GIS Based Analysis of Forest Cover Change in Belgorod Oblast, Russia: 1780s-2010s

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Abstract
The authors studied spatial-temporal peculiarities of river network and forest cover in the territory of the Belgorod oblast in the periods 1780-90, 1870-90, 1980-90 years. The selection of each object studied on the old maps and the subsequent calculation of its contours and areas using GIS technology allows you to accurately reconstruct its quantitative and qualitative characteristics, as well as display them on the map for further analysis. One of the important advantages of the obtained maps is the reliability of the mapping of many geographical phenomena, including the quantitative assessment of spatiotemporal changes in the forest cover within the South of Central Russia for the 200-year period (from the late 18th to the late 20th centuries.). Additional studies with use of cosmic images of 1970 and 2014 made it possible to reveal spatiotemporal changes in the forest areas and squares during modern period.

1. Introduction

In the conditions of fragmentation and insufficiency of written sources about the various components of geosystems of the past, the most complete information can be obtained during the study of multi – temporal maps and, in particular, maps of the periods of the General (late XVIII century) and Special (mid-late XIX century) surveys of the European part of the Russian Empire. The most important advantage of these maps is the accuracy of the display of many geographical phenomena, including the appearance of natural areas was weakly changed by anthropogenic impacts. The growth of anthropogenic transformation of the natural environment is one of the priority tasks, which makes necessary to determine the quantitative and qualitative indicators of natural components in the initial periods of economic development of territories characterized by weak human impacts on landscapes. At present, modern satellite information is one of the most effective sources of data for solving a number of tasks of monitoring the state of components of the biosphere, including forests (Shepashenko et al, 2015, Potapov et al., 2015 and Schmidt et al., 2015). By fixing the state of the earth's surface during specific time sections, satellite data are the most valuable source, allowing studying the spatial-temporal changes in the characteristics of the environment. In particular, the joint use of archival and modern images of high spatial resolution gives the opportunity to quantify the dynamics of forest vegetation areas for many decades (Chendev et al., 2016). The aim of the study is the historical and cartographic analysis of the changes of the areas and ranges of forests in the late XVIII-early XXI centuries, as well as the evaluation of current trends in forest cover in the Belgorod oblast. To solve this problem, the set of methods of geoinformation mapping, as well as quantitative evaluation of multi-temporal satellite information was applied.

2. Objects and Methods

The study area is located in the south of the Central Russian Upland (the center of Eastern Europe) and administratively corresponds to the Belgorod oblast of Russia. In natural aspect, most of the Belgorod oblast is located in the transition zone between forests and steppes - the so-called forest-steppe zone. Skeleton map of the Belgorod oblast with the reconstructed forest areas of the pre-cultural period (XVII century) is shown in Figure 1. Disappearing forests of the Earth is one of the components of close attention of geographers and ecologists. The actual issues are the calculations of the rate of degradation of forest vegetation, as well as the study of modern trends and tendencies of forest cover change. These issues are especially important for the old-developed regions, one of which is the Belgorod oblast. The perspectivity of using the historical and cartographic method is reflected in the works of several authors (Berlyant, 1986, Gedymin and Haritonychev, 1964, Postnikov, 1989 and Chendev, 2005).

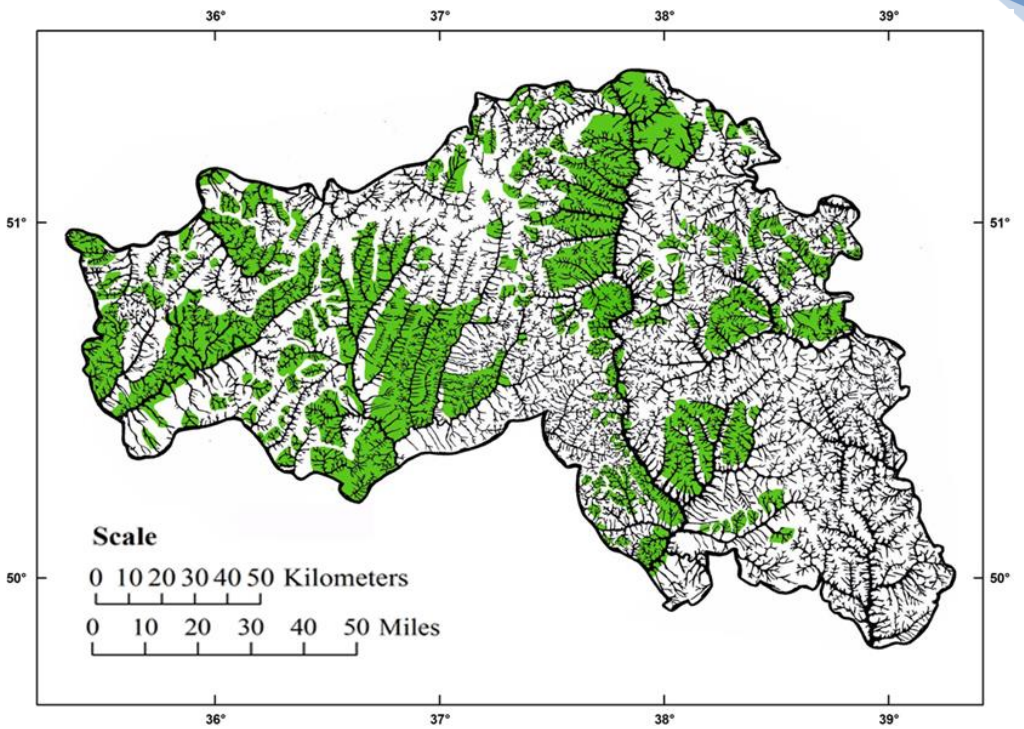

Figure 1: The study area of Belgorod oblast with areas of native forests in the preindustrial period (17th century). (Military Topographic Department, 1868)

In the study the following reliable materials and sources of historical and cartographic research were used.

1. Maps of the districts of the vicegerencies of the period of General land surveying (1780-1790, scale 1:84000), the source of use – the Russian State Archive of Ancient Acts (Moscow). They were made on the basis of decrees and principles of the General Land Surveying of the Russian Empire of the end of XVIII century (RSAAA. (Russian State Archive of ancient acts, 1780, 1783, 1785).

2. Maps of the Special land survey period - topographical survey map (1860-1890., scale 1:126000), the source of use - national library of Russia (Saint-Petersburg) and Russian state library in Moscow (Military topographic department, 1868-1896).

3. Modern (on the state of 1996) topographic map of scale 1:200000 (Topographic map «Belgorod oblast», 1996).

The above-mentioned characteristics of multi-time maps of large scale allow carrying out the qualitative topographic control with using geographic information systems (GIS).GIS technologies allow to reconstruct accurately the quantitative and qualitative characteristics of environmental components, as well as to display them on a map for further analysis (Bugayevskiy, 1998, Tikunov, 2005, Zhurkin and Shajtura, 2009). The stages of working with maps included primary processing, identification, display, qualitative and quantitative calculation of the studied components and, finally, mapping of the results.

During the primary processing of the maps, the material was copied and processed by photo correction programs (using graphic editors), which included the processes of (vectorization), gluing, correction (tuning) of contrast, brightness and sharpness of scanned copies of maps, which allowed to reveal in more detail the objects and contours of the studied components. The further process of research and processing of the images required the use of such geographic information products as ArcGIS, BelGIS, etc. At the initial stage, location survey, scaling, correction of distortions and inaccuracies revealed in the cartographic material were carried out. An important component of this work was the survey of the contours of objects to the modern topographic base. Further, the study area was divided into parts, each of which was subjected to identical processing techniques. GIS-technologies for each part of the future map allowed distinguishing the specific symbol (tone, color, or others) object of study, namely, the forest. On the basis of the obtained images, the gluing of map

fragments was made and the area occupied by forests in each study period was calculated. The results of the historical and cartographic work are shown in Figure 2.

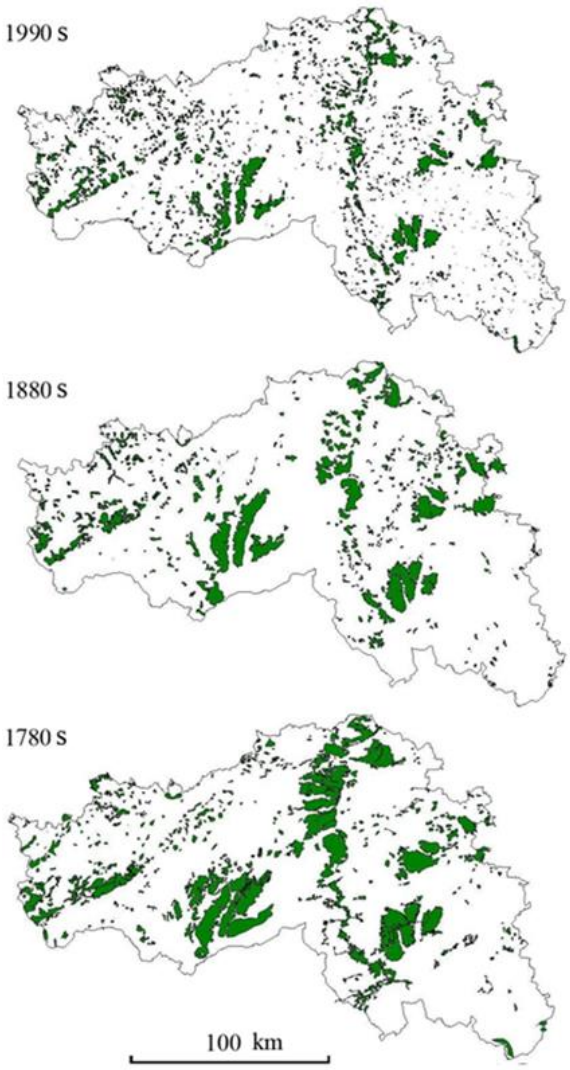

Figure 2: Forests of the Belgorod oblast in different historical periods

In connection with the improvement of quality and availability of space survey materials, it is now possible to simulate spatial - temporal changes in forest cover (Baumann et al., 2012 and Zhang et al., 2014), to analyze the disturbance of the natural structure of the forest (Zhang et al., 2014 and Zhirin et al., 2011). For the detailed retrospective assessment of forest cover, the use of archival space imagery CORONA with spatial resolution of 1-4 m/pixel (1960s-1970s) is of particular interest. The high detail of these satellite data and the parallel use of modern images of similar spatial resolution, as well as multi-temporal polyzonal satellite information offer the possibility of an objective assessment of the spatial - temporal changes in forest-covered lands. At the same time it becomes possible to study the reaction of forests to climate change observed in the modern period on the territory of the southern forest-steppe. Therefore, along with the study of forest cover change over a 200-year period, the study of modern trends in ranges and forest areas was carried out on the basis of the use of multi-temporal satellite images in the period 1970-2014.

Space images selected for the initial date analyzed were created by the CORONA system (https://lta.cr.usgs.gov/declass_1) in the summer of 1970. Satellite images of the modern period were obtained from the resource ArcGISWorldImagery (https://www.arcgis.com/home/webscene/viewer.html) and included mosaics of 2 m/pixel resolution images for the 2014 summer period. Thus, the time interval of the study was 45 years. For all used satellite data the topographic control and geometrically correction were conducted. It was done in the programs ERDAS IMAGINE and ArcGIS. The implementation of this procedure let it possible to accurately combine the different time images with each other, which was the key condition for the analysis of the displacement of the boundaries of forest areas.

Five areas were selected to assess forest cover changes within the region (Figure 3), four of which were in the forest - steppe zone and one-in the northern part of the steppe zone. Specific climatic conditions were corresponding to each key plot, as an indicator of which the hydrothermal coefficient or SCC was taken, the average annual values of which in the Belgorod oblast for the period from 1970 to 2014 varied from 1 to 1.25 (Figure 3). Hydrothermal coefficient (HTC) is an integral climatic index, reflecting conditions of temperatures and precipitation during vegetation period (for Belgorod oblast this period is from May till September). It was suggested in climatology by Selyaninov (Selyaninov, 1928). The HTC formula is next: $HTC = 10R/\Sigma t$, where R – precipitation in millimeters for the period with temperatures above 10 °C, Σt – the sum of temperatures in degrees Celsius for the same period.
Within each of the 5 selected key areas (Figure 3) in the geoinformation environ of ArcGIS, the detailed mapping of forest-covered lands for the analyzed dates was carried out. As the result the vector layers describing the territorial characteristics of forested lands in 1970 and 2014 were prepared. Such detailed accounting of small woodlands was important for reliable estimate of changes in forest cover in the region due to the high patchiness and fragmentation of forest plantations. The example of vector layers prepared for analysis for two compared periods is shown in Figure 4.

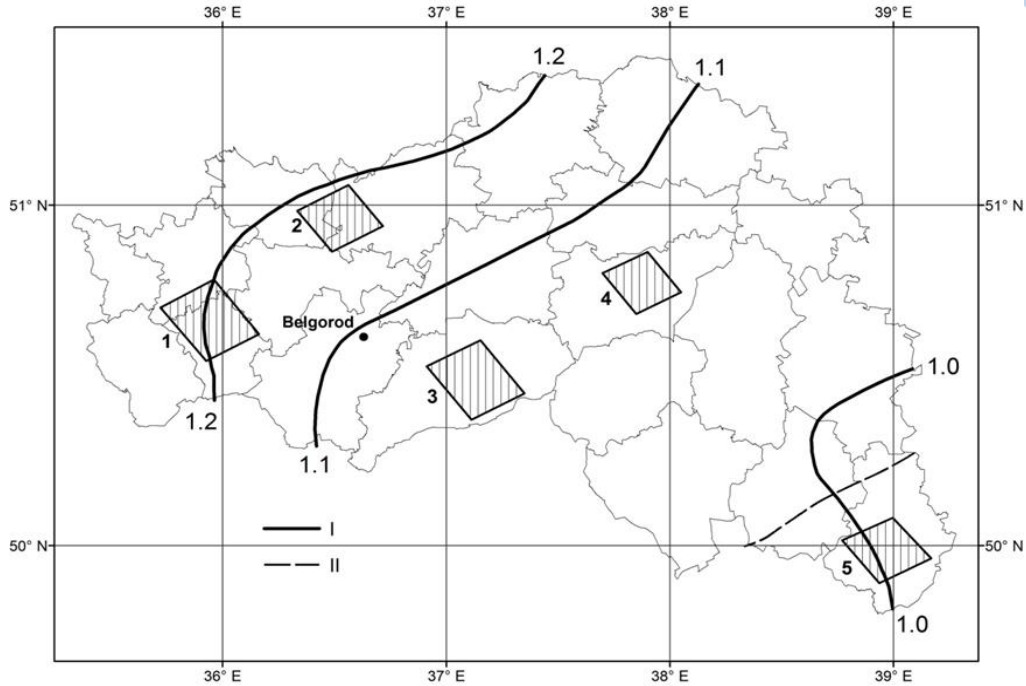

Figure 3: Location of study areas in the Belgorod oblast. Areas of research: 1 – Borisovskiy, 2 – Prokhorovskiy, 3 – Shebekinskiy, 4 – Novooskolskiy, 5 – Rovenskiy. Additional symbols: I –HTC (May-September) isolines for period 1970-2014, II – border of forest-steppe and steppe zones

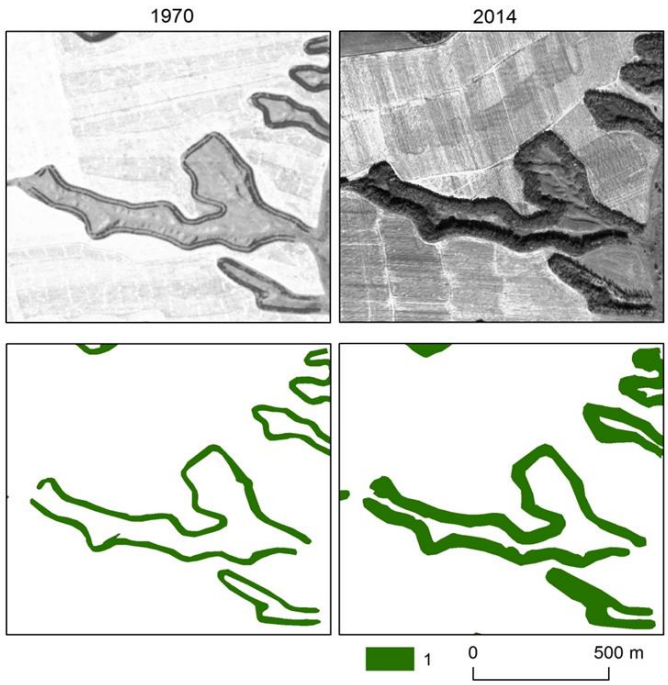

Figure 4: The example of changes in forest covers in the south of the Central Russian Upland in the period 1970-2014

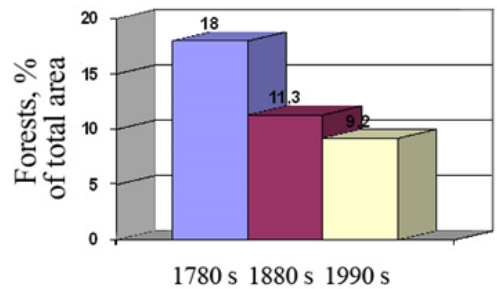

Figure 5: Forest area of the Belgorod oblast in different periods

Table 1: Forest cover of the Belgorod oblast and its parts in different historical periods

Region, natural zone	Forest cover, % of the total area of the Belgorod oblast			Change in forest cover, % of the total area of the Belgorod oblast		
	1780-s	1870-s	1990-s	2-1	3-2	3-1
	1	2	3			
Belgorod oblast	18	11.3	9.2	- 6.7	- 2.1	- 8.8
Forest-steppe zone	17.66	11.04	8.92	- 6.62	- 2.12	- 8.74
Steppe zone	0.34	0.26	0.28	- 0.08	+ 0.02	- 0.06

Table 2: Characteristics of changes in wooded lands, estimated at key sites in the period 1970-2014*

Site	HTC (May-September, average for 1970-2014)	Forest area, ha		Average forest area, ha		Forest cover, % of total area	
		1970	2014	1970	2014	1970	2014
1	1.20	9103.1	12099.9	13.5	8.4	21	29
2	1.17	2855.3	4594.8	12.5	8.8	9	15
3	1.08	8943.2	10824.3	18.2	14.7	22	26
4	1.07	5829.1	7171.8	14.7	11.4	22	27
5	0.99	939.6	1907.1	2.8	2.9	3	6
Total		27670.2	36598.0	13.0	9.2	16	21

On the basis of the obtained data, the analytical sample was formed, which allowed to conduct the quantitative analysis the changes in the area of forest lands that occurred during the analyzed time interval. Growth of forest cover occurred not only in natural forests, but also in artificial afforestations. It is evidenced by the changes in the area of woody vegetation in the area of anti-erosion shelterbelts on the slopes of the gullies (Figure 4). The identified increase in forest cover in areas with natural forests and in the zones of artificial shelterbelts is of fundamental and applied scientific importance. Among the fundamental tasks of further research the task of studying the transformation of soils and indicators of their fertility in areas occupied by forests at different times can be set.

At the final stage, the results were compared with the trends in the dynamics of climatic parameters observed in the southern forest-steppe during the study period.

3. Results and Discussion

The general pattern of changes in forest vegetation in time was the reduction of their areas, which is clearly demonstrated by the maps in Figure 2 and Figure 5, as well as the results of calculations of forest area changes in natural areas within the study area (Table 1).

Based on the analysis of Figure 2, for the 200-year period, the largest areas of forest on the right bank of the river Oskol, watersheds of the Seversky Donets basin, the Vorskla basin (center and west of the Belgorod oblast) were exposed by the maximum reduction. South-eastern (steppe) part of the Belgorod oblast did not have large forest areas even in the late eighteenth century, Revealed there small forest areas are localized mainly in the lowlands, gullies and ravines, they practically had no significant areal change. Not only the areas, but also the configurations of forest massifs have been changed cardinally. Large areas of ravine forests and upland oak woods (in the XVIII century with the area of 20 180 km^2) by the end of the XX century are fragmented on the mosaic of small forest areas. The maximum thinning of forest vegetation was observed on the elevated flat watershed areas (plakors). The scattered sites of the wood remained to greater extent on slope sites, in the ravine-beam network, in some places of river valleys and most often - in so-called agricultural inconveniences. According to the conducted calculations, the area of forests on the territory of Belgorod oblast in the late eighteenth century amounted to 18%, of which the area of forest had – 17.66%, and steppe zone – 0.44%. By the end of the XIX century, the forest area was 11.3%, from them: in the forest - steppe zone-11.04%, and in the steppe zones - 0.26%. At the end of the XX century, the total forest area was 9.2%, from which in the forest-steppe zone - 8.92% and in the steppe zone - 0.28% (Figure 5 and Table 1).

Forests of the forest-steppe zone were subjected by the most degradation, where their reduction during the two-hundred-year observation period was 8.74%, and to the greatest extent (6.62%) it was in the late XIX – early XX centuries. In the steppe zone for the entire study period, the area of forest decline relative to the whole area of the region

amounted to 0.06% and from the late XVIII to late XIX the indicator was more than 0.08%, indicating a slight increase of the forest area from the end of XIX-end XX centuries, which is probably connected with the activities of afforestation in the second half of the XX century on the sands of the South-East (Zus, 1990). Thus, there is the general trend of maximum reduction of forest lands in the forest-steppe zone from the end of XVIII century to the end of XIX century (Table 1). On the basis of space images of ultra-high spatial resolution, forest cover mapping was conducted as of 1970 and 2014 years. Based on the data obtained, it was found that in the whole on the study area for the period 1970-2014 forest cover increased by 31% from the level of 1970 (Table 2), which is the significant amount. The utmost modern forest cover (29%) was observed in the extreme western area, the smallest (6%) is typical for the south-eastern (steppe) area. Based on Table 2 data, we can see that the value of forest cover, as for the initial and so for final analyzed dates in the south-east of the region (north of steppe zone) is significantly different from the forest cover in other test areas (forest-steppe zone). At the same time, the trend of growth of forest cover is clearly observed in each of them. Based on the fact that the growth of forest cover is observed in all analyzed key areas located in different parts of the south of the Central Russian Upland, the positive dynamics of forest cover should not be considered the coincidence of tendencies, but the real process. In other words, the revealed increase in forest cover over the past decades can be considered the regional pattern in the dynamics of the vegetation cover of the studied region.

The increase in forest cover was accompanied by the increase in the degree of mosai city of forest-covered lands. During the analyzed period, the average area of a single forest massif decreased from 13.0 ha to 9.2 ha, this occurred against the background of the growth of the total forest area. In the analyzed key areas, the number of forest areas increased from 2122 in 1970 to 3975 in 2014, or 87 %. At the same time, the least degree of mosaic growth was expressed in the steppe zone, where the average area of a single forest area remained practically unchanged against the background of forest area growth. Thus, on the basis of the results it was found that from 1970 to 2014 in the region there was the increase of forest cover by 5% from the total studied area and by 31% from the value of forest cover at the initial estimated date. In this regard the increase in mosaic distribution of forest stands is observed. The increase of forest cover was typical as for the conditions of the forest-steppe sod for the northern part of the steppe zone.

The climatic relationship with the peculiarities of forest area change in time is found: the maximum increase in forest cover during the two compared periods was observed in the wetter climatic conditions of the study area, i.e. in areas with higher values of the HTC (Figure 6). The increase in forest cover can be explained by the number of reasons. The most important reason is favorable for the growth of forest cover climatic conditions, manifested in the reduction of the duration of the winter period, the increase of its average multiyear temperature and the growth of annual precipitation in the period 1980-2010 (Lebedeva and Krymskaya, 2008).

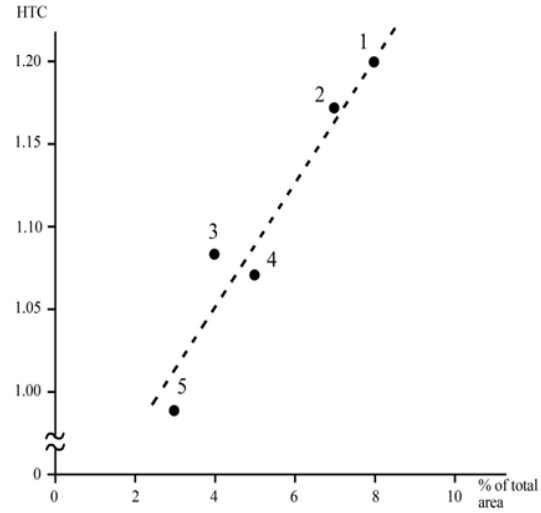

Figure 6: The correlation between the increments of the forest area over the period 1970-2014. (% of the total area of the studied sites) and the value of the HTC (May- September) of the period 1970-2014.The numbering of the sites is similar to Figure 3.

In particular, the increase in air temperature could contribute to the increase in the duration of the period of biological activity. The lower speed of forest formation in the steppe south-east of the Belgorod oblast could be due to the more arid climatic conditions of this territory. The growth of forests could also be facilitated by geomorphological conditions, namely the developed flat-bottom valley network redistributing the flow of atmospheric precipitation, affecting the nature of soil moisture, and through them – on the intensity of forest formation. In addition, in some places, the increase in forest cover could be influenced by anthropogenic factor, which was manifested in the formation of fragmentary shelterbelts formed along the highly developed in the region gully network.

4. Conclusions

As the result of the study, the following important conclusions were obtained.

1. The historical - cartographic analysis of the forest cover change in the Belgorod oblast testifies to the significant anthropogenic transformation of the forest resources of the studied area during the last centuries.

2. Using multi-temporal satellite data for the period from 1970 to 2014 on five key areas of the Belgorod oblast the growth of forest cover, typical for both the forest-steppe zone and the border with the forest-steppe areas of the steppe zone, was determined. The greatest modern forest cover (29%) was observed in the extreme western area, the smallest one (6%) is typical for the south-eastern (steppe) area.

3. Occurring changes in forest cover in the Belgorod oblast are due to the joint influence of changes in climatic conditions (natural factor) and economic activity (anthropogenic factor). Anthropogenic impacts were aimed at reducing the area of forests, and climate changes observed since the second half of the XX century, led to the growth of areas of wooded land.

4. Cartographic materials of the past are reliable sources for historical and geographical research of the state and changes of the natural environment in different historical periods and through the use of geoinformation systems allow:

- to clearly define quantitative and qualitative indicators of environmental components in different periods,
- to identify the time differences between the indicators for each study component,
- to analyze the dynamics of the component composition of the environment,
- to compose maps of the character and intensity of transformation in time of the components of geosystems.

Acknowledgements

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