RESEARCH PAPER

ASSESSMENT OF NATURAL RESOURCE POTENTIAL AND ANTHROPOGENIC LOAD IN THE MACROREGION OF NORTHERN EURASIA BASED ON A BASIN APPROACH

Oleg P. Yermolaev[1], Nurgul S. Sihanova[2*], Yerlan A. Shynbergenov[2*], Roman O. Yantsitov[1]
[1] Kazan (Volga Region) Federal University, Institute of Ecology and Environmental Management, Kremlevskaya, 18, Kazan, 420000, Russia
[2] Korkyt Ata Kyzylorda University, Engineering and Technology Institute, Ayteke bi, 29A, Kyzylorda, 120014, Kazakhstan
*Corresponding author: sihanova.nurgul@mail.ru, shynbergenov.erlan@mail.ru
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ABSTRACT. The environmental component of Sustainable Development for large regions of the Earth can be assessed through the evaluation of the natural resource potential of the territory. The methodological challenge of such assessments is always determined by the type of operational-territorial unit within which the geodatabase is formed. This article details the possibilities of using the basin approach as such units. This approach is one of the most important in humid climate regions where a river network has been developed. Using the example of the Ob' river basin in Northern Eurasia, the article illustrates the application of the basin approach to assess the environmental determinants of Sustainable Development. The studies were conducted in three stages: formation of an GIS database of basin geosystems of the Ob' river basin; creation of a geospatial database on the natural resource potential in the small river basins; selection of criteria and assessment of anthropogenic load on the basin geosystems of the Ob'. A total of 30,738 small river basins were delineated automatically based on GMTED DEM, with a mean area of 66 km^2. GIS integrated geoinformation represents the natural and anthropogenic characteristics of river basins. The assessment of the environmental state of the territory should considerthe types and strengths of anthropogenic loads. For this purpose, the integral indicators used, which directly or indirectly reflect anthropogenic impact: population density, road network density, and the percentage of arable land in the total area. The final indicator of anthropogenic load was calculated as a linear combination of specific variables and ranked into six categories. Thematic and complex maps were created, allowing us to identify the natural background in which the geosystems of small river basins are formed and function, as well as the types and strength of anthropogenic loads on the territory.

KEYWORDS: the Ob' river basin, Western Siberia, small river basins, anthropogenic load, GIS geosystems, geodatabase, geoecology

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INTRODUCTION

The scale of human economic activity has led the biosphere in many regions of the planet to the brink of pre-crisis ecological states. The resistance and compensatory reactions of the abiotic environment are often insufficient to counteract degradation and mitigate negative external impacts on the Earth's biosphere (Ivanov et al. 2020). Currently, in many regions of the planet, especially where economic growth is driven by the involvement of significant natural resource flows with deep processing, the ecological capacity of the environment is exceeded[1]. The cumulative impact of anthropogenic activities poses a significant threat to the regenerative capabilities of regional biosphere sections.Anthropogenic interactions and processes can trigger mechanisms within natural-technical geosystems, potentially leading to cumulative effects that amplify anthropogenic changes in the natural environment. Therefore, prioritizing environmentally safe sustainable development is paramount in the global community's Sustainable Development concept. Within this paradigm, the ecological aspect plays a crucial role in shaping strategies for global economic development. However, effective implementation requires tailored programs adapted to specific regions. The selection of appropriate territorial units for data aggregation and spatial analysis of

[1] Florczyka A.J., Corbanea Ch., Ehrlich D. (2019). GHSL - GlobalHumanSettlementLayer [online]. Available at: https://ghsl.jrc.ec.europa.eu/index.php [Accessed 31 Aug. 2024].

ecological aspects is fundamental. In our view, river basins can serve as the best unit in humid climate conditions of extensive land areas, as they are natural, geosystem units (Yermolaev et al. 2017a, b, 2023a). The river basin, being a unified natural-territorial complex with natural boundaries in the form of orographic watersheds, within which the accumulation, transformation, and movement of solid and liquid substances occur, is a spatial unit that allows for the most objective characterization of the territory (Yermolaev, 2002; Korytnyj, 2001; Lisetskii et al., 2014; Osipov & Dmitriev, 2017). The advancement of Geographic Information Systems (GIS), enhanced availability of remote sensing data, and improved computational capabilities have elevated geographic and ecological studies to new heights.The establishment of a detailed vector database covering river basins and their inter-basin areas across a large region of Russia, coupled with comprehensive geospatial data encompassing natural resource potential, landscape diversity, and land use patterns, enables thorough spatial analysis (Gordeev et al. 1996; Ivanov et al. 2022). This infrastructure not only facilitates ecological studies but also supports environmental management, hydrological assessments, and spatial planning (Yermolaev et al., 2023b).

The aim of this study is to assess the natural resource potential and anthropogenic impact in Russia's macroregion, located in the Asian part of the country - the Ob' river basin. This assessment is based on a basin approach. The study area is characterized by a lack of data on the natural resource potential and economic loads in small rivers geosystems, as well as by fact that the Ob' river, running in a north-south direction, crosses a wide range of landscape zones, including tundra and forest-tundra in the north, steppes and semi-deserts in the south, lowland wetlands, mountainous areas, and high-altitude Alpine meadows and snowfields, all experiencing diverse anthropogenic pressures.

Brief Characterization of the Territory

The Ob' river basin is located in the northern part of the Eurasian continent and is considered the main waterway of Western Siberia. The river Ob' originates in the city of Biysk, in the Altai, at the confluence of the Katun and Biya rivers. The river flows from south to north through vast lowland areas of the West Siberian Plain, resulting in a slow flow. Approximately 85% of the Ob' basin is situated on this plain, often featuring forests and swamps. The river flows through the territories of the Altai Krai, Novosibirsk, Tomsk regions, the Khanty-Mansi Autonomous Okrug (Yugra), and the Yamalo-Nenets Autonomous Okrug. The river flows into the Arctic Ocean, specifically into the Kara Sea. There, the river forms a large estuary with numerous branches and islands, creating the Gulf of Ob'. The Ob' river is listed among the largest rivers in the world, ranking 7th in length in Eurasia and 16th globally. The total area of the Ob' basin is 2,026,457.05 km^2. It is 3680 km long. The Ob' river, along with the Irtysh river, ranks 1st among the rivers of Russia in terms of length and basin area, and 3rd in the Russian Federation (after the Lena and Yenisei rivers) in terms of annual streamflow.

RESEARCH METHODOLOGY

Creation of a Cartographic Model of Small River Basins

The development of a problem-oriented GIS combined with mathematical-statistical methods allows the assessment of the environmental status of small basins and the determination of the causes and intensity of their changes over a wide territory. The foundation of such a geoinformation system is the creation of a GIS layer (GIS database) of river basins. In this case, the river basin serves as the basic operational-territorial unit that allows the formation of a geospatial database (Yermolaev, 2017a, c).

The availability of a GIS database for delineating basin geosystems facilitates a wide range of tasks. These include assessing the natural conditions under which various processes and phenomena develop, the formation of water and sediment runoff in rivers, various types of thematic and complex zoning (e.g., climatic, geomorphological, agro-climatic, anthropogenic, landscape), and evaluating anthropogenic impacts on geosystems. Automated delineation of basin boundaries was conducted using global Digital Elevation Models (DEMs) available in open access. The Ob' river basin's topography can be represented by several well-known and publicly available global models, including:: GTOPO30 with a spatial resolution of 1000 m (30 arc seconds); GEBCO2023 with a spatial resolution of 500 m (15 arc seconds); GMTED2010 with a spatial resolution of 250 m, 500 m, 1000 m (7.5 arc seconds, 15 arc seconds, and 30 arc seconds respectively; spatial coverage 84°N - 56°S (Danielson & Gesch, 2011); SRTM with a spatial resolution of 30 m and 90 m (1 arc second and 3 arc seconds respectively, spatial coverage 60°N - 56°S (Rodriguez et al., 2005), etc. All these models utilize the World Geodetic System 1984 (WGS84) coordinate system and are provided by the United States Geological Survey (USGS). For the creation of the river basin boundary layer, the GMTED2010 model (Global Multi-resolution Terrain Elevation Data 2010) (Danielson & Gesch, 2011, Yermolaev, 2017c) with a spatial resolution of 250 m (7.5 arc seconds) was selected, along with the hydrographic network model from 1:1,000,000 scale maps. The Albers Equal Area projection is chosen coordinate system. These parameters correspond to the accepted level of spatial resolution used in the study, adhering to the cartographic principle of scale consistency. The methodology for identifying basins is detailed in our previous work (Yermolaev et al., 2003a).A total of 30,738 small river basins were delineated within the Ob' river basin. In the next stage, a geodatabase and GIS were created for the natural resource potential and anthropogenic load indicators in the basins. Open data sources were used, with characteristics detailed in the thematic sections below. The set of indicators was determined based on data availability and their relevance for characterizing natural potential, assessing environmental favourability for humans, and understanding the conditions for geo- and ecosystem formation.

RESULTS AND DISCUSSION

Geospatial Database of Small River Basins

A geospatial database of small river basins was developed based on several indicators, including morphometric indicators of relief (Table 1) and hydroclimatic factors. The types of land cover and anthropogenic impacts were also taken into account. All these indicators were added as attributes to small river basins (Fig. 1.)

Basin Area

The area of a basin is an important characteristic that reflects the complexity of the hydrographic network, the intensity of fluvial processes, and the volume of water flow (Fig. 3a). The average basin area is 65.9 km^2. Only ten basins have the smallest area (0.25 km^2). The largest basin, located in the southeastern part of the Ob', has an area of 10,449.7 km^2. According to the calculations, about 62% of the basins have areas up to 50 km^2 (16%) and are evenly distributed across the entire small basin.

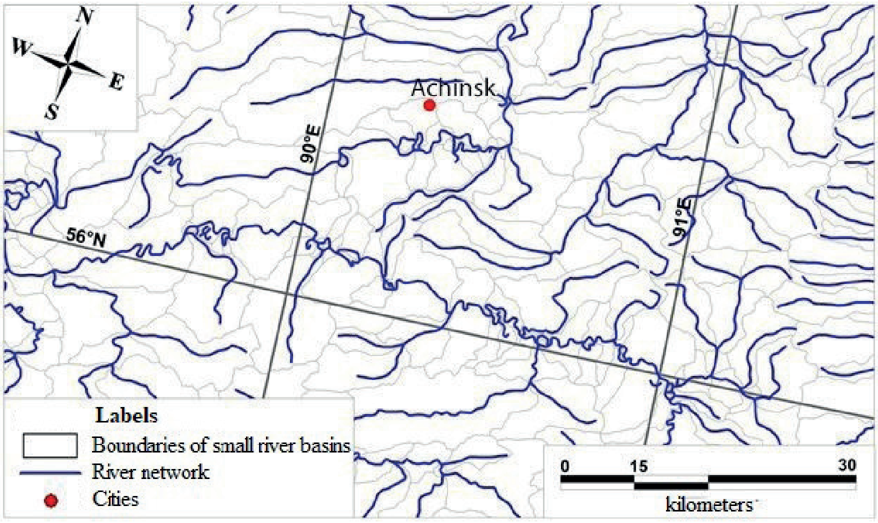

Fig. 1. Fragment of a GIS database of small river basins of the Ob' River

Table 1. Terrain characteristics determined for each basin

Data		Field name
Small basin ID	Dimensionless	Id
Area	km²	Area
Height	Mean, m	Hmean
	Maximum, m	Hmax
	Minimum, m	Hmin
	2% - percentile, m	CMRobi_Q2
	98% - percentile, m	CMRobi_Q98
	Verticaldissection, m	Rel_Elev
Surface slope steepness	Mean steepness, deg.	Slope
Slope length	Mean, m	_Fl_Path_lenmean

Slightly more than 19% of the basins have areas of 50-100 km^2 (20.8%). Larger basins (100-500 km^2) are densely grouped throughout the Ob' basin (5,377 basins), covering 47.9% of the study area. Basins with a maximum area (>1000 km^2) are mainly located in the southern and southeastern parts of the Ob' (in the steppe regions) and number 73, covering 9.1% of the basin area.

Morphometric Analysis

Morphometric analysis is widely used in dynamic geomorphology for assessing hazardous exogenous processes and ecology. In this study, we calculated the following morphometric characteristics of the relief: average height and slope steepness (Fig. 3c, d), aspect, flow line length, and depth of relief dissection. The average values of these indicators were calculated in the Quantum GIS (v.3.10) application using the "Zonal statistics" tool. In SAGA GIS, the 2nd and 98th percentiles of heights were calculated. Thematic maps based on the morphometric characteristics of the relief were created using the MapInfo Pro V. 15.0 GIS application. The Statgraphics package was used for statistical analysis and distribution of the indicators. Below are examples of evaluating some relief parameters.

Average Height

When distributing the basins according to their average height (Table 2), a standard classification of terrain by absolute height was used. A more detailed gradation was applied to the thematic map in order to ensure readability (Fig. 3b). Lowlands account for 81.2% of basin geosystems with an average height of less than 200 m). This category occupies 78.4% of the area of the Ob' basin. Highlands comprise 11.5% of all basins and cover 14.1% of the Ob' basin area. They are mainly located in the south (the Altai and Kuznetsk-Salair mountain regions) and north parts (along the Ural Mountains). Low, medium, and high mountains account for 3%, 2.6%, and 1.6%, respectively, of basins located in northern Altai, covering 7.4% of the total small basin area. The basin with the maximum height (3,151 m) is located in this region.

Various schemes can be used to classify the distribution of average slope steepness within basins. For this study, we classified the small rivers of the Ob' basin according to slope steepness based on Braude's classification (Braude, 1965). The thematic map (Fig. 2) was created with expert input to ensure appropriate gradation.

For the studied area, basins with a slope steepness of up to 10° are predominant, comprising 95.5% of the small river basins and covering 95.3% of the Ob' basin area. The steepest slopes (10° and above) account for 4.5% of the Ob' basins. These are found in the basins of small rivers located in the upper reaches of the Ob', at the sources of the Tom' River, and along the Biya, the Katun', and the Charysh rivers. Basins with very steep slopes (20-30°) occur sporadically in the upper reaches of the Biya and Katun' rivers (210 basins). Extremely steep slopes are found in only four basins, located in the extreme southern part of the Ob' basin, in the Altai Mountains (Table 3).

Table 2. Classification of small basin by height

Meanheight, m	Landform	Number of small basin, pcs.	Share to percentage	Area, km^2	Share to percentage
0-200	Lowlands	24,972	81.2	1,582,519.02	78.4
200-500	Hills	3,548	11.5	285,566.9	14.1
500-1000	Lowmountains	924	3	63,542.68	3.15
1000-2000	Middle mountains	809	2.6	56,734.04	2.8
>2 000	High mountains	485	1.6	29,643.48	1.47
Total		30,738	100	2,026,457.05	100

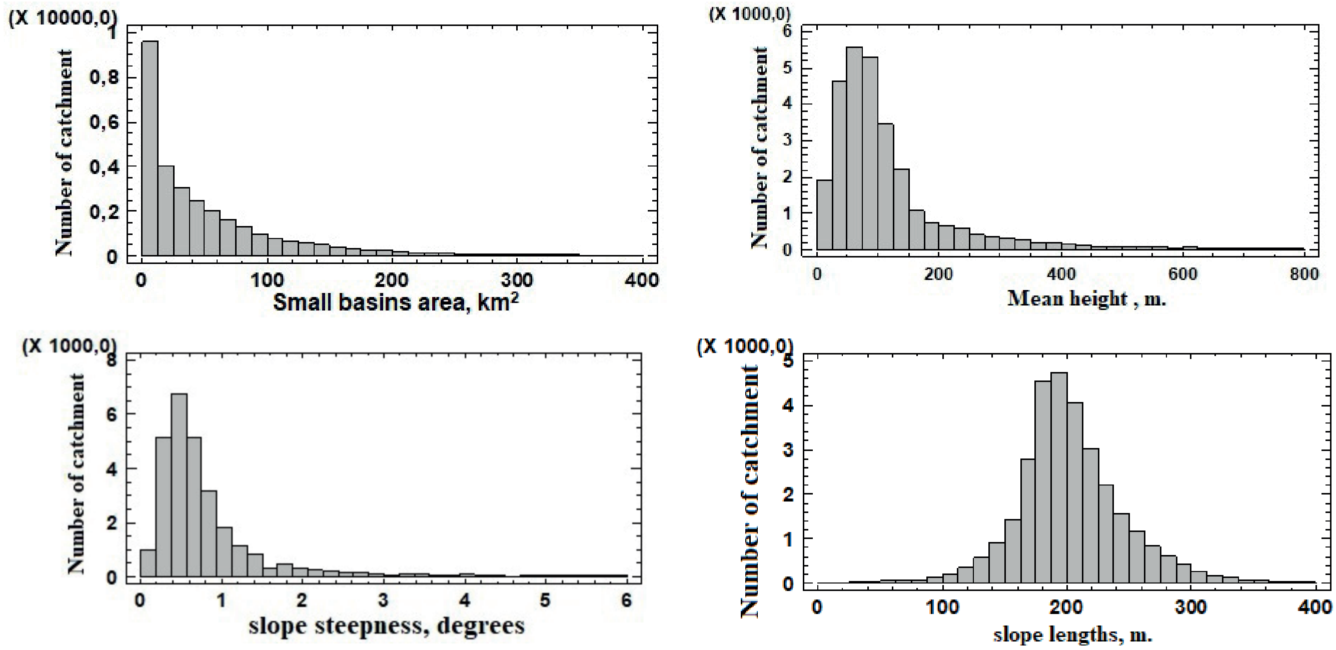

Fig. 2. Distribution of small basin by morphometric characteristics

Table 3. Basic statistics of morphometric characteristics of basin

Indicator	Min.	Max.	Mean	Median	Mode	Std. dev.
Area, km^2	0.25	10 449.7	65.9	31.7	0.31	182.2
Height, m	1	3 150.6	198.7	89.7	6	384.3
Slope steepness, degrees	0.0	33.2	1.7	0.6	0.4	3.4
Slope length, m	0	1 096.6	203.8	198.6	0	47.7

Flow Line Length

Flow line length refers to the distance over which any material can move downslope under the influence of gravity. This indicator was classified in the MapInfo Pro application using the "equalcount" function.

For the basin geosystems, the average flow line length is 204 m. The most common basins have flow line lengths in the ranges of 0-180 m, 180-200 m, and 220-500 m (27.2%, 24.6%, and 28.8% of all basins, respectively). These categories collectively cover 80.6% of the territory. Basins with flow line lengths of 0-180 and 180–200 m are densely distributed in the middle course of the Ob', as well as along both banks of the Irtysh and Tobol rivers. The upper, middle, and lower courses of the Ob' scatter small river basins with flow line lengths of 200–220 m in groups. Basins with the longest flow line lengths (220-500 and >500 m) are located along the Ural Mountains to the west, in the Kuznetsk-Salair mountain region to the south and southeast, and partially in the northern part of the basin (along the 60°N parallel).

Climate

Climatic characteristics of river basins were obtained from the All-Russian Research Institute of Hydrometeorological Information – World Data Center (RIHMI-WDC), which is publicly accessible[2]. Data from 73 weather stations is used for the period 1966-2021. In this section, the following climate parameters are considered

[2] Vserossijskijnauchno-issledovatel'skijinstitutgirometeorologicheskojinformacii - MirovojCentrDannyh (All-Russian Research Institute of Gyrometeorological Information - World Data Center) (VNIIGMI-MCD). (2023). Federal'nyjcentr po gidrometeorologiimonitoringuokruzhajushhejsredy. Temperaturavozduhaikolichestvoosadkov (ezhednevnyedannye) [online]. Available at: http://meteo.ru/data/162-temperature-precipitation#opisanie-massivadannyh. (in Russian) [Accessed 31 Aug. 2024].

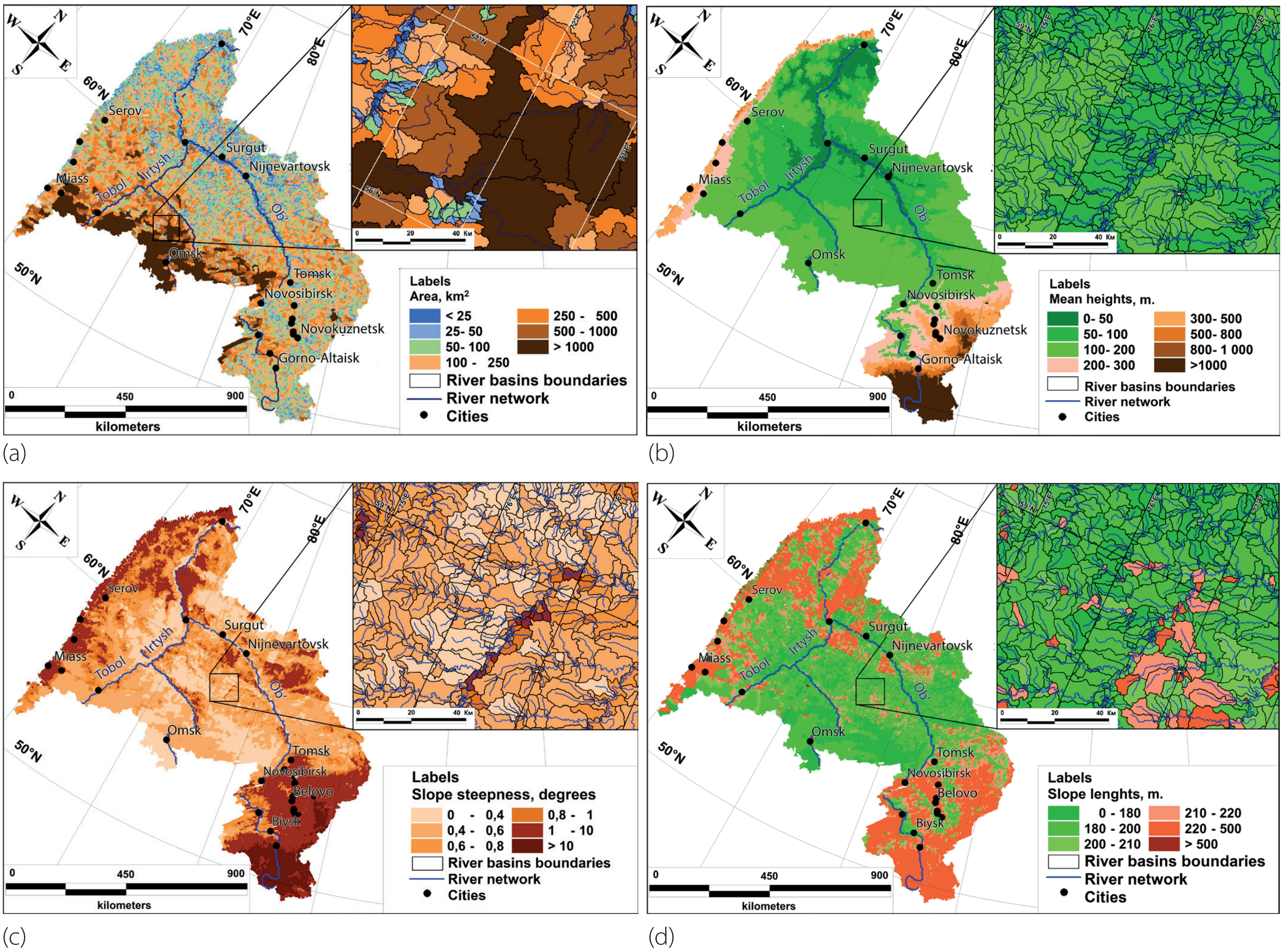

Fig. 3. Maps of morphometric characteristics of small river basins

and analyzed: average air temperature, average January temperature, average July temperature, climate "severity" (expressed as the recurrence of severe frosts below -30° in %), sum of active temperatures, average annual precipitation, average precipitation during the cold period, and average precipitation during the warm period.

Corresponding thematic maps for these parameters were created in MapInfo Pro (Fig. 4), their distribution (Table 4), and statistical analysis was performed (Fig. 5).

The National Atlas of Russia[3] was used as a reference for creating thematic maps, especially for scales and gradations. In the absence of reference maps, values were ranked by expert judgment. Examples of evaluating several climate parameters are provided below.

Mean Annual Air Temperature

The average annual air temperature ranges from -7.7°C in the Ob' River delta (Yamal-Nenets Autonomous Okrug) to 4.1°C in the southern (Altai Krai) and southwestern (Chelyabinsk region) parts of the Ob' basin. This indicator varies in a latitudinal direction. For the lower course of the Ob', the temperature range is from -7.7°C to -2°C (from the Ob' delta to almost the 62nd parallel). Basins with the minimum average annual air temperature values (25 basins) are located in the Ob' River delta near Salekhard. For the middle (from 56-60°N) and upper (from 51-56°N) courses of the Ob', temperatures range from -2-0°C and 0-4.1°C, respectively. The upper course includes basins with the maximum average annual air temperature values (5 basins). The southern and southeastern extremities of the basin (near the mountain structures of the Altai and Sayan mountains) have a temperature range of -2-0°C. The average value of the studied indicator for the entire Ob' river basin is -0.1°C (see Fig. 4).

Mean temperature in January

This indicator moves in a latitudinal direction. Basins with minimum temperatures (from -27.9°C to -22°C) are located in the lower course of the Ob' (the northern and northeastern extremities of the basin) and the southernmost extremity of the Ob' basin. There are minimal values of the analyzed indicator in only four basins (in the upper course of the Ob', near mountain structures). Here, basins with maximum January average temperatures (in the form of areas) are also located, totaling 4. Most small river basins have an average temperature in the range of -22 to -14°C (81.7% of basins), covering 85.9% of the Ob' watershed area. For the entire Ob' river basin, the average value of the studied indicator is -19.4°C.

Mean temperature in July

For this indicator, a pattern similar to the average January temperature is observed. The values range from 7.1 to 20.2°C, with 87.2% of the basins falling within the 16-20.2°C range (covering 90.3% of the Ob' basin area). These basins are located from 64°N latitude up to the mountain structures in the southern part of the basin. Due to the right-skewed distribution of the histogram, the average July temperature for the Ob' river basin is 17.2°C, which is relatively high for this region.

[3] National Atlas of Russia, tom 2, (2007). [online]. Available at: https://nacional'nyjatlas.rf/cd2/territory.html (in Russian) [Accessed 31 Aug. 2024].

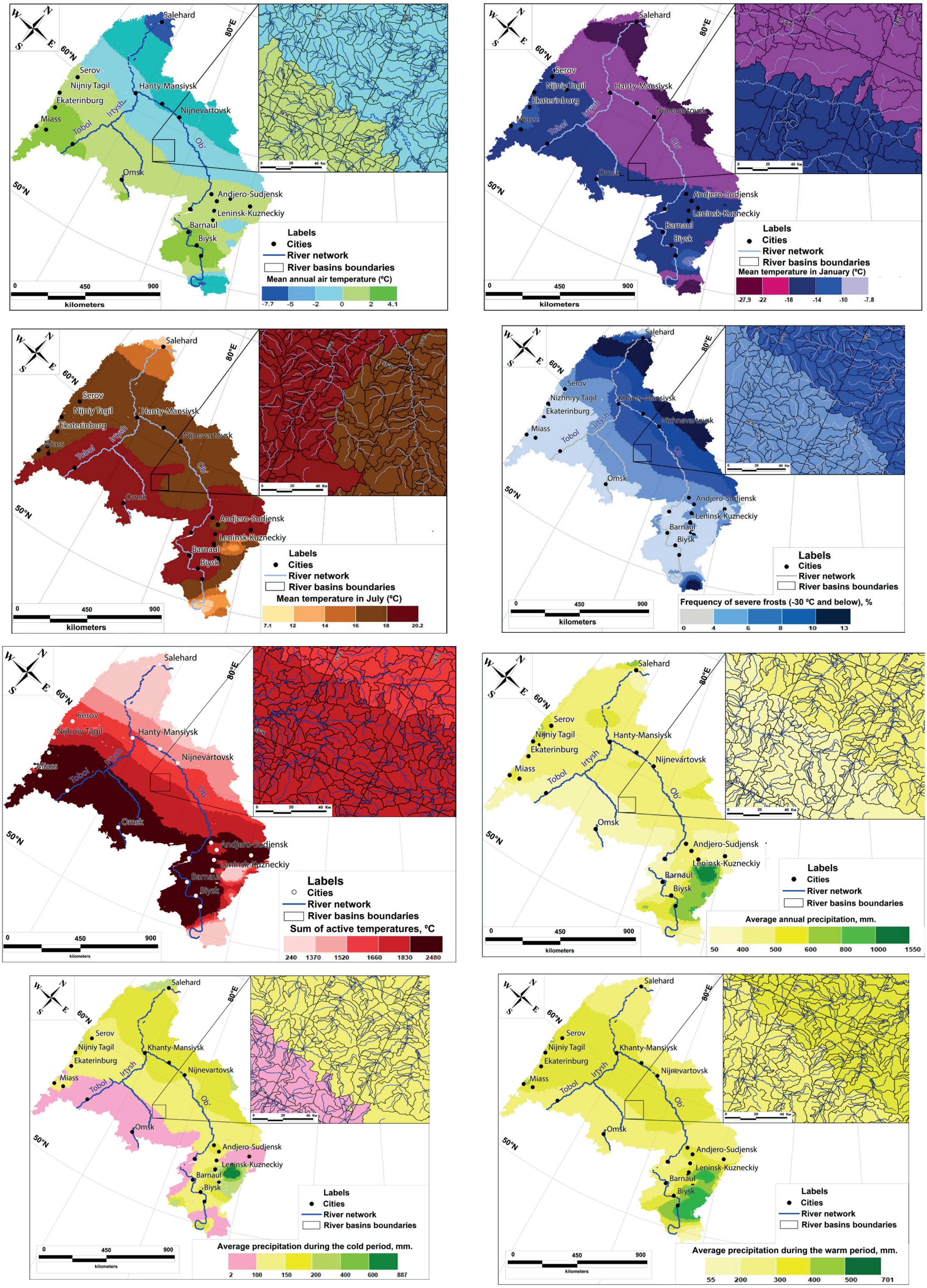

Fig. 4. Maps of climatic characteristics of small river basins

Climate Severity

The intensification of winter frosts, the increased duration of the cold period, and similar factors all contribute to climate severity. It largely determines the suitability of the environment for human habitation. In this study, this indicator is expressed as the number of days (%) with temperatures ≤ -30°C during the cold period (with an average monthly temperature < 0°C). The analyzed indicator varies from 0-14%. In this case, a different pattern is observed compared to the previously mentioned indicators: in the Ob' delta near the Gulf of Ob', the climate is "milder" (0-4%). Then, the climate severity increases up to 64°N latitude, after which it becomes milder again in a latitudinal direction up to the Altai Mountains, where, due to the altitudinal zonation, the climate becomes more severe. Here are the basins with the most severe climate (31 basins). Basins with no days of temperatures ≤ -30°C are located in the steppe regions of the southern part of the Ob' basin (207 basins). The average climate severity for the Ob' basin is 6.2%. 52.7% of the basins have a climate severity indicator in the range of 0-6% (covering 69.1% of the Ob' river basin area).

Precipitation

For the Ob' river basin, the mean annual precipitation is 463 mm. In most basin ecosystems (69% of basins), the average annual precipitation ranges from 400 to 500 mm. The minimum mean annual precipitation (59 mm) is recorded only in one basin, located at the beginning of the Altai Mountains. The highest value (1545 mm) is also recorded in only one basin, located in the southern part of the Ob' basin, in the interfluve of the Tom' and Biya rivers. This is where a cluster of basins with the maximum mean annual precipitation (800-1545 mm) is located. Additionally, the extreme northern end of the Ob' basin hosts a small cluster of basins with relatively high mean annual precipitation (600–800 mm). 69% of small river basins have mean annual precipitation in the range of 400-500 mm and cover 57.9% of the studied area.

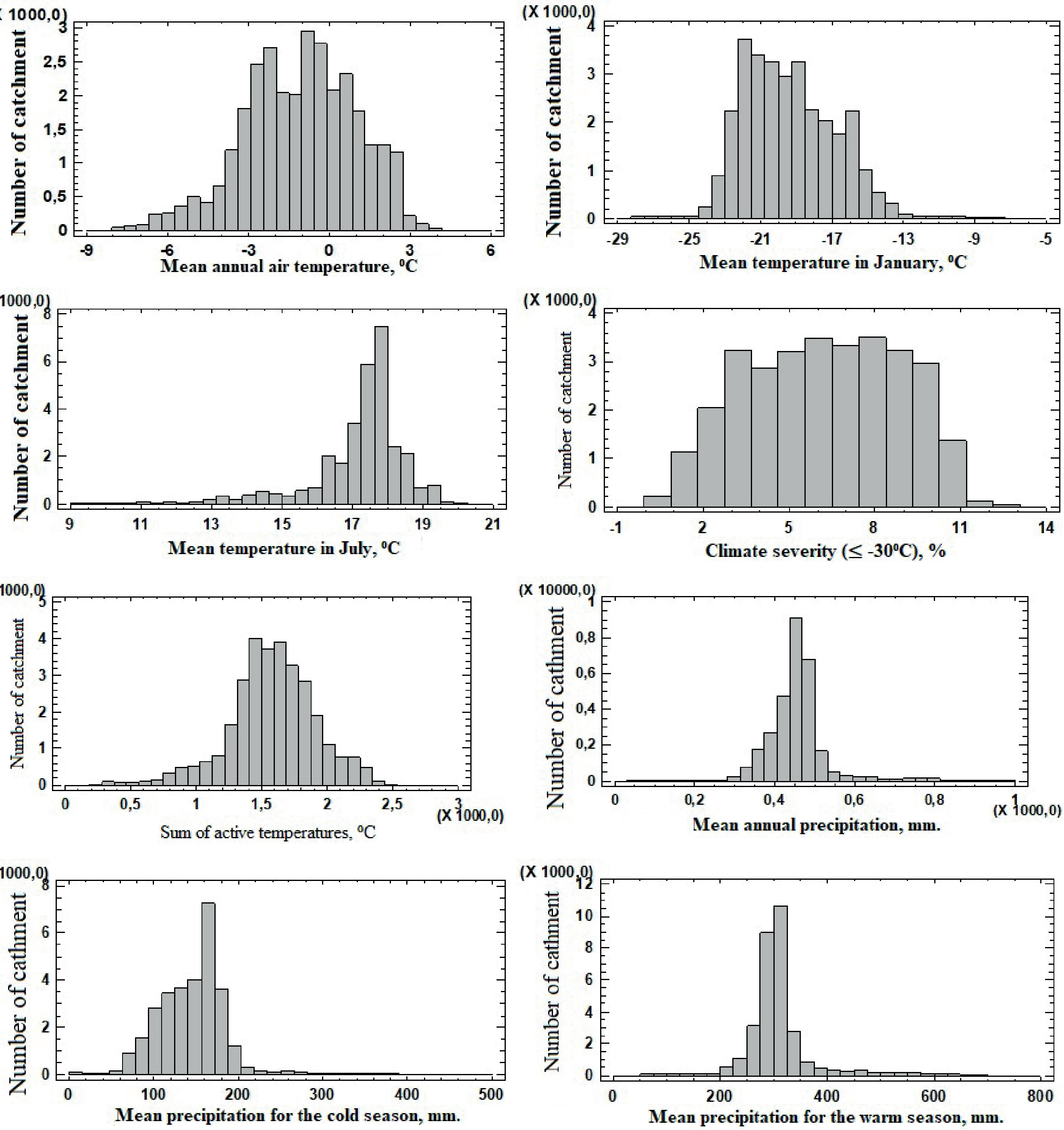

Fig. 5. Distribution of basins by climatic characteristics

Land use is expressed through the predominant types of land cover

The main source of data for creating a geospatial database on land cover types is the raster layer TerraNorte RLC, built based on satellite observations from the MODIS spectroradiometer on the Terra satellite (Bartalev et al., 2012) (Table 5). According to Table 5, the predominant land cover type in the Ob' river basin is deciduous forests (16.5% of the total area of the Ob' basin). This is followed by swamps (15%), meadows (14.2%), and light coniferous evergreen forests (14.1%). The less common are eternal snow and ice (0.04%), deciduous shrubs (0.1%), shrub tundra (0.3%), shrub tundra (0.4%), urbanized areas (0.2%), and deciduous coniferous trees (0.4%).

Table 4. Basic statistics of climatic characteristics

Indicators	Min.	Max.	Mean	Median	Mode	Std. dev.
Mean annual air temperature, °C	-7.7	4.1	-0.1	-1.0	-1.0	2.1
Mean temperature in January, °C	-27.9	-7.8	-19.4	-19.7	-21.3	2.6
Mean temperature in July, °C	7.1	20.2	17.2	17.5	17.8	20.2
Climateseverity, %	0	13	6.2	6.0	8.0	2.8
Sum of active temperatures, °C	249.7	2476.0	1583.9	1590.4	1445.3	330.2
Meanannualprecipitation, mm	59	1545	463	456	472	114
Mean precipitation for the cold season, mm	2	886	153	151	169	71
Mean precipitation for the warm season, mm	55	701	310	303	313	63

Table 5. Land cover types in the Ob' river basin

Code	Typesoflandcover	Area, km^2	Share to percentage
1	Dark coniferousevergreens	120,163.8	5.9
2	Light coniferousevergreens	284,842.1	14.1
3	Deciduous	334,311.3	16.5
4	Coniferousdeciduous (larch) forests	56,275.6	2.8
6	Swamps	304,957.7	15
8	Meadows	288,682.5	14.2
9	Deciduousshrubs	1,771.9	0.1
10	Mixed forests with a predominance of conifers	117,621.4	5.8
11	Mixedforests	89,133.6	4.4
12	Mixed forests with a predominance of deciduous trees	108,427.9	5.4
13	Open soils and rock outcrops	16,943.6	0.8
14	Steppes	24,729.5	1.2
15	Coastalvegetation	65,755.9	3.2
16	Shrubtundra	6,810.2	0.3
17	grassytundra	20,935.4	1
18	Shrubtundra	8,426.8	0.4
20	Riversandreservoirs	29,038.9	1.4
23	Deciduousconiferoustrees (larch)	8,994.3	0.4
24	Freshburning	15,757.7	0.8
31	Urbanizedareas	4,384.8	0.2
32	Eternalsnowandice	845	0 (0.04)
33	Arableland	117,647.2	5.8
Total		2,026,4571	100

For simplifying the construction of a thematic map of land cover types in the Ob' river basin, they were grouped as follows: coniferous forests (dark coniferous evergreens, light coniferous evergreens, coniferous deciduous (larch) forests); deciduous forests; shrubs (deciduous shrubs); aquatic and marsh complexes (swamps, rivers and reservoirs); other vegetation (meadows, coastal vegetation, deciduous coniferous trees, fresh burnings); mixed forests (mixed forests with a predominance of conifers, mixed forests, mixed forests with a predominance of deciduous trees); lands without vegetation cover (open soils and rock outcrops (projected coverage of all plant species less than 20%); steppes; tundra (shrub tundra, grassy tundra, shrub tundra); settlements (urbanized areas); eternal snow and ice; arable land (Fig. 6).

In the upper reaches of the Ob' River, coniferous and mixed forests are fragmented, mainly along the right bank of the basin, closer to the mountainous areas. In the middle and lower reaches of the river, a uniform distribution is observed, but with a prevalence of coniferous forests (see Fig. 6). The area of urbanized areas is 4,384.8 km^2 (0.2%).

Assessment Of Anthropogenic Load On Basin Systems

Human activities have always impacted the surrounding natural environment, but until the 20th century, this influence was not so noticeable due to the Earth's biosphere's ability to regenerate. In the second half of the 20th century, the Earth's population growth and intensified economic activities have led to substantial anthropogenic pressure on the Earth's biosphere, resulting in significant and often detrimental alterations to natural environments. Anthropogenic load is defined as a measure (quantitative and qualitative) of the impact of human economic activity on the surrounding natural environment, leading to its direct or indirect alteration. The impact affects both individual natural components and elements (such as landscapes, biota, river basins, etc.) and natural complexes as a whole. At the same time, their significant transformation occurs (Didenko et al., 2018). The most important elements of the natural environment, including atmospheric air, soil environment, vegetation cover, surface, and groundwater, biotic complexes, are objects of anthropogenic impact exerted by human activity (Miller, 1993). In this study, anthropogenic load was considered based on the definition proposed by Rejmers (Rejmers, 1990). The environmental aspects of sustainable regional development were evaluated through a quantitative assessment of anthropogenic load on basin systems using GIS technologies (Ivanov, 2019; Ivanov et al., 2020; Yermolaev et al., 2023b). For this purpose, a selected range of integral indicators was used, reflecting anthropogenic load directly or indirectly: 1. population density in the basin; 2. road network density (taking into account road type); 3. agricultural development of basins (without ploughing). These indicators comprehensively reflect the degree of economic development in a given area, as they provide a constant impact that is not significantly subject to spatial or temporal fluctuations. Another criterion for selecting these indicators was their availability and potential for data updates over time. The methodology used to calculate the integral indicator of anthropogenic load requires the transformation of selected indicators into a single numerical scale. In scientific literature, logarithmic transformations of the form *log(x+1)* are widely used for a comprehensive assessment of anthropogenic load. This transformation is used for each individual indicator that affects any natural environmental object. Logarithmic transformation is applied to avoid excessive dominance of extreme values on the resulting cumulative map of anthropogenic impact and to adjust frequency distributions, which are usually distorted (Andersen et al., 2013). To ensure the comparability of different indicators, it is necessary to

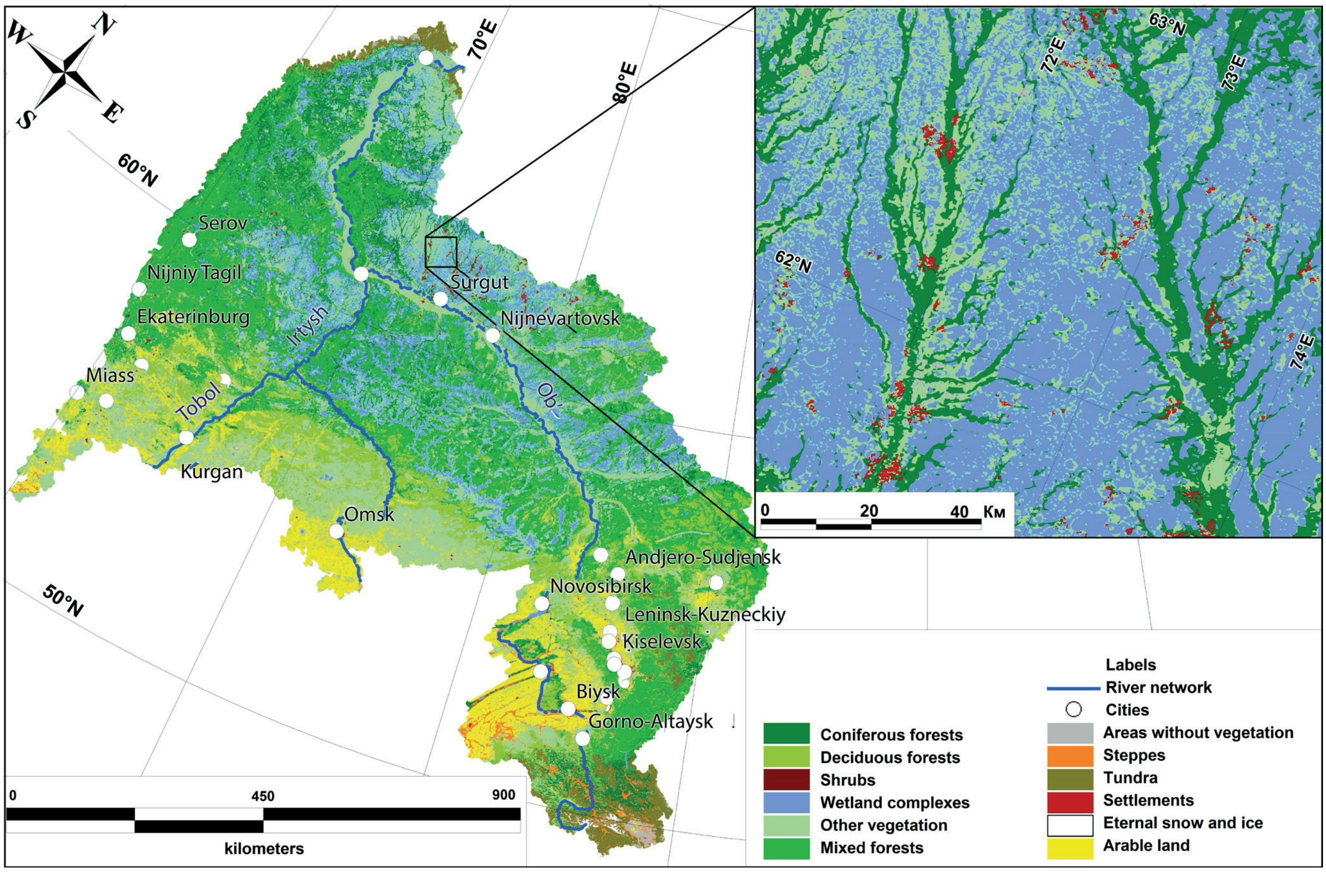

Fig. 6. Land Cover/Land Use map of the Ob' river basin

standardize data on a scale of 0 – 1 according to Eq. (1) (Allan et al., 2013):

$$\left(x_i - x_{min}\right) / \left(x_{max} - x_{min}\right) \quad (1)$$

Population density. Population density is an important measure that indirectly shows how much and what kind of land development (industrial and agricultural) is happening. It also shows how much human activity is affecting natural geosystems.

The primary source of information used is the freely available data from the Global Human Settlement Layer (GHSL) project[1]. This project provides global spatial information about the population over time in the form of built-up area maps, population density maps, and settlement maps. The information is generated using scientifically grounded analytics and advanced technologies for intelligent spatial data analysis. The processing structure of GHSL utilizes heterogeneous data, including global archives of small-scale satellite imagery, census data, and geographic information provided by volunteers. The data are processed fully automatically, resulting in analytical and objective reports on population presence and infrastructure creation.

The project offers a range of products for different time periods, resolutions, and coordinate systems. In our study, the raster grid with population data GHS-POP for the year 2015 was used, with a resolution of 250 m (9 arc-seconds) and the WGS-84 coordinate system. This spatial raster product consists of a set of raster "tiles" depicting the distribution and population density expressed in the number of people per cell (Fig. 7). GHS-POP provides raster grids with population figures for key years: 1975, 1990, 2000, and 2015, provided by the Center for International Earth Science Information Network (CIESIN) Gridded Population of the World (GPW v4.10).

For the Ob' river basin, several raster tiles were downloaded, merged into a single raster, and clipped according to the common boundary of the Ob' river basin and the boundaries of small river basins in the GIS application QGIS. Using the field calculator in QGIS, the total population for each basin was determined. The resulting values were then divided by the area of each basin.

For basins with non-zero density, basic statistics were calculated (Table 6) and a frequency distribution histogram was plotted (Fig. 8).

To account for population density in calculating anthropogenic pressure, this indicator was normalized to a dimensionless form with a range of values from 0 to 1. Therefore, basins with a population density greater than or equal to 1000 people/km^2 were assigned a value of 1 (the maximum possible value). For the remaining basins, the indicator was normalized using the following Eq. (2):

$$\left(\log\left(P_{dens} + 1\right) - 0\right) / \left(\log\left(1000 + 1\right) - 0\right) \quad (2)$$

where P_{dens} is the population density, people/km^2.

As a result, we obtained the normalized indicator (see Fig. 8, Table 7):

We created a corresponding thematic GIS database based on the transformed population density indicator (Fig. 9), where the following pattern is observed: basins with the highest population density are located along the industrial centers of the Urals region (western part of the basin); in the southwest, in the Kurgan, Omsk, and partially in the Tyumen regions. Basins with relatively high population density are concentrated around the oil production centers in the Khanty-Mansi Autonomous Okrug (northeast of the basin). In the south of the basin, the highest population density is observed in the Novosibirsk and Kemerovo regions, in the Altai Republic, and in Altai Krai. Overall, most basins have zero or

Fig. 7. Population raster grid from the GHS-POP project of GHSL

Table 6. Basic statistics of population density in basins (people/km^2)

Quantity(basin)	Min.	Max.	Mean	Mode	St.Dev.	Percentile, %								
						1	5	10	25	50	75	90	95	99
5507	1	4467	46.96	1	204.78	1	1	1	1	4	14	69	199	967

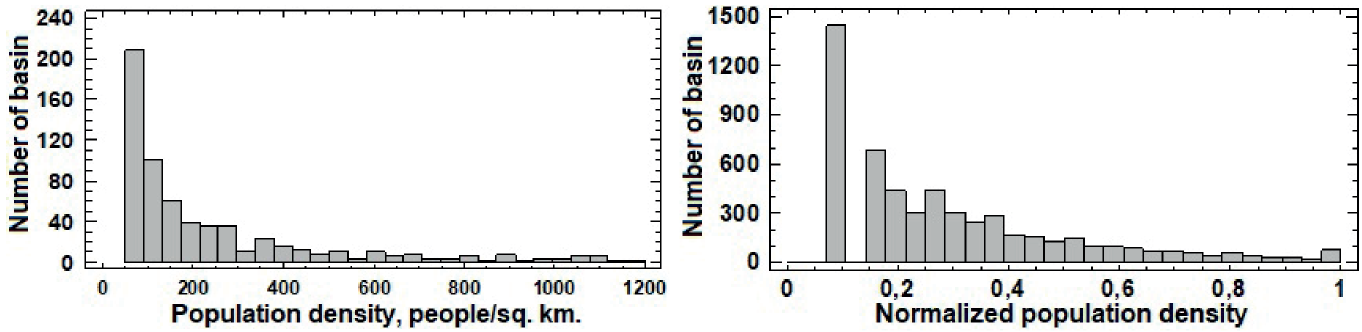

Fig. 8. Distribution of basins by population density indicator

Table 7. Basic statistics of the population density indicator in basins with population density >0 (people/km²)

Quantity (basin)	Min.	Max.	Mean	Mode	St. Dev.	Percentile, %								
						1	5	10	25	50	75	90	95	99
5507	0.1	1	0.3	0.1	0.21	0.1	0.1	0.1	0.1	0.4	14	0.61	0.77	0.99

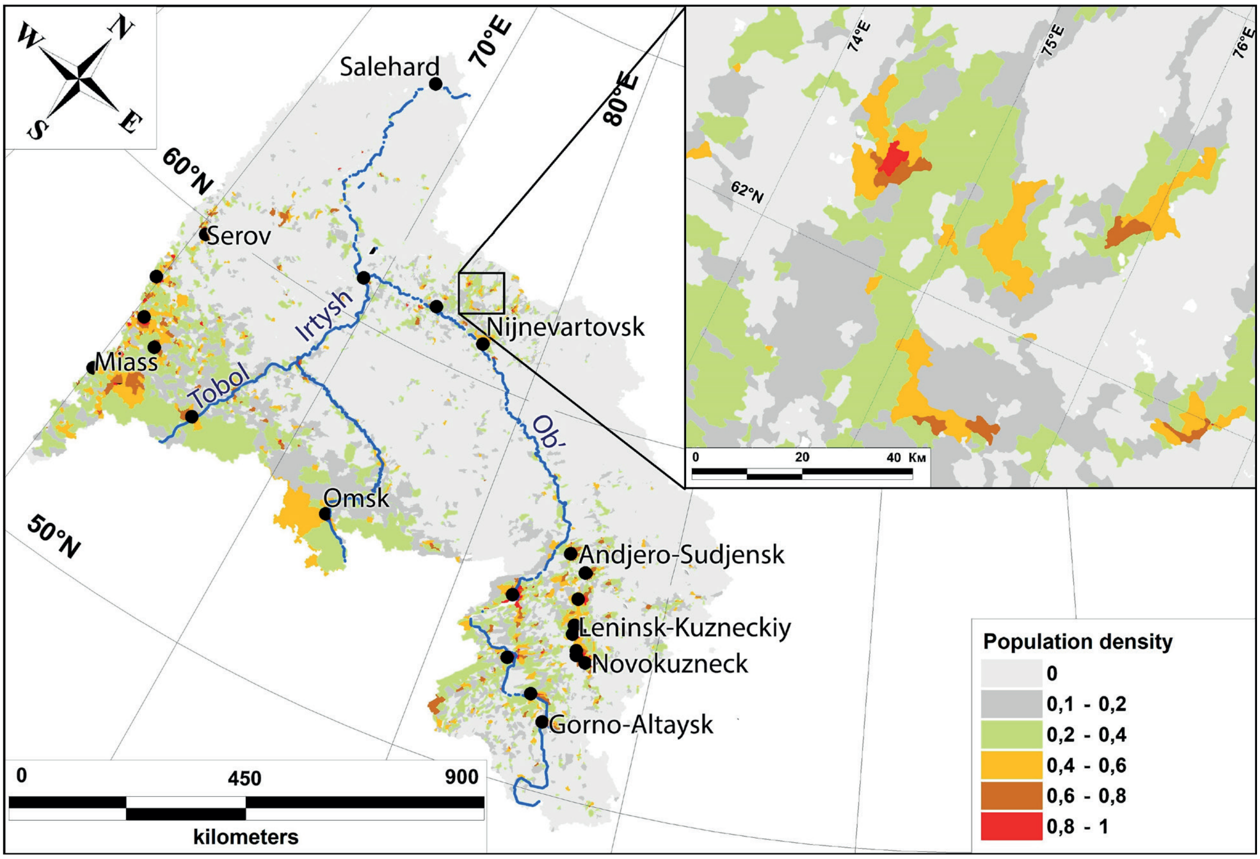

Fig. 9. Normalized indicator of population density in basin geosystems of the Ob' river basin

very low population density due to harsh climatic conditions, vast marshlands (middle reaches of the Ob'), and mountainous terrain (extreme southern part of the basin).

The density of the road network

A well-developed road network is an essential component of any modern state. The road network is a basic component of infrastructure. Roads serve as fundamental infrastructure components, reflecting territorial and industrial development while contributing to anthropogenic pressure. The type and development of the road network largely determine anthropogenic loads of both linear and areal types. Thus, roads passing through various parts of the basin slopes can have anthropogenic effects due to the transformation of surface runoff. It can both interrupt and concentrate. As a result, significant restructuring occurs in erosion, transport, and pollutant accumulation processes. Railways require large land clearances, and in forested areas, they require clear-cutting.

To calculate the road network density in the basins, data from[4] (Haklay& Weber, 2008), as of 2023 was used. During the work, roads and railways were processed. Roads were classified based on their type, with expert-assigned scores ranging from 1 to 5, indicating increasing levels of importance and impact. The scoring system for roads was derived from discussions and consensus within the Russian OSM community[5]). In addition,

[4] OpenStreetMaps. (2023). [online]. Available at: https://www.openstreetmap.org [Accessed 31 Aug. 2024]
[5] OpenStreetMapWiki -RU:Key: highway. (2018). [online]. Available at: https://wiki.openstreetmap.org/wiki/RU:Highway_classification (in Russian) [Accessed 31 Aug. 2024].

load scores were assigned for railways based on the "railway" attribute field. The railway tag is used to denote all types of railways or other transport using rails[6].

Before performing the calculations, the OSM road and railway layers were merged into one layer. All calculations were carried out in the ArcGIS software package (v. 10.4.1). First, in each layer, polylines with the same load score were merged using the "Merge by Attribute" geoprocessing tool. In the next step, the roads were intersected with the boundaries of the small river basins using the "Identify" tool,.Total lengths of roads and railways with the same load score within each basin were calculated using the "Calculate Geometry" tool. As a result, fields with total lengths of two layers of OSM roads with load scores from 1 to 5 were added to the geospatial database of basin geosystems in the Ob watershed.

The density of roads for each category in the basin is calculated as the ratio of length to basin area (km/km^2) (Table 8). The overall indicator (Rpress) for assessing the impact of road density was calculated using the following Eq. (3):

$$R_{press} = R_1 + 2*R_2 + 3*R_3 + 4*R_4 + 5*R_5 \quad (3)$$

where R_1 represents road density with a score of 1 for anthropogenic impact, R_2 represents road density with a score of 2, and so forth.

They adjusted the indicator based on statistical analysis. As a result, it was found that 95% of basins exhibit a road density value below 4. Consequently, a maximum score of 1 was assigned to basins exceeding this threshold. For the remaining basins, the indicator was normalized using Eq. (4):

$$\left(R_{press} - 0\right) / (4 - 0) \quad (4)$$

where R_{press} –the overall road density indicator.

Because of this normalization, the indicator ranged from 0 to 1. Here is the corresponding thematic GIS database (Fig. 10) and Table 9 with the normalized values.

The thematic map constructed using the final road density indicator, shown in Fig. 11, reflects its spatial distribution. The findings are as expected and rational: basins with the highest road density indicators are predominantly located in urbanized areas, mirroring the patterns observed in population density.Additionally, basins with relatively high road density indicators are those intersecting highways and railway lines connecting major cities, regional administrative centers, industrial areas, and major oil production centers. About 56% (17,381) of basins lack road networks due to challenging terrain conditions (e.g., extensive marshlands, etc.). These basins are scattered along the middle course of the Ob' River and in the northern and southern parts of its basin.

Agricultural Land Use

The extent of agricultural land use serves as the foundation upon which any country's agricultural sector grows and develops. It also serves as a crucial indicator of anthropogenic pressure. In this study, the plowed of basins serves as the key characteristic of agricultural land use, reflecting the primary activity of the agro-industrial complex. Often, primary cultivation leads to the complete destruction of native vegetation, which is replaced by agrocenoses or pasturelands. Soils under cultivation, where various crops are grown, undergo disruptions in horizon structure, leading to soil degradation, accelerated anthropogenic erosion, and the movement of organic and mineral pollutants in dissolved form with surface runoff into small rivers and soil-groundwater.

At the initial stage, arable lands were identified separatelyseparately from the TerraNorte RLC raster layer in ArcGIS using the "reclassification by table" tool. The resulting raster layer was vectorized, and the freely available data in each basin was calculated as the ratio of the area of cultivated lands to the total area of the basin. For basins containing arable lands, a frequency histogram was constructed (Fig. 12), and basic statistical indicators were calculated (Table 10), forming the resulting layer of plowed land map (Fig. 13).

Table 8. Basic Statistics of Road Density Indicator in Basins (km/km^2)

Quantity (basin)	Min.	Max.	Mean	Mode	St. Dev.	Percentile, %								
						1	5	10	25	50	75	90	95	99
13357	0.000003	82.7	1.14	0.57	2.96	0.006	0.03	0.07	0.19	0.47	1.06	2.25	3.86	13.02

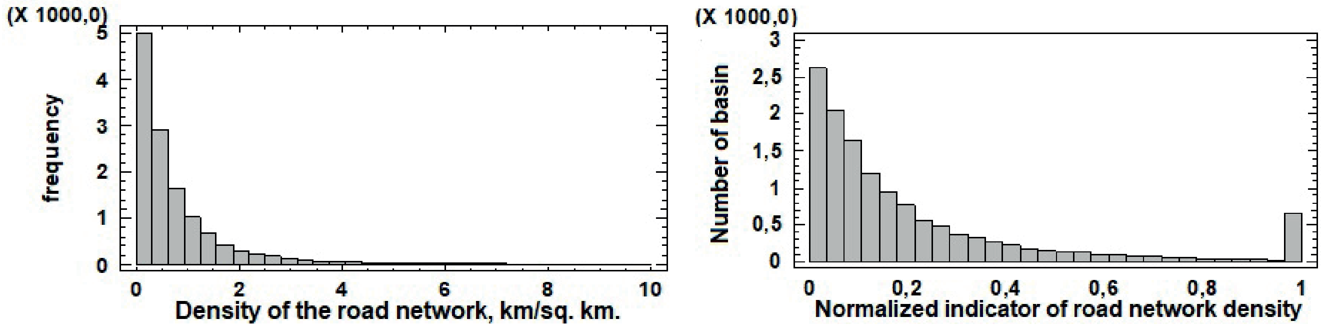

Fig. 10. The distribution of basins according to road density

Table 9. The basic statistics of the normalized road density in the basins (km/sq.km)

Quantity (basin)	Min.	Max.	Mean	Mode	St.Dev.	Percentile, %								
						1	5	10	25	50	75	90	95	99
30738	0	1	0.09	0	0.20	0	0	0	0	0	0.09	0.28	0.50	1

[6] OpenStreetMapWiki - RU:Key:railway. (2016). [online]. Available at: https://wiki.openstreetmap.org/wiki/RU:Key:railway (in Russian) [Accessed 31 Aug. 2024].

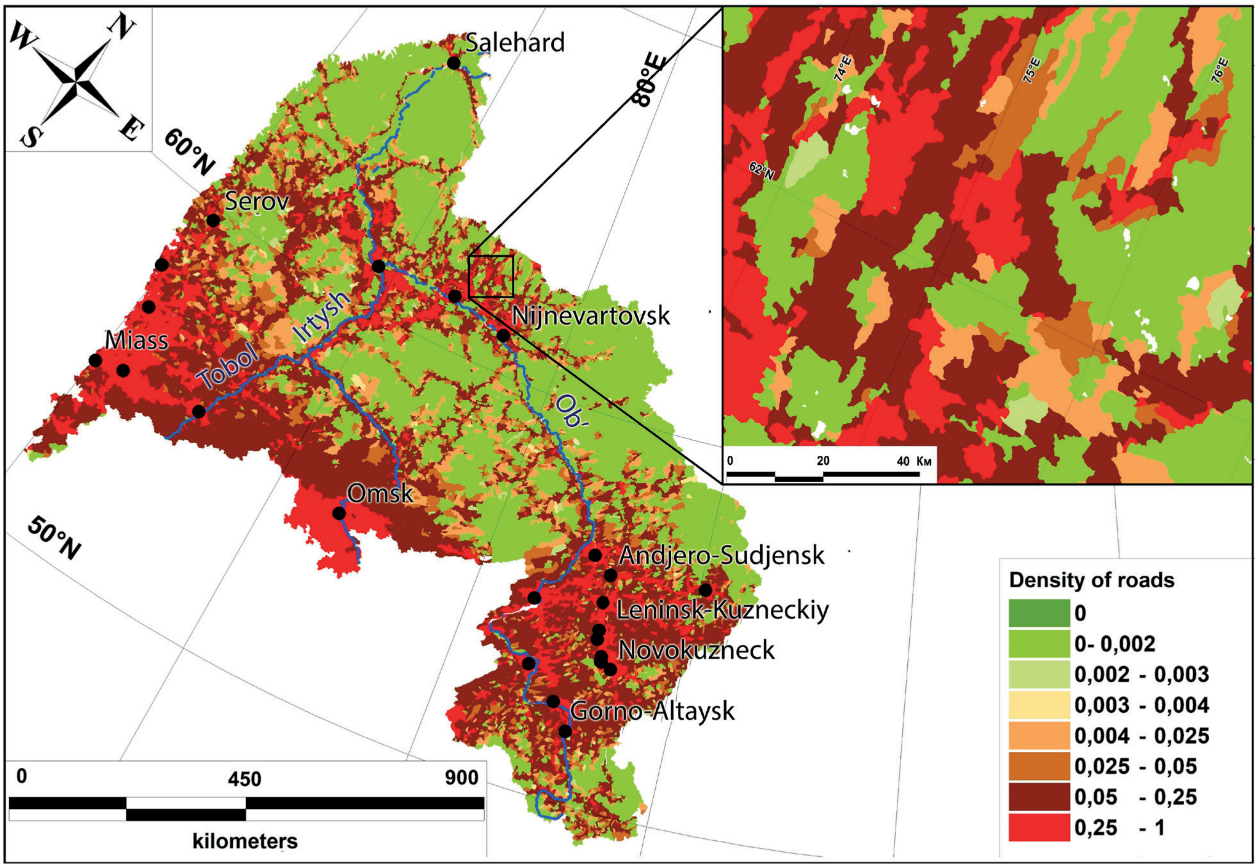

Fig. 11. Final road density indicator in the basins of small rivers within the Ob' river basin

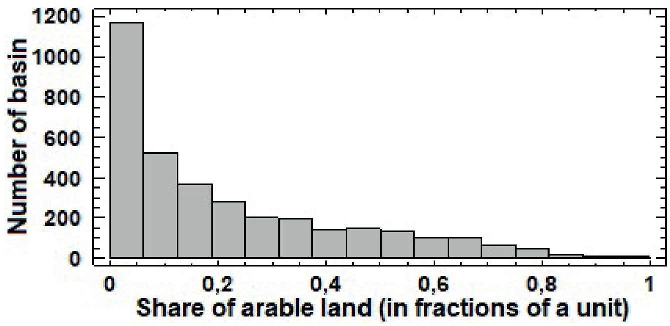

Fig. 12. Distribution of Basins by Agricultural Land Use

Table 10. Basic Statistics and Percentiles of Agricultural Land Use in Basins(%)

Quantity (basin)	Min.	Max.	Mean	Mode	St. Dev.	Percentile, %								
						1	5	10	25	50	75	90	95	99
3493	0	100	21	8	2.47	0.0002	0.003	0.008	0.04	0.13	0.34	0.56	0.67	0.82

Anthropogenic Load

The final indicator of anthropogenic load is calculated as the average of three integral indicators: population density, road network density, and agricultural land use, i.e., a simple linear assessment is used.

The final indicator of anthropogenic load is ranked as follows: very low, low, moderate, high, and very high anthropogenic load (Table 11).

For spatial visualization of the final anthropogenic load indicator, a corresponding thematic map (Fig. 14) has been created, and key statistics have been determined (Fig. 15, Table 12).

Basin ecosystems that do not contain arable land, road networks, or population are classified as basins with zero anthropogenic load (54.3% of basins). These basins, by area, cover 35% of the territory. Basins with a very weak anthropogenic load (35.7%) have a very low population density, averaging 0.73 people/km^2, low road density (measured in hundredths and thousandths of km/km^2), and consequently a very low percentage of arable land, averaging 1.8%. Basins in this category cover almost half of the entire Ob' River basin, accounting for 49.5% of it. Basins of small rivers experiencing weak anthropogenic load (6.6%) have an average population density of 10.7 people/km^2, arable land percentage of 19.4%, predominantly containing field roads (4.68 km/km^2), and cover 6.6% of the territory. Basins with a moderate anthropogenic load form the outer "ring" of urbanized areas, where the average population density reaches 63.4 people/km^2, arable land percentage is 19.4%, and road density begins to increase (0.05 - 0.24 km/km^2). Basin ecosystems with strong and very strong anthropogenic loads (summing up to just over 1% of the total number

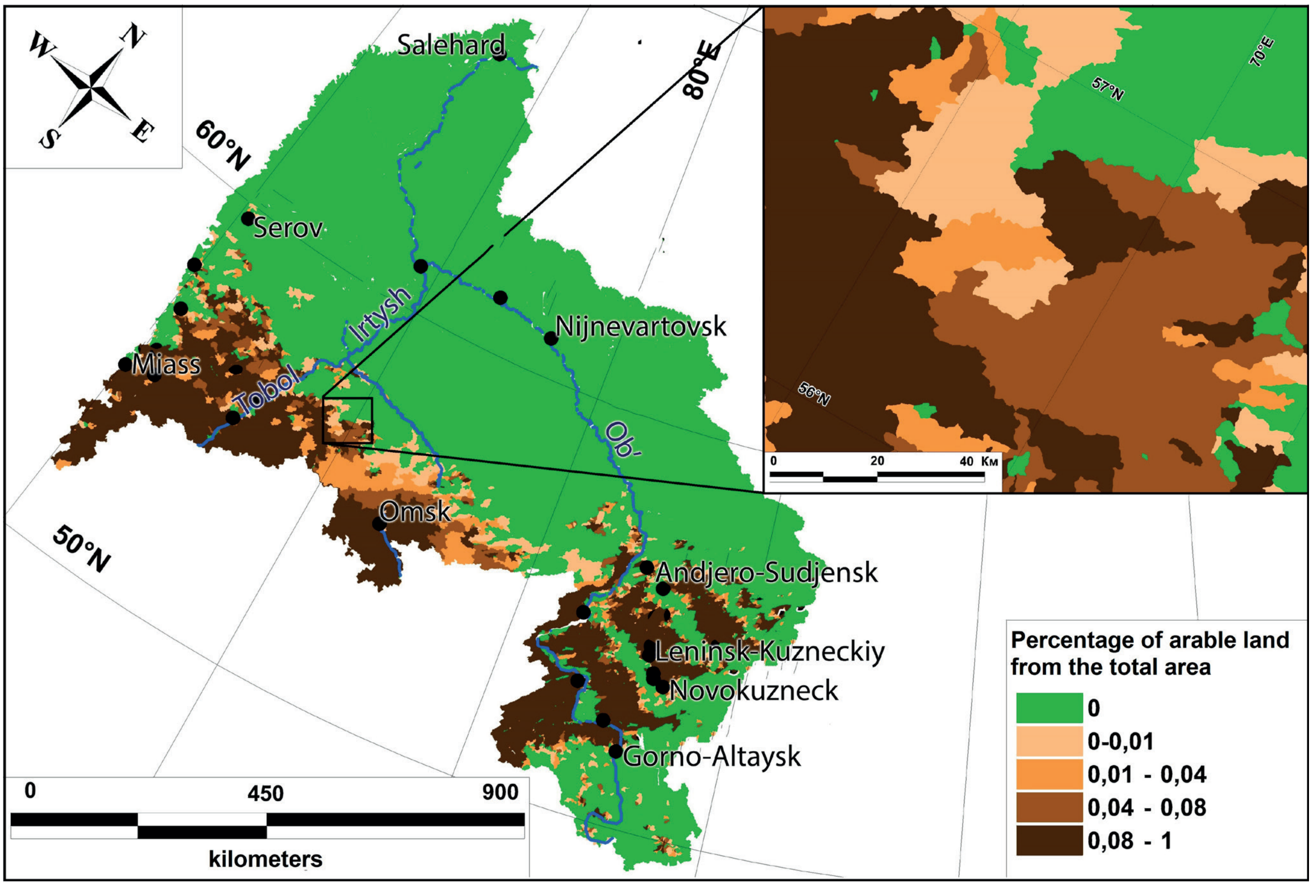

Fig. 13. Map of Agricultural Land Use in Basins of Small Rivers within of the Ob' river basin

Table 11. CategoriesofAnthropogenicLoad

Anthropogenicload			Absent	Veryweak	Weak	Mean	Strong	Verystrong
Interval			0	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	>0.8
Ploughness, %	Min.		0	0	0	0	0	58.3
	Mean		0	1.76	19.4	16.3	12.5	74.5
	Max.		0	66.7	100	100	100	100
Roading, km/km^2	R_1	Mean	0	0,11	4.68	0.45	1.14	0.62
	R_2	Mean	0	0,08	0.30	0.97	3.33	3.72
	R_3	Mean	0	0,04	0.15	0.24	0.57	0.06
	R_4	Mean	0	0,003	0.017	0.0	0.16	0.24
	R_5	Mean	0	0,006	0.06	0.19	0.67	0.019
Populationdensity, people/km^2	Min.		0	0	0	0	11	322
	Mean		0	0.73	10.7	63.4	589.8	525.7
	Max.		0	0.43	415	505	4467	750

of basins) constitute the inner "core" of urbanized areas, characterized by high population densities averaging 589.8 and 525 people/km^2 respectively, noticeable increase in road density including highways and railways. The average arable land percentage in these areas is 12.5% and 74.5% respectively. Together, they cover approximately 1% of the entire Ob' River watershed.

Overall, the situation is as follows: basins with zero, weak, and very weak anthropogenic loads are evenly distributed throughout the entire Ob' river basin territory (totaling 95.1% of the total area). Basins with moderate, strong, and very strong loads are located in the western, northwestern, southwestern (agricultural and industrially developed regions of the Urals), southern (Kuzbass), central, and eastern parts of the Ob' river basin (areas of intensive coal, gas, and oil extraction).

The obtained results effectively reflect the differences in anthropogenic pressure in the spatial aspect. The indicators used to assess anthropogenic pressure on geosystems reflect how much human activity affects the territory , as well as the significant influence of each category of anthropogenic load. The data obtained can be used to address a range of spatial development tasks in this macro-region of Russia and to develop compensatory measures within river basins.

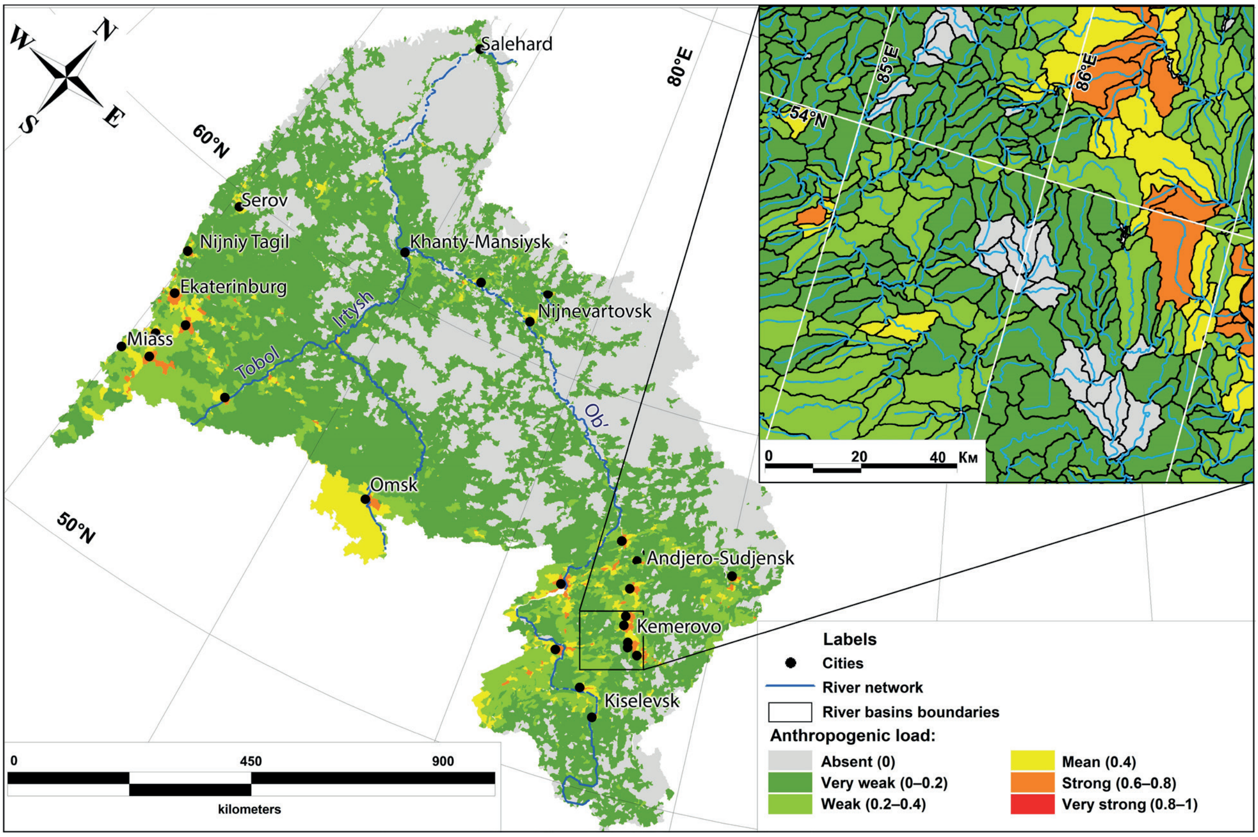

Fig. 14. Map of anthropogenic load on the geosystems of the Ob' river basin

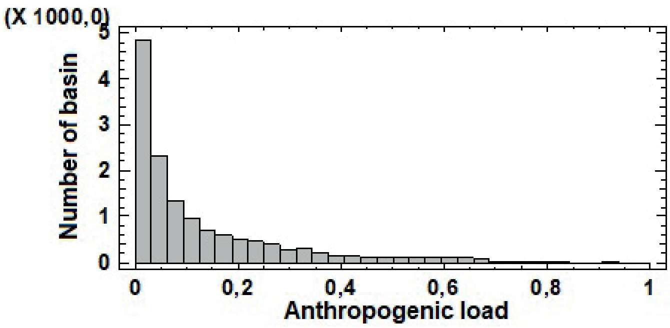

Fig. 15. Distribution of Basins by Anthropogenic load

Table 12. Basic statistics and percentiles of anthropogenic load on basins

Quantity	Min.	Max.	Mean	Mode	St.Dev.	Percentile, %								
						1	5	10	25	50	75	90	95	99
30738	0	0.91	0.06	0	0.12	0	0	0	0	0	0.05	0.2	0.32	0.6

CONCLUSIONS

For the macro-region of Russia within the Ob' river basin, a GIS database of small river basins has been created for the first time, allowing the implementation of a geosystem (basin) approach to territorial assessment. Additionally, a geospatial database has been developed for the first time, detailing the natural-resource potential and indicators of economic development in this territory with the formation of a specialized GIS. The total number of parameters in the database amounts to 12, including morphometric and climatic characteristics, land use types, and anthropogenic load.

The geospatial database enabled an assessment of the territory based on key morphometric relief characteristics, hydro-climatic parameters, types of land cover, and human economic activity. Thematic GIS databases were created for all parameters, the main statistical indicators were determined, and a spatial analysis of the most general patterns of their development in the Ob' river basin was conducted.

Through the system of integrals (population density, road density, and arable land), an assessment of anthropogenic pressure on the geosystems of the small rivers of the Ob' was carried out. According to this assessment, basins with no anthropogenic load predominate (54.3%), due to the low population density in the northern territories, while 35.7% are subject to very weak pressure and 6.6% to weak pressure. Only 3.4% of the territory, located around urbanized areas, is subject to moderate, strong, and very strong anthropogenic pressure.

The results obtained can be used in the implementation of Government Programs for the spatial development of the Western Siberia and Arctic regions within of Russia.

REFERENCES

Allan J.D., McIntyre P.B., Smith S.D., Halpern B.S., Boyer G.L., Buchsbaum A., Steinman A.D. (2013). Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. Proceedings of the National Academy of Sciences, 110 (1), 372-377. DOI:10.1073/pnas.1213841110

Andersen J.H., Stock A., Mannerla M., Heinänen S., Vinther M. (2013). Human uses, pressures and impacts in the eastern North Sea. Technical Report from DCE – Danish Centre for Environment and Energy, 18, 136. http://www.dmu.dk/Pub/TR18.pdf

Bartalev S.A., Egorov V.A., EfremovV.Ju., Loupian E.A., Stycenko F.V., Flitman E.V. (2012). Assessment of the area of fires based on integration of satellite data of various spatial resolutions MODIS and Landsat-TM/ETM+. Sovremennye problemy distancionnogo zondirovanija Zemli iz kosmosa, 9(2), 9-27 (in Russian).

Bartalev S.A., Egorov V.A., Loupian E.A., Khvostikov S.A. (2014). A new locally-adaptive classification method LAGMA for large-scale land cover mapping using remote-sensing data. Remote Sensing Letters, 5(1), 55-64. DOI:10.1080/2150704X.2013.870675

Braude D.I. (1965). Soil erosion, drought and their control in the CBER. M., Nauka, 140 (in Russian).

Danielson J.J. Gesch D.B. (2011). Global multi-resolution terrain elevation data 2010 (GMTED2010) U.S. Geological Survey Open-File Report, 26. DOI:10.3133/ofr20111073

Didenko P.A., Vodop'janova D.S., Skripchinskaja E.A. (2018). Assessment of the stability of landscapes of the Stavropol Territory to anthropogenic load. Nauka. Innovacii. Tehnologii, 2, 127-138 (in Russian).

Ermolaev O.P. Vedeneeva E.A., Mal'cev K.A., Mozzherin V.V., Muharamova S.S., Harchenko S.V., Shynbergenov E.A. (2017c). Mapping basin geosystems of Russia. Treshnikovskie chtenija-2017, Sovremennaja geograficheskaja kartina mira I tehnologii geograficheskogo obrazovanija, Mat. nauch.-prakt. konf., 266-268 (in Russian).

Ermolaev O.P., Mal'cev K.A., Muharamova S.S., Harchenko S.V., Vedeneeva E.A. (2017a). Cartographic model of river basins of European Russia. Geografija I prirodnye resursy, 2, 27-36 (in Russian).

Ermolaev O.P., Mal'cev K.A., Muharamova S.S., Ivanov M.A., Shynbergenov E.A. (2017b). Creation of the GIS «River Basins of Russia». Mat. VI Mezhd. nauch.-prakt. konf. «Aktual'nye voprosy geodezii I geoinformacionnyh sistem», 50-53 (in Russian).

Gordeev V.V., Martin J.M., Sidorov I.S., Sidorova M.V. (1996). A reassessment of the Eurasian river input of water. Sediment, major elements, and nutrients to the Arctic ocean. Amer. J. of Science, 296, 664-691.

Haklay M., Weber P. (2008). Openstreetmap, User-generated street maps. IEEE Pervasive computing, 7(4), 12-18. DOI:10.1109/MPRV.2008.80.

Ivanov M.A. (2019). Geography and geoecology of basin geosystems of the Volga Federal District, dis. …kand. geogr. nauk. Kazan', 197 (in Russian).

Ivanov M.A., Muharamova S.S., Ermolaev O.P. (2020). Assessment of anthropogenic load on the territory of the Volga Federal District using the basin approach. Cifrovaja geografija, materialy Vseros. nauch.-prakt. konferencii s mezhdunar. uchastiem. [online]. Available at, https,//dspace.ncfu.ru/bitstream/20.500.12258/4067/1/127138%20%5BSKFU%5Dnit-2-2018.pdf (in Russian).

Ivanov V., Milyaev I., Konstantinov A., Loiko S. (2022). Land-use changes on Ob River floodplain (Western Siberia, Russia) in context of natural and social changes over past 200 years. Land, 11(12), 2258. DOI:10.3390/land11122258

Korytnyj L.M. (2001). Basin concept in environmental management, monografija. Irkutsk, Izd-vo IG SO RAN, 163. (in Russian)

Criteria and parameters of permissible anthropogenic loads on agricultural landscape components (2005). Kursk, VNIIZiZPJe RASHN, 58 (in Russian).

Lisetskii F.N., Buryak J.A., Zemlyakova A.V., Pichura V.I. (2014). Basin organizations of nature use, Belgorod region. Biogeosystem Technique, 2(2), 163-173. DOI:10.13187/bgt.2014.2.163.

Miller T. (1993). Living in the environment. - M., Progress (in Russian).

O'Callaghan J., Mark D.M. (1984). The extraction of drainage networks from digital elevation data. Comput. Vis., Graph., Image Process., 28(3), 323-344.

Osipov G.K., Dmitriev V.V. (2017). Basin-landscape approach to territorial planning. Informacija I kosmos, 3, 112–117. (in Russian with English summary)

Pogorelov A.V., Dumit Zh.A. (2009). Relief of the river basin Kuban, morphological analysis. M., GEOS, 218 (in Russian).

Rejmers N.F. (1990). Environmental Sciences. Slovar'-spravochnik. M., Mysl', 637 (in Russian).

Rodriguez E., Morris C.S., Belz J., Chapin E., Martin J., Daffer W., Hensley S. (2005). An assessment of the SRTM topographic products. Technical Report JPL D-31639. Pasadena, Jet Propulsion Laboratory, 143.

Serbenjuk S.N. (1990). Cartography and geoinformatics - their interaction. Moskva, Izd-vo MGU, 157 (in Russian).

Shynbergenov Y.A., Sihanova N.S. (2017). Identification of Large Rivers of Siberia (Ob, Yenisei, Lena) by using GIS technology based on remote sensing of Earth from Cosmos. Astra Salvensis, 5(10-1), 541-545.

Vogt J.V., Colombo R., Bertolo F. (2003). Deriving drainage networks and watershed boundaries. A new methodology combining digital elevation data and environmental characteristics. Geomorphology, 53, 281-298. DOI:10.1016/S0169-555X(02)00319-7

Yermolaev O.P. Erosion in the basin's geosystems. Kazan, Publishing House of KSU, 2002, 264 p.

Yermolaev O.P., Mukharamova S.S., Maltsev K.A., Ivanov M.A., Gafurov A.M., Saveliev A.A., Shynbergenov Y.A., Yantsitov R.O. (2023a). Geography and Geoecology of Russia in the Mosaic of River Basins. Geography and Natural Resources, 44(3), 208-214 (in Russian with English summary), DOI:10.1134/S1875372823030046.

Yermolaev O.P., Shynbergenov Y.A., Mukharamova S.S. (2023b). Geoinformation system "River Basins of Russia". InterCarto. InterGIS. GI support of sustainable development of territories, Proceedings of the Int. conf. Moscow, MSU, Faculty of Geography, 29(1), 546–559 (in Russian with English summary), DOI:10.35595/2414-9179-2023-1-29-546-559 (in Russian)