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Systematic Approach in Ecological Zoning

Inna Pivovarova
Department of Information and Computer Technology,
National Mineral Resources University "Mining", 199106 St. Petersburg, Russia

Abstract: The study analyses current concepts of ecological zoning. On a specific example, the need of using a systematic approach in this issue is discussed that means that all research operations performed in the process of zoning shall be interconnected and interdependent and their selection shall be based on a modular concept. A method is presented for statistical evaluation of the uniformity of environmental data in the selected region. Software application for windows platform was developed, making this method friendly for any specialist who works in the field of monitoring and protecting the environment.

Key words: Ecological zoning, evaluation of uniformity, spatially distributed data, GIS technology and statistical methods, interdependent

INTRODUCTION

Zoning or regionalization is an essential part of any in-depth environmental study and often its important center piece. The term "zoning" refers to both the method itself and the result of its application. In the first case, it is a set of techniques aimed at identifying existing zones (areas) and the boundaries between them, in the second it's a synthetic mapping reflecting the integral characteristics of zones on the map by drawing boundaries of territories with such characteristics (Rodoman, 1956). The ecological zoning serves as an information base for decision-making in environmental management, since the purposeful human impact on natural objects is usually spatially localized. After the creation of a zoning scheme, the territory under study can be assessed in terms of fitness for a particular type of use. These assessments are used to recommend such a proper use that matches the specifics of natural processes and regimes in these areas as close as possible. It makes it possible to assign engineering activities to preserve favorable and to mitigate unfavorable conditions. The result is a specific scheme of allocation, organization, mode of operation and the effects of industrial, recreational, bioproduction and conservation areas as well as outlining the areas of adverse anthropogenic impact. This approach allows minimizing costs while maximizing the economic effect. Such an evaluation is especially important for aquatic ecosystems. According to the well-known ecologist and hydrobiologist Ramon Margalef"...chemical composition of river water is an indicator of the health of terrestrial ecosystems in the catchment basin in the same manner as the composition of urine is an indicator of the health of a person" (Margalef, 1992). Therefore, ecologists worldwide have long been paying attention to zoning methods. In 1967, Crowley first presented the concept of ecoregion which refers to the land and water areas with similar ecosystem or being supposed to play similar functions (Crowly, 1967). Basing on this concept, the purpose of ecological regionalization is to provide suitable spatial units for studying, evaluating, restoring and managing the ecosystem (Omernik and Bailey, 1997). The concept of aquatic ecoregion originated from America. It refers to the freshwater ecosystem or living organism and the interrelated land units (Omernik, 1987). The aquaticeco systems regionalization is one of the most important fields of ecological regionalization and it is also the field most successfully studied (Isaac, 1999). Summarizing various approaches to this problem (Klijn *et al*., 1995; Zhou and Xiao, 2010; Bailey *et al*., 1985; Qiting *et al*., 2010), one can single out three currently existing concepts of zoning:

- Descriptive concept which is based on the following statement: synthesis of all available materials about the object being studied allows one to mentally recreate a complete image of the object and logically divide it into a finite set of spatially localized entities of lower order which act as taxa of zoning. As part of this concept, the quality of zoning is determined by the competence of a researcher (in this case zoning is more an art than a science)
- Quantitative concept, the essence of which is the formalization of the original data followed by algorithmic separation of areas using certain statistical criteria. But in the course of this, the integrity of the object is often lost. At the final stages, elements of the expert approach are often used (without justification of the logic of their choice)

- Systemic concept is the synthesis of the two previous concepts assisted by cross-disciplinary developments in the cognition of reality. It is based on the assertion that all research operations performed in the course of zoning (not only the identification of zones) shall be interconnected and interdependent and their selection shall be based on a modular concept. In this way, synthesis of all inputs is ensured and reasonable reproduction of zone's integrity is guaranteed. It is the systemic concept which we propose in this study

MATERIALS AND METHODS

The descriptive module consisted of geographical generalization and visualization of environmental data by means of GIS technologies. With the help of computer software Map Info-GIS, we managed to obtain a rather illustrative image of iron concentration distribution in the Klyazma river system both as scatter plotsand in the form of an electronic map (Fig. 1). The Klyazma river basin is located in the most developed urban area of the Central-Russian Megapolis. Between the cities of Moscow and Vladimira chain of cities arose because of favorable circumstances. This causes high anthropogenic load on rivers. In terms of the scale of industrial production, transportation and public utilities, the central region concentrates >10% of the productive forces of Russia. For the selected study area (from Tarasovka settlement to the city of Vladimir), environmental reporting data showed significant contamination of river waters with heavy metals. The most wide spread elements are copper, zinc, iron, manganese while nickel and lead occur more rarely. When building a GIS project, we used data on the iron content in the river water for 10 years (1995-2004) of environmental monitoring at 14 stations, located in the area 163 km long. We obtained a bitmap-to-vector image where the field of the characteristic being studied is classified in ascending order as a Grid-theme. It is worth nothing that in the MapInfo-GISsoft ware different methods of data interpolation to build the matic surfaces are available. The main ones are IDW, Inverse Distance Weighting Method (weighted average values of neighboring points on the specified number of neighbors

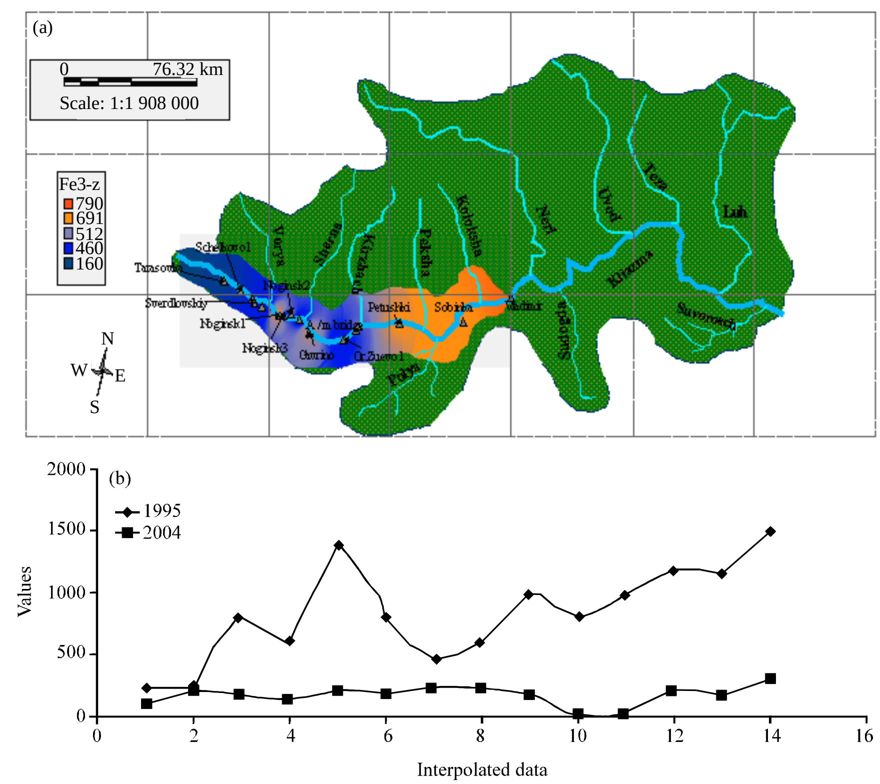

Fig. 1: The distribution of the iron concentration in the river system test site r.Klyazmain the form of an electronic map; a) (interpolated data for 10 years) and b) scatter plot (where data for 1995 correspond to the maximum pollution and 2004 the minimum pollution)

or within a specified radius); Kriging (multistage fitting of mathematical functions for a given number of points or for points within a given radius for interpolation of dependencies on all points); Natural Neighbor (this method finds the closest subset of input patterns to the requested point and applies to them weighted values based on the proportional areas in order to interpolate the value); Bilinear (bilinear interpolation where the value assigned to a point in the new image is calculated with the linear interpolation between the values of the four closest points) and TIN (method in which all the initial points are connected by triangles, resulting in an irregular trigonometric network). If, however, vertical mapper module is not connected to the main MapInfo application than only two methods are available: TIN and IDW. In our particular case, IDW Method proved to be more acceptable to solve the problem because it worked well with a large amount of raw data and displayed the results in a convenient form. The result is as follows: two sites with different iron content in the river system are clearly seen in Fig. 1; the dividing line is approximately in the region of the Kirzhach river, the tributary of the Klyazma from where there is a gradual increase in concentrations up to the boundary of the area under study in the city of Vladimir. This is probably due to the influence of tributaries draining the wetlands.

The quantitative module involved the development of a Statistical algorithm for processing of raw data to assess the spatial uniformity of environmental characteristics in the region of interest. Today, a number of criteria are used in ecology to check the data for homogeneity, allowing determining whether two samples belong to the same general population or not. If the samples belong to the same general population, than possible difference between them shall be within random fluctuations and the samples shall be essentially the same. Parametric criteria require that the sample is distributed according to a particular statistical law. For example, Student's t-test and Fisher's test (Fisher, 1924) require that the distribution of samples is close enough to the normal law. Non-parametric tests do not require any prior information about the sample distribution law. Examples of non-parametric criteria include the Wilcoxon-Mann-Whitney test and the Siegel-Tukey test (Mann and Whitney, 1947). It is also important to note that the environmental objects and their characteristics are closely interrelated through numerous functional dependencies. These dependencies can be univariate (when the function depends on a single variable) or multivariate (when the function depends on many variables). For the study of relationships between variables correlation analysis and regression analysis are used. The correlation analysis reveals the closeness of the relationship between variables. With the help of the regression analysis, researches determine the equations that fit the relationships best of all. In our case, calculations included construction and further analysis of the spatial correlation function based on the assessment of the significance of differences between the actual correlation coefficient and the presumptive coefficient for the total population (Pivovarova, 2014). The mathematical algorithm was as follows: based on the empirical $\tilde{r}(\alpha_{jk})$ and theoretical $r(\alpha_{jk})$ correlation functions, proxy values are determined (according to Fisher):

$$z_{jk} = \frac{1}{2}\ln\frac{1+r(a_{jk})}{1-r(a_{jk})}$$

$$\tilde{z}_{jk} = \tilde{z}(\alpha_{jk}) = \frac{1}{2}\ln\frac{1+\tilde{r}(\alpha_{jk})}{1-\tilde{r}(\alpha_{jk})} + \frac{r(\alpha_{jk})}{2(N_{jk}-1)}$$

and deviations (differences) $z_{jk}-\tilde{z}(\alpha_{jk})$ are calculated for all $c_l^2 = l(l-1)/2$ pairwise distances α_{jk} between the monitoring points. Standard deviations σ_{zjk} are then determined for proxy values z_{jk} from their conditional mean values $\tilde{z}(\alpha_{jk})$ by the equation:

$$\sigma_{zjk} = \frac{1}{\sqrt{N_{jk}-1}}$$

Following the normal distribution of normalized deviation from the mean value within confidence limits:

$$\tilde{z}(\alpha_{jk})-t_{\sigma jk} < z_{jk} < \tilde{z}(\alpha_{jk}) + t_{\sigma zjk}$$

of all $c_l^2 = l(l-1)/2$ of empirical values z_{jk} should fall into P(1) = 0.683 = 68.3% with t = 1 or P(2) = 0.954 = 95.4% with t = 2. Therefore, a necessary and sufficient condition for the correlation function within the territory in question to be homogeneous is that the following inequality:

$$\left|z_{jk}-\tilde{z}(\alpha_{jk}) \geq \sigma_{zjk}\right| \text{ or } \geq 2\sigma_{zjk}$$

is satisfied in approximately 31.7 or 4.6% of the total number of cases $c_l^2 = l(l-1)/2$ of empirical values z_{jk}. In other words, for t = 1 and t = 2, the total empirical number of excesses is:

$$K_э(1) = K_э\left[z_{jk}-\tilde{z}_{jk}\right] > \sigma_{zjk}$$

$$K_э(1) = K_э\left[z_{jk}-\tilde{z}_{jk}\right] > 2\sigma_{zjk}$$

should be close to the theoretically possible number of excesses as per normal distribution, namely:

$$K_e(1) \approx 0.317c_1^2 = 0.317\frac{l(l-1)}{2}$$

$$K_e(2) \approx 0.317c_1^2 = 0.046\frac{l(l-1)}{2}$$

RESULTS AND DISCUSSION

We calculated 91 pairs of correlation ratios between raw data arrays. The correlation graph has been plotted and equations for empirical and theoretical correlation functions have been obtained (Fig. 2). The spatial-correlation function for the region of interest was found to be inhomogeneous; the total number of empirical excesses exceeded the theoretically possible limits. According to σ_{jk}, the number of excesses was 43, according to σ_{jk}-14 while under the normal distribution law it should be 29 and 4, respectively. Example of calculations is shown in Table 1. Taking this into account, we divided the said area into two sub-zones: upper Klyazma and Lower Klyazma for which similar calculations were carried out. The geographical boundary between these two sub-zones is determined from the previously constructed GIS project (Fig. 1). Both sub-zones proved to be homogeneous. The number of excesses for Upper Klyazma as per σ_{jk} was 8 and zero as per $2\sigma_{jk}$; under the normal distribution law it should be 29 and 2, respectively for Lower Klyazma there were no excesses at all.

Despite the good results of using the method, laborious calculations and a large amount of input data predetermined the need to develop a software application to solve the problem. In order to fully automate the entire process of computing from entering raw data through obtaining the result with regard to the homogeneity of the characteristics of interest, it was decided to replace the module for graphical determination of parameters of the equation for empirical and theoretical correlation functions with the construction of the approximating dependencies and further finding approximation parameters by minimizing the total standard error (Least Square Method). Thus, the parameters of the equation of the type y = ax+b were found by the equation:

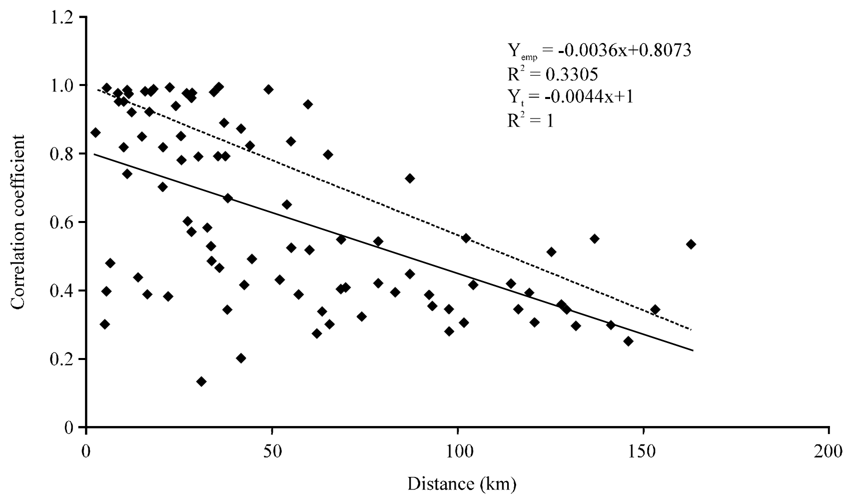

Fig. 2: A graph of pairwise correlation coefficients of the distance between the monitoring points (—: Empirical correlation functions; -----: Theoretical correlation functions)

Table 1: Evaluationof homogeneity of correlation function (a fragment over of calculations is brought on 10 pairs from 91)

Pairs	Distance between monitoring points	Pairwise correlation coefficient	Value of empirical correlation functions	Value of theoretical correlation functions	Z_{jk}	$\tilde{z}_{jk}$	Rejection (Δ)	Mean square error (δ)	Doubled mean square error (2δ)	Case, when a rejection exceeds a MSE (Δ>δ)	Case, when a rejection exceeds a doubled MSE (Δ>2δ)
4-13	141.5	0.293	0.298	0.377	0.397	0.328	0.069	0.33	0.67	-	-
4-12	114.3	0.429	0.396	0.497	0.545	0.446	0.099	0.33	0.67	-	-
4-11	78.8	0.419	0.524	0.653	0.781	0.618	0.163	0.33	0.67	-	-
4-10	54.9	0.521	0.610	0.758	0.993	0.751	0.242	0.33	0.67	-	-
4-9	49.1	0.988	0.631	0.784	1.056	0.786	0.270	0.33	0.67	-	-
4-8	29.3	0.984	0.702	0.871	1.338	0.919	0.418	0.33	0.67	1	-
4-7	22.5	0.994	0.726	0.901	1.478	0.971	0.507	0.33	0.67	1	-
4-6	12.7	0.914	0.762	0.944	1.775	1.052	0.722	0.33	0.67	1	1
4-5	10.8	0.988	0.768	0.952	1.858	1.069	0.788	0.33	0.67	1	1
4-13	141.5	0.293	0.298	0.377	0.397	0.328	0.069	0.33	0.67	-	-

$$a = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}$$

$$b = \frac{\sum_{i=1}^{n} y_i - a\sum_{i=1}^{n} x_i}{n}$$

Where:

n = Number of terms

x_i = The distance between the monitoring points

y_i = Pairwise correlation coefficient

Further, calculations were carried out according to the above algorithm. The result was the implementation of a mathematical algorithm in the object-oriented programming language C++. The software for the Windows Operating System was developed that allows any ecologist who has to deal with zoning to assess the homogeneity of spatially distributed datain the ecoregion of interest within 1 min.

CONCLUSION

The present study describes the systematic concept of ecological zoning where the study process is divided into modules and the result obtained with the help of a module is used as the starting point for the next module. In this particular case, the geographical visualization of the distribution of iron in the Klyazma river water course in the GIS project made it possible to determine the boundaries of ecological regions for further calculations. Furthermore, the results of statistical assessment of uniformityof the environmental data supported preliminary findings regarding the adequacy of dividing the area into two sub-zones; the borders being the same as indicated on the electronic GIS map. In the course of our study, we not only proposed a method for evaluation the uniformity of spatial characteristics but developed a software application for the Windows Operating System, making this method easy to use for all professionals dealing with the classification of water bodies in terms of the degree of ecological disturbance and environmental safety.

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