GEOGRAPHY OF NATURE MANAGEMENT

Integral Assessment of Anthropogenic Impact on the Baikal Natural Territory: Methodological Approaches and Typology of Municipal Districts

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Abstract—The article develops a methodology for an integral assessment of anthropogenic impact with spatial resolution for the municipalities of the Baikal Natural Territory, taking into account the impact on the atmosphere, water, and forest resources; impact of agriculture; solid waste; disturbed lands, and objects of accumulated damage; as well as background impact. Taking into account the significance for the Baikal Natural Territory, the methodology for constructing an integral index for the first time, in addition to official statistics, was supplemented with calculated indicators of emissions from motor vehicles and small vessels, emissions from autonomous heating systems in rural areas and cities. For this, an algorithm was proposed for the first time, including determination of the number and area of buildings based on remote sensing materials, and the amount and type of fuel used, and type of installation based on surveys of the population and heads of settlements. Also, using satellite images, the areas of disturbed lands in all municipalities were calculated and the degree of hazard of their geomorphological position was determined. To determine the weight of indicators, the authors conducted a survey of experts representing the scientific community (specialists in the field of integrated assessments of certain types of impacts or environmental problems of the territory), the expert community (leading rating agencies), and the environmental management system of regions included in the Baikal Natural Territory. The integral indicator made it possible to construct a rating of municipalities and identify key factors in shaping the environmental situation. According to the integral index, five types of territories are identified, followed by subtypes based on the nature of anthropogenic impact on the environment. A high level of impact is typical of large cities and locations of enterprises, especially mining, where a full range of load components operate. An increased level is observed in cities, suburban municipalities with a high load from the life of the population, as well as in large agricultural areas with a developed mining. The average level is typical for a small number of rural areas and towns due to load from agriculture and forestry. A reduced level of impact is formed mainly in semi-peripheral areas, where there is a load on forest resources, and some suburban areas with more developed agriculture. A low level of anthropogenic impact is typical for peripheral, sparsely populated municipal districts with a noticeable share of pollution from autonomous heating systems. A special role in shaping the environmental situation is played by large tracts of disturbed land, high volumes of solid waste, and objects of accumulated hazard left over from the Soviet industrialization period.

Keywords: integral index, anthropogenic impact, comprehensive assessment, Baikal, Central Ecological Zone, Baikal Natural Territory

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FORMULATION OF THE PROBLEM

Solving modern environmental problems is a compromise between the requirements of economic development and need to protect the environment. Effective management of the environmental situation should be based on a comprehensive analysis and assessment of not only the environmental problems of the territory itself, but also their causes. Among them, an important place is occupied by the dynamics and structural transformations in material production and settlement, the significance of which is increasing, especially due to the polarization of recreational impact in overtourism areas.[1] The key to understanding trends in changes in anthropogenic impact (AI) on the natural environment is the analysis of the influence of leading factors.

Any large country is characterized by significant regional and subregional contrasts in the development of socioeconomic processes and, as a consequence, AI. To assess their unevenness, systems of indicators in disaggregated form and synthetic (integral) indicators can be used. The advantage of the latter is in a comprehensive assessment of the totality of the most important (depending on the purposes of constructing such an indicator) socioeconomic processes and environmental conditions. From this follows the demonstrativeness of information about AI in a particular region, achieved by comparing a number of integral indicators. All this determines the growing interest on the part of Russian researchers and management systems in the construction and use of integral indices of AI and the ecological state of territories.

The Baikal Natural Territory (BNT) is a unique natural and economic system, which includes Lake Baikal, the adjacent water protection zone, its catchment area within the Russian Federation, specially protected natural areas, as well as an area up to 200 km wide to the west and northwest of it. This category exists primarily in the legislative field and is regulated by a separate Federal Law.[2]

Lake Baikal at all stages of societal development had a great influence on the surrounding region. Interest in it was primarily dictated by the high natural resource potential of the territory: the lake is rich in valuable fish, in the surrounding mountains there are many deposits of metal ores, and recently oil and gas deposits have been discovered. Lastly, Lake Baikal acts as a natural reservoir. These factors determined the economic development of the territories around the Lake Baikal, associated first with resource development, then (during the Soviet era) with industrial development. Cities and industrial hubs arose on the shores of the lake. Near Lake Baikal, along the Angara River, the Angara−Yenisey territorial production complex[3] arose, specializing in nonferrous metallurgy, forestry and wood processing industries and, hydroelectric power. Currently, tourism and recreational resources of the Baikal Region are becoming increasingly important.[4] All this creates the need to study the environmental and economic aspect of assessing AI on this territory.

However, the economic development of the Baikal Region has not only positive, but also negative consequences. Despite the low population density in the Baikal Region, in the coastal zone of the lake's tributaries, there are a number of large cities, such as Irkutsk, Angarsk, and Ulan-Ude, which together have a population of about 1.3 mln people. Within this territory, there are a number of large industrial centers specializing in heavy industry (the cities of Shelekhov, Angarsk, Baikalsk, and Irkutsk). This creates economic and demographic load on the territory, leading to pollution of the atmosphere and hydrosphere and disturbing the unique natural landscapes and ecosystems. The people living here are also feel this impact. In addition, Lake Baikal is influenced not only by the effects in the coastal zone, but also by the effects within its vast zone of influence. Understanding the need to take this into account in protecting Baikal has led to the emergence of the BNT. In 2021, the law was amended to require regular monitoring of the state of BNT; in addition, at the 44th session of UNESCO, the issue of including Baikal in the list of endangered natural heritage sites was considered.[5] Together, all these features determine the relevance of calculating the integral AI index for municipalities included in the BNT.

DEPTH OF STUDY OF THE PROBLEM

Comparison of foreign and domestic experience showed that foreign integrated assessments have formed the *theoretical basis* for research, having proposed the concept of quality of life and sustainable

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[1] There is no generally accepted definition of overtourism yet, but all experts associate this phenomenon with exceeding the maximum carrying capacity in a tourist destination, primarily social; i.e., overtourism occurs when hosts and guests feel that there are too many visitors and the quality of life in an area or the quality of the experience is unacceptably degraded [cit. according to (Aleksandrova et al., 2021).

[2] Federal Law no. 94-FZ of May 1, 1999 (as amended on December 30, 2021), On the Protection of Lake Baikal.

[3] The Angara−Yenisey territorial production complex (TPC) refers to the TPC of the Angara−Yenisey Region (Bandman, 1980).

[4] The Baikal Region refers to three federal subjects in the vicinity of the Lake Baikal: Irkutsk oblast, the Republic of Buryatia and Zabaykalsky krai (Vinokurov and Sukhodolov, 2008). The terms Baikal Region and BNT are not synonymous; however, the BNT is located within the boundaries of the Baikal Region determined by the Decree of the Russian Federation Government no. 661 of September 6, 2000, On the Ecological Zoning of the Baikal Natural Territory.

[5] Section 7 of the analytical report on the state of conservation of World Heritage sites following the 44th session of the World Heritage Committee. https://whc.unesco.org/archive/2021/whc21-44com-7-en.pdf.

development. Therefore, the methods for obtaining such indices contain multidirectional indicators based on the decoupling effect, when socioeconomic growth should be achieved by reducing environmental indicators, which are included in the integral indices in different shares (City ..., 2017; Environmental ..., 2001; Index ..., 2014; The Green ..., 2012). In *socioeconomic development* indices, there are one or two environmental indicators the contribution of which does not exceed 5%; in the *quality of life* indices, their share averages 10−15%; and in the *sustainable development* indicators, 20−70% (Dobrolyubova, 2015). As a rule, environmental indicators are selected (development of public transport, green economy, potential or use of renewable energy sources, waste recycling, low-carbon development (Bobylev et al., 2012; Bobylev and Porfir'ev, 2016)) or environmental management, transparency, and citizen involvement indicators (strategies for green development, public participation, accounting for risks of natural disasters, transparency, etc.). This type of indicator is most often used when the objects being assessed are not so much territories as companies and enterprises (Sustainable ..., 2015; The Green ..., 2012; UN-Habitat ..., 2012; World's ..., 2019).

In Russian science, starting from the 1980s, the vector triad of impact−change−consequences (Mukhina and Runova, 1977) became the methodological basis of specific methods for assessing the environmental situation, their methodological coherence, and clarity. Therefore, AI indices appeared earlier in Russian practice (Kasimov et al., 2014). They use only load indicators. This makes it possible to create a final rating based on an integral indicator, which is constructed from worst to best, highlighting the main outsiders of the assessment, thereby stimulating their development. Foreign ratings are constructed from best to worst, which allows one to evaluate the competitiveness of subjects and their advantages. This is important because the rating presents information in a form understandable to a wide range of people and reveals defects in the methodology for constructing an integral index (Bobylev et al., 2012).

Domestic and foreign integral assessments have the following common features: first, expanding the boundaries of research through the construction of new methods; versatility of assessments—problems, methods and object of research are not limited in any way (Voloshinskaya and Akimova, 2022); second, increased attention to the technical and technological aspects of assessment, the use of mathematical methods, GIS, etc.; third, the determining factor for the selection of indicators for most integral indices is statistical support.[6] International organizations and a number of countries have accumulated a significant amount of statistical information, which allows the formation of indices according to various goals. The Russian statistical base has a limited set of indicators

with many flaws, but it is gradually being improved, and the provision of information at the level of municipalities is becoming more complete. Particular problems are created by the secrecy of nonfinancial reporting of enterprises, which significantly complicates the accounting of local and cross-border impacts. The factor of statistical security determines that the local level—municipalities—is the most poorly developed. Most estimates are presented at the country, regional, or city level (Bityukova, 2022).[7]

A review of publications in recent years devoted to the widest range of problems of the BNT allows the conclusion that integral assessments of various types of AI for this territory have not yet been carried out, but at the same time numerous particular problems of the territory have been deeply studied (Ekologicheskii ..., 2015; Vladimirov et al., 2016). The most developed topic is analysis of various aspects of recreational activity, where the main emphasis is not so much on the level of its AI on the environment, but on the prospects for expansion and diversification (Aleksandrova et al., 2021; Evstrop'eva, 2021). The problems of AI on the environment of the economic complex have been studied the least. Most often, they are limited to an analysis of the geography of existing and planned industrial facilities and an assessment of areas that have been subjected to mechanical disturbances as a result of the operation of industrial facilities (Baikal ..., 2009; Baikal'skii ..., 2021).

The aim of this study is to develop and test a methodology for the integral assessment of AI in the context of municipalities of the BNT—a territory with an uneven population distribution, which has a complex spatial structure of AI, requiring consideration in assessing the ecological and geographical position of the areas.

MATERIALS AND METHODS

An important feature of the developed methodology is the use of only open official statistical data published by federal structures (Database of Municipalities' Indicators[8] and Unified Interdepartmental Information and Statistical System[9] from the Federal State Statistics Service (Rosstat), the Federal Service for Supervision of Natural Resources (Rosprirodnadzor) database), as well as received at the request of the Min-

istry of Natural Resources and Environment of the Russian Federation from regional authorities. The existing system for preparing municipal statistics and, in particular, settlement statistics is not developed, and this makes it impossible to take into account a significant number of the indicators reflecting a number of factors that are significant for the formation of the environmental situation of territories and, therefore, important in the formation of the integral AI index. Therefore, the authors of the article supplemented the database with indicators unavailable for the municipal level.

—*The volume of emissions from motor vehicles and small vessels* is calculated based on data on the number and structure of registered vehicles (according to the Federal Tax Service) and based on the methodology for calculating emissions from mobile sources recommended by the Ministry of Natural Resources and Environment of the Russian Federation.[10]

—*The area of disturbed lands* was calculated by visual interpretation of high-resolution Sentinel-2, Landsat-8, WorldView-1, and WorldView-2 satellite images with further verification in key areas during expeditionary research. Information on the localization of various types of mineral deposits was obtained from the Russian Federal Agency for Mineral Resource (Rosnedra) website,[11] refined by interpretation and field survey. Using GIS tools, the areas of all contours of disturbed lands were determined for each time slice and their dynamics were assessed for the period from 2014 to 2020 in the context of municipalities of the BNT and settlements of the Central Ecological Zone (CEZ).

—*The volume of atmospheric emissions from combustion of fuel in autonomous heating systems of individual residential buildings* calculated for the first time. For this purpose, an assessment of the number of individual households was carried out, its results were verified according to the estimates of the heads of administrations of rural settlements, and the area of residential buildings within the CEZ was assessed using remote sensing data. The assessment of the area of residential buildings for the entire BNT in the context of settlements was carried out by distributing the values of the residential area available in the Rosstat databases (Database of Municipalities' Indicators) in share to the number of individual households. To assess the significance of the impact of fuel combustion in autonomous heating systems on the atmosphere, in this study, emissions from this process were calculated

at two scale levels: in the context of municipalities for the BNT as a whole and at a more detailed level in the context of settlements for the territory of the CEZ. For this, surveys were conducted among the population, heads and specialists of administrations in 32 municipalities, 57 heads of rural municipal settlements and the population in 125 urban and rural municipal settlements. Surveys of the population and administration representatives were used to identify the types of fuel used in autonomous heating systems of residential buildings, as well as to estimate the average fuel consumption for heating 1 m^2 of living space.

Developed methodology for integral assessment of AI includes 5 stages.

(1) *The choice of priority assessment components* was determined by their significance for the BNT and at the same time by their statistical reliability. Blocks of impact on the atmosphere, water, forest resources, agricultural impact, from the generation of industrial waste and municipal solid waste (MSW), from disturbed lands and objects of accumulated hazard, as well as a background impact (including population, and infrastructure's location and density) were identified in order to eliminate the shortcomings of official statistics, which do not cover a significant part of the impact associated with life activity of the population, especially rural population.

(2) For each block, we selected *indicators* that, complementing each other, adequately reflect different types of anthropogenic impact (Table 1) in accordance with the principles of statistical reliability, consistency, provision of statistical information, expressed territorial differentiation, and presence of clearly interpretable dynamics.

(3) *Normalization* was done using a linear scaling formula. In order to level out the influence of statistical outliers (extreme deviations from the normal distribution of indicator values), the so-called interquartile range method was used to determine the normalization limits. Its essence is to highlight the normalization interval, cleared of outliers, and assign the outliers a minimum or maximum value (0 or 1, if the normalization interval is taken as [0; 1]). The interquartile range value is calculated as the difference between the 75th and 25th percentiles of elements. After determining the interquartile distance, the normalization boundaries [a; b] are determined by formula 1:

$$x_{25} - 1.5(x_{75} - x_{25}); \quad x_{75} + 1.5(x_{75} - x_{25})], \quad (1)$$

where x_{25} and x_{75} are 25th and 75th percentiles of the distribution of the indicator, $a = x_{25} - 1.5(x_{75} - x_{25})$, $b = x_{75} + 1.5(x_{75} - x_{25})$.

The final normalization of all observations is done by formula 2:

$$\text{for} \quad x_i \varepsilon [a; b] - x_i^n = \frac{x_i - a}{b - a}, \quad (2)$$

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[10]Order of the Ministry of Natural Resources and Environment of the Russian Federation no. 804 of November 27, 2019, On Approval of the Methodology for Determining Atmospheric Emissions of Pollutants from Mobile Sources for Summary Calculations of Atmospheric Pollution (registered with the Ministry of Justice of Russian Federation on December 24, 2019 no. 56957).

[11]Federal Agency for Mineral Resource (Rosnedra). https://rosnedra.gov.ru.

Table 1. Indicators of level of anthropogenic impact, maximum and minimum values for the Baikal Natural Territory for 2014−2020

Block	Notation	Indicator	Max	Min
Atmosphere	A_1	Emissions of pollutants from stationary sources recalculated to pollution area (built-up area of settlements), t/km^2	16.4	0
	A_2	Emission density of motor vehicles and small vessels, thous. t/km of route network	8.2	0.041
	A_3	Atmospheric emissions toxicity coefficient	61.6	0.44
	A_4	Emissions from autonomous heating systems, kg/area of built-up land, t/ha	10.8	0.04
Water resources	in 1	Water withdrawal per capita of permanent population, m^3/person	12083.2	0**
	in 2	Wastewater discharge per capita, m^3/person	11695.3	0
	in 3	Discharge of polluted wastewater per capita of permanent population, m^3/person*	951.3	0
Waste	S_1	Volume of generated MSW per capita, thous. t/person	0.65	0.3
	S_2	Reduced volume of waste taking into account hazard classes I−V (municipal and industrial) per built-up area, cond. t/km^2	50.46	0.001
Agriculture	D_1	Share of farmland in total area of the municipalities, %	46.6	0
	D_2	Share of sown areas in total area of farmland, %	63.7	0.2
	D_3	Number of cattle per pasture area, head/ha	486.6	3.4
Disturbed lands	E_1	Share of disturbed lands in total area of territory, %	0.0051	0
	E_2	Presence of objects of accumulated hazard (reflects presence of unreclaimed industrial zones, storage sites for accumulated waste of hazard class I−II, waste sludge reservoirs of hazard class 3, but located near Lake Baikal or rivers flowing into the lake), point score	1	0
Background impact	F_1	Permanent population density, thous. people/km^2	2.25	0.002
	F_2	Road density, km/km^2	6.4	0.006
	F_3	Density of persons (tourists) in collective accommodation facilities per unit of territory, people/km^2	1.8	0
	F_4	Number of registered motor vehicles by class per population, units/person	0.59	0.22
Forest resources	L_1	Share of forests lost under impact of unfavorable factors in total forest area, %	1.6	0
	L_2	Share of forest area affected by fires, %	49.8	0
	L_3	Ratio of actual wood harvesting volume to maximum permissible, %	252.9	0

 * Wastewater discharge includes mainly warm wastewater from fuel energy facilities; contaminated wastewater comes from industry and housing and communal services—their share varies from 10 to 100% in BNT municipalities.
** Water withdrawal in the city of Petrovsk-Zabaikalsky is done on the territory of the Petrovsk-Zabaikalsky municipal district.

where x_i^n is the normalized observation value, and a and b are determined in formula 1;

for $x_i > b = 1$; for $x_i < a = 0$.

(4) To *assess the significance of various indicators, we interviewed* 47 experts from different fields of science, different scientific schools, academic institutes and universities, specialists in the field of compiling environmental ratings and representatives of the environmental management system in the BNT. The experts were selected based on the need to take into account the viewpoint of the scientific community, representa-

tives of the environmental management system, and the expert community covering environmental issues. Among the experts, leading researchers in their fields directly related to the solution of industrial environmental problems and specialists well acquainted with the problems of the BNT were interviewed. Experts were asked to rate on a nine-point scale the importance of indicators characterizing various aspects of the state of the environment. Final weights of indicators (P_i) were obtained by calculating the arithmetic mean of all expert assessments.

Expert opinion on the "Forest Resources" block, which has a significant number of high ratings, then the "Solid Waste" block with a slightly smaller share of high ratings, were consolidated. The "Agriculture" and "Water Resources" blocks is characterized by significant scatter of opinions, largely due to the quality and territorial coverage of the collected statistics. The indicators of the "Atmosphere" block have average values of both the variation coefficient (0.4) and number of high ratings.

(5) The integral anthropogenic impact index (AII) for each municipality consists of seven subindices indicated in formula (3):

$$\text{AII} = \left(\frac{A_1 + A_2 + A_3 + A_4}{4}\right) + \left(\frac{B_1 + B_2 + B_3}{3}\right)$$
$$+ \left(\frac{C_1 + C_2}{2}\right) + \left(\frac{D_1 + D_2 + D_3}{3}\right) + \left(\frac{E_1 + E_2}{2}\right) \quad (3)$$
$$+ \left(\frac{F_1 + F_2 + F_3 + F_4}{4}\right) + \left(\frac{L_1 + L_2 + L_3}{3}\right),$$

where variables $A-L$ (see Table 1) are normalized values multiplied by the weight of the factor determined by experts.

(6) *Peculiarities of Assessment by Municipalities.* Forty-three municipalities (municipal districts (MD) and urban okrugs (UO)) fall within the boundaries of the BNT. Another important feature for research follows from the principles of delineating the BNT: its boundaries include all territories that can influence the ecological state of Lake Baikal (with the exception of those located abroad), limited by orographic and other physical-geographical barriers. From these territories, pollution can enter Lake Baikal by various channels: mainly air in the zone of atmospheric influence and water in the buffer zone. The central zone limits the recipient territory of impact, the place of concentration of natural heritage. The boundaries of municipalities do not always coincide with the boundaries of BNT zones. The boundaries of settlements are more suitable, but even they do not always correspond to the boundaries of the BNT zones. It is actually possible to exclude from consideration the Uletovsky MD in Zabaykalsky krai and Tunkinsky and Muisky municipal districts in the Republic of Buryatia, which are included in the BNT buffer zone in uninhabited parts or protected areas (Fig. 1).

To the greatest extent, the boundaries of the BNT coincide with the boundaries of the municipal zone of atmospheric influence: only 2.2% of the Kazachinsko-Lensky MD's population and 25% of the Cheremkhovsky MD's population live outside the BNT, and there are no sources of AI outside the zone; the load was calculated for the region as a whole. Thirty-four percent of the population of the Eravninsky MD and only 3.5% of the Chitinsky MD live in the buffer zone (only two rural municipal settlements: Beklemishevskoe and Arakhleyskoe). In this case, the indicators of municipal waste generation, water consumption, and wastewater were calculated in share to the population, emissions from autonomous heating systems were calculated for individual settlements, disturbed lands and vehicle emissions; the background load, for settlements; the load on forests, for forest districts.

RESULTS AND DISCUSSION

Component analysis of the impact on the environment, carried out at the first stage, showed that municipalities within the BNT are strongly polarized in the level of impact on water resources and the atmosphere: it is concentrated in the Irkutsk and Selenga areas; such a load here is due to production processes, and in other rural areas, due to the needs of the population.

In general, across the territory of the BNT, autonomous heating systems, in addition to centralized energy and heat supply systems, are the dominant source of emissions in most of the municipality (Fig. 2). This is especially pronounced in areas where coal is used as fuel, which is most typical of individual residential buildings. As a rule, this occurs in two types of settlements: those located in close proximity to coal mining enterprises and in relatively large settlements with high incomes, when it is more profitable to heat large houses using coal boilers (Fig. 3).

The BNT is characterized by a high level of concentration of population and economic activity in several large centers, but at the same time there is also a fairly high degree of population in the rural areas of the southern part of the BNT. A separate source of impact, characteristic of the coastal zone of Lake Baikal, is tourists, including unorganized ones. The factors that determine the ratio of the permanent and temporary population are quite diverse, and are not always determined solely by natural seasonality (Vorob'ev, 2020). For small and tiny settlements, the key factor is their position in the settlement system. The population fluctuates most strongly in rural municipal settlements located on the periphery of the MD and having no access roads, which are characterized by an excess of the summer population over the winter population. According to experts, as a rule, in the centers of MDs and rural municipal settlements, as well as in large settlements with a more favorable
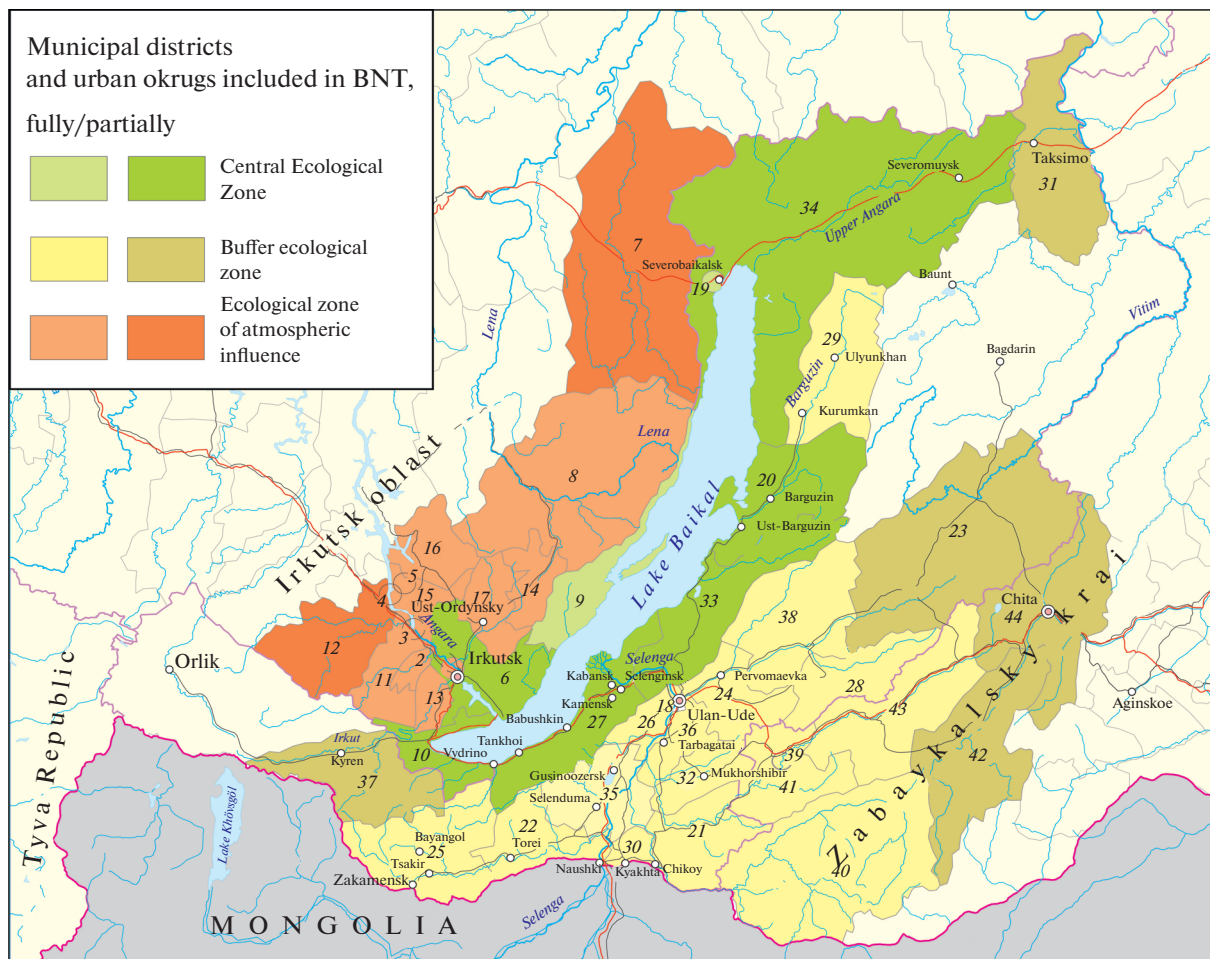
Fig. 1. Municipalities within Baikal Natural Territory and its ecological zones. *1*, Irkutsk UO; *2*, Angarsk UO; *3*, Usolye-Sibirskoe UO; *4*, Cheremkhovo UO ; *5*, Svirsk UO ; *6*, Irkutsky MD; *7*, Kazachinsko-Lensky MD; *8*, Kachugsky MD; *9*, Olkhonsky MD; *10*, Slyudyansky MD; *11*, Usolsky MD; *12*, Cheremkhovsky MD; *13*, Shelekhovsky MD; *14*, Bayandaevsky MD; *15*, Bokhansky MD; *16*, Osinsky MD; *17*, Ekhirit-Bulagatsky MD; *18*, Ulan-Ude UO; *19*, Severobaikalsk UO; *20*, Barguzinsky MD; *21*, Bichursky MD; *22*, Dzhidinsky MD; *23*, Eravninsky MD; *24*, Zaigraevsky MD; *25*, Zakamensky MD; *26*, Ivolginsky MD; *27*, Kabansky MD; *28*, Kizhinginsky MD; *29*, Kurumkansky MD; *30*, Kyakhtinsky MD; *31*, Muisky MD; *32*, Mukhorshibirsky MD; *33*, Pribaikalsky MD; *34*, Severobaikalsky MD; *35*, Selenginsky MD; *36*, Tarbagataisky MD; *37*, Tunkinsky MD; *38*, Khorinsky MD; *39*, Petrovsk-Zabaikalsky UO; *40*, Krasnochikoisky MD; *41*, Petrovsk-Zabaikalsky MD; *42*, Uletovsky MD; *43*, Khiloksky MD; *44*, Chitinsky MD.
*Compiled from:* Population of the Russian Federation by Municipalities, Rosstat. (https://rosstat.gov.ru/compendium/document/13282); Map of the Baikal Natural Territory (1 : 1000000, http://geol.irk.ru/baikal/; the site was created by order of the Ministry of Natural Resources and Environment of the Russian Federation and is maintained under the management of Rosprirodnadzor).

socioeconomic situation, a balance is achieved between city dwellers, coming in the summer period, and shift workers and *otkhodnik*s, returning in the winter. As a result, the size of the actual population (according to surveys and interviews) differs from the registered one on average by no more than 10%. In medium-sized (300−700 people) rural municipal settlements, the excess of the maximum (summer) population over the winter population is within 20%.

The excess of the actual population over the officially registered number of residents is typical of suburban areas of regional centers, where specific suburbanization occurs primarily due to former rural resi-

dents of peripheral agricultural areas renting housing for a long time. Although at present there are no such settlements within the CEZ proper, their appearance in the future cannot be ruled out as transport develops and the zones of influence of regional centers expand.

The general trend in the development of the rural municipal settlement system is polarization, which will intensify due to the erosion of the relatively viable group of medium-sized settlements and their transition to the category of small ones (Fig. 4). As a result, seasonal demographic fluctuations will increase: the number of permanent residents will continue to decrease, and the temporary population, both recre-
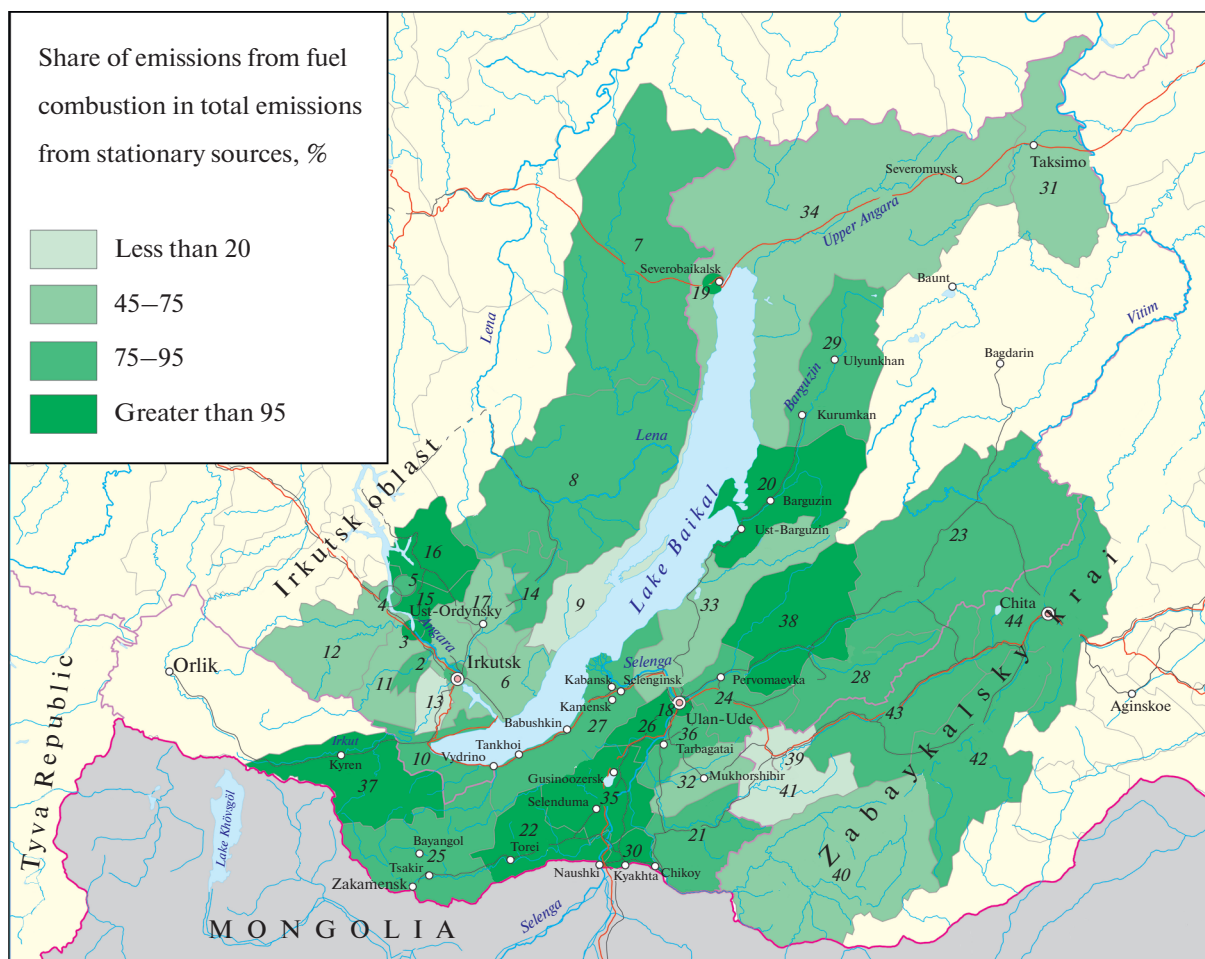
Fig. 2. Share of emissions from fuel combustion in gross volume of atmospheric emissions from stationary sources (excluding emissions from autonomous heating systems) in municipal districts and urban okrugs included in Baikal Natural Territory, %. See caption to Fig. 1 for explanation.

ationists and hired personnel in recreational facilities, will increase.

The population in this AII is included in the "Background Impact" block. When calculating the index at the municipal level, the contribution of the population itself is not too large, and its differentiation by season does not produce significant differences in the index, since it is covered by the contribution of other components or is indirectly taken into account through them, e.g., in the volume of runoff. The role of the population should increase when moving to a larger scale level, primarily for the narrow coastal strip, where the bulk of recreationists are concentrated.

The agricultural impact on the BNT is quite large and has the greatest spatial distribution, which is due to the traditional occupations of the population and the nature of settlement pattern. Logging within the BNT is less active than in the rest of Siberia, but forest resources are also an object of AI, the main factors being deforestation and forest fires. Indicators of load

on forests, despite the fact that not all of them are directly related to anthropogenic factors, are to some extent determined by them. The fires of 2015 had the greatest impact on the BNT: the highest share of forests affected by fires was in the regions of Buryatia immediately adjacent to Lake Baikal (in particular Kabansky MD), as well as in the regions of Buryatia and Zabaykalsky krai to the south, east, and north of the municipalities included in the BNT. The fires of 2019 hardly affected the BNT at all (the main outbreaks were to the north, in the north of Irkutsk oblast and in Yakutia). Among the MDs that open directly onto Lake Baikal, the Severobaikalsky MD of Buryatia was hit. The positions of leading districts in this indicator are very unstable and largely depend on random factors. There are no clear trends, including as a result of inaccuracies in counting in some years (sometimes determined visually by forestry staff).

Integral assessment of the AI level made it possible to construct a rating of municipalities. Based on the values of the integral index, five main types of municipal-
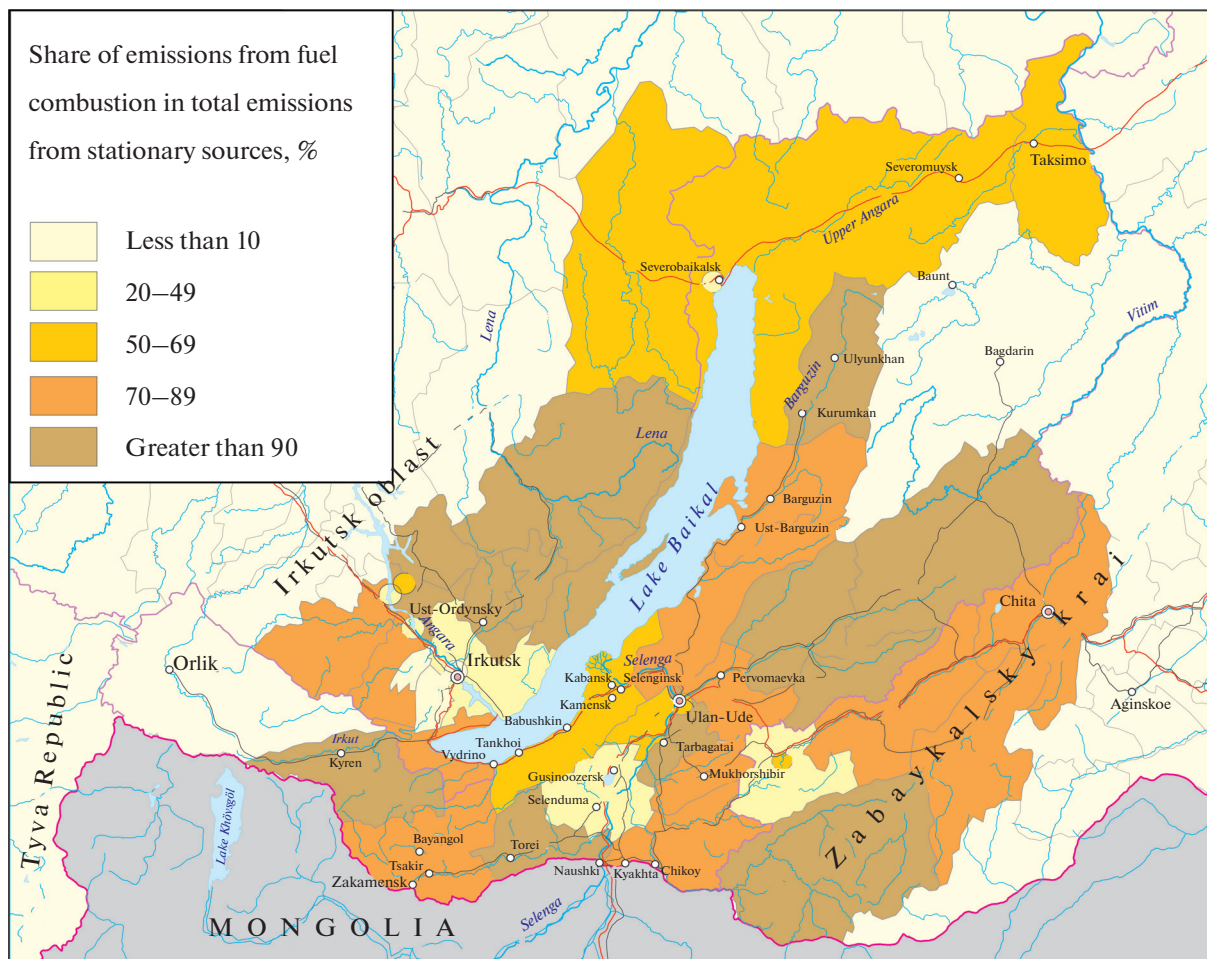
Fig. 3. Share of emissions from autonomous heating systems in municipal districts and urban okrugs included in Baikal Natural Territory, %. See caption to Fig. 1 for explanation.

ities are identified, while subtypes are distinguished according to the structure of AII (Figs. 5, 6).

Type 1 combines the largest municipalities in terms of population and industrial production, in which a high AII value (>0.38) is achieved due to increased values of most types of environmental load. It is represented by two subtypes, differing in settlement structure and geography of the municipalities included in them. A high AI level is usually associated with the placement of large industries and large forms of settlement. Sixty-four percent of industrial production and 42% of the permanent population of the BNT are concentrated in type 1 municipalities (Table 2).

A high AI level is usually associated with a fairly uniform structure of AII. Within the index, the contribution of most subindices becomes approximately equal, since a high AI level is characterized by high values of almost all particular indicators. However, the BNT is characterized by the formation of a high AII level for two completely different types of territories.

Subtype 1a comprises large UOs (Irkutsk, Angarsk, Cheremkhovo, and Usolye-Sibirskoe) within the

Irkutsk–Angara urban agglomeration, located along the transport corridor, the axes of which are the Trans-Siberian Railway and the upper reaches of the Angara
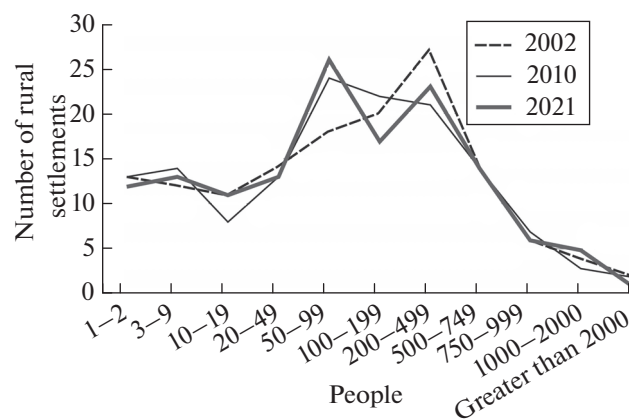
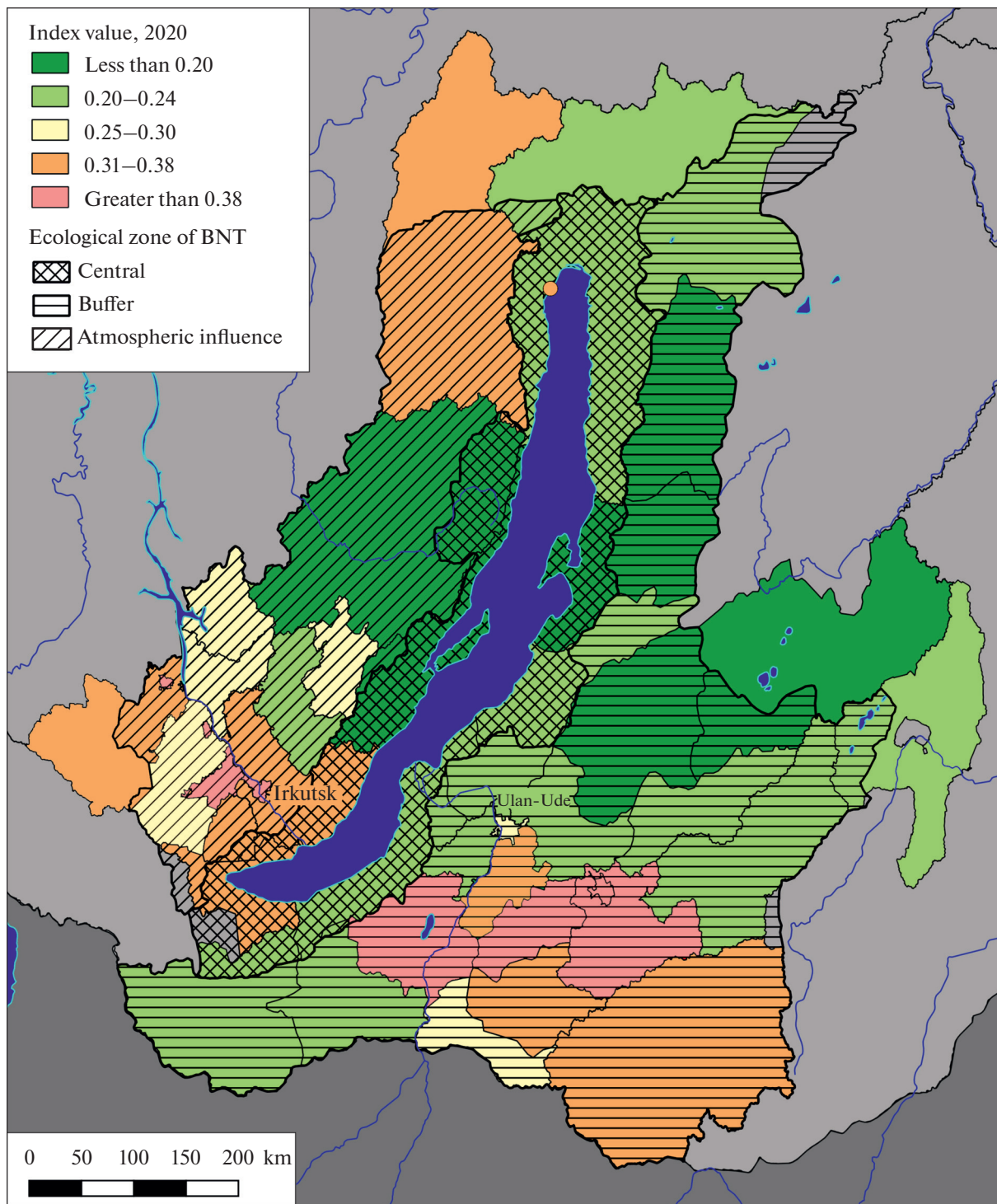**Fig. 4.** Distribution of Central Ecological Zone settlements by population in 2002, 2010, and 2021.

Fig. 5. Integral index of anthropogenic impact for Baikal Natural Territory municipalities in 2020.

River. Here, the highest subindices of impact on the atmosphere and waterbodies are noted; there are significant areas of disturbed land and a strong background impact on the environment due to the high population size.

Subtype 1b includes three MDs in different parts of the BNT (Selenginsky, Petrovsk-Zabaikalsky, and Mukhorshibirsky), in which there are quite large sources of environmental impact: coal mines, nonferrous metallurgy mining enterprises, and thermal
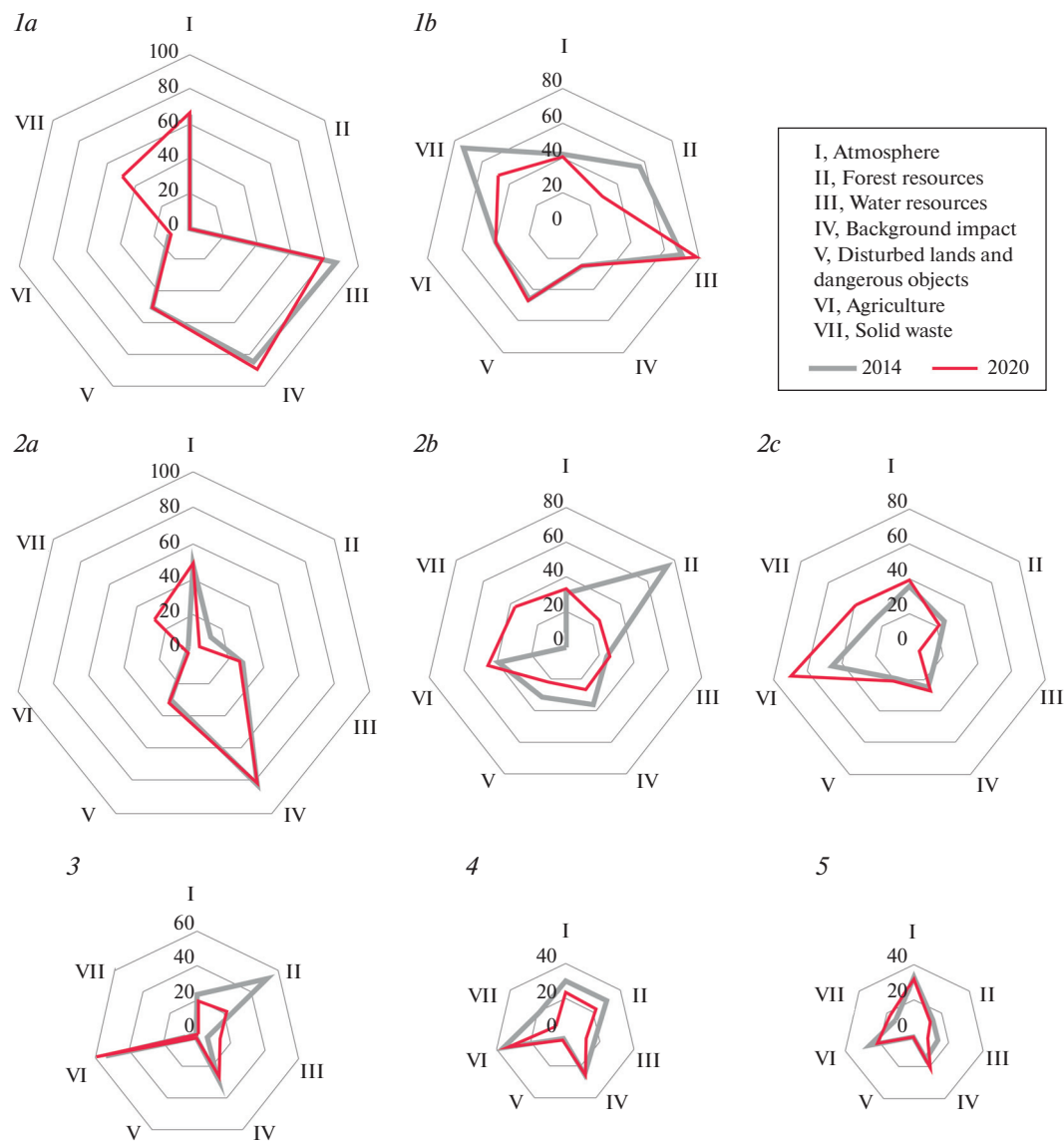
Fig. 6. Types and subtypes of municipalities according to the structure of the AII, 2014 and 2020.

energy enterprises. A peculiarity of *subtype 1b* is the significant impact on the environment of agricultural activities and higher values of the subindex of impact on forest resources.

Type 2 with an elevated AI level includes municipalities with a very high AI value (0.3–0.38), due to large individual sources of environmental impact and, conversely, the reduced influence of other groups of factors. Municipalities of this type are home to 33% of the population of the BNT, 30% of industrial and 25% of agricultural products are produced. Depending on the characteristics of the source, the type is divided into three subtypes:

Subtype 2a includes urban municipalities that, due to their population, have an increased background impact on the environment, with average values of the

subindex of impact on the atmosphere and water resources. These are UOs and MDs in which there is a city (Ulan-Ude UO, Severobaikalsk UO, Shelekhovsky MD, Petrovsk-Zabaikalsky UO, Svirsk UO).

These municipalities are small in area and have a high level of centralized heat and electricity supply based on coal fuel. For Severobaikalsk and Petrovsk-Zabaikalsky, the volume of atmospheric emissions does not exceed 3000 t with a high share of emissions from fuel combustion, but a significant contribution is made by individual heating systems. In the Shelekhovsky MD, the volume of atmospheric emissions is about 40 thous.t, but since the main sources are the Irkutsk Aluminum Plant, Kremniy CJSC, SUAL-PM LLC, the predominance (more than 3/4) in the structure of oxide emissions is technologically determined

Table 2. Main socioeconomic indicators by types of municipalities of Baikal Natural Territory in 2020

Type, *subtype*	Permanent population		Volume of goods shipped and services produced in-house		Agricultural production volume	
	Thous. people	%	RUB bln	%	RUB mln	%
1	1067.5	42.1	512658.6	63.7	6094.4	10.7
1a	*986.7*	*38.9*	*457623.5*	*56.8*	*3719.7*	*6.5*
1b	*80.8*	*3.2*	*55035.1*	*6.8*	*2374.6*	*4.2*
2	840.2	33.1	240817.5	29.9	14447.8	25.3
2a	*557.8*	*22.0*	*198392.6*	*24.6*	*1903.2*	*3.3*
2b	*176.0*	*6.9*	*16267.4*	*2.0*	*3989.8*	*7.0*
2c	*106.4*	*4.2*	*26157.5*	*3.2*	*8554.7*	*15.0*
3	143.4	5.7	18750.8	2.3	21395.1	37.4
4	391.5	15.4	28826.6	3.6	11981.2	21.0
5	94.3	3.7	4168.2	0.5	3265.0	5.7
Total	2536.9	100.0	805221.7	100.0	57183.5	100.0

Source: Rosstat, Database of Municipalities' Indicators.

carbon CO (Gosudarstvennyi ..., 2021). Moreover, due to the low cost of electricity, most individual residential buildings have electric heating. All three cities have an average volume of wastewater (2−5 mln m³), but the share of polluted water is close to 100%. The volume of water consumption is also at the average level; the structure is dominated by household and drinking water. The exception is the Shelekhovsky MD, where the volume of water consumption is extremely small (about 25 000 m³) at the highest level of recycled water consumption. Thus, the relatively smaller influence of the water factor is compensated by a higher level of atmospheric pollution.

However, the main factor remains the background impact due to the high population density, buildings, density of the road network, and high level of motorization.

Subtype 2b includes MDs with increased background impact on the environment (Irkutsky) or with significant areas of disturbed land (Slyudyansky). These two areas are coastal, largely falling within the CEZ, with a high share of seasonal population. There are common factors in the formation of air pollution: atmospheric pollution is largely determined by motor vehicles and small vessels, and to a lesser extent by boiler houses and furnaces in individual residential buildings, which mainly use electricity from hydroelectric power plants. However, there are significant differences in the structure of the index: Irkutsk oblast is characterized by a high load on forests, while in Slyudyansky MD, it is low. The opposite situation is observed with the load on water resources. In the Irkutsky MD there is no recycled water supply, but the volumes of water consumption and wastewater are insignificant; most of this volume is purified by physical and chemical methods (895000 m³).

Subtype 2c includes fairly populated rural areas with a relatively high level of agricultural development (Bichursky, Tarbagataysky, and Cheremkhovsky MDs), as well as peripheral Krasnochikoysky and Kazachinsko-Lensky MDs with a significant role of mining in environmental pollution. The contribution of these municipalities to the volume of agricultural production is five times greater than their share in the volume of industrial production, and almost four times greater than the population. In addition to agriculture, the mining is developed in these areas. In the Bichursky MD, Ugol'nyi Razrez LLC is developing the Okino-Klyuchevskoe lignite deposit, the main consumer of which is the Gusinoozyorsk State District Power Plant. Including for this reason, the Bichursky MD is in third place in the BNT in terms of volume of solid waste, which exceeds 13 mln t. In the Cheremkhovsky MD, 18% of the coal of Irkutsk oblast is mined (including 50% of hard coal) and 100% of the volume of hard coal processing is carried out coal and production of coal concentrate. Boiler houses and the private sector in the region mainly use coal, with the exception of remote settlements. Therefore, the AII of a significant number of municipalities is rather dependent on the volume of industrial production, even for those areas where the contribution of agriculture is large, both in production volumes and in the integral impact index.

The Krasnochikoysky MD is distinguished by its impact on water resources and accumulated solid waste (fourth place among BNT municipalities with a volume of more than 10 mln t) as a result of the activities of small mining enterprises (the main load is formed due to gold mining in a number of artisanal artels), a coal mine (JSC Razrez Zashulansky, JSC Turmalkhan), as well as the developing Malkhan

deposit of semiprecious tourmaline. In the Kazachinsko-Lensky MD, the main anthropogenic impact on water and forest resources is formed as a result of the implementation of the project for the construction of the Power of Siberia gas pipeline. However, the construction of the gas pipeline is still poorly reflected in statistical indicators: the volume of atmospheric emissions has practically not increased, since rotational workers are accommodated either in hotels, apartment buildings connected to centralized heating (as, e.g., in the village of Magistralny), or in special shift workers' camps; motor vehicles, including technological ones, are registered in other territories; waste volumes have increased as villages enter into contracts with a regional operator for waste removal, and their increase is reflected in statistics. Water consumption has increased.

The medium AI level has been identified in a small number of rural areas and towns with exposure to agriculture and forestry (*type 3*). This type (AII = 0.265–0.281) is formed by more rural municipalities with preserved agriculture: suburban Usolsky and semiperipheral Kyakhtinsky MDs, as well as districts of the Ust-Orda Buryat Okrug—Bayandaevsky, Bokhansky, and Osinsky. In the Kyakhtinsky MD, all indicators of agricultural load are at a level slightly above the median, including livestock density. In the Usolsky MD, a high agricultural load is generated as a result of the activities of four fairly large intensive agricultural enterprises. The largest is the Belorechenskoe agricultural JSC, partly located in the Cheremkhovsky MD; the Usolsky pig farm agricultural production complex has a livestock of 108 000 head, and there are other large complexes specializing in the production of milk, meat, and potatoes. In the less developed Bokhansky and Osinsky MDs, the second most important type is the background impact; in Bayandaevsky MD, the impact on water resources is slightly elevated.

A reduced AI level is generated mainly in semiperipheral and some suburban areas with developed agriculture (*type 4*). These are municipalities with similarly low values for most subindices; for semiperipheral municipalities, the main role is played by AI for forest resources; for suburban ones, agricultural and background in the absence of hazardous objects and, as a consequence, large tracts of disturbed land and high volumes of solid waste generation (in the Ivolginsky and Chitinsky MDs—part of the BNT). In the more densely populated Pribaikalsky and Ivolginsky MDs, the share of pollution from autonomous heating systems is also slightly higher. In the Severobaikalsky MDs there is accumulated solid waste generated as a result of exploration drilling of the Kholodninskoe deposit of lead–zinc ores (Vorob'evskaya et al., 2018). In the Khiloksky, Dzhidinsky, and Zaigraevsky MDs, the structure of the index shows damage caused to forest resources as a result of their irrational exploitation.

The Kabansky MD, despite the presence of a pulp and cardboard mill on its territory, is also distinguished mainly by agricultural and background impacts as a result of the life of the population and recreation. OJSC Selenga Pulp and Cardboard Mill (SPCM) is a relatively small enterprise in terms of industry scale (400 000 t of cardboard per year), its hazard consists in its location on the border of the CEZ, on the banks of the Selenga River. However, the water level in the area is assessed as moderate, since the most important achievement of the SPCM is the creation of a closed water circulation system. This has made it possible to stop the wastewater discharge into the Selenga River and eliminate pollution with mineral substances, reduce the consumption of clean water in production from 5.6 to 3.3 mln m^3/year, and reduce the consumption of sodium sulfate in the production of cellulose from 120 to 20 kg/t. Air pollution remains quite significant; the Selenginsk urban-type settlement is included in the list of priority settlements of the Clean Air Federal Project. However, the area of pollution, as a rule, does not reach the settlement, extending to the railway; in addition, the volume of pollutant emissions from the SPCM is gradually decreasing: whereas in 2006 it was 3200 t, in 2020 it was 2700 t. Still, despite all positive trends, carbon disulfide and formaldehyde in the plant's emissions are not decreasing.

A low AI level is typical of semiperipheral or peripheral municipalities with minimal AII values (0.148–0.196), which account for less than 4% of BNT residents, about 6% of agricultural, and only 0.5% of industrial production (*type 5*). They are characterized by moderate and similar values of the subindices of background impact and agricultural activity. At the same time, certain districts may be characterized by a higher load on individual components of the environment: the Eravninsky MD due to a large quarry at the fluorspar deposit, and the Kachugsky MD as a result of the impact on water resources from gold mining. Most areas of this type are also characterized by a relatively high share of air pollution from autonomous heating systems.

CONCLUSIONS

(1) As a result of the study, a fundamentally new methodology for the integral assessment of the ecological state of territories was developed, for the first time based on both official statistics and indicators obtained by combining remote sensing and field survey methods. Additions to previously used integrated assessment methodologies, using different types of data, have made it possible to clarify the real structure of pollution sources and key types of impacts of particular importance to the BNT.

The calculated volumes of emissions from individual residential buildings, which are not recorded by official statistics, showed the importance of taking

them into account for areas with a low level of improvement: within the BNT, this is more than 30% of atmospheric emissions. For the first time, based on tax statistics, emissions from motor vehicles and other mobile sources were assessed in the context of municipalities, which contribute about another 15% of atmospheric emissions. Calculation of emissions from small vessels showed a significant, about 12% of the volume of emissions from mobile sources, contribution of this factor for the territory of the BNT, the specialization of which is becoming more and more recreational.

(2) Based on integral index, formed using the new methodology, all municipalities were considered for the first time as part of a single rating (without taking into account regional boundaries), which made it possible to identify the territorial structure of pollution within the BNT. The main framework of AI sources, formed during the period of accelerated industrialization of the Soviet period, continues to determine both the scale and structure of anthropogenic impact.

The regions and cities of the BNT are highly polarized in terms of the level of anthropogenic impact, concentrating in individual areas, primarily in large urban agglomerations along the Trans-Siberian Railway. Here the level of anthropogenic load is formed by industry and energy. Against a decrease in the weight of the largest sources and the gradual elimination of objects of accumulated hazard, anthropogenic impact is gradually shifting to the metropolitan and coastal areas due to the growing tourist flow, to semiperipheral territories with the intensive development of the mining and forestry industries, as well as to the new development zone along the Baikal-Amur Mainline, an emerging region oil production, and the zone where the Power of Siberia pipeline is being laid.

(3) Rural areas outside of zones with high levels of anthropogenic impact are characterized by background impacts of moderate intensity associated with agriculture and forestry. The new methodology made it possible to identify MDs where the main source of pollution is the individual residential sector, which increasingly houses different groups of recreationists. As a result, underestimation of water and air pollution in such municipalities due to underestimation of significant fluctuations in population and stove heating emissions can reach 50−90% of the volume of emissions from stationary sources recorded by official Rosprirodnadzor statistics.

(4) The developed integrated methodology can be applied to other territories with a high load on water and land resources and with a high share of individual housing construction in both rural and urban areas. It can be used to track the dynamics of the environmental situation and formulate priorities for intraregional environmental policy.

Further improvement of the proposed methodology will require significant improvement in statistical support. This primarily concerns the disclosure of nonfinancial environmental information of enterprises, necessary to verify the dynamics of total indicators and better take into account the anthropogenic impact on the natural environment within the boundaries of individual BNT zones, which do not always coincide with the boundaries of municipalities, as well as information on the number of households at the level of rural municipal settlements required to calculate emissions from nonreported sources.

Expanding the list of indicators developed on a regular basis should include data on the amount of solid municipal waste actually removed from the territory of rural municipal settlements. Updating requires materials from forestry statistics, which for many municipalities have not been updated for decades, and data on the volume of applied fertilizers, which are also calculated in a normative manner at best. The list of indicators presented at the municipal, and not just at the regional level, must also include the area of disturbed land.

CONFLICT OF INTEREST

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

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