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REGIONAL PROBLEMS OF ENVIRONMENTAL STUDIES AND NATURAL RESOURCES UTILIZATION

Morphoindication of Physicogeographical Regions of Orenburg Oblast

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Abstract—One of the main directions of the modern study of landscape structure is the timely updating of the structural and dynamic features of geosystems, taking into account the degree of anthropogenic load. This article examines the historical prerequisites for the development of ideas about the physical and geographical division of Orenburg oblast. A geoinformation analysis of remote sensing data has been carried out using neural network algorithms based on self-organizing Kohonen maps in order to compare the structure of natural boundaries with the actual structure of natural–anthropogenic complexes. For this purpose, we have calculated quantitative indicators (namely, the area of the physical-geographical region, the number of classes (types of tracts), the number of landscape contours, the average number of contours in a class, the average area of one contour, the density of contours in the physical-geographical region, the coefficient of complexity, the maximum possible complexity of a landscape, the absolute organization of a landscape (a measure of imbalance), the relative organization of a landscape, and the coefficient of landscape fragmentation) and indices of differentiation of the landscape structure (coefficients of entropic complexity and Shannon diversity and Ivashutina–Nikolaev, Odum, Gleason–Margalef, and Simpson indices of heterogeneity). Moreover, schematic maps of the region's territory have been compiled, reflecting their spatial distribution over landscape areas. Based on the results of the study, tendencies of changes in the landscape structure of Orenburg oblast have been determined. They include changes in the degree of contouring of geosystems, dynamics of the severity of inter-landscape boundaries, anthropogenic dispersion of geosystems, and the degree of dominance of individual elements of the landscape. Differences in the tendencies of changes in the landscape structure of forest-steppe, petromorphic, and hydromorphic geosystems, in comparison with the arid steppe landscapes prevailing in the region, have been identified depending on the degree of agrogenic and technogenic transformation.

Keywords: structure of geosystems, anthropogenic load, indices of landscape differentiation, steppe zone of Russia, entropy measure of complexity and diversity, contouring

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INTRODUCTION

When improving territorial planning schemes for Orenburg oblast, the issue of updating physical-geographical boundaries, taking into account the structural and dynamic features of agrogenic and technogenic impacts on landscape components, is acute. One problem is drawing the line between steppe and forest-steppe natural zones. The existing physical-geographical zoning of Orenburg oblast has a fairly long history and has been carried out at least four times. First, the identification of natural boundaries refers to the works of S.S. Neustrueva [1]. A different idea of the natural boundaries of Orenburg oblast was given by F.N. Milkov [2, 3] and further developed by G.A. Russkin [4]. The Voronezh trace can be traced in the physiographic zoning proposed by A.A. Chibilev [5, 6], which currently remains the most factually proven in a number of the author's works.

Over the course of 100 years of studying the territory of the region, opposing views of scientists on physical and geographical zoning have often formed. It is generally accepted that all existing landscape maps of the territory of Orenburg oblast are based exclusively on natural factors. At the same time, the destructive impact of agrogenic and technogenic processes is ignored [7, 8]. The history of the development of the region is closely connected with the strong transformation of the morphological structure of steppe landscapes: starting with the nomadic cattle breeding of the Kyrgyz–Kaisak tribes, the resettlement of Russian state peasants from the central black earth provinces, and the first experiments in the devel-

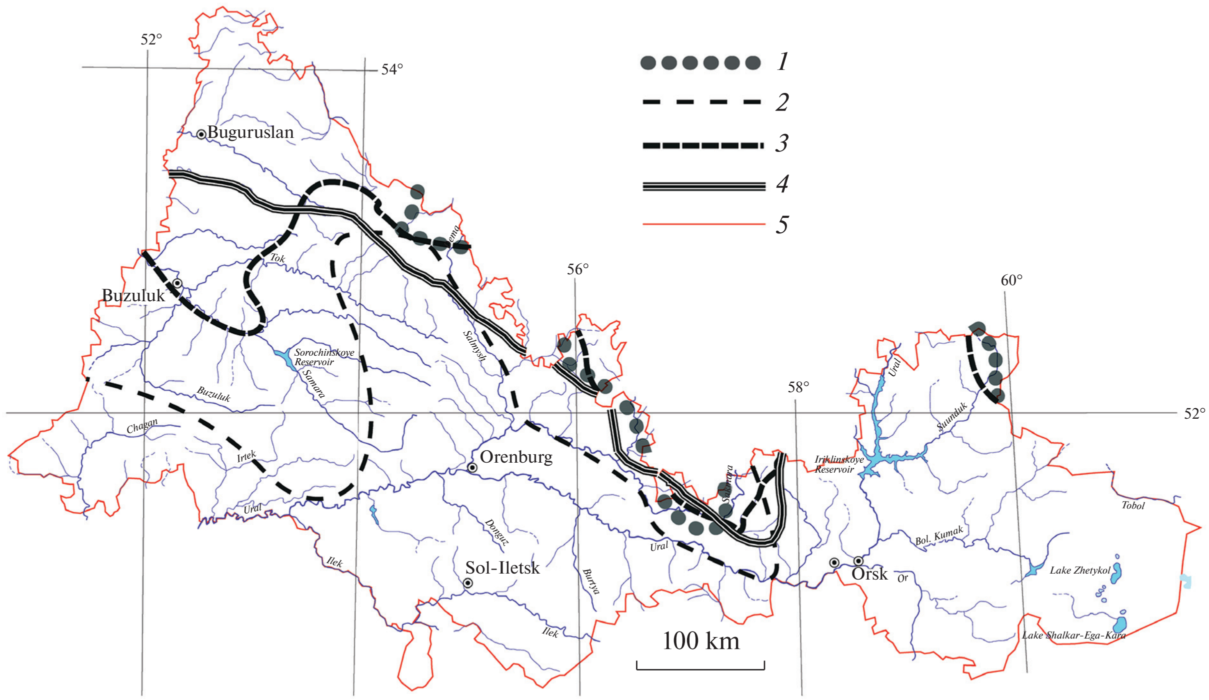

Fig. 1. Shift of the physical-geographical boundary between the steppe and forest–steppe zones of Orenburg oblast as a result of anthropogenic transformation according to landscape mapping data (as per [1–6]). Boundaries between the steppe and forest–steppe zones according to the results of researchers: (*1*) Neustruev [1], (*2*) F.N. Milkova [2, 3], (*3*) Russkin [4], and (*4*) Chibilev [5, 6]. (*5*) Border of Orenburg oblast.

opment of gold deposits, and ending with several agrarian reforms, accompanied by the extensification of agriculture through the inclusion of crop rotation of newly developed virgin territories, as well as the intensification of the development of ore and hydrocarbon minerals. The end of the 20th and beginning of the 21st centuries are distinguished by the emergence of a new (fallow) type of agricultural land, in which low-productive agricultural landscapes fell out of agricultural use, and the formation of fallow and secondary steppe areas occurred. Remote sensing (RS) data provide the opportunity to study the above dynamic processes in the structure of anthropogenic transformation of geosystems over the past decades.

The purpose of this work is to mathematically assess the degree of anthropogenic transformation of the steppe and forest-steppe geosystems of Orenburg oblast over a 30-year period. The main objective of this study is to compare the identified physical-geographical boundaries of Orenburg oblast (2000) with the results of calculating landscape differentiation indices based on deciphered remote sensing data for two time periods (1989 and 2018), which correspond to certain stages of the anthropogenic transformation of steppe geosystems in Orenburg oblast, the leading role among which is played by agrogenic processes and subsoil use processes.

When considering the physical and geographical zoning of the region, special attention must be paid to the definition of zonal and provincial boundaries. Carrying out a comparative analysis of the existing thematic zoning of the region, one can trace a significant trend in the shift of the forest-steppe zone to the northern border of the region. This factor is especially clearly manifested within the Obshchy Syrt (Fig. 1).

Certain features were noted regarding the passage of the key zonal boundary between the forest-steppe and steppe zones. From the zoning performed by Milkov [2, 3] to later versions of Russkin [4] and Chibilev [5, 6], the border between forest steppe and steppe gradually shifts within Obshchy Syrt to the north (see Fig. 1), which is explained by a decrease in forested area as a result of large-area development of arable land and the development of numerous oil and gas fields. According to the zoning of Milkov [2, 3], the southern border of the forest-steppe should pass along the Buzuluk-Chagan watershed of Obshchy Syrt, reaching the valley of the Ural River within the Ural Urema. To the east, the steppe zone forms a submeridional "tongue" that extends far to the north, right up to the upper reaches of the Bolshoy Kinel River. Then the forest steppe descends to the south through the territory of the Orenburg Cis-Urals, again reaching the Ural River valley within the low mountains of the Southern Urals. Russkin [4] draws the boundary between steppe and forest steppe much further north, while including the Borovki River basin and, partially, the Tok-Samara interfluve in the forested areas. This is explained by the presence of the relict coniferous forest and the high degree (for the steppe region) of forest cover on the right bank of the Samara River. According to the zoning by A.A. Chibilev [5, 6], the border part between natural zones is characterized by a smoother nature of its conduction. There are no sharp "tonguelike" branches of natural zones. The border smoothly shifts southward due to the activation of landscape differentiation factors by the foothills of the Southern Urals (barrier effect and increase in absolute elevations). Forest–steppe landscapes cannot be traced within the Orenburg Trans-Urals. Forest areas are fragmented "islands" in nature and do not have a clear species and age structure, which does not allow them to be identified as signs of a forest steppe.

The zoning by Neustruev [1] and Russkin [4] is characterized by symmetry of zonal boundaries, in which there is a synergistic mutual influence of zonal and provincial boundaries, as a result of which the authors often define lithomorphic geosystems of island forests as zonal (Buzuluksky forest and Kvarken forest steppe), and zonal boundaries can be discontinuous (for example, the forest steppe is interrupted in the Salmysh valley). The shift of the border between forest steppe and steppe in the Ural lowlands from earlier to later zoning options goes from northwest to northeast towards the Sarinsky Plateau. Thus, we assume that the trend of shifting the border of the forest-steppe and steppe zones in the northern direction is determined, first and foremost, by the increase in anthropogenic transformation of landscape geosystems of Orenburg oblast in 1940–1980, i.e., during the period described by the well-known concepts of physiographic zoning.

An analysis of the relationship between provincial boundaries when comparing the physical-geographical zoning of the abovementioned authors shows that an almost complete correlation of boundaries is observed in four cases: two sublatitudinal and two submeridional. Sublatitudinal cases are associated with the asymmetry of the watershed spaces of the Obshchy Syrt, where block–neotectonic and structural–geomorphological reasons are combined with latitudinal–zonal ones. Submeridional coincidences of provincial boundaries relate to the western and eastern slopes of the Southern Urals, corresponding to thrust faults.

The physical-geographical zoning taken as a basis and the identified latitudinal–zonal and geological–geomorphological azonal boundaries according to the zoning of Chibilev [5, 6] differ significantly from the data obtained from spectral analysis of the surface by spacecraft.

Thematically deciphered remote sensing data make it possible to trace both the zonal differentiation of vegetation cover, especially on the border between forest–steppe and steppe provinces, and the degree of anthropogenic fragmentation of the territory, the formation of large tracts of arable agricultural landscapes, and techno-geosystems of oil and gas fields with extensive infrastructure.

MATERIALS AND METHODS

When analyzing the features of the morphological structure of the landscapes of Orenburg oblast, the physical-geographical zoning of Chibilev [5] was used, the basis for which was both expeditionary research and the topographic basis of the 1 : 100000 scale and the landscape–typological map of Orenburg oblast by Chibileva scale 1 : 500000 [5]. For an objective understanding of the features of the physical-geographical zoning of the territory of Orenburg oblast, the scientific works of Milkov [3] and Russkina [4] were referenced.

When comparing the structure of modern land use and land use of the Soviet Union, maps of on-farm land management of the administrative districts of Orenburg oblast with a scale of 1 : 25000 [7], forest management schemes for forestry enterprises and forest districts of the region with a scale of 1 : 25000 [8], and a topographic basis with a scale of 1 : 100000 [9] for the period 1984–2010 were used. The use of large-scale cartographic sources was carried out for the most controversial territories (for example, when imposing the boundaries of landscape zoning and anomalous values of indices reflecting the landscape structure).

Thematic maps make it possible to generally determine the dynamics of transformation of the structure of landscapes in the region and are the basis for identifying the impact of various types of environmental management on the landscape [10, 11]. The construction of self-organizing Kohonen maps when analyzing the morphological structure of landscape geosystems based on remote sensing is one of the technologies for automated surface classification [12]. Self-organizing Kohonen maps allow the adaptation of multi- and hyperspectral images for the analysis of landscape structure. The result of surface classification is an RGB model adjusted according to classes that have the closest spectral–brightness parameters [13].

One way to analyze the spatial structure of geosystems is through various mathematical coefficients that reflect changes in the degree of fragmentation of physical-geographical areas and the saturation of contours of certain classes of landscapes [14, 15]. These include the indices of the entropy measure of diversity and complexity (Shannon indices) [16, 17]; the indices of inhomogeneity of Ivashutina–Nikolaev [18], Odum [19], Gleason–Margalef [20], and Simpson [21]; etc. For their analysis, quantitative indicators of the differentiation of the landscape structure were obtained [22], determined according to remote sensing data: the area of the physico-geographical area (S), the number of classes/types of tracts (m), the number of landscape contours (n), the average number of contours in the class (p), the average area of one contour (S_0), the density of contours in the physical and geographical area (k), the complexity coefficient (K_c), the maximum possible complexity of the landscape (H_{max}), the absolute organization of the landscape (measure of imbalance) (H_i), the relative organization of the landscape (R), and the coefficient of landscape fragmentation (K).

The study was carried out based on the results of the analysis of mosaics (13 images for each period under study) of Landsat satellite images of the state of the territory of Orenburg oblast for the period of late May to early June 1989 and 2018. Using the ScanEx Image Processor software package, territory differentiation was obtained using the method of automated remote sensing segmentation (separation of satellite images based on the spatial and spectral proximity of pixels). A database of mathematical parameters has been compiled that includes the abovementioned quantitative indicators of differentiation of landscape structure and index coefficients reflecting changes in the degree of fragmentation of geosystems. A number of numerical indicators have been obtained that characterize each of the landscape areas of Orenburg oblast. It should be noted that indices reflecting the structure of landscape geosystems are widely used both in many regions of Russia (Astrakhan oblast) and at the mesoregional level (the Kuril Islands). At the same time, there is a correlation between low anthropogenic transformation and a high level of landscape diversity, which allows the use of morphoindication as a method for justifying the organization of specially protected natural areas and improving the regional environmental framework. A number of studies propose the use of an intermediate stage in the analysis of landscape morphology—a landscape map [23]. In this case, morphoindication is a term meaning the determination of indicators characterizing the morphological structure of landscape geosystems based on the use of algorithms for the automated classification of surfaces represented by satellite images.

The question of the relationship between surface classification based on satellite images and landscape structure is extremely important for this work. Of course, these concepts are not identical and it is obvious that, to analyze the landscape structure from satellite images, an intermediate stage is required—drawing up a landscape map, after which the parameters of the landscape structure are calculated [23, 24].

RESULTS AND DISCUSSION

The Shannon Diversity Index measures diversity based on two components: occurrence and evenness, i.e., the number of types of patches in the landscape (compositional component) and their even distribution across the study area (structural component). If the index is zero, then in this case we have one contour in the study area. Typically, index values range from 1.5 to 3.5, rarely exceeding 4.5. A decrease in the indicator of landscape diversity through the Shannon index, as a rule, indicates an increase in the extremeness of conditions for the geosystem. Researchers have different views on the issue of interpreting the results of calculations of this index in relation to landscape structure. With its help, they assess the occurrence and uniformity of landscapes [25, 26] and analyze the multifunctionality of environmental management [27]; species richness and uniformity of distribution of natural-territorial complexes [14, 15]; and distribution of land cover classes and spatial and temporal order in real landscapes as a result of the complex interaction of natural and anthropogenic processes [16]. In this study, the most relevant property of the Shannon index seems to be that, the higher its indicators, the greater the density of contours that make up the landscape structure and the more discrete and diverse the landscape structure [28]. An increase in the index value is associated both with an increase in the number of contours and with an increase in the uniformity of their distribution. The last indicator refers both to the evenness of contour areas for each class, and, in general, throughout the entire physical-geographical region.

The general trend for Orenburg oblast is an increase in the degree of contouring and an increase in gradients in relation to the Shannon coefficient between different physiographic regions from 1989 to 2018. An increase in the Shannon index, as a rule, indicates a decrease in anthropogenic transformation of the landscape geosystem. This is demonstrated through the increase in fallow areas both in forest-steppe regions and within the Russian–Kazakh border area. On the contrary, the degree of fragmentation decreased in western Orenburg due to total plowing for industrial crops (sunflower) and in the suburban area of Orenburg. In 1989 and 2018, the degree of diversity of geosystems, determined in accordance with the Shannon index, generally decreased (by 1.1%) and the degree of complexity increased (by 0.3%).

The significance of the Shannon diversity index lies not only in the severity of the degree of dominance of one or several natural–anthropogenic types over the rest [29, 30]. As dominance increases, and therefore evenness decreases, the index value decreases, especially responding to an increase in the degree of rarity or uniqueness of geosystems [26, 31]. In the conditions of landscape areas of Orenburg oblast, which are refugia, the values of the Shannon index are minimal (Buzuluksky Bor 3.79 and Maly Nakas 3.77). Low values of this index are observed for forest-steppe regions (3.69–3.75) and individual southern steppe areas (Aytuarskaya Steppe and Troitskaya Steppe). It is noteworthy that the Shannon complexity index "sags" in the same physiographic areas (but not always) and has a more significant correlation (0.7) with the density of landscape contours.

In general, in Orenburg oblast for 1989 and 2018, the density of landscape contours has increased significantly. This happened in 17 out of 38 landscape areas (with a value of 0.5 contour and higher per 1 km^2). Only in seven did the contour decrease by a similar amount (by 0.4 contours or more per 1 km^2). Obviously, the reasons cannot be only objects of economic activity. Natural disasters and restoration processes of agricultural landscapes play a significant role. On the one hand, the increase in contour due to an increase in the area of fallow steppes in the period 1989–2018 served as a factor in increasing biological diversity; on the other hand, the discreteness of geosystems increased as a result of adaptation to external natural factors that remove the landscape complex from a state of equilibrium and lead to increased fragmentation [32–34].

The coefficient of landscape heterogeneity was proposed by L.I. Ivashutina and V.A. Nikolaev [18]. It is characterized by the fact that, in the presence of the largest number of landscape groups and an equal ratio of their areas in the region, the coefficient reaches a maximum, i.e., equal to 1. If there is only one group of landscapes, then it decreases to a minimum and becomes equal to 0 [31]. An analysis of the dynamics of the heterogeneity index over the period 1989 and 2018 among the physical-geographical regions into which the territory of Orenburg oblast is differentiated shows that, in general, the degree of landscape heterogeneity has decreased. The trend of increasing the level of dominance, leveling interlandscape gradients, and reducing the boundaries between them is not observed everywhere. Physiographic regions covering the southern forest–steppe, as well as the forested steppe landscapes of Obshchy Syrt, the low-mountain steppe landscapes of the Guberlinsky Mountains, and the lake–steppe landscapes of the Turgai Plain, are experiencing the opposite trend: an increase in the heterogeneity index. Thus, forest–steppe, petromorphic, and hydromorphic geosystems, under conditions of a general decrease in anthropogenic load, experience complex restoration processes through complication of the structure; i.e., they react differently to a decrease in agricultural impact in contrast to plain–steppe natural complexes. These processes are facilitated by difficult-to-control spontaneous natural processes: fires, droughts, and insect invasions. The value of the heterogeneity index has leveled off, since its growth is associated precisely with those physical-geographical areas where its indicator was the lowest: “island” pine forests and mountain–forest-steppe forests and complex solonetz–steppe landscapes of the Turgai province peripheral to the region and Utvinskaya Plain, where the growth of the Ivashutina–Nikolaev index is most significant (up to 0.1–0.15) and the impact of natural factors is greatest.

The Odum diversity index characterizes the degree of anthropogenic transformation of landscape complexes and their deviation from the latitudinal–zonal indicators of steppe diversity. This index is highest within the physical-geographical regions that are least affected by various types of anthropogenic impacts. These include various forest areas on the periphery of the region, partly representing specially protected natural areas of federal significance (Buzuluksky Bor National Park, Shaitantau Nature Reserve, and sections of the Orenburgsky Nature Reserve—the Aytuarskaya Steppe and Burtinskaya Steppe), various steppe refugia with preserved secondary steppes in the territories bordering Kazakhstan (the Chibendinskaya Steppe and the Upper Tobolsk Steppe), mountain forests and low-mountain ridge steppes of the Cis-Urals, island pine forests of the Tobol–Ural peneplain plain, and island forests of the Bugulminsko-Belebeyevskaya Upland. We determined the Odum index value (0.02), which identifies physiographic areas with a morphological structure slightly disturbed by anthropogenic processes, and the index value (0.01), which allows us to separate areas with moderate disturbances from the critical stage.

The dynamics of this index in the period from 1989 to 2018 are interesting. It decreased significantly near the Russian–Kazakh border region due to the intensification of fires in the mountain–steppe and southern steppe eastern regions, as well as due to the burning of island forests in the Trans-Urals. The Odum index increased most significantly in the low-mountain forest-steppe territories of the Cis-Urals. In general, there is a general increase in the index in the region, which indicates a decrease in the degree of anthropogenic transformation of the structure of geosystems. However, there is no need to talk about a radical improvement and sustainable recovery dynamics.

The Gleason–Margalef index reflects the relationship between contour and area of an area, showing an inverse correlation with the average number of contours in a class, the total number of contours, and the total area of a landscape unit. The maximum value of the index is typical only for small mountain–forest-steppe and mountain–steppe physical-geographical regions with a minimum number of contours in each type of geosystem. When constructing landscape areas, as the Gleason–Margalef index increases, their areas naturally decrease. Therefore, among the physical-geographical regions with a low index, there are none with a small area, with one exception: the Ilek-Utvinsky syrt upland chalk area 632 km^2 in size has a very small Gleason–Margalef index (5.32). This may indicate that this territory is strongly limited by the administrative border of Orenburg oblast, since most of it is located in Kazakhstan and has the lowest number of landscape classes and, at the same time, a small number of contours in the class.

The next indicator calculated as part of the study was the Simpson dispersion index. It is a very sensitive indicator of dominance of one or more species [35]

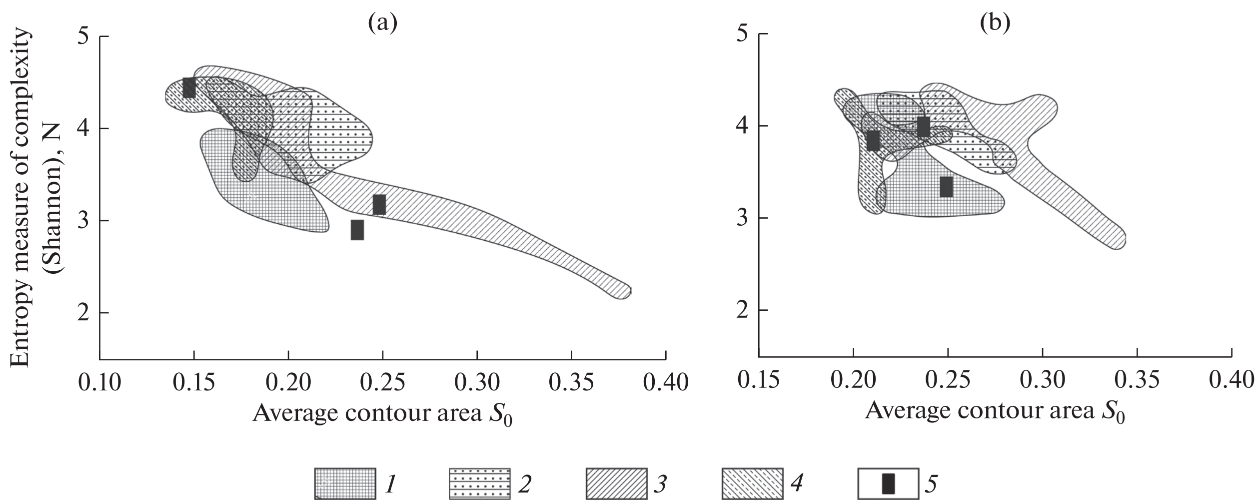

Fig. 2. Ratio of the average contour area allocated when classifying satellite images for Orenburg oblast and the indicators of Shannon's entropy measure of complexity for landscape zones and subzones in 1989 (a) and 2018 (b). Natural areas: (*1*) forest steppe, (*2*) northern steppe, (*3*) southern steppe, (*4*) mountain steppe, and (*5*) steppe mountains.

and is focused on revealing the degree of dominance in the community; it is also quite correct, since it represents a linear combination of the dispersion of the specific volumes of groups [36]. At the same time, if the share of one species (in the case of dominance) tends to 1 and all others to 0, then both indicators also tend to zero [37]. This characterizes the degree of dominance of individual natural-territorial complexes (usually in the rank of tracts or subtracts) within the landscape. However, the minimum values of this index are observed in mountain–forest-steppe regions, small "island" steppe forests and mountain–steppe territories of the Southern Urals. This index has a high correlation (0.88) with the area of landscape areas, which will determine its close connection with zonal (background) geosystems.

Along with the dynamics of various coefficients characterizing the transformation of the morphological structure of landscape complexes, the relationship between the coefficients of chorological, typological, and entropic diversity of landscape structure and relatively simple quantitative indicators of differentiation of landscape structure is indicative. As an example, we chose the relationship between the indicator of the average contour area obtained as a result of surface classification using satellite images and Shannon's entropy measure of complexity (Fig. 2). An analysis of the relationship shows that, on the one hand, physical-geographical zones and subzones identified on the basis of both latitudinal–zonal differentiation and azonal lithomorphic features of geosystems are localized in a certain way (forest–steppe landscape areas are characterized by small contours and small Shannon index values; for the southern steppe, there are large contours and a very significant spread of Shannon index indicators). The graphs for forest–steppe and southern steppe landscape areas almost do not overlap. However, the graphs reflecting the index values for intermediate landscape areas combining the features of forest steppes and southern solonetz steppes that have lithomorphic features (northern steppe, mountain steppe, "island" forests) closely overlap each other. On the other hand, the ratio between these indicators in 1989 and 2018 does not demonstrate absolute constancy. The landscape complexes of the southern steppe are the most dynamic, covering both the Caspian lowland and the Trans-Ural peneplain and the Turgai plain. The landscape areas of the remaining zones and subzones are grouped more compactly and, in terms of the dynamics of indicators, are significantly more stable.

Between 1989 and 2018, there were significant changes in the average contour area within physiographic regions. The general trend is to reduce the average area of contours and increase their density. This trend is observed almost throughout Orenburg oblast. However, it can be most clearly seen in the Trans-Urals and within the axial part of Obshchy Syrt, where the development of fallow stock has acquired an almost landslide character.

A different trend is observed for landscape areas with a significant proportion of forest tracts. The decrease in contours occurred in forest–steppe, mountain–forest-steppe, and forest–pine forest areas, partly due to natural reforestation and partly due to a decrease in deforestation (especially after the creation of the Buzuluksky Bor national park).

Similarities when comparing the parameters characterizing the dynamics of development are demonstrated by the landscape areas of the southern steppe, which are also areas of the Russian–Kazakh border. A slight increase in the size of contours and a decrease in their number is a common feature of the southern regions. It is, of course, difficult to imagine an increase in arable land on these lands. Obviously, constant burning, the merging of tracts of once arable land together, and the formation of secondary steppes (but not weedy deposits) are the main milestones in the development of this territory.

CONCLUSIONS

1. Data illustrating the morphology of geosystems in 1989 reflect the degree of their anthropogenic transformation in accordance with the Soviet economic system and the structure of environmental management.

2. The physical-geographical zoning models developed over the last century (1918–1999) in Orenburg oblast characterize both fundamentally different approaches to landscape differentiation and significant shifts in the degree of anthropogenic transformation of geosystems, as is evidenced by the gradual shift in the forest–steppe and steppe boundaries from the southeast to the northwest of Orenburg oblast.

3. The zonal affiliation of landscape provinces and districts of Orenburg oblast can be indexed through the ratio of the coefficient of Shannon's entropy measure of complexity and the average area of the landscape contour. Parameters reflecting the morphological complexity of landscape areas that differ in latitudinal–zonal or altitudinal differentiation, on the one hand, have significant differences (for example, for lowland areas of the forest–steppe and steppe); on the other hand, they can be relatively similar (for example, for lowland areas of northern and southern steppes and for mountain steppe regions).

4. An analysis of changes in the morphological structure of landscape areas of Orenburg oblast in 1989 and 2018 shows that the degree of anthropogenic transformation of geosystems in Orenburg oblast has decreased (Odum index). This indicator has decreased significantly in the Russian–Kazakh border areas and, on the contrary, has increased in the outlying areas of the region that have environmental statuses (reserves and national parks) or that have prospects for receiving such a status.

5. Indices of the complexity and diversity of the landscape structure of Orenburg oblast reflect for the years 1989 and 2018 a decrease in the evenness of landscape boundaries and an increase in contour density (Shannon index), a decrease in landscape heterogeneity, and an increase in dominance (Ivashutina–Nikolaev index), which is determined both by rather contradictory processes of reducing the previous large-scale agricultural load and by a sharp increase in poorly controlled natural processes (fires, dry winds, and locust invasions).

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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