INTEGRATED ECOLOGICAL-ECONOMIC MODELING OF REGIONS WITH THE USE OF GIS TECHNOLOGIES

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Abstract. The paper shows the process of modeling the integrated map "Scheme of the ecological and economic regionalization of the territory of the Russian Federation on the basis of the mineral and raw materials base of natural adsorbents" using GIS technologies.

The map is based on three main groups of indicators: natural, economic and environmental. The ecological content of the map is characterized by indicators that are potential or actual sources of pollutant release into the environment (nuclear power plants, nuclear reactors, radioactive waste storage and disposal sites, nuclear test sites, industrial enterprises, railways, operating and under construction oil pipelines, hydrocarbon fields, etc.). The economic component of the map is the reserves estimated by the indicators of study and development, the relationship to the subsoil fund and forecast resources. The natural group of indicators is represented by the mineral and raw material base of natural adsorbents (fields and objects of forecast resources) that can be used to prevent harmful emissions and for the ecological and economic rehabilitation of contaminated areas.

Based on the analysis of cartographic data, the ecological and economic areas of the territorial distribution of man-caused environmental impacts and the presence of adsorption raw materials are identified. As an example, a description is given of the ecological and economic model of the regionalization of the Privolzhsky Federal District using the GIS "Mineral resource base of natural adsorbents of Russia" developed at the Federal State Unitary Enterprise TsNIIgeolnerud.

Keywords: ecological and economic area, mineral, use, data base, adsorbent, geoinformation, mapping, modelling, Privolzhsky Federal District

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Economic activity and the functioning of production complexes inevitably lead to the accumulation of a huge amount of gaseous, liquid and solid waste into the environment. However, the ecological capacity of the natural environment is limited, which leads to a direct ecological danger caused by the inability of natural biota to withstand the destabilizing effect of anthropogenic impact. In addition, negative qualitative changes in the habitat are also caused by social and economic consequences, therefore, the issues of its protection, preservation and rehabilitation become more demanding.

In solving problems on the protection of the environment, the elimination of the negative impact of man-made factors, natural adsorbents – mineral-rock formations that have unique adsorption, ion-exchange and filtering properties – will undoubtedly play a big role.

Interest in natural adsorbents is explained by their cheapness and availability. They cost ten times cheaper than synthetic ones (artificial zeolites, silica gels, alumogels, activated carbon, etc.), while at the same time, in many areas of use, they produce the same or close to them effect. By means of simple and accessible methods of activation and modification, it is possible to increase the adsorption activity of natural adsorbents by 2-5 times, to create on their basis new products with prescribed properties that are not inferior to artificial analogues. And in this case, the cost of products obtained is 3-5 times lower than that of synthetic products.

In Russia, more attention is paid to assessing the environmental situation in a particular region, city, specific territory, and hence the need for accurate, reliable and objective information about the territorial resource status of natural adsorbents for use in environmental purposes. Environmental problems often require immediate and adequate actions, the effectiveness of which is directly related to the speed with which information is processed and presented.

One of the effective forms of representation and analysis of spatial information is the map, since almost all the objects studied (natural, industrial, social, etc.) are geographically bound and have multicomponent characteristics and connections. The map as a model created on the basis of geoinformation technologies, acquires the status of an "instrument" for the analysis, synthesis and evaluation of spatial information. Geoinformation modeling creates not only new

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information models and information resources, but also allows imagining with fewer costs possible processes where the components of nature, economy and man closely interact.

The specialists of the Federal State Unitary Enterprise CNIIgeolnerud developed a geoinformation system (GIS) for the territorial resource status of Russia's natural adsorbents – the GIS "Mineral resource base of natural adsorbents of Russia" (Bulatova et al., 2010). The purpose of the GIS is informational and analytical support for the research and use of the mineral and raw materials potential of natural adsorbents (zeolites, zeolite-containing rocks, bentonites, opal-cristobalite rocks, palygorskites, vermiculite, glauconites, etc.) for environmental purposes in ecologically unfavorable regions of Russia.

As a result of these studies, an information and cartographic model (ICM) was created, on the basis of which an integrated map "Scheme of ecological and economic zoning of the territory of the Russian Federation on the basis of using mineral and raw materials base of natural adsorbents" was built.

The materials of FSUE CNIIgeolnerud (Kazan), Kaluga branch of FSUE VIEMS, the State balance of mineral resources of the Russian Federation, and the Federal State Statistics Service served as information basis for the construction of the ICM.

The factual data bank consists of databases that contain primary geological and economic information about fields and facilities of forecast resources, enterprises that develop natural adsorbents, volumes of extraction and production, prices for mineral raw materials and products, sources of technogenic pollution, semantic support in the form of terminological directory, as well as software that provides data entry.

A map data bank consists of digital maps united by a common plan, arranged and coordinated in scale, coordinate systems, content and conventional signs. To maintain the cartographic databases and issue thematic maps, the professional GIS system ArcView GIS 3.2 was used. The structure and composition of the cartographic database is shown in Table 1.

The information-cartographic model is cartographic and related to it factual information (Table 2).

The process of modeling the integrated map was carried out in several stages:

- collection and preparation of primary factographic, cartographic information;
- integration of factual and cartographic information on the basis of selected indicators;
- sequential selection, description and mapping of the territory's regionalization objects on the map (geological and economic areas);
- statistical analysis of primary geological data, interpretation and mapping of zoning results using GIS technologies;
- elaboration of justifications of priority directions for the use of natural adsorbents for environmental purposes.

Based on the developed model, three types of maps were identified in the structure of a cartographic data bank: geological, economic, ecological and integrated. Figure 1 shows the structure of factographic and cartographic resources, information flows and their connections.

The I type of maps combines maps reflecting the geological and economic characteristics of the state of mineral resource base of natural adsorbents of Russia

- The map *"Mineral and raw materials base of natural adsorbents of the Russian Federation"* shows the

Sl. No	Map Name / Groups of thematic layers	Mineral resource base of natural adsorbents	Map of geological and economic feasibility study for the development of the MRB of NA	Location map of technogenic pollution	Scheme of ecological and economic regionalization
	1	2	3	4	5
1	Subsoil areas of natural adsorbents	+	+		+
2	Regionalization objects		+		+
3	Objects of the producing and processing industry		+	+	+
4	Objects of transport infrastructure	+	+	+	+
5	Ecological situation of the territory			+	+
6	Objects of technogenic load that affect the state of the environment			+	+
7	Objects of socio-economic infrastructure	+	+	+	+
8	Objects of energy infrastructure			+	+
9	Objects of territorial-administrative regionalization	+	+		
10	Objects of the basic topographic framework	+	+	+	+

Table 1. Structure and composition of the cartographic database

Groups of thematic layers	Thematic layer	Main characteristics of the object in the database
1. Subsoil areas of natural adsorbents	Objects of the State Balance of Reserves Objects of the State Cadastre of fields and occurrence of minerals	General information (name of the object, type of mineral); Geographic and administrative situation (the federal district, the subject of the federation, geographical coordinates); License; Geological and economic characteristics of the object (geological and industrial type, study and development of the object, state of the subsoil fund, scale of the object); Scope of use.
	Objects of forecast resources	General information (name of the object, type of mineral); Geographic and administrative situation (the federal district, the subject of the federation, geographical coordinates); Mineragenic characteristics (mineragenic rank of the object, geological-industrial type); Study and recommendations for further development; Scope of use.
2. Regionalization objects	Borders of ecological and economical regions (EER) by types of technogenic pollution	Name of EER; Type of raw materials; Explored reserves of adsorption raw materials at the fields of the distributed and undistributed reserves; Forecast resources (P1, P2, P3).
	Geological and economical regions (GER)	Name of the GER; Type of raw materials; Explored reserves of adsorption raw materials at the fields of the distributed and undistributed reserves; Forecast resources (P1, P2, P3); Production.
	Industrial and raw materials units	Name of the industrial and raw materials unit; Type of raw materials; Explored reserves of adsorption raw materials at the fields of the distributed and undistributed reserves; Forecast resources (P1, P2, P3); Production.
3. Objects of the producing and processing industry	Mining enterprises	Name of the enterprize; Mineral resource; Lisence; Production.
	Processing enterprises	Name of the enterprize; Mineral resource; Lisence; Range of products; Volumes of production.
4. Ecological situation of the territory	Ecological state of the area	Assessment of the ecological state of the area
	The level of urban pollution	Air pollution assessment
	Radioactive contamination of the area	Pollution level of the area.
	Ecological situation of rivers	Assessment of the rivers state in terms of water quality
5. Objects of technogenic load that affect the state of the environment	Nuclear power plants, CHP plants, regional power plants, industrial enterprises, mineral deposits, radioactive waste disposal sites, nuclear test sites, nuclear reactors, etc.)	Name of objects Subject of the Russian Federation

Table 2. Composition and structure of the information-cartographic model

Groups of thematic layers	Thematic layer	Main characteristics of the object in the database
6. Objects of transport infrastructure	Car roads	Type of object (by importance)
	Railways	Type of object (by importance)
7. Objects of energy infrastructure	Oil pipelines	Type of object
	Gas pipelines	Type of object
8. Objects of socio-economic infrastructure	Settlements	Administrative status
9. Objects of territorial-administrative regionalization	Federal Districts Subjects of the Russian Federation	Territory name The administrative status of the territory (the federal district, the subject of the federation)
10. Objects of the basic topographic framework	Coordinate grid Hydrography	Nomenclature of sheets of scale 1:1,000,000 The name (rivers, lakes, water reservoirs, seas, oceans)

Table 2. Composition and structure of the information-cartographic model (continue)

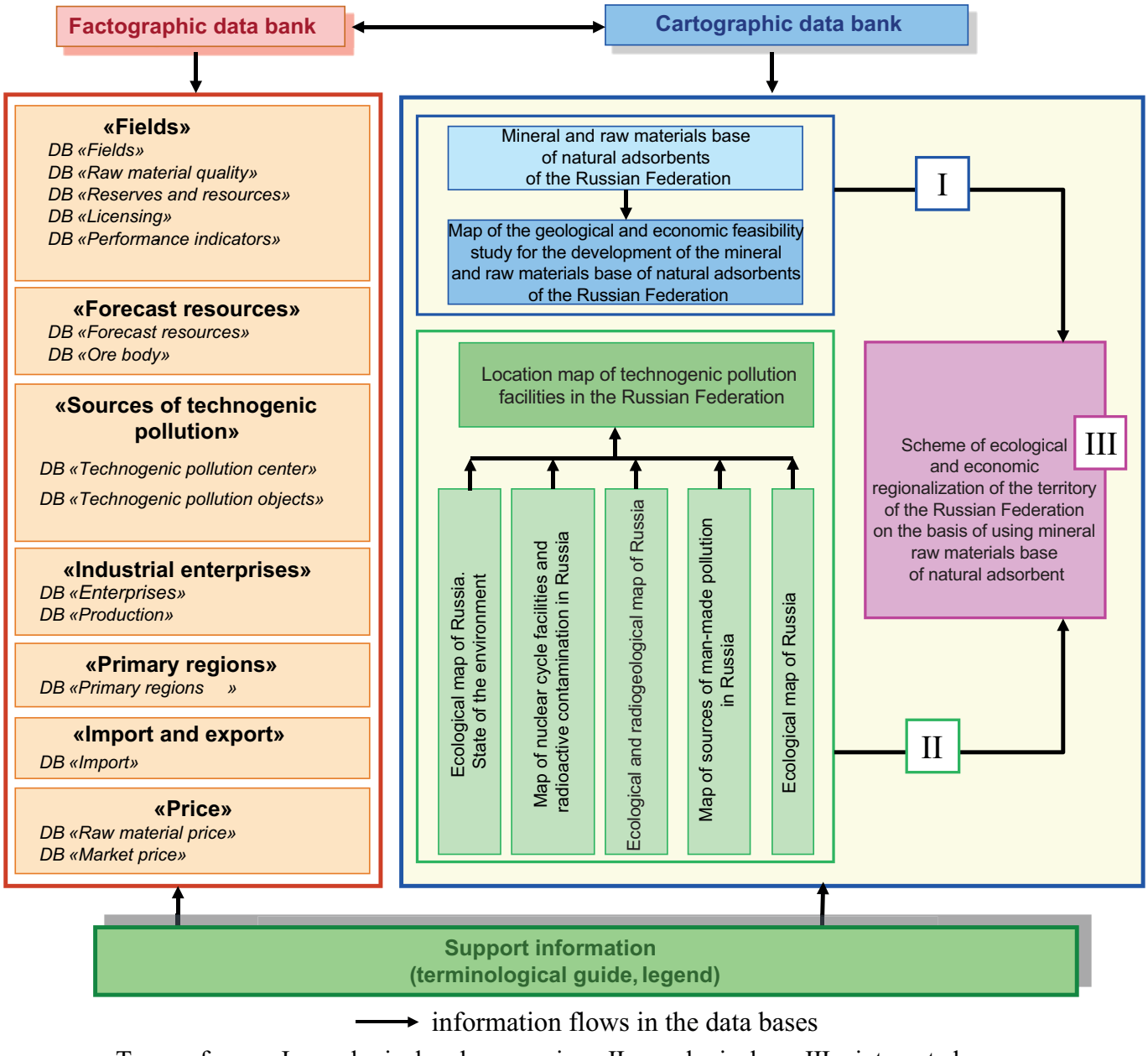


Figure 1. The structure of factographic and cartographic resources

location of natural adsorbents on the territory of Russia (129 fields and 54 facilities of forecast resources).

- The *"Map of the geological and economic feasibility study for the development of the mineral and raw materials base of natural adsorbents of the Russian Federation"* reflects the current state, use and prospects for the development of the mineral resource base of natural adsorbents of Russia. The map identifies objects of geological and economic zoning: *industrial and raw materials sites, geological and economic areas.*

The II type of maps reflects the ecological condition of the territory, intensity and types of man-made impact on the environment.

The *"Location map of technogenic pollution facilities in the Russian Federation"* shows technogenic systems and facilities that negatively affect the ecological state of the environment, including the geological environment. It was created on the information base of previously published thematic maps, namely, "*Map of sources of man-made pollution in Russia*" (1995), "*Map of nuclear cycle facilities and radioactive contamination in Russia*" (1995), "*Ecological map of Russia. State of the environment*" (1999),"*Ecological and radiogeological map of Russia*" (1995).

The main result of the simulation was the creation of an **integrated map (the III type)** of ecological and economic zoning: *"Scheme of ecological and economic regionalization of the territory of the Russian Federation on the basis of using mineral raw materials base of natural adsorbent"*. The map is based on three main groups of indicators: natural, economic and environmental.

The natural group of indicators is characterized by the mineral and raw materials base of natural adsorbents (fields and objects of forecast resources). Analysis of the resource potential state of natural adsorbents (Afanasyeva et al., 2009; Distanov, Konyukhova, 2005) shows that Russia has the necessary raw materials to use for environmental purposes. Their total explored reserves amount to more than 3.2 billion tons; the forecast resources for P1 + P2 category are 2.4 billion tons.

An important economic component of the map is the reserves estimated by the indicators of study and development, the relationship to the subsoil fund. The ecological content of the map is characterized by such indicators as the degree of ecological condition of the territory (satisfactory, moderately acute, acute and tense); industrial enterprises making the largest contribution to the pollution of the territory; radiation pollution associated with technogenic factors; railways; existing and under construction oil pipelines, etc. Hydrocarbon fields, fields of metals and other minerals, potential or actual sources of pollutants into the environment are also indicated on the map.

Thus, on the basis of the analysis of cartographic data, the areas of the territorial distribution of man-caused environmental impacts were identified. The objects of natural adsorbents put on the map are intended to play the role of a mechanism for solving environmental problems and ensuring the ecological and economic safety of the population. As a result, 13 ecological and economic regions were separated in the territory of the Russian Federation by types of technogenic pollution and nearby fields of adsorption raw materials.

Let us consider the model of ecological and economic zoning in the Privolzhsky Federal District (PFD) as an example.

The technogenic impact on the geological environment in the PFD manifests itself unevenly. In the north of the district in the Republics of Udmurtia, Bashkortostan, in the Kirov, Perm, and Nizhny Novgorod regions, the sources of pollution of the geological environment are forest, paper, energy and engineering industries. While in the southern part of the Privolzhsky District contamination of the geological environment occurs at the expense of the mining and metallurgical industry, where in the settlements there are numerous dumps of overburden, substandard ores, tailing dumps that occupy a large part of the surrounding lands and become permanent sources of air pollution, soils, surface and groundwater. Such are the settlements in the Orenburg and Perm regions.

Significant sources of pollution are numerous oil fields in the Republics of Tatarstan, Bashkortostan, Udmurtia, Orenburg, Samara, Saratov, Perm regions. Increased technogenic loads exist in the regions of large cities and industrial hubs in the Republics of Udmurtia and Tatarstan, Orenburg, Samara, Ulyanovsk, Saratov regions at the expense of chemical and petrochemical industries, machine-building complexes, ferrous and non-ferrous metallurgy, oil processing, production of construction materials that have constant negative impact on the ecological situation.

If agricultural production in the northern regions of the PFD is of moderate intensity, then in the south – fields of grain crops, where mineral fertilizers are excessively used, are also a source of contamination of the geological environment.

In the Privolzhsky Federal District there is a developed transport infrastructure. The operating length of the public railway tracks is 15228 km, the length of the hard-surface roads is 162.3 thousand km, and the inland navigation routes – 6453 km.

Elevated concentrations of pollutants in the air (solids, sulfur dioxide, dioxide and nitric oxide, carbon monoxide and specific pollutants) are typical for areas with a high level of production development, high population density and a developed transport infrastructure. Absolute indicators of emissions of pollutants into the

atmosphere in the Privolzhsky Federal District make up 5,172,874 thousand tons per year (Kiryushin, 2016). The "leaders" with the largest emission indicators are such regions as the Orenburg region, the Republic of Bashkortostan, the Republic of Tatarstan, the Samara region and the Perm region. The next group of emissions includes the Nizhny Novgorod and Saratov regions, the Republic of Udmurtia. The regions with the lowest absolute emissions are the Republic of Mari El and the Republic of Mordovia (Figure 2). In 2006, the cities of Balakovo, Kazan, Naberezhnye Chelny, Nizhnekamsk, Saratov, Syzran are included in the list of cities in Russia with the highest level of air pollution (Ecology and Nature Protection, 2008).

Analysis of the calculation of the pollution specific values (in this case, emissions of pollutants into the atmosphere) in relation to the size of the territory, showed that there are significant differences in the values between the subjects (Figure 3). By the least emissions of specific values, such subjects as the Kirov region, the Penza region and the Perm region are allocated. At the same time, such regions as the Samara region, the Republic of Tatarstan and the Orenburg region have high values, both in terms of absolute and specific emission indicators (Kiryushin, 2016).

The Orenburg region has the highest rate of pollutant emissions from all sources of emissions per inhabitant – 544 kg/person. Specific volume of

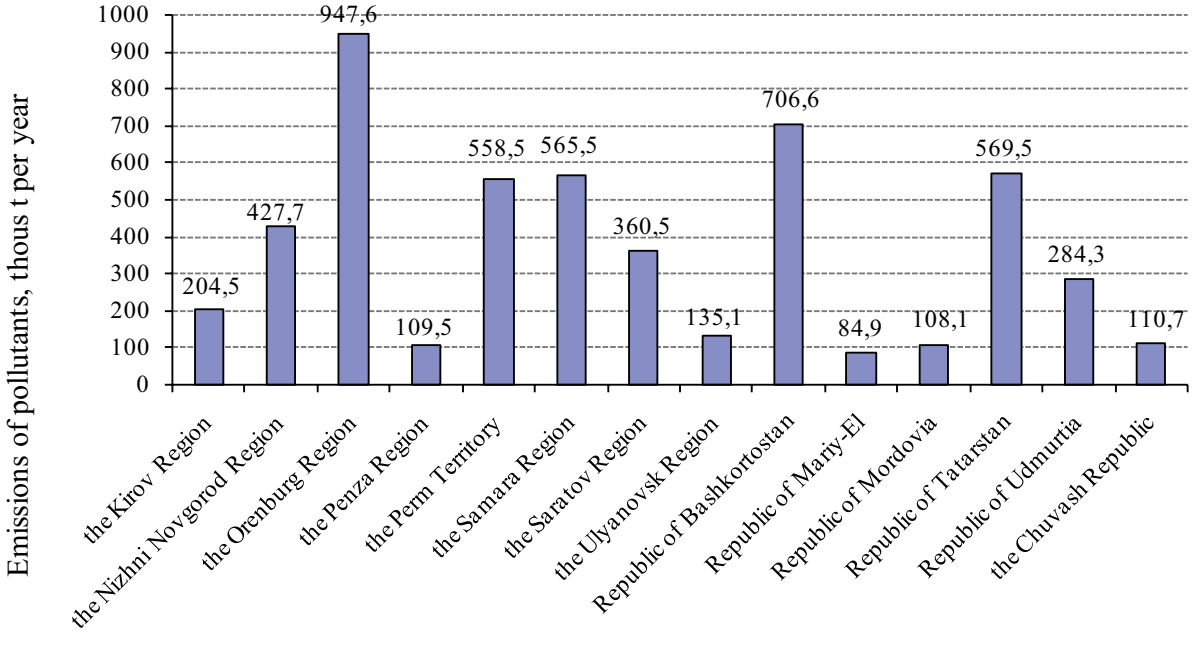


Figure 2. Total emissions of pollutants into the atmosphere according to the subjects of the Privolzhsky Federal District

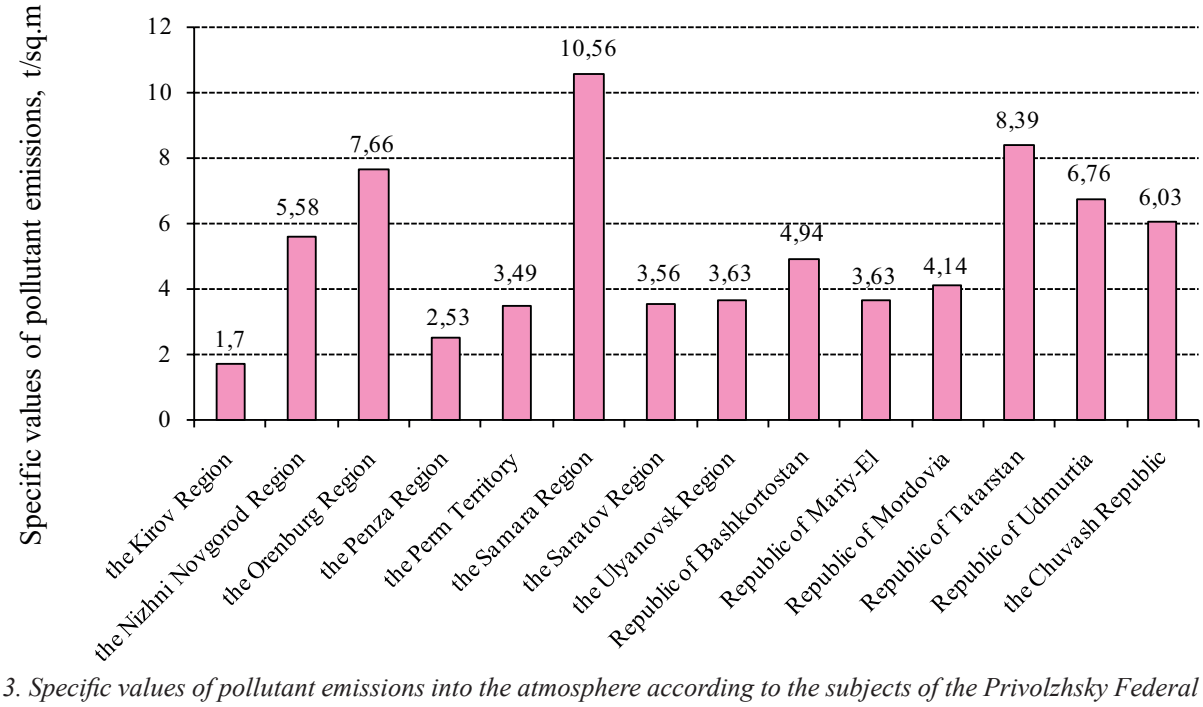


Figure 3. Specific values of pollutant emissions into the atmosphere according to the subjects of the Privolzhsky Federal District

pollutant emissions per capita in the atmosphere is higher than the average for the PFD in Perm Territory (257 kg/person) and Samara Region (222 kg/person) (Ekologiya i okhrana prirody..., 2008).

The PFD has numerous fields of adsorption raw materials (diatomites, flasks, bentonite-like clays, glauconites, etc.) that can be used for ecological and economic rehabilitation of ecologically unfavorable areas. On the territory of the District, according to the ecological situation and the availability of adsorption raw materials, two ecological and economic regions (EER) – Privolzhsky and Orenburg (Figure 4, 5) are allocated.

Privolzhsky ecological and economic region occupies the Saratov, Samara, Ulyanovsk regions, the eastern part of the Penza region, the Republic of Tatarstan and

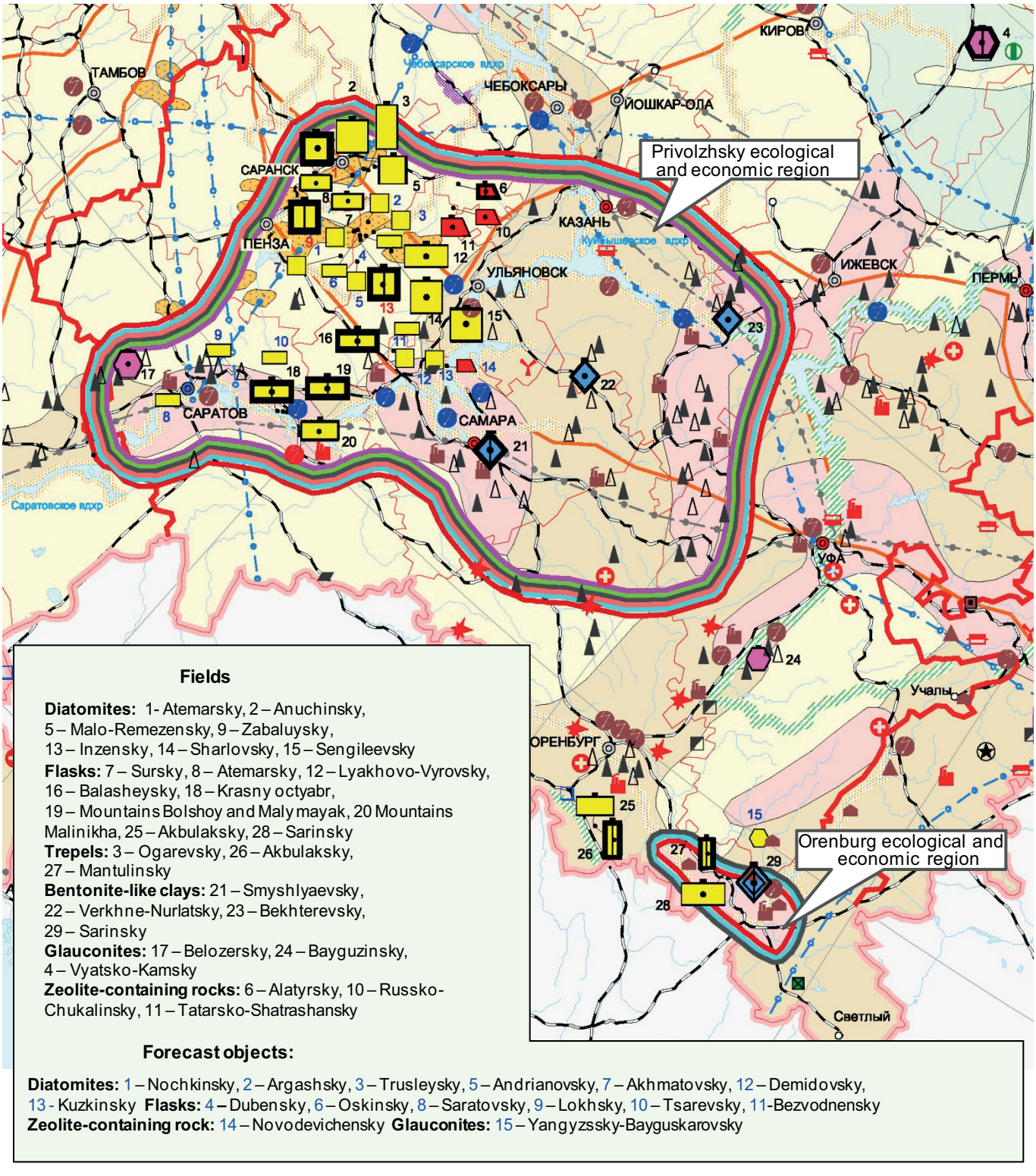
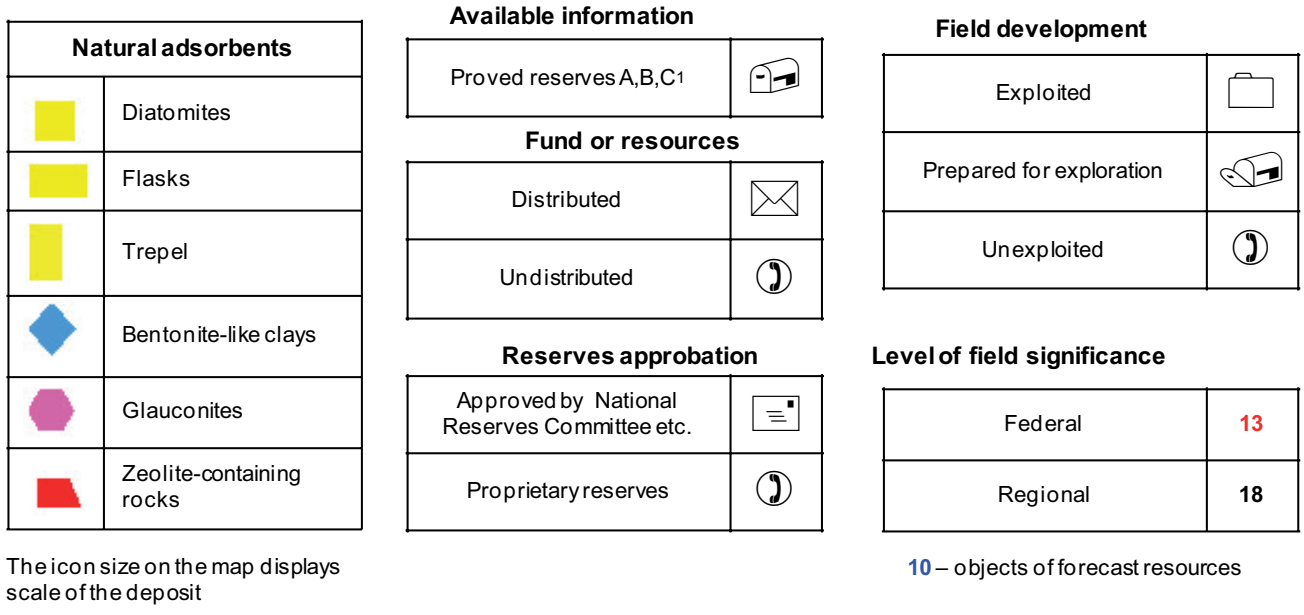
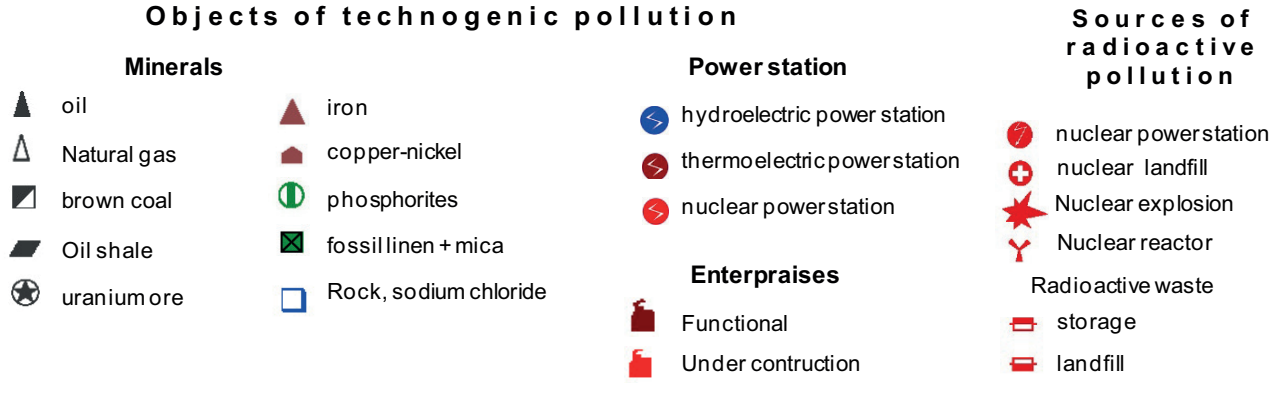
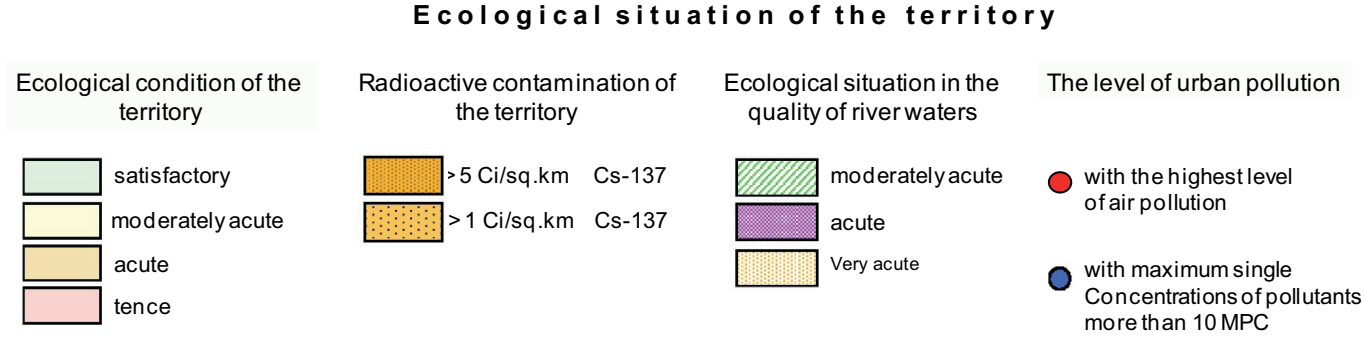


Figure 4. Model of ecological and economic zoning of the Privolzhsky Federal District on the basis of the mineral and raw materials base of natural adsorbents







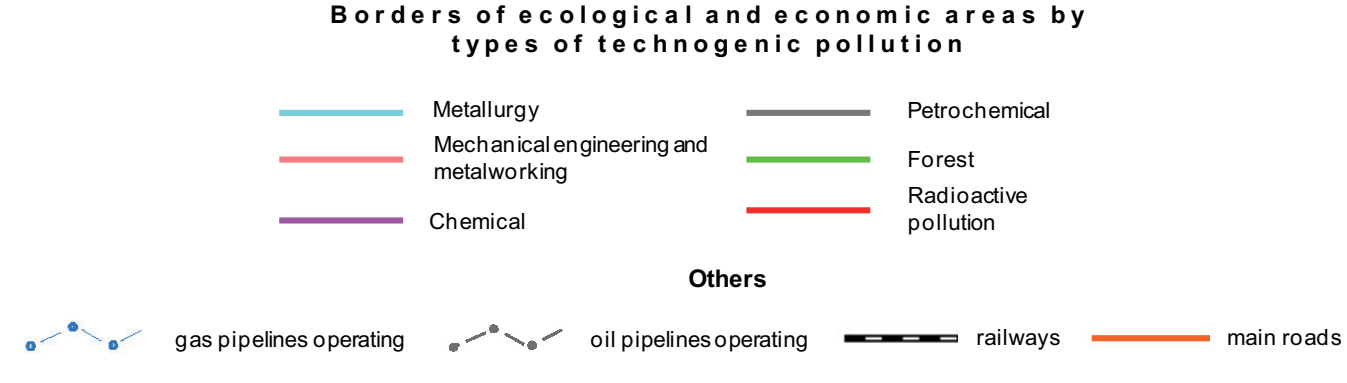


Figure 5. Legend to the model of ecological and economic zoning of the Privolzhsky Federal District

The explored reserves of adsorption raw materials				Forecast resources
Raw materials	Total	Undistributed reserves	Distributed reserves	
Bentonite-like clays	46,255 mln. tons	22,888 mln. tons	23,367 mln. tons	P_1 -2,1 mln. tons P_2 – 13 mln. tons
Glauconite	10,33 mln. m^3	6,96 mln. m^3	3,37 mln. m^3	-
Diatomite	148,02 mln. m^3	29,85 mln. m^3	118,17 mln. m^3	61,65 mln. m^3
Flask	596,7 mln. m^3	184,3 mln. m^3	412,4 mln. m^3	57 mln. m^3
Tripoli	58,18 mln. m^3	34, 06 mln. m^3	24,12 mln. m^3	-
Zeolite-containing rocks	94,54 mln. tons	0,57 mln. tons	93,97 mln. tons	9,05 mln. tons

Table 3. Reserves and forecasted resources of the Privolzhsky EER

The explored reserves of adsorption raw materials			
Raw materials	Total	Undistributed reserves	Distributed reserves
Flask	23,88 mln. m^3	23,88 mln. m^3	-
Tripoli	12,39 mln. m^3	0,53 mln. m^3	11,86 mln. m^3
Bentonite-like rocks	14,38 mln. tons	-	14,38 mln. tons

Table 4. Reserves of the Orenburg EER

Mordovia. Strong and acute ecological situation in the region is created by a powerful industry – enterprises of ferrous and non-ferrous metallurgy, chemistry. Dozens of oil refineries operate on the territory of the region, which have a negative impact on the environment. The largest number of them is located in the Samara region, Saratov region, the Republic of Tatarstan. Significant sources of pollution are oil fields in the Republic of Tatarstan, Samara, Saratov, Ulyanovsk and Penza regions. The Balakovo NPP and the nuclear reactor in Dmitrovgrad are potentially dangerous. In addition, the "Chernobyl radioactive trace" can be traced in the Penza and Ulyanovsk regions.

The Privolzhsky ecological and economic region has significant reserves and forecast resources of bentonite-like clays, opal-cristobalite rocks (flasks, diatomites, trepel), glauconites and zeolite-containing rocks (Table 3), which are potential sources of adsorbents.

As the model of ecological and economic regionalization shows, in areas with intensive oil production and refining, bentonite-like clays of Bekhterevsky and Upper Nurlatsky (Republic of Tatarstan), Smyshlyaevsky (Samara region) fields can be used for desulfurization of oil products at oil refineries, gas drying, purification of drinking and sewage water. Glauconite sands of the Belozersky field (Saratov region) for the rehabilitation of territories contaminated with oil spills. Opal-cristobalite rocks can be used for cleaning sewage and drinking water, air in the concentration areas of industrial enterprises, and in the area of radiation contamination of arable land, preventing their transfer to plants (areas of the Penza region). Flasks are also suitable for these purposes, for example, of the Surinsky field. To clean the radioactive waters of the Balakovo NPP, flasks of the Volsky group can be used (Mountains Big and Small Mayaki, Red October, Malinikha Mountain).

The Orenburg ecological and economic region is a region of concentration of mining and metallurgical enterprises creating a tense ecological situation. Natural adsorbents available in the region (Table 4), like bentonite-like clays of the Sarinsky field and opal-cristobalite rocks (the Sarinky field flasks and the Mantulinsky field tripoli) can be used to treat sewage and drinking water, gases and air at mining plants, thereby preventing pollution of the natural environment .

Conclusion

The information-cartographic model created with the help of the GIS, as a digital product, covers information about the mineral resource base of natural adsorbents, enterprises developing natural adsorbents, the ecological situation in Russia's regions and sources of man-made pollution. The database on the Privolzhsky Federal District contains more than 200 technogenic pollution facilities, 28 fields and 16 forecasted resources.

The obtained results of geoinformation mapping make it possible to identify zones of ecological tension

and thereby determine priority measures for rational nature management and ensuring environmental safety of the regions.

The developed model of ecological and economic zoning of the territory based on the use of the mineral and raw materials base of natural adsorbents can become the basis for subsequent, more detailed studies in the field of nature management and environmental protection for all regions of Russia.

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