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INTEGRATED APPROACH TO ENVIRONMENTAL IMPACT ASSESSMENT ON GEOSYSTEMS

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Abstract

This article discusses the use of an integrated approach to the environmental assessment and provides an analysis of different methods of quantitative evaluation of anthropogenic impact on the environment. A method that minimizes the subjectivity of the evaluation is proposed. Special attention is paid to the algorithm used for selecting the most relevant characteristics for the integrated assessment of the human impact. The combination of the basin approach, GIS technologies, statistical methods and mathematical modeling 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: anthropogenic impact, integrated assessment, spatial analysis, geographic information systems, environment, nature management.

Introduction

The integrated approach to the study of geosystem properties and their comparison to the man-caused load is the best for the integrated quantitative assessment and development of solutions for optimization of environmental management in the investigated territory. Therefore, it is important to develop effective methods of analysis of spatial-temporal regularities of geosystem functioning in the context of strong anthropogenic pressure. It should be pointed out that a significant methodological difficulty lies in the fact, that ecosystems represent a complex system of interconnections, whose functioning and development depends on many various factors. This task as well as the solution to the problem of environmental protection and optimization has a very distinct spatial aspect; therefore, the study of geosystems is impossible without the use of modern geographic information technologies, mathematical and cartographic modeling.

In foreign literature the specialized methods developed for the anthropogenic impact assessment are known as Envi-

ronmental Impact Assessment [1]. These methods consider different categories of the impact, use different coefficients, normalization methods, and weight indices [2].

For quantitative assessment 3 approaches are mostly used: indicator analysis [3]; the analysis of groups of indicators according to different categories of the impact and calculation of intermediate index [4]; calculation of final index [5]. There are also methods that combine all three approaches and, thus, are considered to be more universal [6]. The most widespread way of final evaluation found in Russian, as well as in foreign literature is a sum of weighted normalized indicators [7]:

$$\boldsymbol{F_i = 2W_f \times Ind_i,} \qquad (1)$$

where F_I is final index; Ind_i is a normalized indicator; W_f is a weighting coefficient.

It is important to mention that methods based on score assessment have significant flaws; for instance, one can receive similar or even the same number of points for different objects and situations even if the impact of factors on the final result is uneven; even the use of weight indices to increase or decrease the impact of the factors does not help. Thus, the use of this method in the process of assessment can significantly distort the real picture of the object. Despite the obvious imperfection of numerical score, the given approach is widely used for an ecological assessment due to its relative simplicity of comparison of objects to each other and easy interpretation of results [8].

The literature devoted to the anthropogenic impact assessment gives great attention to the evaluation of relation between different types of land use and the quality of ecosystems [9], development of a catchment basin classification system [10], biological indicators of ecosystem health [11], assessment of index of biological integrity for the evaluation of problems of water pollution [12] etc. All these studies demonstrate that human activity affects ecological functions and integrity of ecosystems; however, there are relatively few works devoted to the integrated quantitative assessment of the level of the anthropogenic impact, which can be explained by the complexity of data processing and interpretation.

Therefore, taking into consideration a high volume of information and spatial aspect, which has to be considered in quantitative assessments of the anthropogenic impact, traditional simple methods are frequently used together with different integral approaches with domination of statistical methods, GIS, spatial analysis, modeling as well as other combined techniques [13,14]. Besides the main task of the integrated assessment, they are aimed at solving problems related to the functioning of the human-landscape system with a broad spectrum of spatial and temporal scales where the landscape processes are occurring [15], as well as at dealing with their unpredictability and nonlinearity [15].

Regression analysis is one of the most popular approaches to statistical processing [17]. Despite its limited possibilities in comparison to other modeling approaches, its relative simplicity of implementation, interpretation, and visualization makes it attractive to many analysts. Even if more complicated methods are used, the regression approach appears to be valuable for parameterization of a model and a check with the help of empirical data [18].

With the help of GIS technologies and methods of spatial analysis different spatial data of different types (vector, raster ones) and scale is being efficiently processed; besides, operations of overrunning, buffering, combining and comparison of spatial data from different sources are being conducted [19]. The tools built into GIS systems are not always sufficiently effective for a complex analysis of a large mass of data; therefore, they are most frequently used together with spatial analysis and modeling methods realized in specialized statistics packages [20].

Methods

The basic method of this study was analysis of existing approaches to environmental assessment in order to develop optimal algorithm for evaluation of anthropogenic impact. The main purpose - to avoid subjectivity in calculating and analysis of the results, typical for methods that use point and expert assessment. Therefore, main accent in techniques development we made on the use of statistical methods. The following tasks were solved – selection of spatial units for analysis, development of method of selection and validation of indicators, search of objective approach to evaluate the intensity of anthropogenic impact on geosystems. Assessment of different economic sectors contribution in total anthropogenic impacts was also very important. 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».

Results

Spatial unit's selection. One of the requirements of conducting spatial assessment is the necessity to analyze facts on the basis of the smallest OTU and to avoid larger arbitrary OTU, except for the time when they are related to the analyzed data [21]. The relatively small sizes of elementary basins allow presenting the investigated territory in segments while minor area variation prevents from visual domination of any areas during spatial assessment. A large amount of elementary basins provides sufficient sampling for statistical data processing. Another important factor is the simplicity of isolation of these OTU and the possibility of a well-founded transition to the OTU size in case of a change of the generalization level of works.

The choice of indicators for conducting the assessment. Information that characterizes the anthropogenic impact

and the state of the environment and is contained in the rest of the layers 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. Such division is not accidental: we believe it is an important task to assess the contribution of different industries to total load on separate components as well as the environment as a whole. Therefore, the characteristics of the state of the environment were also divided into groups reflecting the state of such environmental components as air, soils, surface water and groundwater, vegetation cover.

As a result, an extensive base containing data of different types and dimensions is developed; therefore, we will give a special role during the analysis of available information to methods of determination of significance of indicators and the choice of factors corresponding to the requirements of an ecological assessment. We believe that the use of too many indicators without pre-selection as well as the use of limited amount of indicators based on the expert analysis can affect the assessment results in a negative way. We divided the choice of a list of indicators for the reliable assessment into several stages.

It is important to normalize data that represent a set of indicators of different dimension:

$$\frac{X_i + X}{S_x} \qquad (2)$$

whereS_x is root-mean-square, or standard deviation. At the same time the variance of all variables will be equal and have equal weight when statistical methods are used. As the distribution of indicators characterizing environmental components are often far from normal, methods of bringing distribution to normal are used; in our case the logarithm of indicators was taken.

An important aspect which deserves our attention is the probability of having multicollinearity of predictors, in other words, of a close correlation between factors selected for the analysis, that jointly influence a general result. If two or more factors change to a large degree simultaneously, their individual contribution is impossible to distinguish, and, as a result, the assessment becomes less effective. One way to check the multicollinearity of the explanatory variables is to analyze the value of coefficient VIF (Variance Inflation Factor), which is calculated as $VIF_i = 1/ (1- R^2)$ for every *i-th* variable. Here R^2 is a coefficient of determination in the equation of linear regression where the analyzed predictor *i* is dependent on the rest of the factors selected for the analysis. If coefficient VIF> 5 for one of the predictors, we can see its collinearity with explanatory variables; in this case predictors that duplicate each other can be removed from the planned model. Another way of solving the problem of multicollinearity is to receive one new

combined indicator from collinear predictors.

After processing all the available data in such a way it is necessary to evaluate the correlation of indicators of the state of the environment and factors of the impact of various industry branches on environmental components, and above all, understand the structure of their interrelation. It will help not only to group interacting natural and anthropogenic indicators but also to eliminate unimportant ones from the further processing. The most frequently used way for selection of data is constructing a matrix of correlations between considered indicators or graphs, and selecting those which have a tighter link. At the same time we proposed to use ordination methods, which are not quite traditional for the impact assessment.

Ordination is a general concept for designation of multidimensional methods of data processing. The method is widely used in ecology to study the relation between vegetation and environmental conditions [22, 23]. In case of use of ordination methods to assess the influence of different affecting factors on change of the state of environmental components, check established classifications and reveal internal data structure. So, ordination is a qualitative method that helps to make preliminary hypotheses about the correlation of indicators on the basis of their graphical presentation. The advantage of this approach is that it shows the structure of interaction even if the connections between indicators are not strong.

Thus, we can separate a group of indicators most related to one or another environmental component for further assessment. For each indicator of the state of the environment, ordination can be conducted several times with a different set of impact indicators.

Thus, sifting all the variety of indicators through a «sieve» of criteria of significance, as a final result we get a list of factors which can be used to receive a reliable estimate.

Quantitative assessment. 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 furthest neighbor method was used for classification while Ward's method with Euclidean distance was chosen for distance measurement. This method aims to receive as compact clusters as possible. Histograms of distribution of all indicators were constructed for each cluster in order to describe the level of anthropogenic load which characterizes the received clusters.

Factors contribution. In case of an integrated assessment, the task of defining contributions appears to be complex and requires the use of mathematical modeling methods. Having built a mathematical model of the state of an envi-

ronmental component on the basis of selected impact indicators, we, then, can rely on the coefficients belonging to one of the factors of the impact to estimate its contribution to the impact on 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.

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.

Conclusion

Thus, in the process of the assessment of the anthropogenic impact and the state of geosystems different methods are applied: morphological analysis, expert assessment, cartographic, statistical methods, information theory techniques, mathematical analysis, modeling procedures and others. The majority of these techniques provide quantitative reflection of the anthropogenic impact and the state of the environment with the help of point assessments, ordinal, interval or relative scales, etc. Combination of different methods presents more or less objective picture of the impact on the environment. First of all, it is necessary to thoroughly analyze the structure of correlations between the components that are explored; then, based on the analysis, choose a list of indicators. For more correct assessment it is important to combine mathematical statistics and modeling methods which if used properly, will help to receive a more exact result. At first glance proposed approach looks complex and multistage. Meanwhile, it solves a difficult problem of choosing a limited number of indicators from a range of original factors of the ecological assessment corresponding to the requirements of statistical validity, as well as significant for the conducted assessment. It all makes the process of the analysis not only more correct, but also significantly simplifies the assessment due to the decrease of the number of indicators.

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