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ASSESSMENT OF IMPACTSON GEOSYSTEMS IN OIL PRODUCTION REGION

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Abstract

This article presents a sample assessment of contribution of several impact sources to the groundwater condition in the intensive oil production region (PJSC Tatneft) (Tatarstan, Russia). The method proposed is designed to minimize the subjectivity of the assessment and permits to derive the map of a man made impact on the groundwater. The use of river basins is argued as a main spatial unit for characterization of the anthropogenic impact and the environment state due to its scalability properties. Proposed combination of GIS technologies, spatial analysis and statistical approach makes it possible not only to quantify the human impact on the environment, but also to determine the contribution of individual industries as well as to evaluate the quality of the assessment.

Keywords: basin approach, anthropogenic impact, integrated assessment, spatial analysis, geographic information systems, environment, nature management.

Introduction

Activities of the oil and gas industry inevitably have a negative impact on the environment, which often leads to a change in natural systems, and to a violation of the mechanisms of their functioning and sustainability.

A great number of large industrial enterprises, an intensive agricultural use of the territory, a dense transportation infrastructure also determine anthropogenic pressure on the studied region. Due to these conditions an integrated approach of assessment of the anthropogenic impact has to be used in order to define only one industry out of all the variety of industrial facilities and, thus, define the level of its influence and contribution to the general anthropogenic impact on the analyzed territory [1].

The level of the impact on the environment depends not only on a type of an impact and its intensity, but on characteristics of natural components. The geosystem approach is the best to provide the complexity of the assessment of environmental conditions and environmental management control as it presents the system of operational-territorial units where the uniformity of physical parameters can be observed and the system connections

between natural components are considered.

The subject matter of the study is a big Russian oil company Tatneft. It has operated for more than 65 years on the compactly situated territory (around 32000 km²) on the east of the Russian plain in the area of high landscapes of forest and steppe zones [2]. The oil production is carried out in the territory of highly fertile arable lands, a large amount of forests (around 30%), a dense network of rivers and lakes; hundreds of towns with population of more than 1.1 million people are located here. The production infrastructure of Tatneft enterprises includes more than 37 thousand wells, 54 thousand km of different pipelines, hundreds of various plants, thousands of kilometers of industrial roads; more than 35 thousand hectares of land are alienated for economic activity. The maximum production of oil was reached in the 1970s when the company produced up to 100 million tons of oil per annum. At present the production level has decreased to 30 million tons. In total, more than 3 billion tons of oil has been extracted from the subsoil these years. The company has begun vigorous activity on development of bitumen fields using borehole thermal methods. These factors have led to a very significant change of the state of the environment. The impact on groundwater and surface water has been especially serious.

The choice of this area is conditioned by existence of a large database on the environment features and anthropogenic impact factors, which provides the basis for objective assessment of anthropogenic impact.

In the practice of the impact assessment, as well as of the evaluation of the man-made impact and the state of geosystems, different methods are applied: the use of separate indicator factors [3, 4], morphological analysis, analogies, expert assessment [5], weighted normalized indicators [6], GIS [7], statistical methods [8], spatial analysis [9], information theory techniques, theory of sets, methods of algebra and geometry, mathematical analysis, mathematical logic, modeling procedures and others. The universal method does not exist; therefore, the choice of a method for solution of a particular problem has to be based on set objectives, as well as the completeness and quality of available information. The correct assessment requires combination of mathematical statistics and modeling methods which if used properly, will help to receive a more exact result. All studies were performed on the project Russian Science Foundation (RSF) "Geography and Geoecology of rivers and river basins of the European Russia: spatial analysis, estimation and modeling".

Methods

We used the basin approach first suggested by R. Horton (1948) [10] as the spatial basis for conducting the collection of indicators and the integrated assessment of the anthropogenic impact. The advantage of using river basin boundaries as spatial units is the fact that they represent a geosystem formation with all intrinsic properties and natural borders. Moreover, the basins meet to the full extent the requirements for representativeness of spatial units and are easily redefined if the generalization level

has to be changed.

Information that characterizes the anthropogenic impact and the state of the environment was unified and recalculated for basins. The characteristics of anthropogenic impacts were divided into groups reflecting the impact of various branches of industry (agriculture, the oil and gas industry, transport communication and others) on the environment. The preliminary analysis of the indicators of the impact with relation to the state of environment was conducted on the basis of ordination. Proceeding from the assigned task and nature of the source data, a method of redundancy analysis (RDA) based on linear relationship between variables was chosen [11]. In this method, features of the anthropogenic impact and indicators the environment state are depicted as vectors (axes) in single ordination space. The closer is the vector representing the indicator of the environment state to the vector of the impact feature (the smaller is the angle between the vectors), the stronger is the correlation between them (fig. 1). Thus, we can visually separate a group of impact features most related to one or another environmental component for further assessment. A correlation analysis accompanying the ordination is necessary to quantify the correspondence between impact feature analysed and an environment state indicator. As a final result we get a list of impact features which can be used to receive a reliable estimate of environment state.

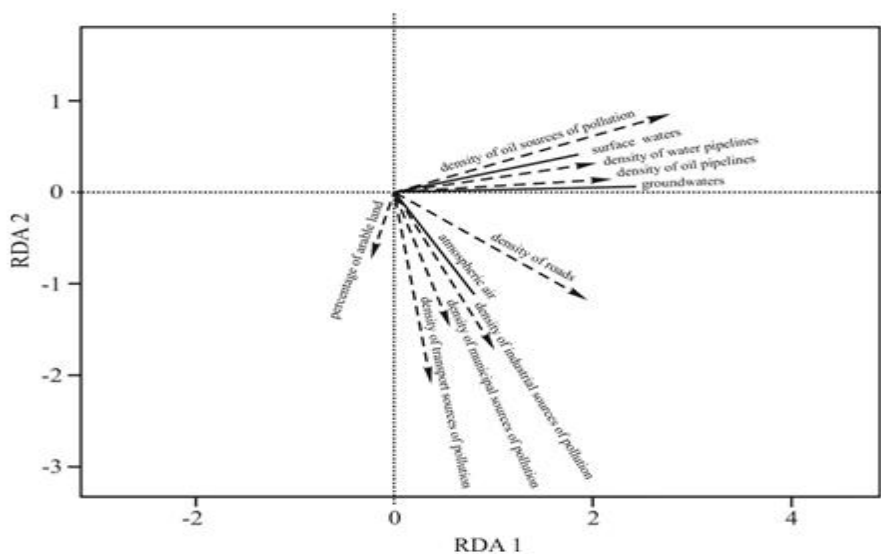


Figure 1. An example of selection of impact features with the help of ordination (solid line – axes of indicators of the state of environmental components, dashed line – vectors characterizing features of the anthropogenic impact)

To avoid subjectivity of an ecological assessment typical of its traditional methods, we chose a cluster analysis as a mechanism for selecting basins with a certain level of the impact on an environmental component. The Ward's method of clustering with Euclidean distance as a distance measure were chosen. This method aims to receive as

compact groups (clusters) of basins as possible (compact in terms of environment state similarity). Histograms of distribution of all impact features were constructed for each cluster in order to describe the level of anthropogenic load which characterizes the received clusters.

In case of an integrated assessment, the task of defining contributions appears to be complex and requires the use of statistical models. Having built a model relating the state of an environmental component to the selected impact indicators, we, then, can rely on the coefficients of the model to estimate the contribution of the impact indicators to a considered environmental component. Besides, having constructed a model with the use of the indicators selected for the assessment of the anthropogenic impact, we can evaluate its quality and reliability by comparing the modeling results with the original characteristics of the state of environmental components. Several statistical models can be proposed. In a case of dealing with rank indicators of the state of the environment it is possible to use Linear Discriminant Analysis (LDA) or Quadratic Discriminant Analysis (QDA). The difference between predicted and actual value of the state of the environment is presented as the difference between classes of the state: the smaller the difference is, the more accurately the model describes the impact on the component. If the dependent variable (environment state indicator) is distributed continuously, Generalized Regression Model (GLM) can be used. Statistical analysis (ordination, correlation, regression and discriminant analysis) was implemented by the means of the R 2.7.0 environment.

Results

In this article, we present a sample assessment of contribution of several impact sources to the groundwater condition in the intensive oil production region (PJSC Tatneft). As the criterion of the state of the groundwater, the map of groundwater pollution compiled by V.I. Mozzherin and A.N. Sharifullin was used [12]. Indicators of human impact have been obtained within the framework of the environmental impact assessment in JSC Tatneft activity region [13]. On the basis of the conducted cluster analysis a map of the anthropogenic impact on the groundwater was received (fig. 2). As a result, all the basins were divided into 4 classes; three of them reflect the level of the impact from moderate to critical, while the remained class shows the territory with no impact on the groundwater.

Next, with the help of statistical models, the contribution of impact sources to the groundwater condition and the quality of impact evaluation were quantified.

We constructed a linear discriminant model for a separation of groundwater contamination classes in accordance with the features of the anthropogenic impact: The groundwater = Density of pipelines + Density of water pipes + Density of roads + Density of oil sources of pollution.

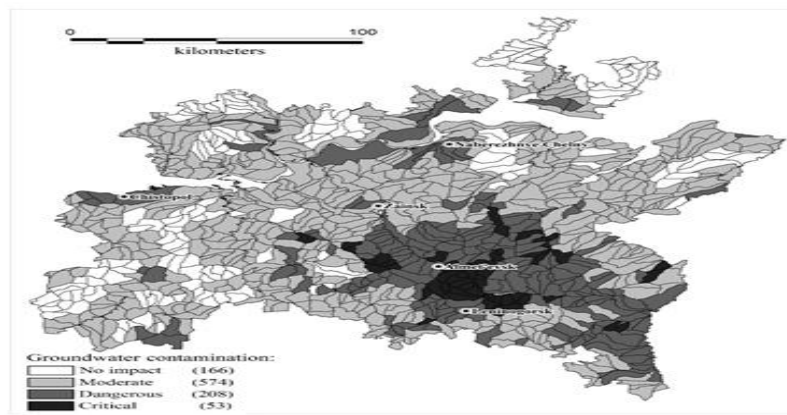


Figure 2. A map of groundwater contamination.

Table 1: Probability of classes (representation of classes, proportion of observations of state of the environment classes of the total number of observations).

Class of groundwater contamination	1	2	3	4
Proportion of class from the total number of observations (basins)	0.17	0.56	0.21	0.06

The table 1 demonstrates that the number of basins belonging to the smallest class of a dependent variable is related to the number of basins of the largest class as 1 to 9 while the allowed relation is 1 to 10. In this case it is recommended [14] to either remove the small class of basins from the model or add it to a similar class.

Table 2 demonstrates that the averages of each indicator (from the density of pipelines up to the density of oil sources of pollution) have distinct values in each class.

Table 2. Group average.

Class of groundwater contamination	Density of oil pipelines, km/km ²	Density of water pipelines, km/km ²	Density of roads, km/km ²	Density of oil sources of pollution, pcs/km ²
1	-0.39	-0.37	-0.17	-0.46
2	-0.29	-0.26	-0.13	-0.34
3	0.65	0.70	0.36	0.80
4	1.47	1.14	0.44	1.86

Table 3. Coefficients of linear discrimination (division).

	LD1	LD2	LD3
Density of oil pipelines	0.367	-0.239	1.176
Density of water pipelines	0.284	0.971	0.032
Density of roads	0.110	0.572	-0.141
Density of oil sources of pollution	0.918	-0.719	-0.914

Table 4. Linear discriminatory component contribution to the division of classes.

LD1	LD2	LD3
0.988	0.012	0.0001

The coefficients of linear discrimination (tab. 3) allow defining the contribution of factors of the impact to total load on groundwater. As the first discriminatory component makes the greatest contribution (tab. 4) to the division of classes, we use it along with the coefficients of linear discrimination to place the indicators in order of the decrease of their contribution to the division of classes of the groundwater contamination:

- density of oil sources of pollution;
- density of pipelines;
- density of water pipes;
- density of roads.

The analysis results show that the density of oil sources of pollution correlates best with the class of groundwater contamination (makes a greater contribution to the pollution or was used to a larger extent while estimating the class of the groundwater contamination). Mostly due to this indicator, the discriminant analysis can divide basins into classes of the state of the environment.

Table 5. The ratio of observed groundwater contamination classes to predicted (linear discriminant analysis).

Classes		Observed			
		1	2	3	4
Predicted	2	168	543	101	8
	3	1	17	75	22
	4	1	4	36	25

The data presented in table 5 allow us to evaluate the quality of modeling of a dependent variable (groundwater contamination) with the help of the discriminant analysis and selected impact indicators. As is seen, 643 observations (basins) are correctly classified with the help of the constructed discriminant model (fig. 3). That is around 64% of all data in relation to the total number of observations (1001 basins).

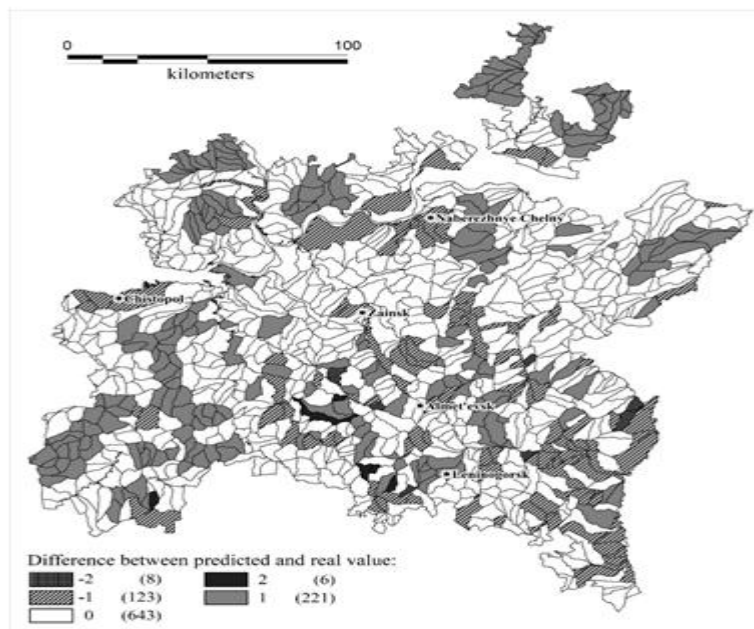


Figure 3. A map of differences between predicted and real value of the groundwater condition (linear discriminant analysis).

The class of less polluted waters (1st class) can absolutely not be recognized; for discriminant analysis this class (around 17% of all observations) is completely identical to the 2nd class of groundwater contamination. Table 2. shows that the average indicators of the 1st and 2nd classes of groundwater contamination do not sufficiently differ. The 3d class of water contamination is more often than not defined as less polluted than it is (101 cases of incorrect rating as 2nd class, 10 % of observations); in other words, the level of pollution is underestimated.

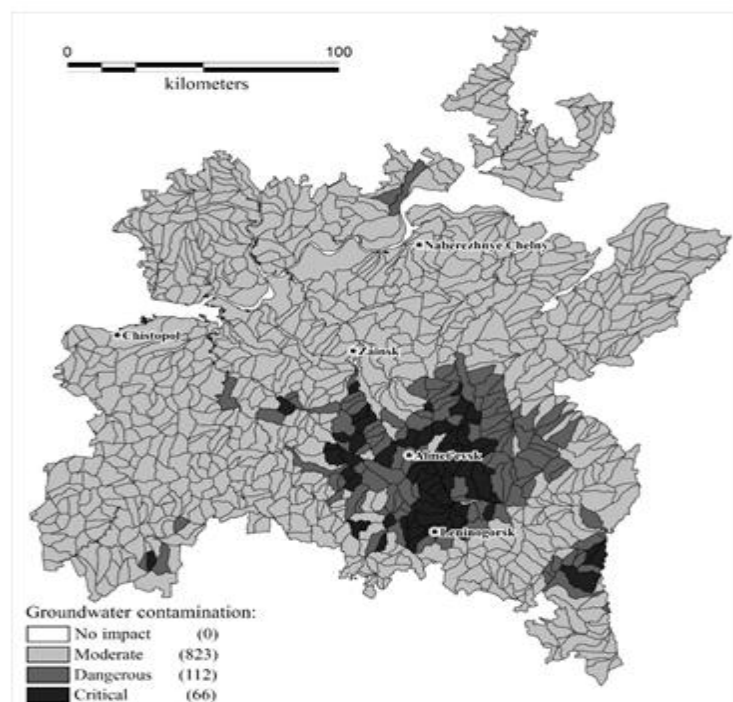


Figure 4. A map of the predicted groundwater condition (linear analysis).

In 50% of cases the 4th class is also confused with the model of the 3^d class of pollution (22 basins) and the 2nd (8 basins); in other words the level of contamination is underestimated. The constructed map of predicted by the model groundwater condition (fig. 4) confirms strong influence of the factors that describe the impact of the oil industry and prevail in the model.

At first glance, the use of quadratic discriminant analysis gives a better picture as the model depicts the 1st class, "lost" during the linear discriminant analysis (tab. 6).

Table-6. The ratio of observed groundwater contamination classes to predicted (quadratic discriminant analysis).

Classes		Observed			
		1	2	3	4
Predicted	1	138	368	38	2
	2	27	161	53	5
	3	4	31	104	32
	4	1	4	17	16

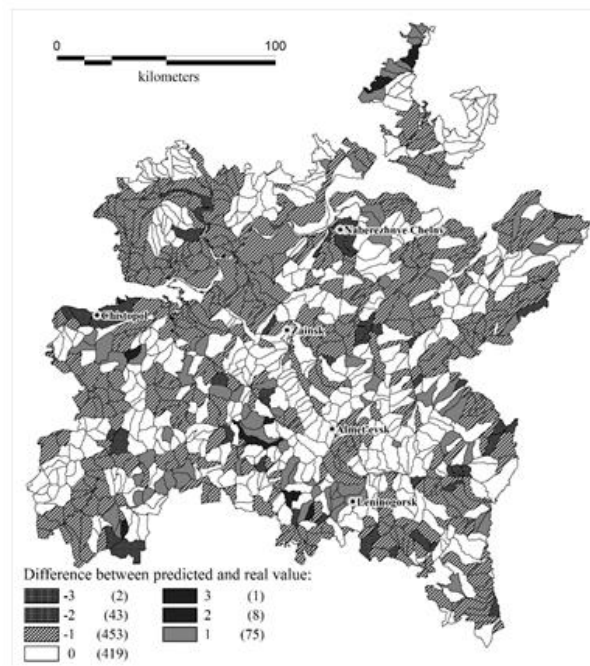


Figure 5. A map of the predicted groundwater condition (quadratic discriminant analysis).

The model better describes the 3^d class, but more than 3 times worse describes the 2nd class of the groundwater condition. That is also confirmed by the constructed map of differences (fig. 5). Almost 60% of observations are interpreted incorrectly, but the majority of them are distributed between the 1st class and 2nd classes. Nevertheless, due to the appearance of the 1st class the map looks more adequate and closer to the original (fig. 6).

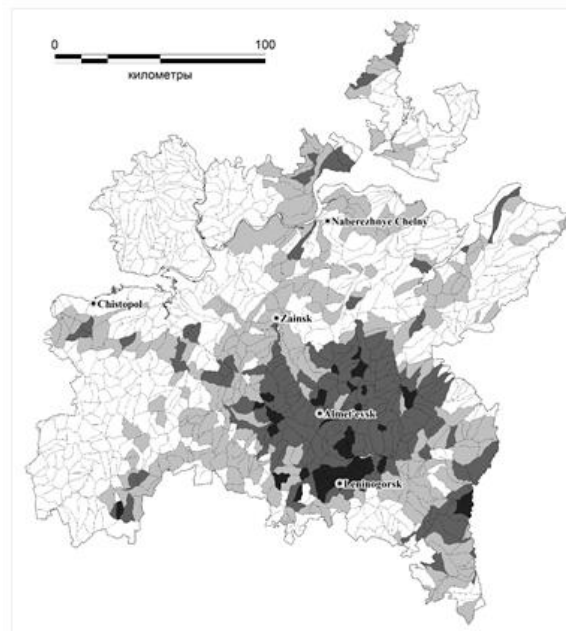


Figure 6. A map of the predicted groundwater condition (quadratic discriminant analysis).

The difference between the model classification of the degree of groundwater contamination and the factual one can be explained by the following reasons.

- The model needs additional indicators of anthropogenic pollution which would help to unambiguously separate the basins belonging to the classes of high and low contamination rate.
- Models of transport and accumulation of pollutants in space are not taken into consideration. Thus, as a consequence of spatial transfer, pollution can affect basin groundwater, which is exposed to low anthropogenic load, and, as a result, the level of groundwater pollution will be underestimated.
- The duration of the impact along with accumulation and pollutant output related to it are not taken into consideration, which leads to the underestimation of the level of the groundwater pollution.
- The work on prevention of groundwater pollution (wastewater treatment facilities, eco-friendly technologies of oil extraction, construction of roads, etc.) is not considered, which in case of conducting an external formal assessment, can lead to reevaluation of a possible level of the basin groundwater pollution.
- Resistance of water-bearing rocks/materials/beds and the barrier functions of vegetation cover to anthropogenic influence and transfer of pollution from sources to groundwater is not taken into consideration; this can also lead to reevaluation of a possible level of the basin groundwater pollution. It is also important to consider that the resistance and barrier functions can have a non-linear connection with the load; thus, if the anthropogenic impact is high, these functions can be adequately expressed, whereas during the increase of the load these functions may not manifest at all.

Conclusion

A method of quantitative assessment of the anthropogenic impact on basin geosystems in a region of intensive oil production is established. It is based on the use of a complex of statistical methods with an application of GIS technologies.

One of the advantages of this method over existing approaches to the anthropogenic assessment is a special role given to an algorithm used for selection of indicators based on the assessment of their value. The rigorous selection of indicators, as well as the refusal to use weighting coefficients is enhancing objectivity of the final evaluation. Another advantage of the developed approach is the possibility to assess the contribution of various sectors of national economy to the impact on geosystems by using methods of mathematical modeling.

Testing of the method showed that the map of the anthropogenic impact on groundwater received on the basis of the constructed model differs from the factual one. It can be explained by insufficiency of factors used in the model, their quality, as well as non-linearity of correlations between indicators describing the anthropogenic impact and characteristics of the state of environmental components. Nevertheless, despite the mentioned limitations of the constructed model, one can admit that it is quite in agreement with the observed picture of the level of the groundwater pollution. More detailed selection of indicators and an analysis of received models will help to obtain a more veracious result while conducting an integrated assessment, as well as define the role of each of the indicators of the anthropogenic impact in the influence they have on a certain environmental component.

The findings of the current impacts evaluation can be used as a basis for environmental impact assessment at the stages of the planning of industrial activities.

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