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SYSTEMATIC STUDY
OF ARID TERRITORIES

Geoinformational Support of Monitoring of Natural Landscape Transformation in the Basin of Lake Baikal on the Basis of Retrospective Cartographic Materials

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Abstract—The results of the retrospective use of maps in the study of nature management and dynamics of the geographical environment in the central part of the Lake Baikal basin in the 20th century are presented. The spatial and temporal parameters of the dynamics of the forest cover and tilling of the territory in the 20th century are defined, the metric assessment of transformation of natural landscapes is completed, and areals of their degradation are identified.

Keywords: retrospective maps, dynamics of the geographical environment, nature management, transformation of landscapes, GIS monitoring.

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INTRODUCTION

The modern period of social development is characterized by the continuous transformation of natural
1 landscapes and increasing anthropogenic pressure on the geographic environment. The increased use of
1 natural resources, expansion of old natural–anthropogenic systems, and creation of new ones in some cases led to a change in the course of natural processes and the appearance of transformed and completely converted landscapes; problem areas and areas of ecological risk have emerged. In the Baikal region, the main problems from negative effects of nature management are caused by the predominance of light-textured soils and semiarid climate conditions, which promotes activation of erosion and a decrease in the biodiversity of intensively used areas.

The indicator of economic activity is the dynamics of geographical objects and processes, which is fixed with cartographic and aerospace materials in the form of changes in the compilation and substantial characteristics of the used territory. Monitoring and investigation of these changes are of great practical importance, since they allow us to determine the level of
1 anthropogenic impact on the environment, detect negative and positive aspects of nature management, and formulate recommendations on optimization for management authorities. The application of GIS technology in studying the dynamics of the geographical environment allows us to automate the usage of multitemporal spatial materials, improves the accuracy 2
and efficiency of investigations, reduces the level of subjectivity, and provides the ability to manipulate significant amounts of geodata. Development of the 3
methodological foundations of geoinformation moni- 4
toring of the dynamics of long-term natural and socioeconomic processes is an important research direction. An urgent task is the creation of a reliable methodological apparatus on the basis of GIS technology that allows us to store large arrays of multitemporal 2
dimensional data, analyze them and obtain new information on changes in natural landscapes, and respond to user requests and promptly provide information in any form.

MATERIALS AND METHODS

Currently, in all spheres of territorial activity a large amount of geographical documents has accumulated, and the most relevant and in-demand are sources that show the spatial parameters of the earth's surface (maps, plans, drawings, satellite images, etc.). The basis of the spatial data is thematic and topographic maps of different years of publication, representing different time models of the physical–geographical and socioeconomic state of the territory and serving as a source of information for the metric evaluation of the dynamics of the geographical environment. Thus, the topographic maps made at different times by the Corps of Military Topographers, the State Department of Geodesy and Cartography, the General Staff of the Soviet Union, and RosCartography are the informational basis for geoinformational monitoring of the dynamics of nature management. They have been created for about two hundred years in common map projections and coordinate systems; they are characterized by the unity of objects and displayed parameters, similarity of accepted classifications, and continuity of principles and methods of generalization. For these reasons, these maps are reliable and legitimate metric documents in the study of long-term dynamics of the geographical environment and quantitative assessment of the transformation of natural landscapes.

In order to keep track of the parameters of economic development of Lake Baikal basin and the negative effects of nature management, a GIS system of natural management monitoring (GISMP) based on the ArcGIS package was developed and implemented at the Baikal Institute of Nature Management, Siberian Branch, Russian Academy of Sciences. GISMP is a software-controlled tool for periodic cartographic registration of objects and processes of nature management, which allows interactive evaluation and prediction of the long-term dynamics of economic use of the territory and changes in the region's environment.

The informational basis for GISMP is a collection
2 of multitemporal databases of cartographic raster and vector data. The first time-cut in GISMP is represented by sheets of a topographic map created by the Corps of Military Topographers in 1896–1914 at a scale of 2 miles to 1 inch (1 : 84000) in the cross-cylinder of a Gauss projection (Postnikov, 1985). To assess the suitability of retrospective maps as monitoring instruments, an analysis of their accuracy and completeness of content was conducted, together with the study of the geographical literature, additional cartographic materials, and statistical sources of the beginning of the 20th century. To determine the accuracy and principles of generalization, a comparative analysis of the retrospective map with a contemporary one similar in purpose was carried out. Based on the analysis, we can conclude that the assessed maps are highly informative sources and show in detail the physical and geographical situation and system of nature management of the territory in the early 20th century. They are an important metric basis for monitoring the evolution of the geographical environment of the Baikal region, since they are the result of the first geodetic survey of the displayed part of Russia. The considerable amount of factful information in these maps allows us to use them in studying long-term natural (desertification, waterlogging, etc.) and socioeconomic (mining, migration, etc.) processes. In addition, they record the state of the earth's surface during the construction and beginning of operation of the Trans-Siberian Railway and are the main material in studies of the impact of the highway on the region's geographical environment. Estimation of the accuracy established that the main problem in using retrospective maps as instruments of monitoring is the distortions of the topographic basis, the minimization of which is carried out by geometric operations of the software.

During the process of automation of retrospective maps, the layer-by-layer vectorization of elements of the content is implemented, as well as the creation of attribute tables of layers that are generated automatically when one exports to the ArcGIS environment (Table 1). This creates geoinformational resources for monitoring nature management, which register physical and geographical parameters of objects of nature management at the beginning of the 20th century and represent a set of vector layers (shp-files) and single-valued attribute tables (dbf-table) placed in the ArcGIS environment. The informational structure of the resource database is developed on the basis of content elements of topographic maps: hydrography; human settlements; road network, vegetation, soil, industrial, agricultural, and social facilities; and relief. Resources have a mathematical basis, classification of content elements, and accuracy analogous to the parameters of contemporary geoimages, and they can be used to implement all of the analytical operations of the software environment. To display the modern temporal cutoff, sheets of topographic maps of scale 1 : 100000 from the 1998 edition were used (Roskartografiya). The combination of multitemporal vector layers of the objects of 2
nature management was performed by operations in the software environment.

DISCUSSION OF THE RESULTS

The researched territory represents the central, most developed part of the basin of Lake Baikal. It is located in the forest–steppe zone, where taiga and steppe vegetation types connect. The relief is partitioned with a prevailing altitude of 600–1000 m above sea level. Sloping landscapes occupy about 60% of the total area (Mikheev, Ryashin, 1977). Chestnut soils dominate, covering large areas of intermountain basins and having the lightest texture. Over 80% of their area is light loam and sandy loam, which are highly susceptible to aeolian deflation with the formation of dust storms in a semiarid climate. Tilled lands are becoming an arena for the development of soil deflation and the spatial basis for the appearance of local areals of degradation of natural landscapes (Subregional Program ..., 2000).

Analysis of the map-reconstruction of the investigated territory prior to the accession of Transbaikalia to Russia allows us to say that the landscapes of the

The technique of automation of retrospective maps for monitoring of nature management

Stages of monitoring	Operations of monitoring
Editorial and preparatory work	Evaluation of cartographic materials, development of the editorial instructions
Formalization of sheets of retrospective maps	Scanning of sheets, creation of raster coverings on the parameters of the original map projection, vectorization of elements of content (EasyTrace)
Creation of retrospective object layers	Export of vector layers into the medium of ArcGIS, gluing of object layers, editing of layers, creation of topology
Geometric correction of retrospective object layers	Projection of the modern topographic basis by the parameters of the original map projection, creating a network of registration points, coordinate transformation of retrospective layers over the network of registration points, assessment of the accuracy of conversion, editing of layers using the "rubber sheet" algorithm, updating the topology of retrospective layers
Filling of attribute tables of retrospective layers	Development of a system of classification and coding of objects of nature management, input of attribute data by layers
Creation of object layers of the dynamics	Combination of retrospective and modern vector layers on the necessary time slices, removing fission-fragment polygons, topology updating, editing of attribute tables
GIS mapping of the dynamics of nature management	Creation of GIS project, mapping of the dynamics of nature management, spatial assessment of dynamics, ranking of the territory by the degree of dynamics
GIS modeling of the dynamics of nature management	Spatial modeling of the dynamics (geometric, projection, scale, network analysis, buffering), substantive modeling of the dynamics (mathematical, semiotic), modeling through requests
Presentation of monitoring results	Inventory maps of dynamics of nature management objects, synthetic maps of relationships of dynamics of nature management objects, analytical maps of zoning and division of the territory in relation to the environmental consequences of dynamics of nature management, forecast maps of development scenarios of nature management, query system of dynamics of nature management, graphical and tabular materials

studied part of the basin were subjected to external influence mainly by grazing livestock, since farming had a low prevalence among the indigenous population. Moreover, it concentrated within local humid areas. The plowing was carried out in holes, where erosion was uncharacteristic. This is evidenced by the arable form of land use near the ancient villages, which continued for centuries. With the entry of Transbaikalian lands into the Russian territory (17th cent.), peasant farmers began to come here. The transformation of natural landscapes began with the selection of sites for cultivation, which later determined the development of settlements and road networks. Arable lands were selected mainly on vacant areas near rivers and streams. Immigrants who settled in the forest—steppe were looking for glades to reduce the need for forest clearing. The first arable lands appeared near the fortified town of Udinskii (Ulan-Ude) at the end of the 17th century. Later, a few scattered centers of plowing appeared up the Selenga River to the city of Selenginsk. The most developed areas were valleys of the Chikoi and Khilok rivers.

Based on the analysis of map-reconstructions of nature management of the researched territory at the end of the 19th century, it can be concluded that the structure of agricultural lands was in many ways determined by the predominant soil type. The most valuable were the arable lands situated on chestnut, chernozem, and gray forest soils. They were usually located in typical steppe and forest—steppe depression holes, which include flanked deluvial—proluvial steppe and plain landscapes. The investigated territory was characterized by a high saturation of natural feeding grounds: hayfields and pastures. Hayfields were located on alluvial and meadow swampy soils. Pastures were represented by steppificated spaces, with much of their area consisting of chernozem, chestnut, and alluvial soils. The highest-quality hayfields and pastures were located in intermountain basins on sloping lands.

In the 20th century, especially the second half, the scale of the impact of nature management on the landscape significantly increased. Agricultural development required extensive spatial resources, resulting in the reduction of forest cover in the valley basins (Fig. 1). In the investigated territory, lands were restructured and the cultivated area increased significantly due to the plowing of light sandy and sandy loam soils. Arid intermountain basins became subject to changes in the natural processes occurring in their biota. Changing of natural processes in the soil layer over large areas, associated with plowing of virgin and fallow lands, led to the extensive development of erosion. Such human impact factors as increasing population density; advancement in technological forms of cultivation; and increasing specific pressure on vegetation due to the growth of livestock, fires, and deforestation increased the negative effects.

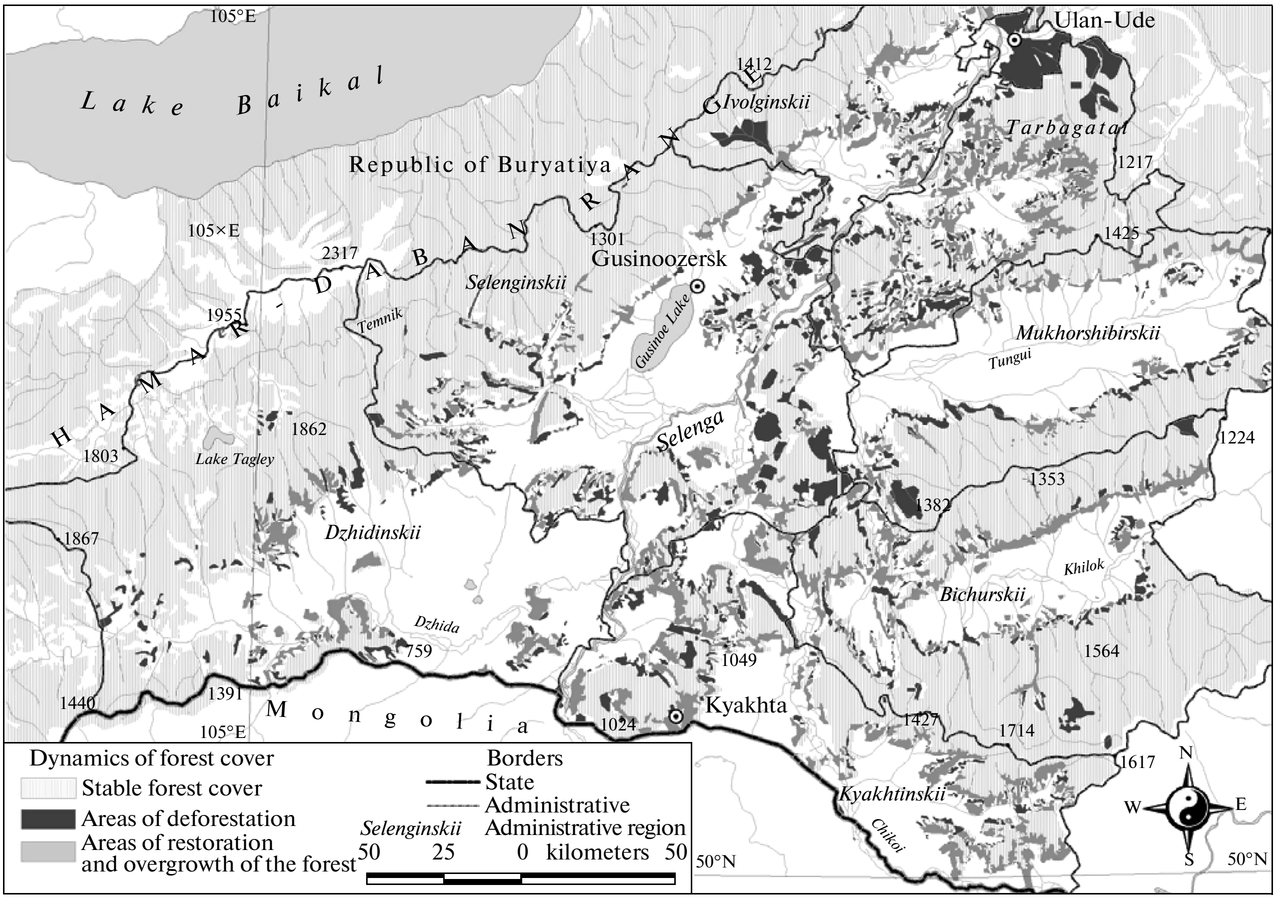


Fig. 1. Dynamics of forest cover in the 20th century.

2 3 GIS analysis of multitemporal geodata shows that the largest areas were plowed during 1958–1972, which led to the transformation of vulnerable flanked, plain, and terraced dry steppe and sandy-loam depression holes (Fig. 2). In general, in the investigated territory the minimum size of areas of arable lands increased over 100 years by 5 times; the average and maximum size increased by 3 and 4 times, respectively. The total cultivated area increased by 2 times, and the total number of areals decreased by 1.5 times, indicating significant fragmentation of arable lands at the beginning of the century and less vulnerability of nat-
2 ural landscapes. The combination of multitemporal layers of plowing with a digital relief model allowed us to reveal different trends in the high-altitude dynamics of arable land, but in general it can be argued that in the investigated territory during the 20th century

(1) low-lying arable lands (600 m) in the landscapes of the bottoms of basins with minimal angles of inclination of the relief and high water table were neglected;

(2) the cultivated area of the most highly plowed high-altitude zone (from 600 to 800 m) on sloping terrain increased insignificantly;

(3) the cultivated area on the high exposed surfaces and in holes with steep relief (above 800 m) increased considerably.

In addition, the dynamics of arable lands according to the relief is accompanied by rapid development of a road network, which leads to intense linear erosion as a result of a mismatch in orientation on landscape terms and at large angles of inclination.

Areas of wind erosion appeared almost simultaneously with the upturning of the virgin lands, but intensification of erosion began after 1980. Currently, such areals are a characteristic feature of arid areas in the bottoms of intermountain hollows on friable deposits that are not protected by natural or artificial means. On most of the investigated territory, on the steppe and dry steppe landscapes, areas displaying erosion processes are especially characteristic of arable land. In an extreme form of degradation, this leads to the appearance of shifting sands, which has an adverse

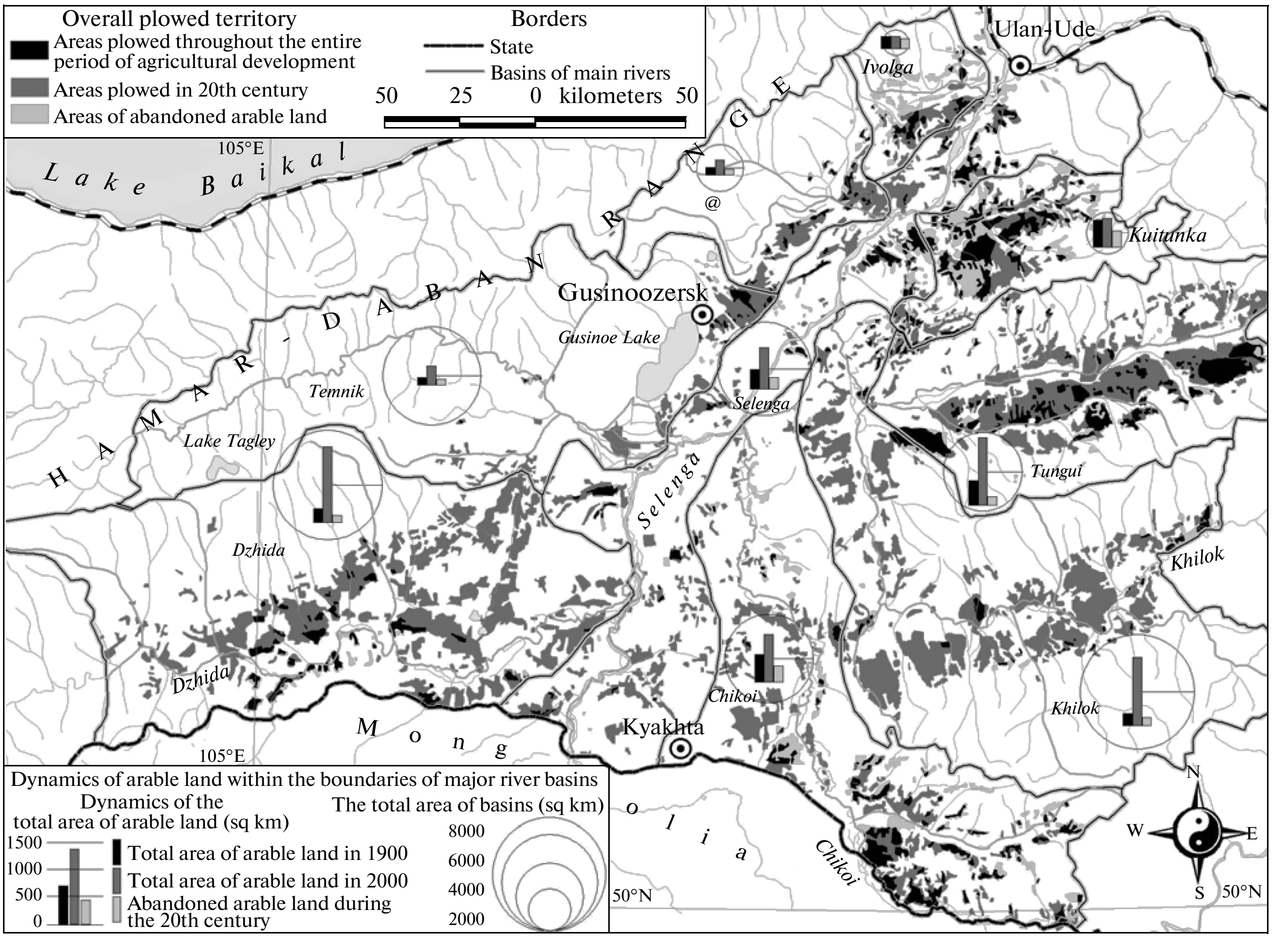
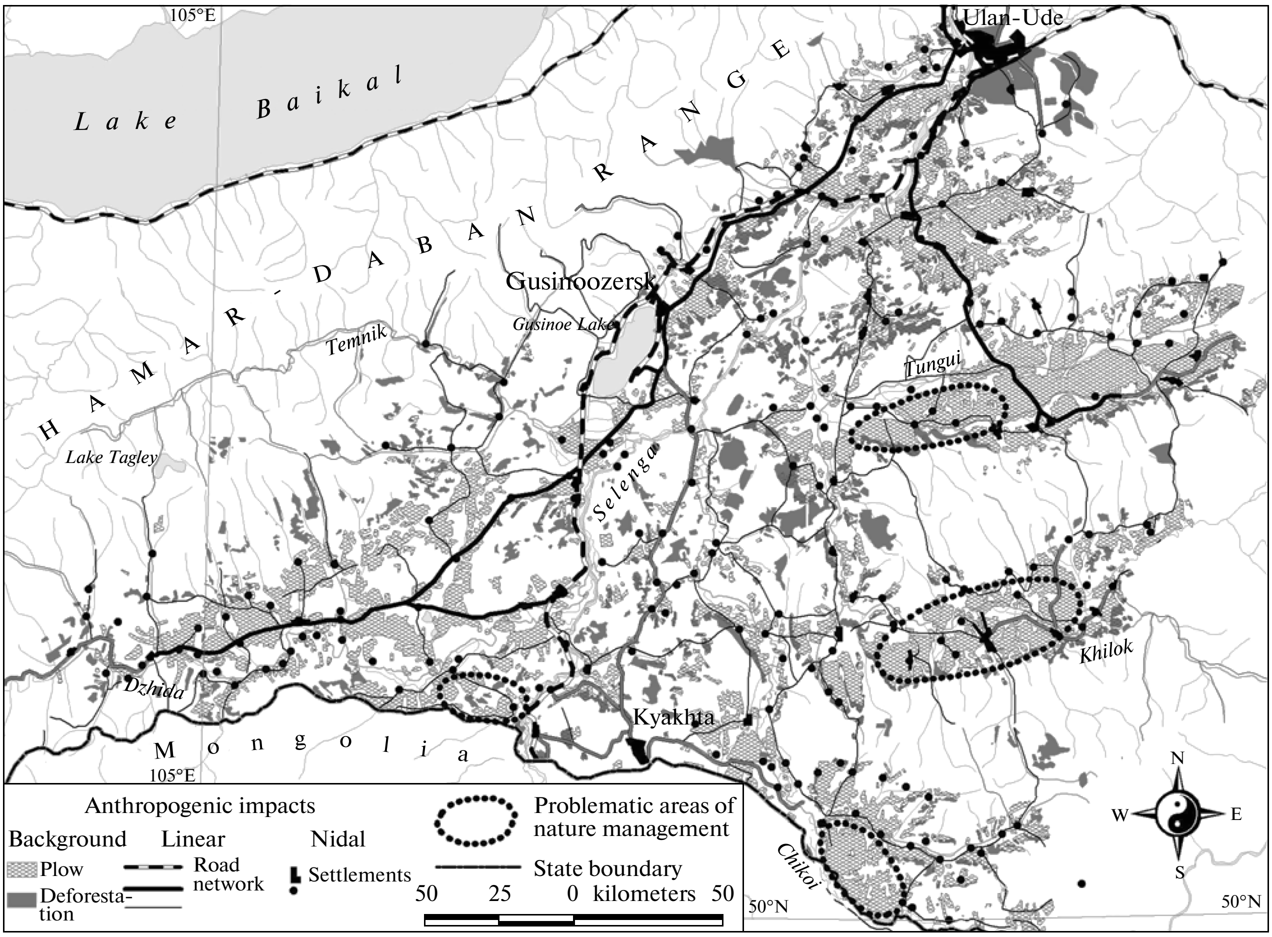


Fig. 2. Dynamics of arable land in the 20th century.

effect on surrounding natural systems. Most significantly, areas of such lands have increased on agricultural fields of the Mukhorshibirsk (more than 40%) and Bichurskii (more than 30%) regions.

Along with wind erosion, up to 25–35% of degradation processes is due to water erosion, which develops mostly in mountain areas of forest–steppe and partially of the steppe landscapes, where a sufficient amount of precipitation falls. In such areas, soil cover deprived of natural protection is intensively destroyed under the influence of temporary streams, often of a downpour nature. The main display of water erosion is gullies. Forest–steppe territories are covered by gully erosion to a lesser extent, although the amount of precipitation is relatively high. This is explained by preserved forest areas, which contribute to the suppression of the hydrodynamic energy of the water flow. The most intensive erosive processes appear in the forest–steppe landscapes on arable lands, which are formed on loess rock of light texture. It was found that, other things being equal, the value of physical parameters of the ravine is in direct proportion to the period of plowing, the time of abandonment of the site, and slope of the relief. Plowing itself has a negative impact on natural landscapes of the studied area not only because it causes mechanical transformation of the earth's surface, but mainly as a result of surface soil erosion, which is caused by wind and water.

The combination of multitemporal layers of the 2
dynamics of arable land and modern erosion of agricultural lands allowed us to reveal and spatially record areas of concentration of sites of degradation (Fig. 3). Such areas are observed in the farms situated close to Selenga River, as well as the long-plowed area and on farms with large areas of arable land. The formation of sites of degradation of the earth's surface is caused by the coincidence of the peak wind regime with the most arid period (April–June), as well as the low degree of forest cover in the investigated area. The closest connection between the dynamics of arable lands and the intensification of the accompanying erosion processes appears in the southern areas of the investigated terri-



1 **Fig. 3.** Anthropogenic surface conversion.

tory, especially in the Dzhidinsk region, whose landscapes were plowed only in the 20th century.

Field registration of sites of degradation of natural landscapes through global positioning receivers allowed us to identify regional features and determine the spatial and temporal invariants of their dynamics, as well as to perform metric estimation of the parameters of erosion processes. It was found that such areas are polygonal objects 150–200 sq m in area with centrifugal dynamics and seasonal nature of development. As a rule, together they form areas of surface washout with a total area of 3.5 sq km. As a result of field surveys on sites of degradation of natural landscapes, it should be concluded that, on the assessed territory, erosion appears most significantly in the spring on the plains areas devoid of tree plantations on arable lands in the bottom of the river valleys. Areas with a joint manifestation of the various stages of development of linear erosion were identified and explored. It was established that, on the side valleys of large river basins, the risk of erosion is largely determined by the area of open space, rather than by slope of relief and soil type. In the investigated region, erosion occurs not only on cultivated arable lands, but also on fallow lands, where it appears more intensively, since the manifestations of erosion are not removed by plowing.

In general, the seasonal activation of erosion processes in such areas is observed on almost all farms on the investigated territory; depending on the location, it has varying degrees of intensity, and the main influence here is the spatial position of the farm and the type of occupied terrain. Natural taxa, types of landscape and holes, do not as a rule coincide with economic units. Several farms can coexist in one landscape, and several holes may occupy adjacent positions on one farm.

Changes in the structure of land fund categories on the studied part of the Lake Baikal basin have recently been characterized by a decrease in lands used for agriculture; industry; the forest fund (with an increase in lands of specially protected territory); city, township, and village governments; and reserve lands. In general, across the investigated territory a recent reduction of arable lands and an increase in deposits can be traced, which can be viewed as a tendency to transition from converting dynamics of natural landscapes to recovery dynamics.

CONCLUSIONS

Currently, the availability of GIS software and usability of its interfaces, the development of telecommunication mapping services and applications, and the technical upgrading of all the procedures of spatial research contribute to the fact that most research in the geosciences is implemented on the basis of microprocessor technology, and geoinformational monitoring is becoming a major research method in the world.

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SPELL: 1. anthropogenic, 2. multitemporal, 3. geodata, 4. geoinformation