ANALYSIS OF THE CURRENT STATE OF SHELTERBELTS BY THE REMOTE SENSING DATA: RUSSIA, BELGOROD OBLAST

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ABSTRACT

Visual decoding of SPOT satellite images from the 1980s and images from the ArcGIS World Imaging platform (2017) has allowed define decreasing of the density of shelterbelts in the Belgorod oblast by 11% over 35 years. The areas of disturbed and abandoned tree stands that occupy about 16% of the existing shelterbelts length were marked. The reasons for the reduction of shelterbelts are their aging, lack of systematic care, destruction due to increasing the area of settlements. The opposite relationship between the length of disturbed and abandoned shelterbelts and the values of the hydrothermal coefficient (HTC) was revealed: in more arid climatic conditions of the Belgorod oblast (at the HTC lowering), the viability of shelterbelts decreases. On the southern slopes with steepness of more than 4°, the reduction in the length of shelterbelts at the decrease in the HTC occurs faster than on the slopes of other exposures. In the XX century, 10.3 thousand km of protective shelterbelts were created on the slopes of arable lands over 2° (46% of the cultivated area), about 50% of them are deviated from the contour lines direction by more than 30°, which leads to soil erosion and the formation of scours, and then - ravines. Only 8.7% of contour (properly located) shelterbelts of the total length of protective shelterbelts on arable lands were revealed. According to additional calculations, for 35% of properly located protective shelterbelts, but without taking into account other important factors of their placement on the slopes, the potential soil loss exceeds the permissible values by the average of 41%, accelerating the development of soil erosion. In order to protect the soil from erosion, new projects for creating shelterbelts must be developed and implemented, taking into account calculations of potential soil loss and relief features.

Keywords: shelterbelts, spatial-temporal dynamics of shelterbelts, inventory of shelterbelts, space images of high spatial resolution

INTRODUCTION

Long-term agricultural use of lands leads to various kinds of disturbances in the landscape system. To eliminate them and maintain high productivity of lands, adaptive landscape farming systems have been developed, in which agroforestry is one of the key events. The positive ecological role of shelterbelts is observed in the wide list of publications [1-7 et. al.].

Mass construction of shelterbelts in Russia began in the late 1940s – early 1950s, the works continued until the 1980s, and then the volumes decreased sharply, which was largely facilitated by the change of statehood and the absence of owners of these territories [8]. For today, the stand of shelterbelts is thinned out, and in some cases is completely eliminated [9, 10].

In view of the important role of shelterbelts in agricultural landscapes, the aim of this study is to analyze the spatial-temporal dynamics and the ecological state of shelterbelts in the old-developed agricultural region of Russia - the Belgorod oblast.

Such studies are required the providing by different-time cartographic material. Despite the considerable volume of sources on the use of satellite images in forestry, there is a shortage of studies analyzing the state of shelterbelts for regions.

MATERIALS AND METHODS

The study was conducted for the territory of the Belgorod oblast with the area of 27.1 thousand km^2, the main part of which is located in the forest-steppe zone, and the South-Eastern part - in the steppe zone.

The study area corresponds to the south of the Central Russian Upland and it is an undulating plain, rising in the north and having weakly expressed slopes to the west – southwest and east – southeast. More than 63.7% of the territory belongs to erosionally dangerous slopes with steepness of more than 2°, 46 % of which belong to arable lands (6.94 thousand km^2) [11].

Since the Belgorod oblast is located in the Central Chernozem Region of Russia – in the area with favorable conditions for the development of agricultural production – the largest share in the land structure accounts for agricultural lands, the area of which is more than 70% of the total area. Forests are occupied 2,419 km^2 (8.9%), and forest stands that are not part of the State forest fund, covered by 905 km^2 (3.3%), which is insufficient for the territory of forest – steppe. According to the authors [12] for forest-steppe environmental conditions, the total woodiness should be from 13 to 25%.

A number of authors [13] point out the complexity or even impossibility of using remote sensing methods for shelterbelts decrypting due to their small width. Modern images of high and ultra-high spatial resolution can compete with aerial images in terms of object detail [14, 15] and in this case, visual interpretation allows carrying out more precise inventory and monitoring of forest stands [16].

In this study, the tools of the ArcGIS 10.2.2 software package were used. As cartographic materials the maps of land use scale of 1:10 000, at that 32% of them refers to the updating 1980-1981 (north-western part of the region) were applied. The remaining part is characterized by the state for 1955-1956. Retrospective analysis of satellite images (SPOT 1980s. etc.) also showed the lack of full coverage by them of the study area (covered 42%). Therefore, the extrapolation of data for the 1950s and 1980s by reference key sites, evenly situated in the Belgorod oblast with the total area of 4410 km^2 was conducted.

To study the current state of shelterbelts (2017), satellite images were used (the World Imagery Base Map with a spatial resolution of 0.6 m / pixels) in the ArcGIS package. These materials cover the entire territory of the Belgorod oblast. All spatial data was combined by using the WGS 1984 UTM Zone 37N projection coordinate system.

To create skeleton maps of the spatial-temporal dynamics of shelterbelts, on the first step the vectorization of shelterbelts on the land use maps S 1:10000 and their subdivision into antierosion (on slopes), field protective and roadside variants was carried out.

At the second step, these data were updated from satellite images by visual decoding. According to created maps, it was revealed that new shelterbelts were planted during the periods between surveys, some shelterbelts were completely disappeared from the turnover (Fig. 1A), and some of them have the broken, fragmented tree stand (Fig. 1B).

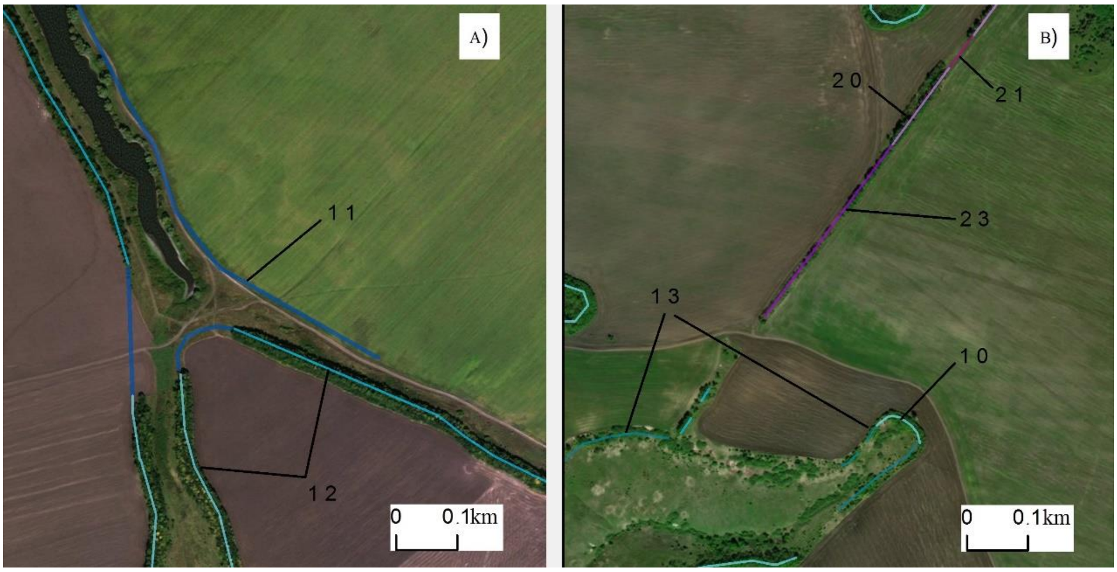

Figure 1. Updating maps of shelterbelts (fragment): A) 11 – antierosion disappeared shelterbelt; 12 – antierosion new shelterbelt; B) 10 – extant antierosion shelterbelt; 13 – disturbed antierosion shelterbelt; 20 – field protective shelterbelt; 21 – disappeared field protective shelterbelt; 23 – disturbed field protective shelterbelt (fragmented forest stand)

The corresponding indexes were assigned to all plots, herewith the shelterbelts selected along the maps were undergone by special processing to assign the attribute information to the disappeared or disturbed parts of shelterbelts (see Fig. 1).

To build the map of the density of shelterbelts the «lines density» tool with the search radius of 2.5 km was used. Digital terrain model and constructed morphometric maps based on this model were calculated on the basis of the topographic map S 1:100000 digitized by us earlier [11]. The tools «zonal statistics», «spatial statistics», «analysis», etc. were used for the aggregate analysis of thematic rasters and shelterbelts dynamics.

RESULTS AND DISCUSSION

Currently, shelterbelts are evenly distributed throughout the Belgorod oblast (Fig. 2). Areas with the shelterbelts density of less than 0.5 km/km^2 are more often confined to areas that are occupied by forests or settlements.

The average density of shelterbelts is 1.1 km / km^2. For reference areas that have different times map materials, we defined the length of shelterbelts and their density in different periods (table 1).

As can be seen from table 1, the density of antierosion shelterbelts was increased by 4.5 times in the study area since 1955 to 1980, and the density of roadside shelterbelts was increased by 2 times. After the dissolution of the USSR, works on afforestation were stopped and only in the last decade they have resumed. In this regard, at the present stage, there is a decrease in the density of shelterbelts in comparison with the 1980s (table 1).

Extrapolation of the established changes to the entire territory of the Belgorod oblast gave quite satisfactory results (table. 2). About this in particular the close values of the extrapolated percentage composition of all studied categories of shelterbelts for 2017, and the actual data obtained by analyzing modern satellite information are testified (table 2).

The results of extrapolation over the entire territory of the study area show that the total length of shelterbelts from 1955 to 2017 could increase from 13.3 to 29.6 thousand km (table 2), however, in 1980, the length of shelterbelts could be higher than the current one by 12%. Thus, the maximum density of shelterbelts was observed in the 1980s. The old-growth shelterbelts increasingly were affected to degradation - this was revealed for key areas with land use maps of the 1950s. Another important reason for the elimination is the reduction of shelterbelts with the increase the area of settlements.

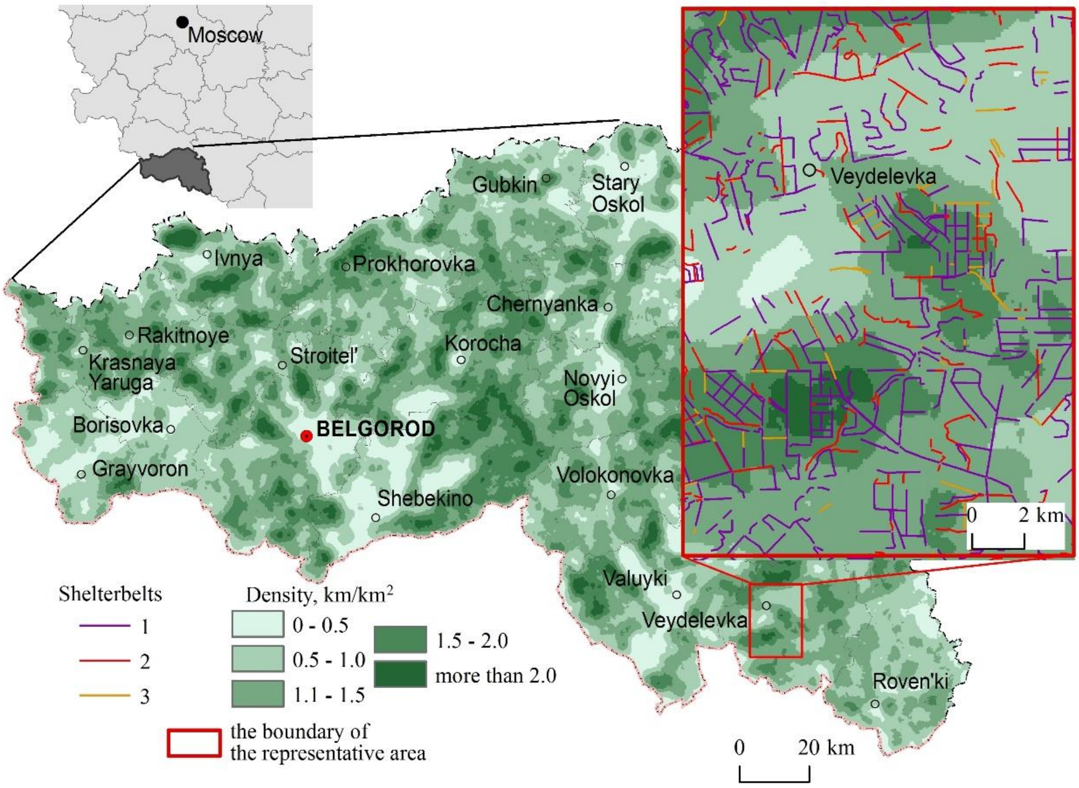

Figure 2. Shelterbelts in 2017 (1 – existing, 2- disappeared, 3- disturbed)

Table 1. Density of shelterbelts on reference key areas of the Belgorod oblast on different times map materials, km/km^2

Type of shelterbelts	1955	1980	2017	Difference 1980 – 1955	Difference 2017 – 1980
Antierosion	0.13	0.59	0.54	0.46	-0.05
Field protective	0.23	0.47	0.45	0.24	-0.02
Roadside	0.13	0.16	0.15	0.03	-0.01
Total	0.49	1.22	1.14	0.73	-0.08

Table 2. Length of shelterbelts in the Belgorod oblast in different periods

Type of shelterbelts	Length in different periods, extrapolated on the basis of correspondences according to table 1			Length in 2017 according to satellite images, km / % from the entire length
	1955, km	1980, km	2017, km / % from the entire length	
Antierosion	3527	16009	14652 / 47	14467 / 49
Field protective	6241	12753	12210 / 39	10276 / 35
Roadside	3527	4341	4070 / 13	4816 / 16
Total	13296	33103	30933 / 100	29559 / 100

It should be noted that 3.7% of shelterbelts planted in the XX century, at the beginning of the XXI century, were disturbed to some extent, another 10.7% were completely disappeared, of which 44% are field protective shelterbelts and 38% are antierosion ones (Fig. 3).

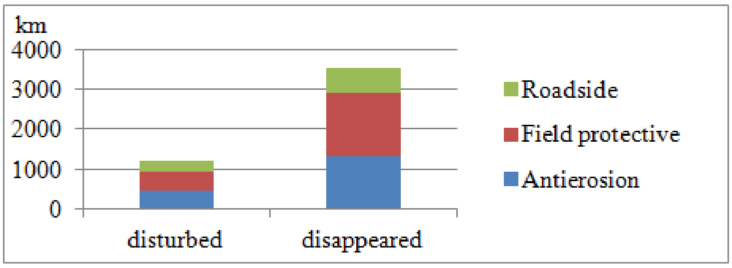

Figure 3. Disappeared and disturbed shelterbelts at the present period, identified by the analysis of different times materials

On average, in the territory of the Belgorod oblast, 0.96 km per 1000 km of total shelterbelts length planted before 1955 are eliminated from turnover annually. The mean annual rate of loss for younger shelterbelts that appeared in the period 1950-1980 is 0.23 km / 1000 km. The loss of shelterbelts integrity and the formation of their fragmentation, according to our calculations, occur at the rate of 0.13 km / year per 1000 km of shelterbelts. On average, the degradated shelterbelts in the study area were oriented mainly from west to east, which may be related to the general direction of the slopes of the region.

The combined analysis of the slope steepness map and the map of shelterbelts shows that antierosion shelterbelts are more often disturbed or disappeared on slopes with a steepness of 4.7°, and field protective ones - on slopes with a steepness of 2.2°. The influence of slope exposure on the integrity violation of the shelterbelts was not revealed. But during the visual analysis of the skeleton maps it was noted that on the declivous slopes of the southern exposure the more expressive sparseness (fragmentation) of shelterbelts is more often occurred.

According to the combined analysis of modern satellite information and the slope steepness map, the antierosion shelterbelts are located on average on slopes with a steepness of 5.1±2.9°, field protective – 2.3±1.7°, roadside - 1.6±1.5°.

47% (4783 km) of field protective shelterbelts belong to slope lands (more than 2°). They require the contour placement across slopes, when orienting the shelterbelts along horizontals (the contour lines). However, about half of them deviate from the horizontals by more than 30°, which creates prerequisites for erosion processes development. In a number of cases on satellite images, the soil scours near not true located shelterbelts were found (Fig. 4).

As seen in Fig. 4A, in the central part of the shelterbelt, as the result of the runoff concentration, strengthening soil erosion formed a clearly visible scour, which is transformed into gully lower down the slope. In the other case (see Fig. 4B) was formed not a single scour, but a system of micro-stream network of scours.

The potential soil loss for the shelterbelts that were correctly designed on slopes relative to contour lines (parallel to them) was calculated. It was found that in 35% of cases, soil loss even on them exceeds the permissible values by the average of 41% (from 6 to 70%). This indicates the insufficiency of shelterbelts, too large distances between them, and the incorrect location of the first shelterbelt in the upper part of the slope.

Separate study on revealing of shelterbelts dynamics in different climatic conditions by using of the Selyaninov hydrothermal coefficient (HTC) has been executed.
When the values of the HTC decrease, i.e. in the more arid climate of the studied region, the length of field protective shelterbelts is reduced most of all (Fig. 5). Thus, the number of disappeared and disturbed shelterbelts increases from the north and north-west to the south and south-east in accordance with the decrease in the values of the HTC.

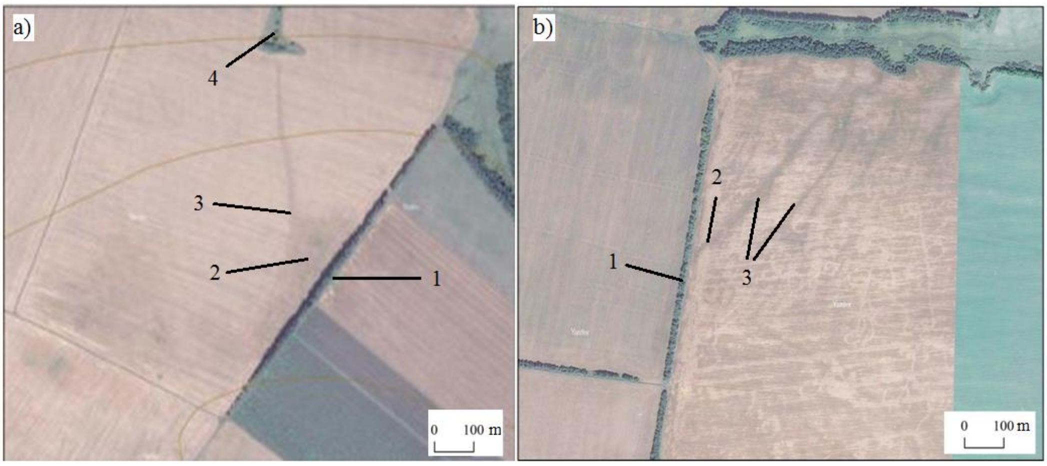

Figure 4. Adverse effect of not properly located shelterbelts: a) 1- shelterbelt with a deviation from the contour lines on 40°, 2-soil erosion zone, 3 - formation of scour; 4 - gully; b) 1- shelterbelt with a deviation from the horizontal on 80°, 2-soil erosion zone, 3 - formation of scours (explanation in the text)

The separate stage of the conducted study was to identify correlations between the observed degradation of shelterbelts and climatic features in the reference areas. As a result, for the 1955-2017 it was found that the change in the density of disappeared and disturbed shelterbelts is inversely proportional (r = -0.60) to the average value of the HTC (Fig. 5).

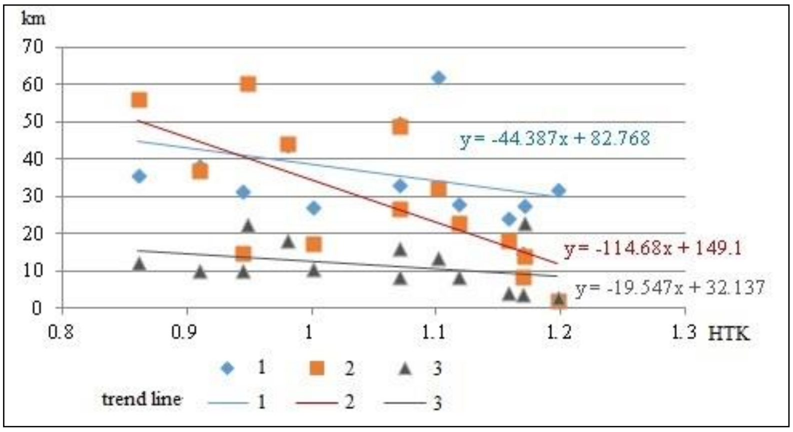

Figure 5. Dependence of the shelterbelts length decrease in time (km) from the values of the HTC for key reference areas (1 - antierosion, 2 – field protective, 3-roadside)

CONCLUSION

As the result of the implementation of state programs, the length of shelterbelts in the Belgorod oblast has been increased from the middle of the XX century to the present time by more than 2 times, but 2525 km of shelterbelts that existed in the last century have been eliminated from the turnover, and another 1470 km have the partially broken (fragmented) forest stand. According to our calculations, about a quarter of straight shelterbelts on arable lands should be replaced with contour (along the relief horizontals) ones. Shelterbelts degradation is more revealed in the more arid parts of the Belgorod oblast, especially on the southern declivous slopes, which requires careful selection of the shelterbelts species composition and a general science-based adjustment of measures to optimization the shelterbelts fund.

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