International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 20 (2015) pp 41178-41184

The Basin Approach And Mapping To The Anthropogenic Impact Assessment On The East Of The Russian Plain

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Abstract

The given paper considers the methodological aspects of the Atlas mapping for the purposes of Sustainable Development in the regions of Russia. Requirements for the Atlas's structure and content were outlined. The approaches to mapping of "an ecological dominant" of Sustainable Development conceptually substantiated following the pattern of a large region of Russia. The Atlas proposed to be developed, can be considered by its spatial scope as the regional one and by the content as the fundamental complex science-reference mapping guide which characterizes the environment situation in the east of Tatarstan, the conditions and factors that determine it, the tendencies to the change of the ecological state in the territory and in the centers, the measures to reach an ecological equilibrium. Several maps were built as example of regional mapping to estimate impact of oil and gas industry on the environment and to develop solutions for natural resources optimization on the study territory. The complexity of natural systems and the need to integrate large number of factors required the use of modern methods of geoinformatics, information technology, mathematical and cartographic modeling. "Map of cumulative anthropogenic impact" allows through the selected parameters to identify the impacts caused by agricultural activity and "Integral environmental assessment map" – oil and gas industry impact on the environment. A technique for quantifying of different sectors of the economy contribution to human impact on the certain components of the landscape realized by the example of forest vegetation.

Keywords: Basin Approach, Anthropogenic Impact, Integrated Assessment, Spatial Analysis, Geographic Information Systems, Sustainable Development, Atlas, Mapping, Environmental Assessment.

Introduction

The human activities industry inevitably have a negative impact on the environment and often leads to changes in natural systems, disruption of their functioning and sustainability mechanisms. During the first half of the XX-th century, the negative effect on economic activity on biosphere was smooth out by the natural process of homeostasis occurring in it. In the next ten-year period, a large-scale society's activity has led biosphere on the brink of the pre-crisis state of the environment. At present, the ecological capacity of the environmental in many regions of the earth exceeds the standards, especially where the ecological growth is determines by involving into the economic activity of a human the influx of natural raw resources and their profound processing. All these processes bring nearer to a possible damage of regenerative probabilities of the regional parts of the biosphere. In accordance with this law, the anthropogenic flows formed in the bounds of nature-technical geosystems can interact, so that their summation produced the cumulative effect stipulating the increase (in time and space) of a range of spreading of the anthropogenic changes in nature environs. Thereby, the purpose to assure an ecologically safe Sustainable Development (SD) of the world's community favoring to meet the essential needs of people in conjunction with the environment protection and its reproduction, assumes ever-greater importance. In accordance with the principles of SD as far back as 1996 in Russia there was approved 'The Concepts of Transition of the Russian Federation to the Sustainable Development'. This concept assumes the recognition of three components: the balanced application of ecosystems, the effective economics and the social welfare (a fair society) that gain to meet the needs of present and future generations. This approach supposes a through regard of ecological factors that determine the parameters and the rate of a human's economic activity, which directly or indirectly exert anthropogenic influence of one other force on the environment.

In our view, the uniform system of complex scientific-reference ecological-geographical is nesessary as a base for the maintenance of the SD concept in the territories of the Russian federation subjects or certain regions. In this case, the assessment of the ecological situation in the regions can be solved by the conjugation of the two interrelated system – the mapping and the Geoinformational ones [13], [5], [20]. Geoinformational systems and GIS-technologies in the period when a society is transiting into the SD model might play a significant role. The regional thematic and complex atlases which solve the problem of informational-geographical maintenance for fundamental science, applied science, national economics under the conditions of the transit period might be basic for the development of the SD. The attractiveness of approach also substantiated by the fact that the information in the atlases initially given in the systematized, formalized and uniformed; it has the characteristics of the Geoinformational system and was the prototype of the GIS-technology.

We suggest creating a science-reference Atlas for a large region of Russia, where a diversified in force and intensity, the national economy exerts its influence on the environment surroundings – region of a large-scale oil-gas extracting complex JSC "Tatneft". The high intensity of national economy activity that especially strictly reveled for the last 200 years is follow by the considerable reorganization of geosystems. There occurred the transportation of geosystems from the basic (natural) state into the nature-anthropogenic and anthropogenic analogues. The first serious anthropogenic pressure on environment was a result of the mass lands ploughing up which caused deforestation and virgin meadow lands steppe vegetation destroying [17], [2], [7]. This has led to the radical reorganization of erosion-accumulative process. As a result, there appeared a rapid soils degradation, mass development of ravines systems, small rivers silting and rivers top links reduction. In the main of different structure river-basin erosion, represented by erosion belts formed on the ploughed up hills [19], [12].

The second stage of the influence on the landscapes in study region deals with the industry's development. However, the industry's effect on the landscapes had an adversely affect in pollution of different natural surroundings, damage of landscapes components. By more than 60 years of functioning of enterprises of "Tatneft" oil fields occupy an area of more than 38 thousand km^{2}in Republic of Tatarstan, about 40 thousand oil wells, more than 55 thousand km of pipelines, hundreds of different installations, thousands kilometers of highway placed in its territory. During that period more than 3 billion tons of oil was extracted. Technological impact in the region of JSC "Tatneft" caused not only by oil industry [9]. Large number of major industrial enterprises, intensive agricultural use of the territory, dense transport infrastructure is also largely determines the anthropogenous impact on region environment. In such circumstances, integrated approach in environmental impact assessment is necessary [20], [21]. This allows to determine impact level and particular industry sector contribution to the overall technogenic pressure on the study area.

Methodology

i. Atlas concept and operational units

The main goal of this article is to develop the concept and structure of the Atlas "Tatneft" and the Sustainable Development" and to demonstrate proposed methods of integral environmental assessment as example of regional mapping. Atlas can be considered by its spatial scope as the regional one and by the content as the fundamental complex science-reference mapping guide which characterizes the environment situation in the region, the conditions and factors that determine it, the tendencies to the change of the ecological state in the territory and in the centers, the measures to reach an ecological equilibrium. Besides, the Atlas's stuff are to serve as the basic to make decisions concerning the plans on the industry's location, i.e. the foundation of Strategic Ecological Assessment, the main objective while compiling the Atlas proposed, is the mapping of the "ecological dominant" of the SD with perspective to apply its stuff for the creating a system of support to implement decisions on the SD.

An integrated approach to the environment components properties study and comparison with the existing technogenic impact is the most correct to evaluate the potential impacts of oil and gas industry on the environment and develop solutions to optimize nature in the study area. Geosystem approach is the best way to provide integrity; it allows selecting a representative conjugate series of operational territorial units (OTU) for spatial analysis of the environmental impact by economic activities. In these units, a regular uniformity of the physical parameters of environment is observed and systemic linkages between natural components are taken into account [4].

We'll focus on the ideology of a river basin approach. This variant of territorial division is most useful in the humid Plains of the Earth temperate belt, where the main role in relief formation is played by the permanent and temporary water flows [12]. The founder of the basin approach R. Horton [8] proposed a river basins analysis system, including the definition of order, structure of river network and its role in basin and riverbed erosion development [8]. An important feature of these territorial units is the fact that they represent geosystem formation with all its features and natural boundaries and also meet the requirements of representativeness to the maximum extent. One of the requirements for spatial assessments – data should be analyzed on the basis of the smallest territorial units and avoid larger arbitrary ones, except when they relate to the studied data [1]. The relatively small size of elementary basins allows to present study area fractionally, slight variation in size avoids visual dominance of any areas in spatial assessment. Another important point is the ease of their borders selection and the possibility of reasonable transition to different size when generalization level is changes.

Of course, basin approach for all its obvious advantages is not deprived lacks. Thus, its use in the arid landscape zones, in bedded, wetland and lacustrine relief conditions, with continuous development of permafrost rocks can be problematic, as well as in the case of upland type broad watersheds [19]. Despite this, river basin approach use is the most reasonable in spatial assessments of economic activity impact on the environment, environment state conditions forecasting and environmental protection measures development [6], [3].

For the purpose of spatial analysis 713 watersheds of 2-3 orders with unique ID created by Straler-Filosofov classification. Each territorial unit is evaluated on various parameters.

ii. *Anthropogenic impact assessment*

The most common technique for estimated indexes integration is numerical score. Their simple summation usually used for generalized assessment that not sufficiently substantiated due to significant differences in the importance of individual parameters and various contributions in geosystems disturbance [14]. This approach often leads to incorrect conclusions. Integration can be performed more accurately when final assessment is calculated as sum of weighted scores for individual components [20], [16]. Preliminarily all values must be normalized for ease of handling to range from 0 to 1, where 0 corresponds to the minimum score, and 1 – max.

Weighting coefficients for an objective evaluation of each indicator contribution were calculated. They are determined by allocating one of the indicators, which, according to experts, changes most "synchronously" with the required integral evaluation. This indicator is called the general (Xgen). According to this index "synchronicity" change all other particular scores along with the required integral evaluation is estimated. Usage of usual pair correlation to evaluate "synchronicity" is undesirable because initial indicators are expressed in scores, i.e. not absolute but ordinal. Therefore, we used the Spirmen rank correlation coefficient. Then, among the resulting pair correlation coefficients maximum one was selected and by dividing the rest pair correlation coefficients by maximum weighting index for individual indicators was obtained. Further sum of the weighted scores calculated for each basin and ranked from 1 to 5 at the final stage of landscapes disturbance evaluation for the convenience of subsequent analysis. The most disturbed basin geosystems match 1 point, the least - 5 points.

To collect information from various territorial unit containing data about the state of components of the environment and anthropogenic impacts and to translate the results of the integrated analysis on the basins, regular grid with a step of 250 m used.

As a result, the evaluation maps were constructed – "Map of cumulative anthropogenic impact" (Fig. 1) and "Integral environmental assessment map" (Fig. 2). The third map was built (Fig. 3) to demonstrate necessity and possibility of evaluation of different contribution of various sectors of the economy in total anthropogenic impact. For this map, we used GIS technologies and methods of landscape pattern evaluation, proposed by Victorov [18].

Results

i. Atlas mapping for Sustainable Development

We suggest presenting the three levels of mapping in the Atlas: 1) the regional – the territory of JSC "Tatneft" activity; 2) the local – the most ecologically dangerous regions in the territory of " JSC "Tatneft" activity" 3) the municipal – certain industrial units and cities.

The Atlas should cover the main trends of the ecological mapping: the natural conditions, anthropogenic exertion and natural surroundings change, assessment of ecological state of the environment surroundings elements, medical-ecological situation, economic and social consequences after its worsening, ecological safety strategy. The ecological factors and conditions, trends for their development produced concerning all geospheres: litho-atmo-hydro-bio-pedo-techno- and sociosphere. The Atlas considered as the kernel of the whole complex of the mapping provision to solve the problems of the ecology in the region of JSC "Tatneft" activity. In particular, the negative exertion on the environment by other pertains to national economy complexes.

The fundamental scientific-methodical principles and methodological approaches while the Atlas's compiling are as follows: 1) the richness of content and systematization (a systematical approach) stipulating complexness, adequacy of the spatial structure reproduction, reaction on external and internal interrelations on natural and nature-anthropogenic formations; 2) the ecological trend of the mapping, the revealing of the regions ecological structure; 3) the compatibility with the basic systems indices of the territorial development and the necessary information on practical application of the results if the mapping [15]; 4) the diversity and multi scale applicable initial material; 5) the use of specially prepared electronic "layers" in vector format as the base; 6) "mental zooming" [10] which enable to user while working with the Atlas to search in order to extend one's knowledge from general to detailed one.

The Atlas should meet the following requirements: the exhaustive and detailed for the given scale and extent of the knowledge, the depiction of the reliable ecological information; the thematically richness and the validity of the ecological characteristic of the whole territory and certain regions; dividing a territory into regions, assessment indices, tendencies to development, prediction of ecological situations, recommendations on ecological safety provision, contemporaneity of information and a possibility to renew it, maps maximum visualization, their availability for a large number of users [22].

The Atlas is to represent by itself the system that includes analytical, complex and synthetically maps. This mean that they must be inventoried, evaluation, predictable and recommendational ones. The purpose it could serve and its type will determine the Atlas's structure, by peculiarities of the nature of a region under investigation, to what extent it studied, anthropogenic transformations, and informational provision. It will have the maps of natural, of social-economical themes and complex ecological maps of regional and local levels. Several trends of thematically mapping suggested to be distinguished in the Atlas's structure: 1) the background history of oil-fields mine working; 2) the nature preservation technologies while oil extracting; 3) the assessment of natural conditions of a humans vital activity; 4) unfavorable and dangerous natural processes and phenomena; 5) the anthropogenic effect and environmental surroundings change; 6) the social-economical ones; 7) the medical-ecological and geochemical ones; 8) the nature preservation, the nature use management and the nature's response.

A few basic layers of the operational territorial units (OTU) of the spatial analysis are used in the Atlas. For example, the first section of the Atlas is devoted to the nature's characteristics and small rivers ecological state, the rivers basin of the stream order is the main type of OTU. In the landscape section – these are the terrains types and stows.

In the section of the regional assessment on the anthropogenic exertion on the environments surroundings and in the integrated maps – all sorts of the OTU including the enterprises, municipal districts, bounds of oil-gas extraction

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 20 (2015) pp 41178-41184

companies (OGEC), forestry, hunting grounds, raster grids enclosure.
The inner unity of the Atlas realized owing to the following facts: the minimum numbers of map projections (Gauss–Kr ger); the minimum short-scale row (1:1 150 000; 1:1 120 000); maps construction in accordance with the uniform basic geographical principles; by mutual agreement on different maps legends, scales and gradations with the uniform level of generalization; the observing the common principles of shaping and the style of design. At the first stage, the electronic variant of the Atlas made. It made overall in Mapinfo GIS and, in particular, in Surfer. Within these groups the other numerous groups can distinguished. The maps of unfavorable and dangerous processes and phenomena subdivided in accordance with the types of processes – of endogenous and exogenous origin. Among the maps of the anthropogenic effects on the natural surroundings one can differentiate the maps of the influence on different nature's spheres – atmosphere, hydrosphere, lithosphere, biosphere, etc.
In this way, all thematic groups brought together into four main sections: 1) the introduction (the maps of a general condition and social-economical state, a region's rating in Republic; 2) the components of natural, social-economics systems that form the conditions for the ecological situations; 3) the integrated maps of exertion and change of the environment; 4) the strategy to reach an ecological equilibrium.

ii. Regional level mapping

ii.i Map of cumulative anthropogenic impact

One of the basic maps, which is required for a comprehensive estimation of the territory. It was based on the borders of OTU, the relevant to the drainage basin.
At weighted scores calculation, as noted above, the choice of the general indicator (Xgen) is essential, and we selected total vegetation area (forests and meadows) in the basin geosystems. Vegetation cover largely determines the comfort of environmental conditions for human life, plays the role of ecological frame of territory, defining diversity of ecosystems and their resistance to external impacts.
The following indicators were taken as particular: the cultivated area (% of basin area), gully dissection density (km/km^2), eroded soil area (% of basin area), road network density (km/km^2), settlements area (% of basin area), forest and meadow communities disturbance category (scores), forest cover reduction index (% of basin area) for the period from 1800.
Thus, 9 particular indicators used in calculation of cumulative pressure on basin geosystems. As seen from their list, they represent almost all aspects of the economic impact on the landscapes: transport, timber industry, urban and agro-industrial complexes. In addition, vegetation disturbance was taken into account in the assessment.
Using the technique of weighted scores requires caution in choosing not only general, but also the entire system of particular indicators. Temptation of mechanistic account of the greatest possible range of parameters can lead to large errors and incorrect conclusions in spatial analysis.

The strength and direction of linkages between the impact factors (Xi) and environment favorability indicator (Xgen) are shown in Table 1.

TABLE 1. Correlation coefficients between the general indicator (Xgen) and impact factors (Xi)

The correlation coefficient with X_{gen} (total vegetation area)							
X_1 cultivated area	X_2 settlements area	X_3 eroded soil area	X_4 gully dissection density	X_5 road network density	X_6 forest Disturbance	X_7 meadow disturbance	X_8 forest cover reduction
-0.95	-0.22	-0.13	-0.09	-0.11	0.78	-0.12	0.16

The results of the spatial analysis of the environmental situation in the region by the method of weighted scores presented on "Map of cumulative anthropogenic impact" (Fig. 1). For degree of anthropogenic impact the following relations obtained: very strong – 207 basins, strong – 273, average – 157, moderate – 57 basins and weak – 19 basins.
Thus, in the study region more than two thirds of basin geosystems are influenced by strong and very strong anthropogenic impacts.

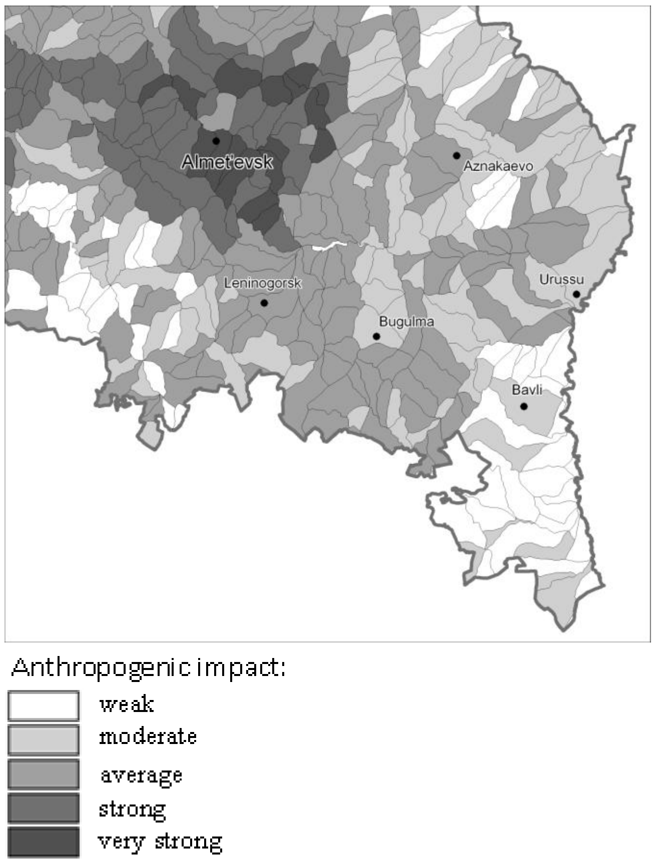

Fig.1. Map of cumulative anthropogenic impact

ii.ii. Integral environmental assessment map

To solve this problem the above-described method of weighted scores and GIS spatial analysis technology used.

The difference is that pair correlation coefficients between Xi and Xgen calculated in more accurate way: in absolute values, instead in scores. In integral estimation a large range of environment components indicators included. They are expressed by different sum of scores and represented as geographic information layers.

All indicators used in the evaluation were divided into two groups. The first – "processor" [11] group includes indicators describing anthropogenic influences. By combining them, you can single out share of the impact of one or another economic complex on the environment. "Processor" group indicators, subsequently were taken as Xgen, included 12 types of impacts (total specific anthropogenic impact, taking into account linear, point and area sources of environmental pollution and the volumes of produced hydrocarbons, the proportion of land occupied by oil and gas facilities, etc.). "Indicator" group formed by indicators reflecting consequences of anthropogenic impacts on the environment. It consisted of 14 indicators (complex index of air pollution; chloride contamination of ground and surface water, degree of river water pollution, overall incidence of the population, etc.). The use of geo-information approach and the weighted scores technique (Table 2) allowed to create assessment maps on individual components and the final integral map (Fig. 2). Analysis of the map showed that areas with moderate and high degree of disturbance prevail in study region.

TABLE 2. Correlation coefficients between Xgen ("processor" group), and the individual components of the environment ("indicator" group)

Environment components (impact indicators)	Correlation coefficients	
	Summary anthropogenic impact	Impact by oil and gas industry
Groundwaters	0.24	0.63
Surface waters	0.12	0.72
Soils	0.05	0.00
Air	0.12	0.09
Vegetation	0.27	0.62
Fauna	0.16	0.10
Man	0.16	0.27
Landscapes	0.31	0.04

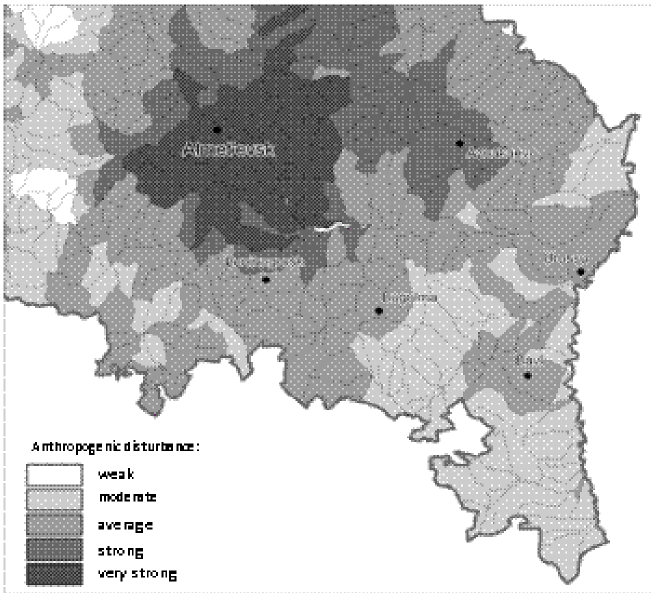

Fig.2. Integral environmental assessment map

In the center of map a kind of core with strongly disturbed basins formed, related to the eastern part of Almetyevsky, western – Aznakaevsky and southern – Sarmanovsky municipal districts where major oil extraction conducted. Weak and moderate level of disturbance is typical to wooded undisturbed basins of Nurlatsky, Cheremshansky, Zainsky, Leninogorsky, Aktanyshsky and Elabuzhsky municipal districts.

Overlaying of "Map of cumulative anthropogenic impact" and "Integral environmental assessment map" gives in general a good convergence of boundaries with similar categories of human impact and disturbance of the environment. Differences between final maps are due for usage of much broader spectrum of anthropogenic impact types, as well as taking into account its intensity on "Integral environmental assessment map". Comparison of resulting synthetic maps and list of estimated indicators shows that first map allows highlighting the impact caused mainly by agricultural activities, and second – the oil and gas industry impact on environment.

ii.iii. Contribution in anthropogenic impact assessment

As we can see above, most frequently, in the analysis of the factors determining the environmental condition of the territory, the indicators of state of certain components of environment are used. At the same time it is extremely important not only component-wise grouping of environmental indicators, but also division of anthropogenic impacts characteristics on the groups characterizing various sectors of the economy to determine their quantitative contribution to the overall effect. For this purpose, we evaluated the "separating" fragmentation of forest vegetation (on the contribution of various sectors of the economy) as a form of human impact within the boundaries of the basin geosystems. It is assumed that an increase of forests fragmentation degree decreases their resistance to human impacts, also violated ecosystem connection and biodiversity.

Vegetation pattern is perhaps the most physiognomic geocomponent and also indicator of landscape pattern [18].

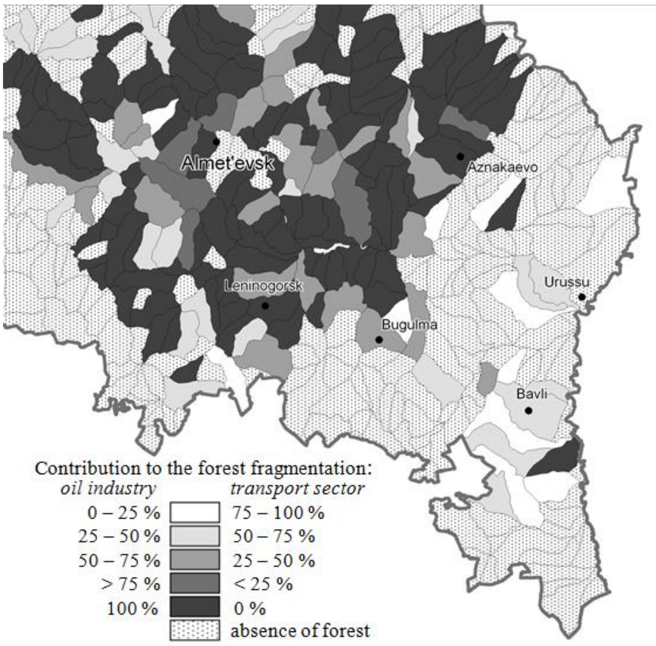

Fig.3. Assessing of oil industry contribution in anthropogenic impact on forest vegetation

To assess the contribution to forests fragmentation, we used electronic layers of forests contours, road networks (transport sector), linear objects of the oil industry (oil pipelines, water) and watershed boundaries as OTU. As a result, data that quantitatively characterize the forest fragmentation were obtained: the average contour area, the fractional index, degree of differentiation contours size, which allows estimating of anthropogenic impact. Several indicators characterizing fragmentation of contours evaluated. As the main fragmentation index average forest contour area decrease in % of the initial was chosen. Degree of contours differentiation showing spread of contours area was also evaluated within each OTU.

Final electronic map (Fig. 3) allows to evaluate by forest fragmentation not only the overall level of anthropogenic impact, but also to determine the contribution of the oil industry impact on vegetation within the boundaries of the basin geosystems.

Conclusion

Within the bounds of the development of the strategy of ecological safety in the region of JSC "Tatneft" activity, the Atlas, in our opinion, will contribute to choose a way to optimize environmental management, environmental surroundings, improvement of living conditions and people's health and to define the strategy and tactics of the ecological policy in the region East Russian Plain. The Atlas will also favor to provide the uniform informational-methodical ecological investigations, and considered as the scientific foundation with the aim of perfection and development of the ecological monitoring network. Atlas's map analysis one can get the additional data including those that might provide to reach the management decisions. The Atlas that created, its structure, the methods of the creation of the maps of a different content applied as the model one while developing and providing the informational maintenance to the programs of sustainable development of different regions of Russia.

In spatial analysis of the environmental impact of oil and gas complex in landscaped zones of the Earth with well-developed drainage system (for Russia is the temperate zone of humid Plains), the basin principle of ecological state evaluation is most expedient. It is this approach and the use of modern GIS technologies in the evaluation of anthropogenic disturbance allows quantifying the multiple aspects of human impact and of environmental components state. Used technique based on a river basin approach allows spatial analysis of human impact in the region of intense oil production as on individual components as well as on environment in general. In addition, the basin approach is effective in determining of contribution of various sectors of the economy on the state of individual geocomponents of environment.

Acknowledgements

The work is performed according to the Russian Science Foundation (project №15-17-10008).

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