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DEVELOPMENT OF THE SOCIAL AND ENVIRONMENTAL MAPS OF THE BIG CITY BASED ON SOCIOLOGICAL, GEOSPATIAL AND ARTIFICIAL NEURON NETWORKS METHODS: THE CASE OF THE CITY OF KAZAN, RUSSIA

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Abstract. The main objective of the research is to apply up-to-date methods of neural network, geospatial and artificial neuron networks methods to create a social and ecological map of Kazan, Russia. The main variables for the urban zoning included citizens' environmental concerns, intentions towards environmental proactive behavior and environmental behaviors. The assessment of the city's landscape characteristics considered along with public opinion of the citizens allowed authors to create the most adequate model of the spatial map of an urban area. The findings suggest that the most environmentally consciousness and active citizens, on the one hand, represent the most environmentally vulnerable groups, on the other hand, high-resource groups. The results could be explained with the domination of post-material values (to which the healthy environment belongs) among high-resource groups of Kazan citizens, on the other hand, and the activation of the environmental self-protective behavior among vulnerable groups of citizens living in the environmentally hostile city areas.

Key words: GIS, artificial neuron networks, social mapping, urban territory, environmental concern, environmental behavior, postmaterialism.

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1. INTRODUCTION

Well-being of population and quality of life within large modern cities depend on a large number of factors, such as the level of economic well-being of citizens, degree of access to health care, development of infrastructure, and etc. An important role is played by the favourable environmental conditions. These conditions are comprised of the state of water resources, presence of green zones, level of air pollution, and many other indicators of environmental comfort. It is extremely difficult to adequately assess the entire set of factors; however, there is a subjective way of assessing the state of environment: sociological methods of researching public opinion of citizens. This approach does not replace, but successfully complements more objective methods of assessing the state of urban systems, allowing analysis of the issue from the residents` point of view, i.e. the interested party. A city, as a spatial structure, is a very heterogeneous entity. Different parts of a city, depending on the spatial situation, residential proximity to industrial production facilities, places of accumulation of pollutants, and foci of infectious diseases, indicate different intensity of harmful factors. This spatial heterogeneity should be taken into account while making managerial decisions, predicting unfavourable for population zones, and implementing pro-ecological measures. It is recommended to divide the area into zones of residential and industrial development on a mandatory basis, as well as to separate central districts of a city from the suburbs. Still, such instructions are rather general and recommendatory.

In Russia, data on environmental conditions are summarised at different levels: municipal districts, major cities, and constituent entities of the Russian Federation. At the same time, it is assumed by convention that an administrative district (for example, Kazan) is an integral entity with the similar environmental situation throughout. Based on this assumption, management decisions are made, even though it is a very crude approximation for analysis of urban areas and the diversity of social processes. This method facilitates mistakes in the spatial distribution of environmental issues mentioned by public, what leads to the impossibility to determine what specific parts of the city have high concentration of environmental issues. The implementation of specific measures to improve the environmental situation and area of residence are too generalised and, as a result, lead to inefficient solutions.

In this study, we will suggest an alternative model of urban zoning that is different from the administrative one. Within the framework of this model, urban zoning is undertaken based on citizens` perception of the ecological situation and environmental behaviours in their city. Moreover, it compares public perception with objective indicators of environmental pollution considering spatial heterogeneity of the territory. Therefore, functional differentiation of the territory, assessment of the city's landscape characteristics (relief, vegetation, soil, population density, residential structure, and production processes) considered along with public opinion of the citizens will allow us to create the most adequate model of the spatial organisation of an urban area. Each model`s area division can be viewed as a basic element for a wide range of issues. An area division in this case is a relatively homogeneous territory for which it is possible to generalise the research information and make management decisions.

2. RESEARCH METHODOLOGY

The main objective of the research is to apply up-to-date methods of neural network, geospatial and artificial neuron networks methods to create a social and ecological map of Kazan.

At the first stage, all available cartographic data were collected into an integrated geographic information system (GIS). Having undertaken various researches (Yermolaev & Selivanov, 2014) (Selivanov & Yermolaev, 2010), we have created an extensive authorial geographic information database of Kazan, which can be used as a basis for this study. We have prepared, digitised, and integrated both thematic maps, such as a Kazan soil cover map, a map of genetic types of quaternary deposits in Kazan, a Kazan engineering geological ground area map, a map of terraced areas, maps of relief and morphometric characteristics of Kazan, a map of water objects and green belt of Kazan, a map of the city road network, and etc.; as well as integrated maps, for instance, a map of functional zoning in Kazan and Kazan urban and landscape zoning map.

Out of the variety of GIS layers, layers containing detailed data on residential development in Kazan (location of houses, house and apartment numbers, type of construction, exact geographic location) are of particular relevance, since it is extremely important to determine the exact coordinates of each respondent. For analysis of the obtained results, maps of location of objects of industrial and transport infrastructure, objects of ecological, sport, and recreation infrastructures in Kazan, and other objects that affect the ecological state of the environment and the state of health of citizens are also important. All the existing GIS layers have been combined into an integrated system on the base of Esri ArcGIS 10.1, as the most advanced and flexible platform for creating GIS systems of any level of difficulty.

At the second stage of the research, it was necessary to obtain, process, sort, and map the results of the mass representative sociological survey of the population of Kazan aged 18 years or older. A multistage stratified quota sampling model (n=1750) have been used. The main purpose of the sampling is to obtain reliable and comparable information that reflects opinion of the national adults living in Kazan. This sampling presents the adult population of the city by sex, age, and area of residence. All data on each survey participant were carefully checked both by the content (whether all the key questions were answered, all integral indexes were adequately constructed), and spatial (accuracy of the specified address, object existence) criteria. Respondents who did not pass the verification process were excluded.

At the third stage, it was necessary to create the resulting maps based on separate indicators from the survey created for Kazan residents. Out of the great variety of methods on digital map creation, we have chosen two main approaches. The first one is generalisation of the data obtained within the framework of Kazan urban and landscape zoning model, created using methods of artificial neural networks as the most adequate Kazan zoning system. One of the numerous applications of artificial neural networks (ANN) is solution of complex issues of classification (regionalisation) of spatially distributed data, generalisation of these data, and identification of sites (typological regions) with relatively homogeneous values. Nonparametric methods based on Kohonen neural networks (Kohonen, 1984) allow to approximate a steady alteration in the properties of an object. As topological relations are given as a position on the ordinate plane, the process of data formation is defined as Self-Organizing Maps (SOM) algorithm, and the result is viewed as a «map» of properties or characteristics.

The mathematical analysis of SOM is difficult due to the heuristic principles of the algorithm. As a result, Kohonen neural networks and their generalisations are currently the only way to obtain ordination and to reveal the structure of objects using all data (Saveliyev, 2004). It is due to adaptability and self-organisation of the neural network, which does not require preliminary calibration of data, and resistance to noise and distortion.

There are a number of works where ANN have been successfully used for the purposes of landscape, erosion, and geomorphologic zoning of the Middle Volga territory and the Republic of Tatarstan (Saveliyev, Yermolayev, Mukharamova & Maltsev, 2005). Within the framework of researches on geoecological mapping of Kazan by O.P. Yermolaev and R.N. Selivanov, urban and landscape zoning model for Kazan has been proposed (Yermolaev & Selivanov, 2014). We will use this model to generalise the data obtained during the sociological survey. The elaborated scheme of urban zoning offers significant advantages in comparison with the traditional scheme of administrative zoning of cities (districts, ground plots, microdistricts), as it reflects not only the type of functional use of the territory; but also features of the landscape structure of the city. Synthesis of data at this spatial level will allow to create the most adequate zoning system based on the studied indicators for Kazan.

The second approach under the third stage of the project is empirical Bayesian kriging (EBC), the most advance, accurate, and innovative method of geostatistical interpolation. It builds adequate models even with limited input data. The Bayesian approach allows us to use as additional information preliminary knowledge formulated in a probabilistic form as prior distributions. Prior distributions together with the data allow us to estimate the uncertainty zones (the boundaries of values) of the variable under study. When applying EBC method, the most laborious aspects of constructing a correct spatial data model are automated (Demyanov & Savelyeva, 2010). If the preliminary (prior) information refers to the knowledge on the spatial trend, then Bayesian kriging is formulated (Omre, 1987). In addition, EBC differs from other kriging methods, as it takes into account the error associated with the estimation of the main semivariogram. Other kriging methods construct a semivariogram based on the data on known locations and use this semivariogram for unknown locations. This process implies that the calculated semivariogram is true for the interpolation region. Not taking into account the uncertainty of the semivariogram calculation, other kriging methods underestimate the standard interpolation errors (Pilz & Spöck, 2007).

The main advantages are the automated selection of key statistical parameters of modelling, the least interpolation error in comparison with other kriging methods, the ability to work with different types of input data and high accuracy for a small sampling size. The main drawbacks are associated with significant demands on performance of computing equipment and the fact that processing is much slower compared to other kriging methods. The method is also sensitive to the missing data. Thus, on the basis of literary sources (Chilès & Delfiner, 1999), we have determined the optimal set of input parameters for the EBC method: the "empirical transformation" of the input data and the "K-Bessel distribution with the excluded trend" (as the most accurate and significant). For all variants of thematic map, the obtained models have been cross-validated on coincidence of empirical variations with the central part of the semivariogram spectrum. As a further test, the final graphs or QQ-plots have been constructed. They show the quantiles of the difference between the interpolated and measured values, and the corresponding quantiles from the standard normal distribution.

To each resulting map one with information on the reliability and significance of the interpolated data has been built. In that way, it is possible to clearly identify which parts of the city show the most reliable results of interpolation. After that, the analysis and evaluation of the peculiarities of the spatial structure of sociological indicators have been carried out.

3. FINDINGS

Based on the results of a mass representative survey of the population of Kazan, a spatial map of the distribution of citizens` environmental concerns has been created. It includes features of natural terrain, infrastructure, and configuration of social issues and processes of the studied territories. The case study was conducted on the city of Kazan, Russia. Kazan with a population of more than a million is the capital and largest city of the Republic of Tatarstan, situated in the European part of Russia.

The main environmental variables that we focus our attention in the study include environmental concern and environmental sound behavioural practices. In this fashion, we are interested to draw a conclusion regarding citizens' environmental concerns and behavioural practices in general and concerning exact geographic location of critical zones or territories with valuable natural features. Great attention has been paid to the significance of the results of the study. It is important to mention that not all indicators of concern level are statistically significant (significance level is below 60%), due to the inadequacy of sampling for some urban zones. Accordingly, we will analyse only those areas where the level of significance is higher than 80%.

The environmental concerns of Kazan residents have been measured on the scale from 1 to 5, where 1 is the minimum value for environmental concern, and 5 is the maximum; the statement to respond to is «I am concerned about the ecological situation in the place of my residence». Figure 1 presented the results with the red zones for residents with highest environmental concern and green zones – for the lowest. The results portrays two ambivalent tendencies: the most concerned, on the one hand, the residents living in the ecologically more favourable territories of the city (near the rivers, forest-park areas) in areas with an elite housing; on the other hand, the residents living in ecologically vulnerable districts of Kazan (near the industrial enterprises).

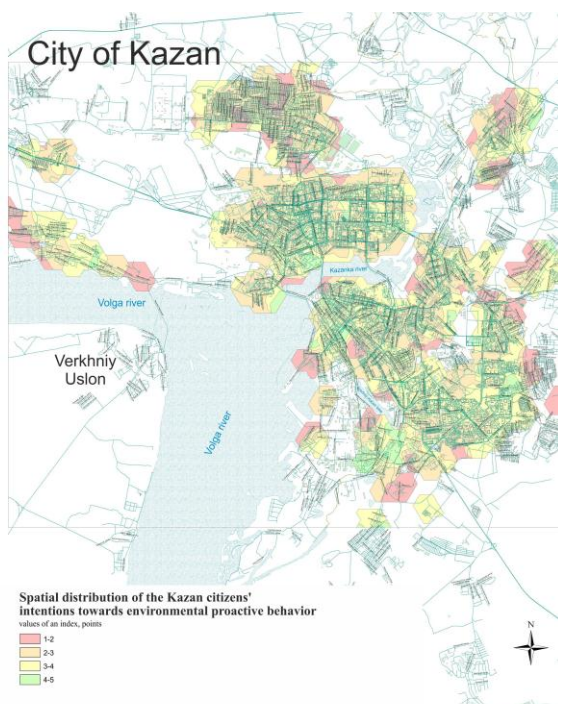

Figure 1. Spatial distribution of the environmental concern of the Kazan citizens

The integral index of Kazan citizens' intentions towards environmental proactive behavior were measured on the scale of "1" to "5" (where "1" – represents lowest degree of the environmental activism, while "5" – for highest) for the following statements: 1)"Government compared to citizens is more effective is solving environmental issues"; 2) "I can personally influence the environmental decision-making"; 3) "I am ready to advocate my rights for the good state of the environment".

Figure 2 shows the results of the analysis with green zones for the lowest environmental active share of citizens and for red zones – for the highest. Consistent with previous findings, the results suggest that the most environmentally responsible citizens, on the one hand, represent the most vulnerable groups (the group living near the industrial enterprises and the dangerous polluting zones), on the other hand, – high-resource groups.

Similar patterns were observed for the environmental behavior practices. We constructed the Environmental behavior index. The respondents were asked to agree or disagree with statements assigned to different forms of environmental consumption and environmental behavior on a scale from "1" (lowest degree of agreement) to "5" (highest degree of agreement) for the following statements:1) "I take part in the protests on the environmental issues"; 2) I take part in the various environmental activities (for example, planting trees in the neighborhood, etc.)"; 3) "I try to filter the drinking water/buy bottled water[1]"; 4) I am a member of the environmental group/club".

Figure 4 shows green zones for the highest environmental sound behaviors and for red zones – for the lowest. The findings also correspondent with the main trends for the environmental awareness and intentions towards environmental sound behavior practices. The environmentally active citizens lives in the luxury central areas of the city nearby the parks and privet green reservoirs (middle and upper middle class) with good environmental quality. On the hand, similar high level of environmental sound practices is true for the group of working class who lives in the environmentally underprivileged areas and daily struggles for the decent quality of the environment.

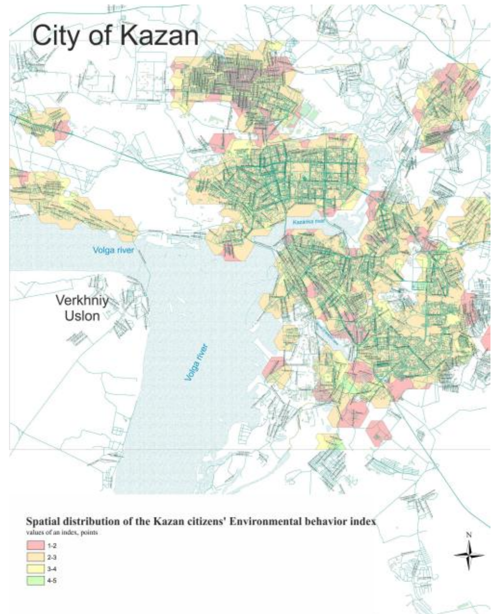

Figure 2. Spatial distribution of the Kazan citizen's intentions towards environmental proactive behavior

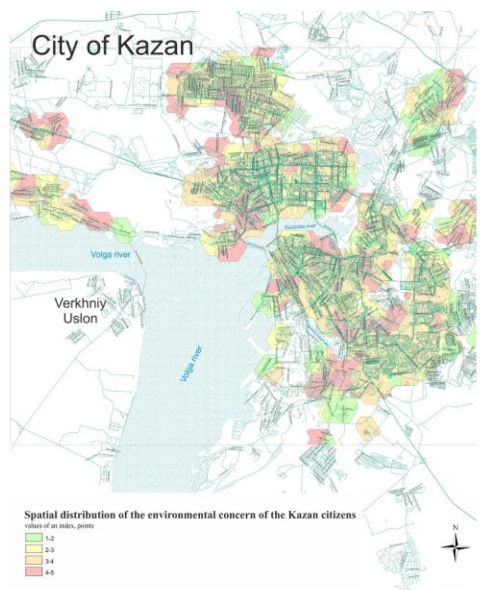

Figure 3. Spatial distribution of the Kazan citizens' Environmental behavior index

[1] In Russia, the environmental practices include consumption of bottled water due to the low quality of drinking water in most cities of the country: according to the sanitary-chemical and microbiological parameters, it does not meet acceptable standards; more than half of the water supply networks needs to be replaced (Ermolaeva, 2016)

4. CONCLUSION

Along with the rapid development of the information technologies, social mapping is enhancing its popularity under city planning and urban decision making, local communities' empowering, etc. (Ermolaeva, Safiullin, Yermolaev & Selivanov, 2015). In this study in the form of the case study on the city of Kazan (Russia) with the employment of the sociological and geospatial methods, we suggested an alternative model of social mapping in relation to spatial heterogeneity of the territory. The main variables for the urban zoning included citizens' environmental concerns, intentions towards environmental proactive behavior and environmental behaviors.

The findings portrays that the most environmentally consciousness and active citizens, on the one hand, represent the most vulnerable groups (the group living near the industrial enterprises and the dangerous polluting zones), on the other hand, – high-resource groups.

5. DISCUSSION

The above-mentioned tendency could be explained with the domination of post-material values (to which the healthy environment belongs) among high-resource groups of Kazan citizens, on the other hand, and the activation of the environmental self-protective behavior among vulnerable groups of citizens living in the environmentally hostile city areas.

The latter restates the numerous critic of the Inglehart theory that postmaterialist values (for example, for the environmental secure state) represent higher needs and are met only as lower material needs are satisfied. Thus, according to the latest data, environmental concern is equally high both in developed and developing societies (Brechin & Kempton, 1994) (Dunlap & Mertig, 1995). The rationale behind this lays in the assumption that quality of an environment is no longer seen as a postmaterialist value and that environmental degradation is increasingly recognized as a direct threat to health and welfare worldwide.

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