the average values for male and female pupils are almost identical. While in the index of misconceptions, a slightly higher value is observed for male pupils (M=4.13; SD= 2.29) compared to female pupils (M=3.99; SD= 1.81), but the difference is very small. The results of the t-test showed that there are no statistically significant differences between male and female students in the indices of scientific understanding, misconceptions and ignorance ($p > 0.05$).
Table 3 shows the results of the χ^2-test for examining gender differences in the occurrence of misconceptions in individual questions related to the natural-geographic characteristics of Asia.

Table 3. Gender differences in misconceptions by questions (Chi-square)

Question	X^2	df	p	Male %	Female %
Q1	0.00	1	.998	40.1	40.1
Q2	0.38	1	.536	40.7	44.1
Q3	0.03	1	.857	23.5	24.3
Q4	**7.14**	**1**	**.008**	**51.2**	**65.5**
Q5	2.59	1	.107	26.5	19.2
Q6	0.19	1	.666	54.3	52.0
Q7	2.31	1	.128	49.4	57.6
Q8	**4.30**	**1**	**.038**	**37.0**	**26.6**
Q9	**5.39**	**1**	**.020**	**55.6**	**42.9**
Q10	1.87	1	.172	34.0	27.1

Note: χ^2 – value of the χ^2 test; df – degrees of freedom; p – level of statistical significance.

The results show that for most questions, no statistically significant differences are observed between male and female pupils ($p > 0.05$). However, statistically significant differences were registered for three questions (questions 4 ($\chi^2 = 7.14$, $p = .008$), 8 ($\chi^2 = 4.30$, $p = .038$) and 9 ($\chi^2 = 5.39$, $p = .020$) which indicate that in these teaching contents there are certain differences in the occurrence of misconceptions according to gender. In question Q4, women showed a significantly higher tendency to misconceptions (65.5%), while in questions Q8 and Q9, men had statistically higher percentages of misconceptions. According to conventional statistical criteria, results with p-values higher than .05 indicate that there is no statistically significant association between the examined categorical variables [6].

In addition to the analysis of gender differences, the research also examined whether there are statistically significant differences in the prevalence of misconceptions depending on the regional affiliation of the pupils. The results of the One-Way ANOVA analysis are shown in Table 4.

Table 4. Average number of misconceptions by municipality with results of One-Way ANOVA analysis

Municipality	M	SD	Homogeneous Subset
Aerodrom	**2.50**	**1.76**	**1**
Prilep	3.93	1.85	2
Gostivar	4.20	2.00	2
Radovish	4.32	1.97	2
Gazi Baba	4.40	2.21	2
Dojran	4.88	1.86	2
Chair	**5.00**	**1.51**	**2**

From the results shown in Table 4, it can be noted that the lowest average number of misconceptions was registered in the municipality of Aerodrom (M=2.50), while the highest was observed among pupils in the municipality of Chair (M=5.00). The results of the post hoc analysis show that the municipality of Aerodrom forms a separate homogeneous subgroup, while the remaining municipalities belong to another subgroup, which statistically indicates a lower number of misconceptions among pupils in this municipality.

DISCUSSION AND CONCLUSION

This method of research is used to "catch" the misconceptions that pupils have that they create throughout the process of their education. An interesting fact is that by using diagnostic tests before studying the teaching content, teachers can analyze and strategize which teaching methods to apply in order to eradicate misconceptions among pupils. According to Novak [19], some pupils learn mechanically, whereby knowledge is retained in the short term and they can answer the questions asked correctly at the moment. Such knowledge is not retained in long-term memory and therefore often leads to misinterpretation of concepts or loss of knowledge.

According to the results obtained, it can be concluded that seventh-grade pupils have misconceptions about the teaching content related to the natural-geographic characteristics of Asia. The average value of the misconception index is higher compared to the scientific understanding index, confirming the fact that conceptual misconceptions are a common occurrence among pupils. The occurrence of misconceptions among pupils about this content can be linked to the fact that natural-geographic concepts are more specific and related to pupils' everyday experiences, and therefore lead to the more frequent formation of erroneous, but stable representations, as emphasized in their research by Francek [7] and Dove [5]. Particularly worrying are the results for the questions about the Gobi Desert (4.1%) and the deepest freshwater lake - Lake Baikal (4.4%), where scientific understanding of these concepts is worryingly low, while the combined prevalence of misconceptions and ignorance exceeds 90%. These results indicate significant gaps in pupils' prior knowledge. The analysis of gender differences showed that gender is generally not a significant factor in the formation of misconceptions. Statistically significant differences were determined for certain questions by gender, which indicates that there may be different levels of understanding for certain teaching contents. Regional analysis through One-Way ANOVA reveals statistically significant differences between municipalities, where pupils from the municipality of Aerodrom stand out with a lower number of occurrences of misconceptions compared to pupils from other municipalities. While the municipality of Chair records the highest level of occurrence of misconceptions. Such regional differences can be associated with several factors, such as: teaching practices, quality of teaching, availability of teaching materials, as well as social and cultural influences. Within the framework of this research, pupils were surveyed in order to determine from which sources they acquired their prior knowledge about the natural-geographic characteristics of Asia.

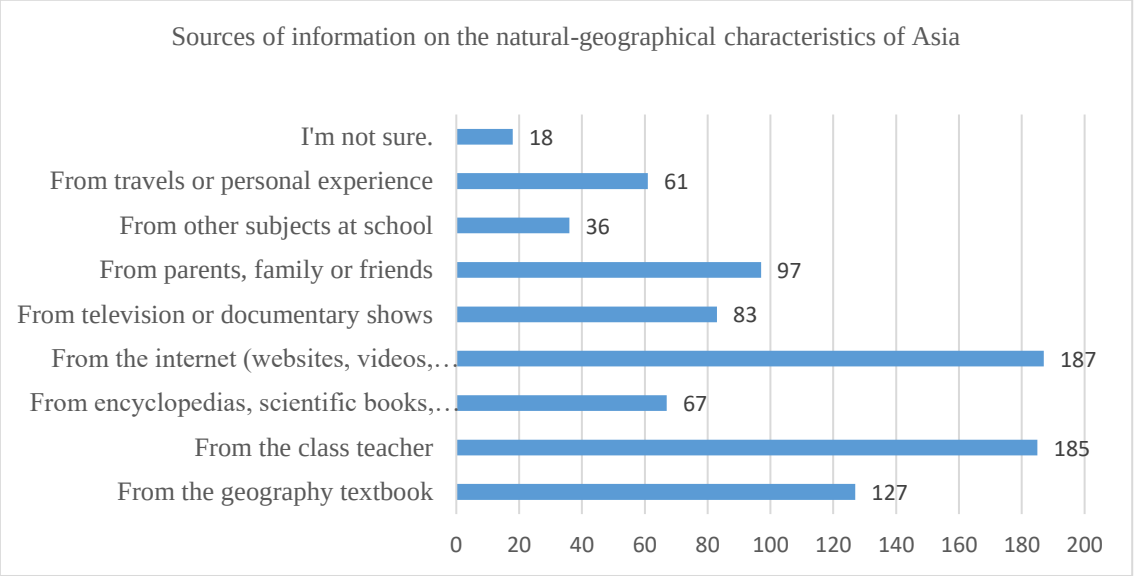


Figure 3. Sources of information regarding the natural-geographic characteristics of Asia among pupils before studying the instructional content

According to the results shown in figure 3, it can be seen that pupils get most of their information about the given topic from the Internet (187 pupils), i.e. using certain websites, videos, social media, etc., as well as from the teacher (185 pupils). A significant number of pupils indicate that they also get information from geography textbooks (127), as well as from parents or friends (97).

The dominance of the Internet and informal media as primary sources of prior knowledge can be a significant factor in the formation of misconceptions, since online content does not always provide scientifically accurate and pedagogically appropriate information. Textbooks also represent an important source of information for teachers and pupils and can directly influence the formation or maintenance of misconceptions [16]. These results indicate that in addition to formal education, pupils also rely heavily on informal sources of information. According to Guerra-Reyes et al. [12], informal media represent one of the main sources of misconceptions among pupils.

The results indicate the need for a systematic diagnosis of the pupils' prior knowledge of the curriculum content before teaching geography and the application of strategies aimed at discovering and overcoming misconceptions, such as discussions, using visual and cartographic materials, and activating critical thinking among pupils. In the second phase of this research, a post-test is planned after studying the curriculum content about Asia, in order to determine whether the identified misconceptions have been overcome or are still present. By analyzing the results of the pre-test and post-test, a comparison will be made as to whether the conceptual misconceptions among pupils were just a preconception or are already permanent misconceptions.

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SOCIOECONOMIC IMAGE OF ASIA FROM THE STUDENTS' PERSPECTIVE: RESULTS FROM THE FOUR-TIER DIAGNOSTIC PRE-TEST

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ABSTRACT

The demographic diversity and dynamic urban processes make the socio-geographical profile of Asia a significant challenge for understanding among primary school pupils. This paper aims to determine the initial level of understanding of seventh-graders regarding key concepts related to population and settlements in Asia. The research was conducted using the four-tier diagnostic pre-test, which enables a precise distinction between genuine knowledge, misconceptions (deep-rooted incorrect understandings), and a lack of knowledge (random guessing), by measuring pupils' confidence in their answers. The test was designed to identify their prior knowledge and patterns of reasoning before the formal processing of the curriculum for Asia. The research is based on the assumption that pupils possess general knowledge regarding this topic acquired from various informal sources, which contributes to the formation of persistent and incorrect understandings of certain concepts. Before the main data collection, a pilot study was run to examine the functionality and reliability of the diagnostic test. The testing was conducted among pupils from several primary schools situated in various urban and suburban areas. The results indicate the presence of pronounced misconceptions and conceptual ambiguities, particularly related to population density, urban centers, and religion.
The analysis of the obtained results enables to identify content areas that confuse geography teaching and represents a starting point for improving instructional strategies and curricular content in primary education.

Keywords: socio-geographical characteristics, Asia, pupils, seventh grade, diagnostic pre-test, misconceptions

INTRODUCTION

Due to the complexity of the study material, the content of Asia represents a challenge in the geography curriculum in seventh grade. This stems from the fact that this continent has the highest population density, large megacities, radical differences in living standards, and exceptional confessional and linguistic diversity. Pupils in geography class already have some formed knowledge about the socio-geographic characteristics of Asia, acquired through certain media, social networks, pop culture, and family stories. The knowledge they have gained is not always complete or accurate and often leads to the formation of misunderstandings, i.e., the creation of misconceptions. At the outset, to

identify misconceptions, it is necessary to distinguish between preconceptions, misconceptions, and errors. A preconception is defined as an incomplete or naive representation that a pupil possesses before formal learning of the curriculum, while a misconception is a misformed mental construct that arises after exposure to a scientific model or theory [2]. Misconceptions are interpreted as individuals' attempts to assimilate new information into existing conceptual structures that contain information contradictory to the scientific view [19]. On the other hand, an error refers to a response that is scientifically considered incorrect. The misinterpretation of concepts, known as a misconception, has been intensively researched since the early 1980s and has been the core of empirical research in learning science in recent decades [16]. Incomplete knowledge and incorrect conceptions are a natural part of pupils' cognitive development. Misconceptions often appear when these incorrect conceptions persist. Then, pupils build new knowledge on the wrong foundations, and such often present incorrect mental models [13]. According to Kocová and Marada [11], pupils have more misconceptions in human (socio-economic) geography than in physical geography. The authors explain this by the fact that physical geography topics are considered more complex, which is why more attention is paid in teaching to their correct understanding. Additionally, the teaching content of human geography is characterized by a greater degree of alternative and subjective interpretations of reality, both by the teacher and by the pupils, which reduces the ability of teachers to anticipate critical points and potential misconceptions in advance. In human geography, there are also numerous factors that influence their formation, such as family, peers, political elites, and mass media. Pupils enter the learning process with their own interpretive frameworks that influence the way they gain new knowledge [3]. From an early age, pupils develop naive theories about the world, which influence the way they interpret new information [19]. During the educational process, misconceptions about certain concepts are gradually identified, but they often remain stable and difficult to correct. This way of registering and eliminating firmly rooted misconceptions should be analyzed from a pedagogical and psychological point of view. There are many misunderstandings that are spread when people transmit what they have heard, without analyzing that information. Often, misconceptions are established due to imprecise expression. Everyday speech is used more, which is often not precise enough to describe or delimit scientific concepts. By using analogies from everyday life transmitted in everyday speech and relying heavily on visible effects and changes, it is easy to create so-called misconceptions [10]. In science, many misconceptions and assumptions persist for a long time. In geography teaching, pupils should learn how to think about social and spatial problems, and not just have ready-made views imposed [14].

The purpose of this paper is to determine the initial level of understanding of students in 7th grade of key concepts related to population and settlements in Asia and to detect misconceptions.

METHOD

This research used the descriptive method using a four-tier diagnostic pre-test to record and classify the structure and frequency of misconceptions and prior knowledge among the tested pupils. The research was conducted in four phases.

Preparation phase

For this research, a four-tier diagnostic pre-test was created in order to identify pupils' prior knowledge and misconceptions before they were formaly introduced to the teaching unit on the socio-geographic characteristics of Asia. The use of two-tier diagnostic tests for detecting misconceptions was carried out by Treagust [18]. Later, these tests were upgraded by Hasan, Bagayoko, and Kelley [9] and Caleon & Subramaniam [1] by introducing the index of certainty of answers and the explanation, that is, they developed diagnostic tests with three and four tier.

The created diagnostic pre-test contains 10 questions related to the population and settlements in Asia. The test structure includes four tiers: the first tier contains answers with four suggested statements, the second tier measures the confidence of the answer through three levels - I am not sure, I am somewhat sure, and I am very sure. The third tier requires an explanation of the reason in four offered alternatives and the fourth tier measures the confidence of the reason. This allows for a precise distinction between scientific understanding, misconceptions (strongly rooted misconceptions) and lack of knowledge (random guessing). Scientific understanding is diagnosed when the pupil answered correctly and explained the reason correctly and showed high confidence. Misconceptions are detected when the pupil gave an incorrect answer with an incorrect reason, but expressed high confidence in both. Lack of knowledge is determined when the pupil gives an incorrect answer and an incorrect explanation, followed by a low level of confidence. The test questions are based on the content of the seventh grade textbook [12], which is officially used in primary schools in the Republic of North Macedonia.

Before the general testing was performed, a pilot test was conducted on 20 pupils to check the functionality and understandability of the test. Only data on the first tier of all ten questions was analysed, i.e. on the content accuracy of the answers. By applying the internal consistency coefficient Cronbach's Alpha (α) before the wide application to 339 students, the results showed that it was 0.440, which is below the acceptable threshold and requires revision before final use. Cronbach's Alpha was used to assess the internal consistency reliability of the test and measures the extent to which items in a test measure the same construct and its values range from 0 to 1 [17]. George and Mallery [5], proposed the following rule for interpretation: $\alpha \geq .9$ – Excellent, $\alpha \geq .8$ – Good, $\alpha \geq .7$ – Acceptable, $\alpha \geq .6$ – Minimally acceptable, $\alpha \geq .5$ – Poor, $\alpha < .5$ – Unacceptable. Therefore, the test was reviewed by experts in the field of geography teaching to provide additional validation of the test.

Implementation phase

The survey was conducted on 339 seventh-grade pupils in seven municipalities in the Republic of North Macedonia, of wich, 47.8% male and 52.2% female. The largest number of tested pupils (72) is in the municipality of Prilep, and the smallest number of tested pupils (15) is in the municipality of Chair (Table 1). The number of tested pupils by municipality is not uniform, but does not affect the final obtained. According to official data from the State Statistical Office, the total number of enrolled seventh grade pupils in the 2024/2025 school year is 20,116[18] pupils, with the tested sample falling within the statistical representative sample.

[18] State Statistical Office (2025). Primary and secondary schools in the Republic of Macedonia, 2024/2025. Available at: https://www.stat.gov.mk/pdf/2025/2.1.25.07_mk.pdf [15]

Table 1. Sample Structure (N=339)

Feature	Category	n	%
Gender	Male	162	47.8
	Female	177	52.2
	Total	**339**	**100**
Municipality	Gazi Baba	63	18.6
	Chair	15	4.4
	Aerodrom	48	14.2
	Dojran	32	9.4
	Prilep	72	21.2
	Radovish	50	14.7
	Gostivar	59	17.4
	Total	**339**	**100**

The pupils' testing was conducted in December 2025 in one primary school in each of the seven municipalities. The pupils would take the test in writing during geography class for 15 minutes. The testing was anonymous, in agreement with the geography teacher and the pupils' parents.

Data processing phase

After the testing was finished, the data from the written tests were entered into an electronic Excel database. In the initial phase, all responses from all four tiers were entered in letters, and then binary coded. Based on the combination of the accuracy of the answer and the reason and level of confidence, using predefined formulas in Excel, each response was categorized into three categories: scientific understanding, misconceptions and ignorance. The data were then processed in the statistical package SPSS (Statistical Package for the Social Science). For each question, the absolute frequency and percentages were calculated separately. Indices of scientific understanding, misconceptions and ignorance were determined with a calculated mean value (M) and standard deviation (SD). The normality of data distribution was checked by Shapiro-Wilk test. The Shapiro–Wilk test indicated a statistically significant deviation from normality ($p < .001$). However, for large sample sizes even small deviations from normality may lead to significant results without substantially affecting parametric statistical tests [6]. Homogeneity of variances across groups was examined using Levene's test, a classical procedure for testing the equality of variances [4]. The results indicated that the assumption of equal variances was not violated ($p = .655$). Data by gender were analyzed using an independent t-test (Independent Samples t-test) and a Chi-square test of independence. Analysis of differences by municipality was conducted using a One-Way ANOVA with a Tukey HSD post-hoc test.

Data analysis phase

Before conducting statistical data processing, the internal consistency of the entire test was checked, which was acceptable (Cronbach's $\alpha = 0.679$; $N = 339$; 10 items).

Table 2 shows the percentage representation of the three categories: scientific understanding, misconceptions and ignorance separately for each question.

Table 2. Distribution of categories by question

Question	Topic	Scientific understanding %	Misconceptions %	Ignorance%
Q1	Population size	**49.9**	23.6	24.4
Q2	Population density	17.1	30.7	46.0
Q3	The most sparsely populated	**0.0**	**47.2**	**52.8**
Q4	Developed areas	38.1	20.3	36.3
Q5	Million-plus city	20.1	28.6	44.2
Q6	Religion	10.9	**38.4**	**49.6**
Q7	Megapolis	37.2	18.0	36.0
Q8	Youngest population	5.6	31.9	**60.5**
Q9	Labour force	29.8	25.4	36.0
Q10	Population size	**54.3**	18.0	22.4

From the results shown in Table 2, it can be seen that questions where the percentage of ignorance is highlighted are the most dominant. Pupils mostly do not know (60.5%) where the youngest population in Asia is located, on the other hand, the fact that a very small percentage of pupils (5.6%) have knowledge of this content is worrying.
While, in question 3, one critical piece of information stands out, which is that none of the pupils answered correctly which region in Asia is the least populated, on the contrary, they had misconceptions (47.2%) or no knowledge at all (52.8%) about this teaching topic. It is also worth noting that in the question related to religions, pupils stand out with the occurrence of misconceptions (38.4%) and ignorance (49.6%). In socio-geographical questions, the category of ignorance is more pronounced, which indicates that pupils more often do not have a clear idea than they have a stable, but erroneous conception.
For a more detailed analysis of the results for the different categories of pupils responses, figure1 shows the mean (M) and standard deviation (SD) for the indices of scientific understanding, misconceptions, and ignorance.

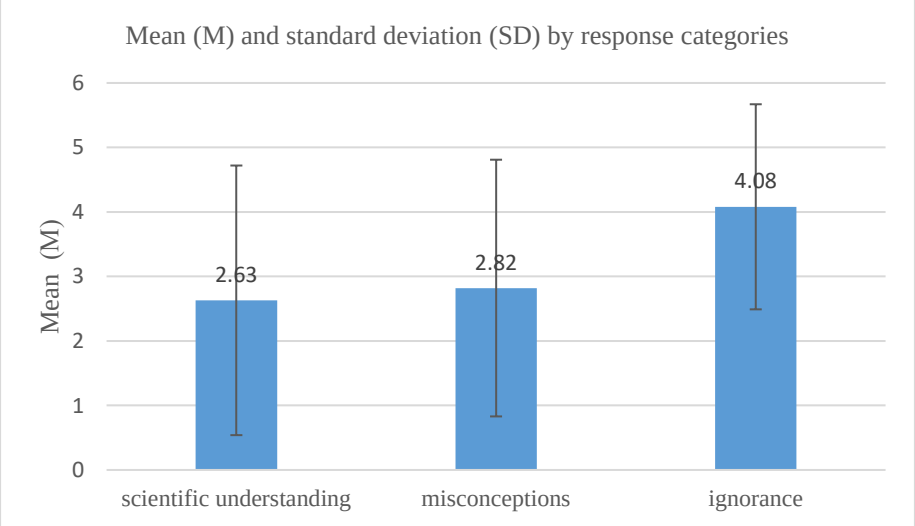


Figure 1. Mean (M) and standard deviation (SD) for the indices of scientific understanding, misconceptions, and ignorance.

From figure 1 it can be seen that the highest average value is registered for the ignorance index and is M=4.08 (SD=1.59), while the indices for misconception (M=2.82; SD= 1.99)

and scientific understanding (M=2.63; SD= 2.09) are almost identical. These data once again confirm the fact that the topic about the socio-geographic characteristics of Asia does not cause misconceptions, but primarily a lack of knowledge.
Figure 2 presents the distribution of pupils according to the number of misconceptions they have.

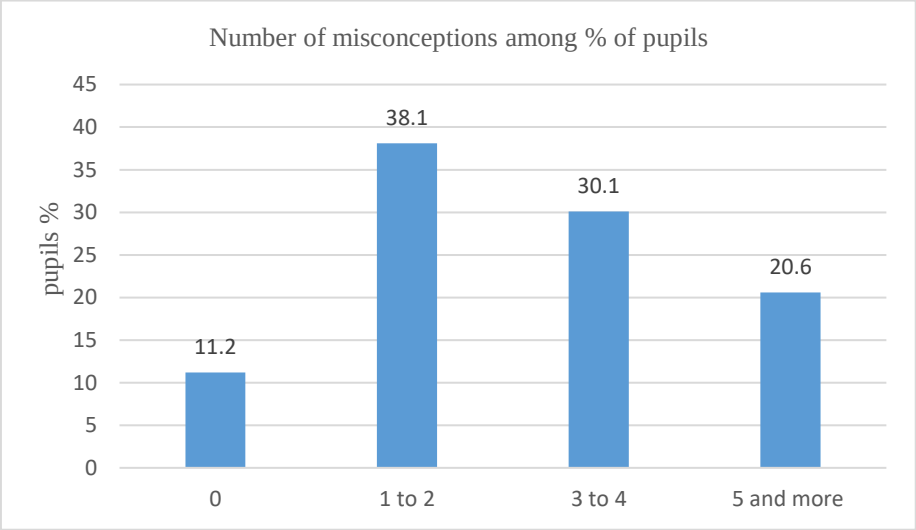


Figure 2. Distribution of pupils according to the number of total misconceptions

As can be seen in the figure, the largest percentage of pupils have 1 to 2 misconceptions (38.1%), which indicates that a large number of pupils have individual misconceptions of certain concepts. The percentage of 3 to 4 misconceptions (30.1%) is also highlighted. A very small number of pupils (11.2%) did not show that they had misconceptions. It can be concluded that specific conceptual misunderstandings are prevalent among most pupils; conversely, a total lack of misconceptions was noted in a relatively small proportion of the participants. To determine possible differences by gender, an analysis of the mean (M) and standard deviation (SD) of the indices of scientific understanding, misconceptions, and ignorance was performed.

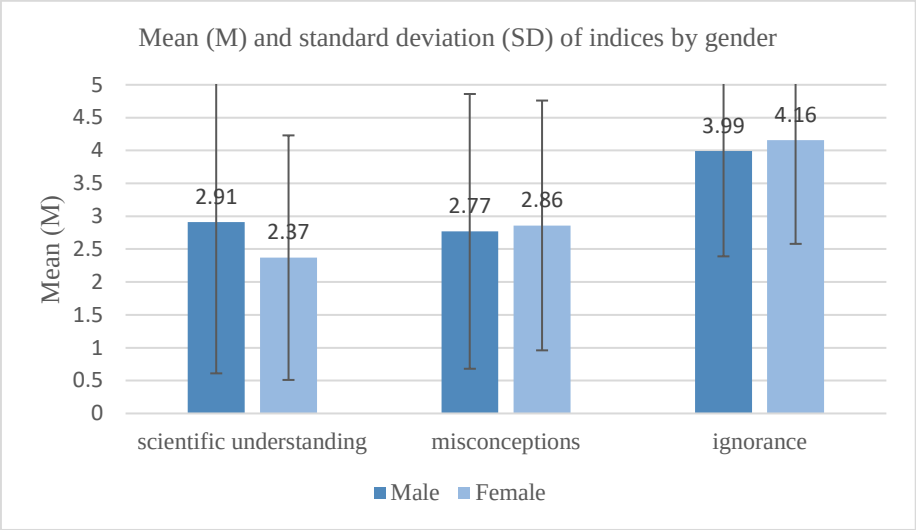


Figure 3. Mean (M) and standard deviation (SD) of the indices of scientific understanding, misconceptions and ignorance by gender

The analysis with the independent t-test presented in figure 3, does not show a statistically significant difference between male and female pupils in the misconception index (t = -0.43, p = .668) and the ignorance index (t = -1.02, p = .310). In contrast, a significant statistical difference ($p < 0.05$) was determined in the scientific understanding index, where male pupils have a higher average value (M=2.91; SD=2.30), compared to female pupils (M=2.37; SD=1.86). Based on the results presented in table 3, the Chi-square analysis reveals that there are no statistically significant gender differences in the prevalence of misconceptions across all ten questions ($p > .05$). According to conventional statistical criteria, results with p-values higher than .05 indicate that there is no statistically significant association between the examined categorical variables [8]. These findings suggest that gender does not act as a differentiating factor in the formation of geographic misconceptions among primary school pupils. Both male and female pupils exhibit similar patterns of conceptual errors regarding the socio-geographic characteristics of Asia.

Table 3. Gender differences in misconceptions by question (Chi-square)

Question	X^2	df	p	Male %	Female %
Q1	0.33	1	.568	22.2	24.9
Q2	0.29	1	.587	32.1	29.4
Q3	0.57	1	.451	45.1	49.2
Q4	0.30	1	.584	21.6	19.2
Q5	0.32	1	.571	27.2	29.9
Q6	0.23	1	.635	37.0	39.5
Q7	2.74	1	.098	21.6	14.7
Q8	0.71	1	.399	29.6	33.9
Q9	2.32	1	.128	21.6	28.8
Q10	0.27	1	.601	19.1	16.9

Note: χ^2 – value of the χ^2 test; df – degrees of freedom; p – level of statistical significance.

The research analyzed whether statistically significant differences appear in the prevalence of misconceptions depending on the regional distribution of the pupils. The results of the One-Way ANOVA analysis are shown in table 4.

Table 4. Average number of misconceptions by municipality with results of One-Way ANOVA analysis

Municipality	M	SD	Homogeneous Subset
Aerodrom	**2.33**	**1.95**	**1**
Prilep	**2.49**	**1.88**	**1**
Gazi Baba	2.60	1.85	1/2
Gostivar	2.97	1.92	1/2
Chair	3,07	1.67	1/2
Radovish	3.14	2.11	1/2
Dojran	**3.84**	**2.27**	**2**

Based on the results shown in table 4, it can be noted that there are certain differences in the number of misconceptions between the municipalities. The municipalities of Aerodrom (M = 2.33) and Prilep (M = 2.49) belong to the first homogeneous subgroup and stand out with a low number of misconceptions. While the municipality of Dojran (M = 3.84) stands out with the highest number of misconceptions and belongs to the second homogeneous group. The remaining municipalities have a moderate number of misconceptions.

DISCUSSION AND CONCLUSION

The results of this research indicate that pupils are more ignorant about the socio-geographic characteristics of Asia. This stems from the fact that socio-geographic concepts are more abstract and less present in everyday contexts, which is why pupils often do not have a clear idea. The result about the least populated area — Siberia (question 3), where the scientific understanding is 0.0%, is worrying. This is the only case in the entire research where not a single pupil gave a scientifically correct answer, with ignorance of 52.8% and misconceptions of 47.2%. Similarly, critical are the results for religions originating from Asia (question 6; 10.9% scientific understanding) and the region with the youngest population (question 8; 5.6% scientific understanding), which indicate serious conceptual ambiguities in the area of demographic and religious aspects of the population in Asia. According to the number of misconceptions, present among a significant portion of pupils, the need for more systematic recognition and correction of erroneous conceptual understandings in the teaching process is highlighted. The analysis of gender differences showed that gender is generally not a significant factor in the formation of misconceptions. Regional analysis through One-Way ANOVA reveals statistically significant differences between municipalities. The municipalities of Aerodrom (M = 2.33) and Prilep (M = 2.49) record the lowest average index of misconceptions, significantly standing out from the other municipalities. In contrast, the municipality of Dojran records (M = 3.84) the highest values of misconceptions. These regional differences can be associated with the influence of the teaching process, the availability of teaching materials, social and cultural factors that influence the formation of prior knowledge among pupils.

As part of the testing, one additional question followed (question 11) were pupils should determine where they had the most information about this teaching unit before they studied it at school.

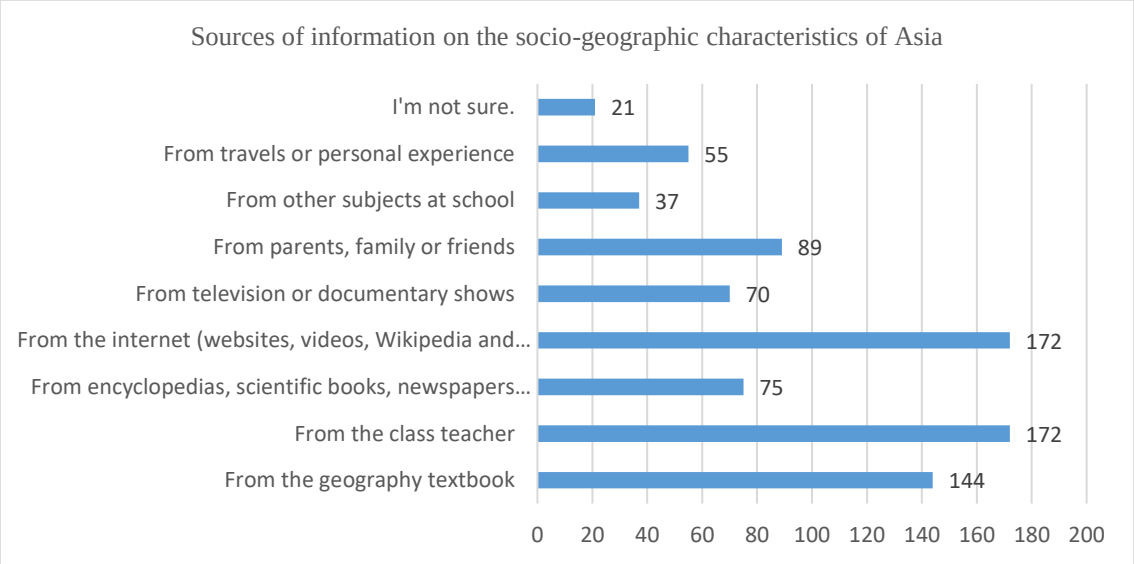


Figure 4. Sources of information about the socio-geographic characteristics of Asia among pupils before studying the curriculum content

According to the results shown in figure 4, it can be noted that pupils gained the most prior knowledge about this content using websites, videos, social networks (172), as well as from the teacher in class (172). They also highlight the geography textbook as a second source (144). These results indicate that in addition to formal education, pupils also rely to a large extent on informal sources of information. According to Guerra-Reyes et al. [7], they indicate that informal media represent one of the main sources of misconceptions among pupils.

With this research, we found the so-called "critical points" for the pupils. Then we move on to the formal study of the teaching content about Asia using monological and dialogical teaching methods by the teacher. In the second phase of this research, the pupils are going to be re-tested using a diagnostic post-test with four tiers that will be conducted after studying the teaching content. Then, it will be detected whether the recorded misconceptions have been eliminated and were only preconceptions or remain as firmly rooted misconceptions. Once the misconceptions have been established, we move on to finding the source, how they arose, and finding a way to permanently eliminate them. It is worth noting that with the frequent use of artificial intelligence in everyday life and in the teaching process, it would be practical to conduct research on what percentage of pupils use it to obtain some information related to the teaching content. With that result, it can be determined whether artificial intelligence "helps" to create misconceptions or to remove them.

In order to reduce misconceptions among pupils, it is necessary to encourage their critical thinking and critical reasoning. This means that when a pupil draws conclusions critically, he/she only specifies terminology, distinguishes facts from opinions, asks relevant questions, and makes a comprehensive review. That is, he/she carefully examines the problem, asks logical questions, exposes assumptions, sets criteria, seeks evidence, and notes what data is missing. Then he/she evaluates the arguments, analyzes the data, thinks about other possible explanations, rejects information that is not correct, evaluates the conclusions, draws conclusions, and revises opinions [10].

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SECTION
PHYSICAL GEOGRAPHY

HYDROLOGICAL ANALYSIS OF THE HIGH WATERS OF THE KUTINSKA RIVER, SERBIA

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ABSTRACT

The Kutinska River, located in southeastern Serbia, is a left-bank tributary of the Nišava River, drains a basin of 231 km2 with elevations from 203 to 1810 m a.s.l. In this study, maximum annual discharges recorded over a 30-year period (1991–2020) at the "Radikine Bare" gauging station were analyzed to assess the probability of high-water events. Several probability distributions – Normal, Pearson Type 3, Gumbel, Log-Pearson Type 3, and Log-Normal – were examined in order to compare their statistical performance in modeling hydrological extremes. The results of the flood-frequency analysis were evaluated using the Kolmogorov–Smirnov test and the Chi-square test, with empirical frequencies determined using the Weibull formula. Goodness-of-fit testing indicates that the Pearson Type 3 distribution provides the most adequate representation of the observed dataset. The resulting design discharges provide a reliable basis for flood-hazard assessment, water-resources management, and spatial planning within the basin.

Keywords: Kutinska River, probability distributions, maximum annual discharge, Kolmogorov–Smirnov test, Chi-square test.

INTRODUCTION

River systems and their floodplains play a central role in socio-economic development and environmental sustainability [40], [21]. River discharge reflects the integrated response of a river basin to climatic variability and catchment characteristics and, as such, provides valuable information on hydrological conditions [34]. At the catchment scale, streamflow constitutes a key hydrological variable resulting from the interaction of climatic drivers, land-surface properties, and subsurface geological characteristics operating within the basin [39]. According to the flow classification framework proposed by Pfannerstill et al. [29], streamflow conditions can be grouped into five hydrograph-based categories defined by exceedance probability: very high flows (< 5%), high flows (5–20%), moderate flows (20–70%), low flows (70–95%), and very low flows (> 95%). High flows and floods represent natural and recurring extremes of river flow regimes worldwide [12].

High waters are a hydrological phenomenon characterized by a rapid rise in water level and increased river discharge, most often associated with intense and long-lasting precipitation, rapid snowmelt, or their combined occurrence [22], [19]. High-flow events may cause only limited disturbances when their magnitude is low. However, sufficiently

intense events can lead to long-lasting effects by altering riparian vegetation, modifying channel morphology, and removing accumulated silt and debris from the streambed [38]. High-flow events often lead to intensified flooding and erosion, particularly in urban areas where low infiltration capacities amplify runoff processes [26].

Floods represent the most pronounced manifestation of high-water conditions and reflect the hydrological regime of a river basin [36]. They are among the most harmful natural hazards, resulting in significant loss of human life and cause widespread damage to land, infrastructure, and economic activities in affected areas [3], [2], [7]. Flooding occurs when water exceeds the conveyance capacity of river, stream, or lake channels, leading the inundation of normally dry areas [19]. Flood frequency analysis is a statistical approach used to quantify the relationship between extreme discharge magnitudes and their probability of occurrence [11]. In hydrology, this method is essential for estimating design discharges with specified return periods, which are required for water resources management, hydraulic structure design, and environmental assessments [18], [31]. Flood frequency analyses are commonly conducted using a range of probability distributions, including the Normal, Log-normal, Gumbel, Pearson Type 3 (P3), and Log-Pearson Type 3 (LP3) distributions [10], [32], [35], [44].

In Serbia, numerous studies have focused on the analysis of high-water conditions, maximum annual discharges, and floods, both on large rivers and in torrential catchments. Gavrilović et al. [13] analyzed the most signifacant floods in Serbia during the 1960–2010 period, calculating flood occurrence probabilities for 21 hydrological stations located on the Danube, Sava, Tisa, Tamiš, and Velika Morava rivers, with the aim of assessing the frequency and spatial distribution of extreme hydrological events. At the local scale, Plavšić and Ivetić [30] examined the coincidence of maximum annual discharges of the Danube and Sava rivers in the Belgrade area, highlighting the importance of simultaneous high-water occurrences on major rivers. An analysis of flood frequency and the spatio-temporal characteristics of historical torrential floods in the Šumadija based on discharge records and archival documentation, identified a chronology of 344 torrential flood events recorded between 1929 and 2020, confirming the high exposure of the region to extreme hydrological phenomena [28]. Đokić et al. [9] analyzed maximum, mean, and minimum annual discharges in the Gaberska River basin, applying the LP3 distribution to estimate the probability of high-water occurrence and corresponding return periods, thereby confirming the pronounced torrential character of the river and the high variability of its discharge regime.

Despite the growing body of research on high-water conditions and flood-frequency behavior in Serbia, the frequency characteristics of annual maximum discharges of the Kutinska River remain insufficiently documented. Therefore, this study aims to analyze annual maximum discharges recorded at the “Radikine Bare” gauging station during the 1991–2020 period, evaluate several commonly used probability distributions using goodness-of-fit tests, and estimate design discharges for selected return periods relevant to flood-hazard assessment and basin planning.

STUDY AREA

The Kutinska River Basin is located in southeastern Serbia and covers an area of approximately 231 km2, while the main river channel extends over a total length of 43.03 km. The basin is characterized by pronounced altitudinal variability, with elevations

ranging from 203 to 1810 m above mean sea level [16]. A total of 31 rural settlements are situated within the basin [14].
The geological structure of the basin is dominated by Proterozoic schists, with Mesozoic carbonate formations and Pliocene gravel and sand deposits occur locally. The basin is influenced by a moderate continental climate, with a mean annual air temperature of 9.12°C and an average annual precipitation of 767 mm [15].
The Kutinska River represents the most important tributary of the Nišava River in its lower course and originates in the southeastern part of the basin, at the foothills of the Suva Planina Mountain. Its most significant left-bank tributaries are the Grkinja River and the Dragovska River, while the main right-bank tributaries include the Buča River, the Čagrovačka River, and the Šebetska River [8].

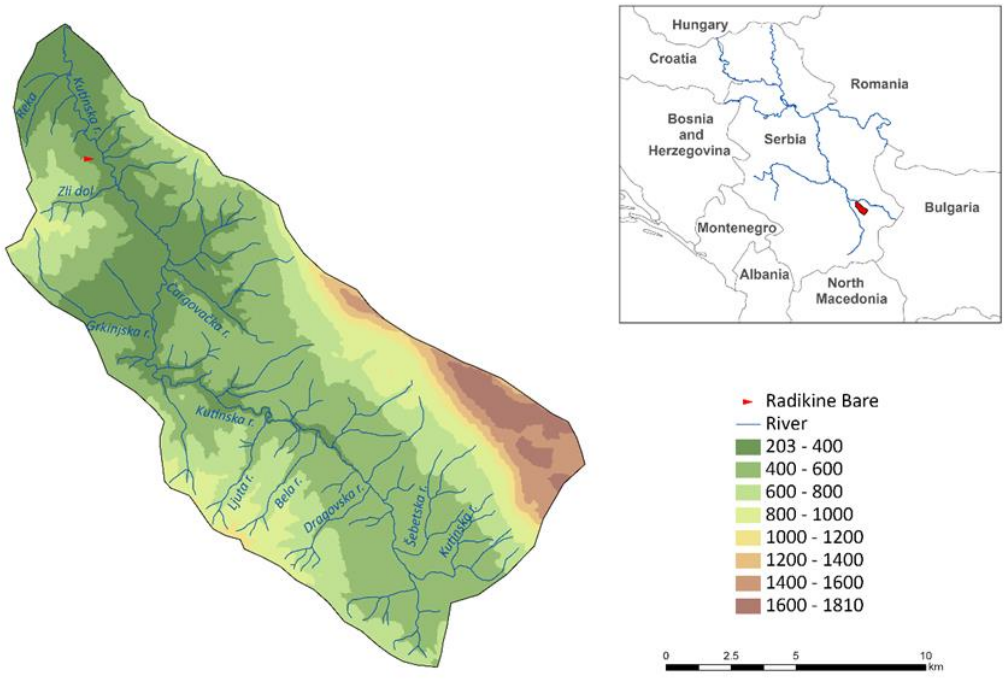


Figure 1. Location of the Kutinska River Basin and the "Radikine Bare" hydrological station

METHODOLOGY

The hydrological analysis was conducted using maximum annual discharge (Qmax) data recorded at the Radikine Bare gauging station on the Kutinska River. The dataset was obtained from the Republic Hydrometeorological Service of Serbia (RHMZ) – Surface water yearbooks [33]. To describe the statistical behavior of maximum annual discharges and to estimate their probabilities of occurrence for selected return periods, several theoretical probability distributions commonly applied in hydrological frequency analysis were considered.
The normal distribution represents a class of continuous probability distributions that share an identical overall form, while differing in their location and scale parameters, which correspond to the mean value and the standard deviation, respectively [1]. A continuous random variable X is said to follow a normal distribution if it is characterized

by the mean μ and the variance σ2, and is denoted as X∼N(μ,σ2). The probability density function of the normal distribution is defined as:

$$fx(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \quad -\infty < x < \infty \tag{1}$$

The cumulative distribution function is given by:

$$Fx(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{(y-\mu)^2}{2\sigma^2}} dy = \frac{1}{2}\left[1 + \text{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right],$$

$$-\infty < x < \infty, -\infty < \mu < \infty, \sigma > 0 \tag{2}$$

where *erf* (.) denotes the error function, and μ and σ represent the location and scale parameters of the distribution, respectively.

The log-normal distribution shares several properties with the normal distribution, with the key difference that the random variable is expressed in logarithmic form. A defining feature of the log-normal distribution is that it is limited to positive values and exhibits marked positive skewness. These characteristics are commonly observed in frequency distributions derived from hydrological data analyses [43]. The probability density function and the cumulative distribution function of the log-normal distribution are given by:

$$f(x) = \frac{exp\left(-\frac{1}{2}\left(\frac{\ln(x)-\mu}{\sigma}\right)^2\right)}{x\sigma\sqrt{2\pi}} \tag{3}$$

$$F(x) = \varphi\left(\frac{lnx-\mu}{\sigma}\right) \tag{4}$$

where φ denotes the Laplace integral, i.e., the cumulative distribution function of the standard normal distribution.

The P3 distribution is a three-parameter probability distribution commonly applied in flood frequency analysis due to its ability to model positively skewed hydrological data [20]. The P3 distribution for a random variable X is defined by the probability density function (Eq. 5):

$$f(x) = \frac{1}{|a|\Gamma(b)} \frac{(x-c)^{b-1}}{a} exp\left[-\left(\frac{x-c}{a}\right)\right], \tag{5}$$

where *a*, *b* and *c* denote the scale, shape, and location parameters, respectively. For $a>0$, the distribution is positively skewed and defined for $x \geq c$, whereas for $a<0$ it is negatively skewed and defined for $x \leq c$. The mean, variance, and coefficient of skewness are given by Eq. (6):

$$\mu = c + ba \qquad \sigma^2 = ba^2 \qquad \gamma = 2a/(|a|b^{1/2}), \tag{6}$$

Two commonly used standardizations for $X \sim P3(a, b, c)$ are:

$$Z = \frac{X-c}{a} \qquad K = \frac{Z-b}{b^{1/2}} = \frac{X-c-ab}{ab^{1/2}} \tag{7}$$

The standardized variable Z follows a one-parameter (standard) gamma distribution.
In flood frequency analysis, the LP3 distribution represents a generalized form of the two-parameter lognormal distribution by incorporating an additional skewness parameter in logarithmic space, which enables a more flexible representation of asymmetrically distributed hydrological data. In this formulation, the random variable Q is transformed as *Y=ln(Q)*, where *Y* follows a P3 distribution with parameters *α, β,* and τ [17].

$$f_Q(q) = \frac{1}{|\beta| q \Gamma(\alpha)} \left(\frac{\ln q - \tau}{\beta} \right)^{\propto -1} \exp\left(-\frac{\ln q - \tau}{\beta} \right) = \frac{1}{|\beta|\Gamma(\alpha)} \frac{exp\left(\frac{\tau}{\beta}\right)}{q^{1+1/\beta}} \left(\frac{\ln q - \tau}{\beta} \right)^{\propto -1} \quad \text{for } (\ln q - \tau)/\beta > 0 \tag{8}$$

The Gumbel distribution (EV1) is a two-parameter probabilistic model widely applied in extreme hydrologic characterization, particularly for the analysis of maximum annual discharges and high-water events [24]. For maxima, the probability density function is expressed as:

$$f(x) = \frac{1}{b} e^{-\left(\frac{x-a}{b}\right)} e^{-e^{-\left(\frac{x-a}{b}\right)}}, \; -\infty < x < \infty \tag{9}$$

The parameters of the Gumbel distribution were estimated using the method of least squares. Empirical cumulative probabilities were first determined using the Weibull plotting position formula:

$$F(x) = \frac{m}{n+1}, \; \mathrm{m} = 1,2,\ldots,\mathrm{n}, \tag{10}$$

where *m* is the rank of the observations in a sample of size n after sorting the data in descending order.
To enable parameter estimation by linear regression, a double logarithmic transformation was applied:

$$y = ln\left[ln\left(\frac{1}{F(x)}\right)\right]. \tag{11}$$

The estimated parameters were subsequently used to compute theoretical probabilities and design discharges for selected return periods.
The Chi-square (χ^2) test was applied to evaluate the adequacy of the fitted probability distributions comparing observed and expected frequencies across predefined class intervals [27], [4]. The test statistic is expressed as:

$$\chi^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i} \quad (12)$$

where oi and ei are the observed and expected class frequencies for the i-th interval (bin) and k is the total number of classes. Smaller χ^2 values indicate a closer agreement between the empirical data and the theoretical distribution, and the computed statistic is compared with the critical χ^2 value at the selected significance level to assess the goodness of fit.
The Kolmogorov–Smirnov (K–S) test is a non-parametric goodness-of-fit procedure used to quantify the agreement between an empirical cumulative distribution function (ECDF) and a specified continuous theoretical cumulative distribution function (CDF). In contrast to the chi-square test, the K–S test does not require class grouping and is therefore often suitable for relatively small samples. The test statistic is based on the greatest vertical deviation between the empirical and theoretical CDFs and is defined, for an ordered sample xi (i=1,…,), as:

$$D = \max\left[F(x_i) - \frac{i-1}{n}, \frac{i}{n} - F(x_i)\right] \quad (13)$$

where $F(x_i)$ denotes the theoretical CDF evaluated at the i-th ordered observation and n is the sample size. This formulation is equivalent to expressing D as the maximum absolute difference between the ECDF and the theoretical CDF [37], [42].

RESULTS AND DISCUSSION

Table 1 summarizes the annual maximum discharges (Qmax) recorded during 1991–2020 and indicates pronounced interannual variability. The dataset comprises 30 annual maximum values, with a minimum of 0.70 m3/s observed in 1994 and a maximum of 55.90 m3/s observed in 2012. Several years exhibit notably high peaks, including 1991 (51.90 m3/s), 1996 (47.80 m3/s), 2005 (48.10 m3/s), and 2018 (35.60 m3/s), highlighting the occurrence of occasional high-magnitude events. In contrast, most years are characterized by substantially lower maxima (often below 20 m3/s), suggesting a positively skewed distribution of annual extremes dominated by infrequent but significant high-flow episodes.

Table 1. Annual maximum discharges (Qmax) recorded at the “Radikine Bare” gauging station (1991-2020)

Year	Qmax (m^3/s)	Year	Qmax (m^3/s)
1991	51.90	2006	16.80
1992	10.80	2007	7.50
1993	4.39	2008	7.80
1994	0.70	2009	8.70
1995	16.00	2010	28.80
1996	47.80	2011	3.05
1997	19.20	2012	55.90
1998	21.90	2013	13.00
1999	34.00	2014	13.30
2000	7.26	2015	5.81

2001	21.70	2016	15.30
2002	10.70	2017	16.40
2003	7.49	2018	35.60
2004	9.00	2019	29.30
2005	48.10	2020	9.43

The mean annual maximum discharge is 19.25 m3/s, with a standard deviation of 15.40 m3/s, indicating pronounced interannual variability. The coefficient of skewness (*Cs* ≈ 1.03) reveals a positively skewed distribution, suggesting the occurrence of infrequent but significant high-water events.

Based on the statistical properties of the dataset, the P3 probability distribution was selected for modeling maximum annual discharges. Several candidate probability distributions (Normal, Log-normal, EV1, LP3, and P3) were evaluated using the K–S test and the χ^2 test at the 5% significance level ($\alpha = 0.05$). A comparative summary of the test outcomes is presented in Table 2. In the $\chi 2$ test, a distribution was accepted when $\chi^2_{obs} < \chi^2_{crit}$ (at $\alpha = 0.05$ and the reported degrees of freedom); otherwise it was rejected. For the selected P3 model, the K–S test was additionally examined at $\alpha = 0.01$ and $\alpha = 0.10$, and the null hypothesis was not rejected at any of the applied significance levels.

Table 2. Goodness-of-fit comparison for candidate probability distributions (K–S and χ^2 tests, α=0.05; n=30)

Distribution	**K–S**	**K–S p-value**	**χ^2 (observed)**	**χ^2 (critical)**	**df**	**Decision (α = 0.05)**
Normal	0.20	0.17	30.44	14.07	7	Reject (χ^2 fails)
Log-normal	0.12	0.78	14.92	14.07	7	Reject (χ^2 fails)
P3	0.09	0.95	15.89	16.92	9	Accept
LP3	0.09	0.95	2.13E+06	15.51	8	Reject (χ^2 fails)
(EV1)	0.92	0.00	2.38E+13	12.59	6	Reject (K–S and χ^2 fail)

These results are consistent with evidence from comparative flood-frequency studies. Turhan and Değerli [41] analyzed maximum-flow records from stations in the Eastern Mediterranean Basin in southern Turkey, focusing on the Göksu River near Kravga Bridge. They evaluated several candidate distributions (Normal, Log-normal, EV1, P3 and LP3) using the K–S and χ^2 goodness-of-fit tests and ranked P3 as the most suitable model overall. This is consistent with our results and supports the use of P3 for positively skewed annual maxima, where reliable representation of the upper tail is critical for design-discharge estimation.

Comparable applications in Serbia and the wider region report similar patterns when annual maxima exhibit positive skewness, with P3 (and, in some cases, LP3) frequently providing an adequate fit compared with two-parameter alternatives. For example, Milijašević [25] applied a P3 framework to high-water analysis of the Đetinja River (Šengolj station), while Lešćešen et al. [23] analyzed annual maxima of the Sava River at

Sremska Mitrovica and discussed the suitability of P3/LP3 within regional flood-frequency practice. This regional evidence is consistent with our results, where the positively skewed Kutinska River series (Cs ≈ 1.03) is best represented by the Pearson Type III distribution.

The K–S test yielded a maximum deviation of D = *0.090* with a *p-value* of *0.949*. Since the p-value exceeds all applied significance levels, the null hypothesis cannot be rejected at α = 0.01, 0.05, and 0.10, indicating excellent agreement between the empirical and theoretical cumulative distribution functions. This result supports that the P3 distribution adequately represents the statistical behavior of maximum annual discharges in the Kutinska River basin.

The χ^2 test further supports these findings at the 1% and 5% significance levels, as the calculated χ^2 value (15.89) is lower than the corresponding critical values for nine degrees of freedom. At the 10% significance level, the null hypothesis is rejected, which can be attributed to the sensitivity of the χ^2 test to class definition and small expected frequencies in individual intervals. Such behavior is well documented in hydrological frequency analyses and does not undermine the overall suitability of the selected distribution.

Table 3. Design discharge estimates (Xp) derived from the Pearson Type 3 distribution for selected return periods (T) and annual exceedance probabilities (P) at the "Radikine Bare" gauging station (1991–2020)

T (years)	P(%)	Kp	$X_p=X_{sr.}+K_p(T)*S$
1000	0.1	5.37	101.95
200	0.5	3.99	80.70
100	1	3.38	71.31
50	2	2.78	62.07
25	4	2.04	50.67
20	5	1.96	49.44
10	10	1.32	39.58
5	20	0.75	30.80
2	50	0.67	29.57
1.25	80	-0.81	6.78
1.11	90	-0.99	4.01
1.01	99	-1.19	0.93

Using the P3 distribution, design discharges for selected return periods were estimated (Table 3). The results indicate a pronounced decrease in discharge values with increasing annual exceedance probability. Extreme events associated with long return periods are characterized by the highest estimated discharges, with a value of 101.95 m^3/s for the 1000-year return period, whereas more frequent events show substantially lower magnitudes. For return periods of 100 and 50 years, the estimated discharges are 71.31 m3/s and 62.07 m^3/s, respectively, reflecting the pronounced variability of high-flow conditions. Discharges corresponding to short return periods (≤10 years) are considerably smaller, indicating a rapid reduction in flow magnitude with increasing event frequency. The fitted P3 frequency curve is shown in Figure 2.

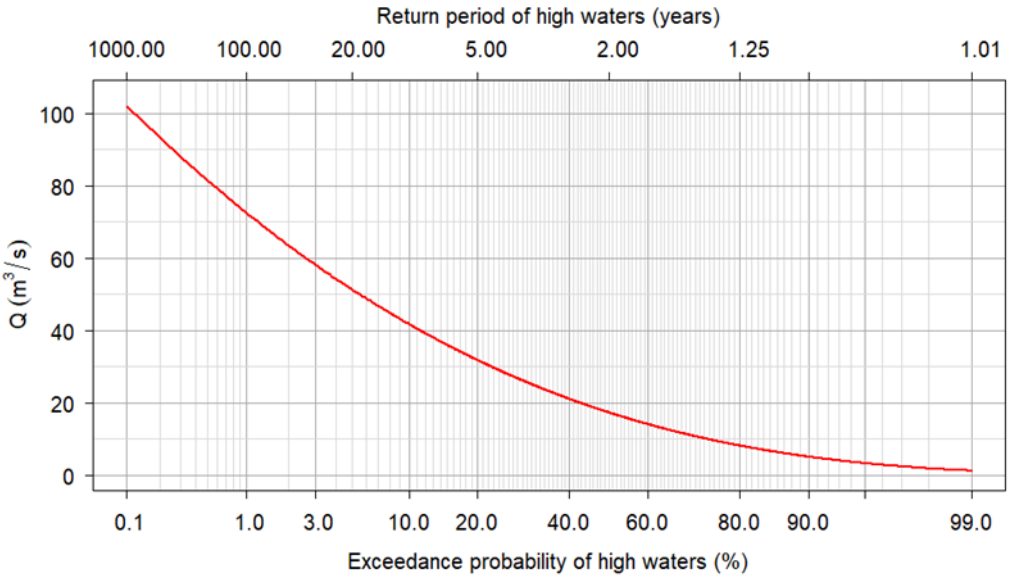


Figure 2. Pearson Type 3 frequency curve of annual maximum discharges at the "Radikine Bare" gauging station (1991–2020)

Overall, the results demonstrate that the P3 distribution provides a statistically robust and physically meaningful basis for the analysis of high-water regimes in the Kutinska River basin. The obtained design discharges represent a reliable foundation for hydrological interpretation and can serve as a supporting framework for water-resources management and basin-scale planning studies.

CONCLUSION

This study examined annual peak discharges at the "Radikine Bare" gauging station on the Kutinska River (1991–2020) to describe the high-water regime and provide design-relevant estimates. The record shows a clear "few large events dominate" pattern: most annual maxima are moderate, while only a small number of years produce very high peaks. This highlights the importance of representing the upper tail properly when estimating rare high-water events.

The analysis produced a coherent set of design estimates across the considered range of return periods, together with a fitted frequency curve that can be used directly in practice. Beyond individual numbers, the results offer a consistent way to compare event magnitudes at different exceedance probabilities and to communicate the expected scale of high-water events in the Kutinska River Basin.

Design discharges derived from the P3 model increase systematically with return period, which is consistent with the expected behavior of extreme hydrological events. The resulting estimates, together with the fitted frequency curve, provide a consistent quantitative basis for high-water hazard assessment and for supporting water-resources management and basin-scale spatial planning in the Kutinska River Basin.

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