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The Use of Automated Geomorphological Clustering for Purposes of Urban Planning (The Example of the City of Kazan)

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Abstract: Differentiation of the relief into separate elementary geomorphological sections yields the basis for most adequate determination of the boundaries of urban geosystems. In this paper the results of approbation of relief classification methods based on Artificial Neuron Networks are presented. The developed model of the restored landscapes represents the city territory as a system of geomorphologically homogenous terrains. The results can be used in the analyzing of informal arrangement of a territory, which is necessary for the adjustment of visual properties of a landscape by planning methods.

Key words: Artificial Neuron Networks · Relief classification · Landscape planning · Geomorphological clustering · City territory · Urban landscape · Functional zoning

INTRODUCTION

City is a complex system for sanitation, utilities, land usage, housing and transportation within a compact settlement area. Such clustering of people predetermines high concentration of the entirety of economic and social relations, which inevitably leads to the creation of a complex and sometimes self-contradictory, system. The conflict of interests in the given system generates a considerable and diverse set of problems to do with most different aspects. One of such aspects is a sphere of effective planning and protection of the environment.

Land-use planning and adoption of managerial decisions in conditions of urban territories, from the viewpoint of inventory and proper organization of a geographical space, would be facilitated if a city was built on a plain site of homogeneous genesis. Unfortunately, managerial decisions in cities are often made either without regard to any natural characteristics of a specific territory, or with regard to just a few factors. As a case in point one can take the development of the infrastructure for the World University Games to take place in 2013 in the city of Kazan. Planned comprehensive transformation of a number of natural ecological systems (river Kazanka, Lake Kaban, coastal territory, etc), neglect of a scientifically grounded impact of such transformations on the environment and of public opinion led to the escalation of the social unease in the city.

Qualified managerial decisions in a big modern city should be based, first of all, on full and reliable information on key subsystems; in particular, on the environmental situation in the city. Attempts at distinguishing in a city of landscape elements of different taxonomy by traditional approaches are oftentimes doomed to failure by virtue of either full or partial transformation of soil covering, biogeocenoses, underground waters and even composition of underlying rock. In this sense "landscape" mapping of urban territories should be based on the most reliable diagnostic property allowing for regional differentiation of geosystems, the source of a true information about the landscape structure of a city - the relief. Differentiation of the relief into separate elementary geomorphological sections yields the basis for most adequate determination of the boundaries of urban geosystems.

Development of computer engineering and advanced information technologies allow for the use of modern geoinformation systems for effective modeling of the environment. Application of GIS technologies in the landscape mapping proved to be very successful,

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in particular, in classification of landscape units. Artificial Neuron Networks (ANN) are among the newest signal-processing technologies in the engineer's toolbox, allowing for the objective zoning even without regard to the detailed information about the processes in a given system. Kohonen self-organizing maps (SOM) are one of the types of ANN. They are often used for resolution of most diverse problems, ranging from refilling data gaps to the analysis of data and search of consistent patterns. ANN is a powerful mathematical tool which can be used in construction of reliable non-parametrical models of complex natural ecological systems. However, the "black box" elements inherent to the given classification call for the verification of the adequacy of models built on neural networks. Obviously, the most reliable method of verification of classifications are field surveys of the city territory, which allow for the on-site justification of marking out certain landscape units. This seems to be very important, as though KSU scientists have attempted to classify landscape units, no verification of the given methodology has been done so far.

Thus, our research is aimed at the approbation of Artificial Neuron Networks method (Kohonen's Self-Organizing Maps) for purposes of automated zoning of a modern city's territory on the example of the city of Kazan.

Main research objectives: development of a digital model of relief of the city of Kazan; approbation of relief classification methods based on ANN and expert estimations; creation of a SOM-based map of urban geosystems; verification of the received results of classification, clarification and enlargement of landscape units; determination of the applicability of the method in question for purposes of zoning of big cities' territory, identification of strengths and weaknesses.

Experience in the Field of Application of Landscape Approaches in the Cities: Foreign authors usually define urban landscape as a natural-anthropogenic system combining features of both natural (relief, flora, soil, fossils, etc) and cultural components (population density, apartment block structure, production processes and communications) [1]. In the opinion of a number of foreign experts, application of ecosystem and landscape approaches is quite a recent development in management of urbanized areas [2]. Whereas the main effort is aimed at the development of the landscape planning for purposes of effective management of large-scale natural-anthropogenic objects [3]. Obviously, foreign experts are eager to develop landscape and ecosystem approaches with a view of their further application in solving specific problems of big cities.

Expansion of the sphere of application of landscape approaches is also informed by the important tendency of intensification of efforts aimed at determination of economic effectiveness of certain planning tasks. Thus, for example, according to the results of the study of dependency of the cost of real estate on the proximity to the "green main structure" of the city, the absence of green zones leads to significant reduction of real estate prices in Marion county of Indianapolis [4]. Similar attempts at economic estimation of urbanized landscapes can be also found in the works of other experts [5, 6].

Perhaps, the most interesting development in the area is represented by the works on delimitation of complex natural systems. The systems' boundaries should not be necessarily determined by conventional administrative boundaries of urban territories, municipalities, or districts. According to the results of content analysis of interview data from environmental planners working for cities in western Washington [7], approximately 42% of respondents pointed at the significance of delimitation of natural ecosystems. Often the task of precise delimitation of the boundaries of certain natural ecosystems within large agglomerations does not have a universal decision algorithm, remaining a pure theoretical concept lacking any potential for practical realization. Other experts arrive at similar conclusions [8], pointing at serious difficulties in the course of introduction of ecologically-based and landscape-based planning.

Thus, it may be concluded, that in foreign countries the important problem of determination of a landscape structure is still in need of resolution.

At the suggestion of L.S.Berg [9], a section of the Earth's crust characterized by relative homogeneity of geologic-geomorphologic conditions is the main territorial unit of natural geography referred to as a geographical landscape. The very term "geosystem" was introduced in 1963 by V.B.Sochava [10] as a synonym to a "natural complex". In opinion of G.Miller, geologic-geomorphologic base exerts determining influence on less stable NTC components: redistribution of warmth and humidity is governed by the lithogenic base properties, relief in particular; whereas soils, flora and fauna are "selected" dependent on certain localities. Hence the lithogenic base is stable and inert, resistant to external influence [11]. In opinion of I.Kruglov [12], the main

structure of the urban landscape is made of natural NTC elements and components, whereas the anthropogenic cover – of man-made elements of urban environment. A. Dmitruk [13] distinguishes natural, anthropogenic and technogenic components of the urban landscape, while considering two types of components – morpholithogenic and architectural – in the course of the landscape analysis of the urbanized territories. On the whole, it is exactly a combination of heterogeneity of natural components and numerous types of functional use of urban territory which yields various combinations of attributes (types of urban landscapes), especially if a multifunctional district is located at the interface of several natural complexes.

Using Artificial Neuron Networks for Purposes of Spatial Planning: The last few years have witnessed a rapid increase of interest to ANN technologies. Such a renaissance of interest was informed by both theoretical and application-specific achievements. New opportunities opened up for their application in the spheres earlier associated only with a human intellect, such as creation of intelligent machines endowed with a human-level ability to learn and remember. Education of such machines is the experience-driven development: essential intrinsic properties are obtained in the result of processing of information via generalization of precedents. Classification and generalization of geographically dispersed data and the identification of sites with conventionally homogeneous values are among most perspective spheres of application of ANN technologies.

Non-parametric methods based on Kohonen's neural networks [14] allow for the approximation of non-stop alteration of the object's features. So far as the topological relations are predetermined by the position on the ordination plane, the process of formation of the reflection of data is determined as an algorithm of "self-organizing" maps (SOM), whereas the very result represents a "map" of features or characteristics. Such "maps" relating to topographic reflections can be effectively used in recognition of data structures and as a toll of two-dimensional visualization of data. Traditionally SOM is considered to be an empirical algorithm. Conclusions about the structure of data are made on the basis of visual analysis of the received map. The main advantage of the SOM model is its ability of generalization, i.e. correct reflection of new data on the ordination plane [15]. Mathematical analysis of SOM is a difficult enterprise by virtue of the heuristic base of the algorithm. Thus, so far Kohonen's neural networks and their generalizations remain to be almost the only tool (due to adaptability and self-organization of a neural network which does not require any preparatory calibration of data and is resistant to noises and distortions) to obtain ordination and identify the structure of objects with regard to the entirety of data [15].

In our case the received classes can be interpreted as surrogate NTCs represented by the probabilities of presence of certain components of a landscape system, which makes SOM, inter alia, the instrument of landscape classification and analysis.

Some authors attempted to apply ANN for purposes of landscape zoning. They received very interesting results – geomorphologic classification applied within the entire territory of the Republic of Tatarstan. And the scheme of complex zoning of the Middle Volga region (landscape, erosion and environmental assessment) [16-22]. As it was already mentioned, in opinion of many experts the landscape structure of the territory will depend largely on such classifications. Similar approach in automated NTC zoning has to do with the calculation of proximity of vectors-objects with the application of the so-called potential functions. [23]. Diakonov and Puzachenko also insist on the possibility and necessity of application of the results of automated classification of morphometric data for the determination of NTC boundaries.

In our opinion, only field studies can prove the efficiency of the new methodology in comparison with the traditional method of field landscape research. It should be emphasized, that we have not come across any works on automated urban zoning or evidence of adequacy of the received results. Given the available positive experience of application of the given methodology, high potential of the results, relatively low level of investments needed it is possible to conclude about the urgency of work in the given direction.

Methodology and Results: Having analyzed the abovementioned presuppositions, we have formulated the following string of logic. It is necessary to build a detailed digital model of the relief and calculate the latter's certain morphometric characteristics, process the received results and perform classification of the relief with the use of ANN methodology. Then we should identify the received classes and interpret the results of the automated zoning. Next is the important stage of verification of the adequacy of singling out certain classes within the territory of the city in question. It should be emphasized, that exactly

field study would allow for most comprehensive representation of the potential and effectiveness of application of automated methods of spatial differentiation of urban territory. Upon the implementation of the empirical research, necessary corrections are to be made to the scheme of geomorphologic zoning of the city. The received map material can then be incorporated with the information about the functional zoning of the territory and then used for singling out urban geosystems of different ranks.

First stage: analysis and digitalization of the detailed large-scale topographic map of Kazan. Digital model of the relief with a grid size of 10m has been produced. We have used this data for building various analytical maps of certain morphometric characteristics of the relief: height, slope, exposition, profile and plan curvature.

Calculated morphometric values were transformed into a data matrix. Matrix lines corresponded to minimal territorial units, rows – to parameters describing the state of a given element. Various characteristics were adjusted to a unified standard scale and the degree of significance of each separate parameter was determined. Then it was necessary to accomplish the landscape classification with the use of neural networks. Landscape zoning with the application of the neural networks included the use of application-specific software and methodological recommendations developed by members of the Department of Mathematical Modeling of Kazan Federal University. This has made it possible to carry out both classification of terrains for Kohonen's neural network and their ordination in the space of attributes. Software packages use training algorithms without the use of a tutor, whereas weight coefficients are redistributed for each specific operational-territorial unit (OTU). After several iterations of the "education" process, neural network leads to gradual clumping of groups of OTU's with similar sets of morphometric parameters. Eventually, all positions get clumped and grouped within the space of attributes.

Interim result of work (Fig. 1) has been received after the application of the software developed by A.Saveliyev. 81 classes have been distinguished. Such atomism was eliminated by way of consolidation and interpretation of the obtained results on the basis of classes' affinity. Figures 2 and 3 illustrate the result of consolidation of classes for Sammon's projection. Processing of the received result forestalled the laborious stage of interpretation and consolidation of classes.

The final product, geomorphologic zoning map, includes good representations of bench complexes (Fig. 2), although the flood-plain bench and first terrace above flood-plain turned out to be united. Most likely, first terrace above flood-plain has been distinguished on the basis of other parameters, such as lithogenic structure. Identification of territories with different slopes yielded good representation of terrace cusps and ravine-gulch network. Accumulation and denudation slope sections are clearly visible, too. Poor representation of classes determined by the leading role of plan curvature and a questionable weighty part of exposition probably resulted from insufficient calibration of initial parameters of the program.

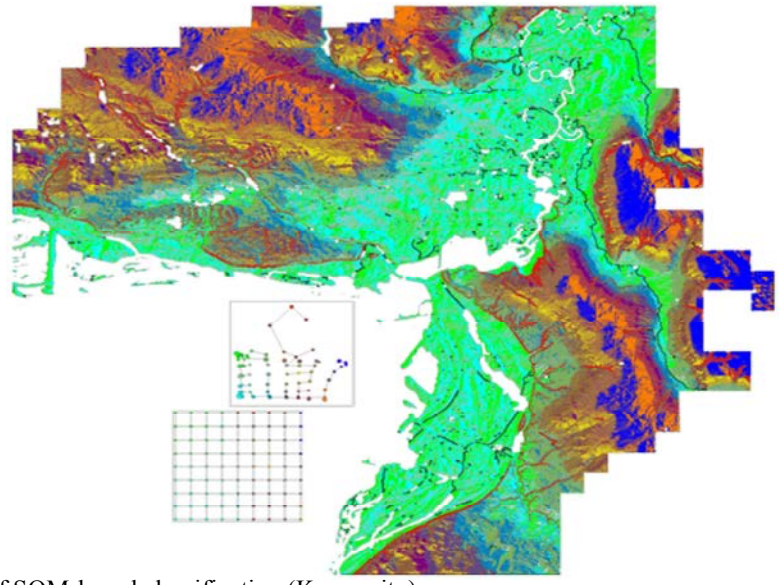

Fig. 1: Initial result of SOM-based classification (Kazan city)

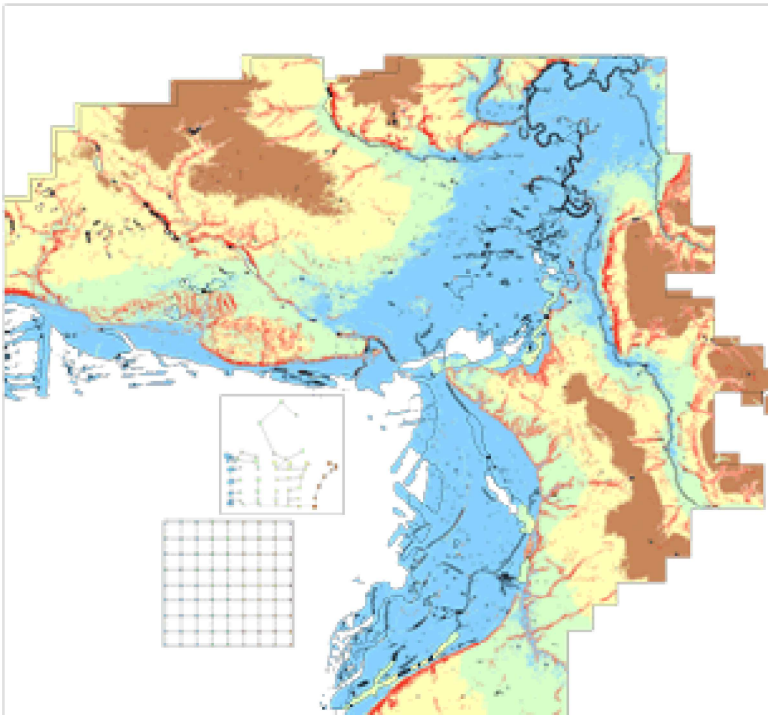

Fig. 2: Identification of classes result for consolidated classes (Kazan city)

Fig. 3: The environmental condition of house with the traditional scheme of the city zoning in Kazan

Verification of Automated Zoning Results Our project was also aimed at the verification of information received in the result of the automated zoning. Certainly, a thorough check of the implemented zoning of territory is required, as this is the only way to confirm the adequacy of demarcation of certain homogeneous zones. In this particular case the general mechanism of identification, causes and sequences are more or less clear. The ANN-

based system has processed the parameters of the basic morphometric characteristics, accomplished a comprehensive process of their recombination with the identification of terrains, where the values of the given parameters are conventionally the same. Obviously, a very likely outcome is that the ANN-based zoning plan will be very different from the real division of the city into separate systems. Field study will eventually provide us with an answer to this and many other questions.

The received results of classification have been matched with a satellite image of the city a topographical map. It has allowed for easy determination of one's position in the field, as well as affiliation of a given position to a certain SOM-identified zone. More than 200 control points have been described for Kazan. Position of each control point was thoroughly documented and photographed. Key positions have been accompanied with a detailed description which included the evaluation of the main physical characteristics and geo-ecological parameters. The selection of points has been done with proper regard to transitions between adjacent zones, including consideration of both geographical accuracy and general characteristics of transitional areas.

The following example represents one such description, including photographs. There is also a map with the plotted key control points at which comparisons have been made.

Tedious analysis of the SOM-based zoning plan proved a good fit of field data to the available maps. In 87% of cases previously determined borders of significant landforms matched SOM-based results. Many borders of the marked up zones, although similar in shape, spaced certain distance (100 – 200 m) from their real location.

This can be explained by the overlay error occurred in the course of operation with various source maps. Obvious discrepancies have been detected in just a few cases (3-4% of the total number of points). In our opinion, these obvious "faults" resulted from errors inherent to the initial digital model of the relief, as well as a general probability of the emergence of "artifacts". Field work has provoked another interesting development – correction and consolidation of many classes distinguished by the results of consideration of the influence of the exposition factor. Certainly, at the stage of setting of initial conditions of zoning, exposition had been rated among most important indexes. In the case of broken relief, space orientation of slopes could lead to the identification of most diverse landscape bodies. However, in the conditions of the Volga-river valley the given difference turned out to be of minor importance. Thus, such consolidation of classes reduced their number to six.

An Example of Application of the Classification Results: We want to show a comparison of different methods of spatial information and show the strengths of the city landscape model. For instance, Figure 3 illustrates index distribution of "environmental condition of house" over the city of Kazan by using the traditional scheme of the city zoning. For comparison, Figure 4 shows a similar spatial data, but aggregated over the urban landscape model.

Analyzing spatial distribution of citizens' opinion (Fig. 4) one can make a conclusion regarding citizens' environmental concern over environmental problems in general and identify the exact geographic location of problematic zones or territories with valuable natural

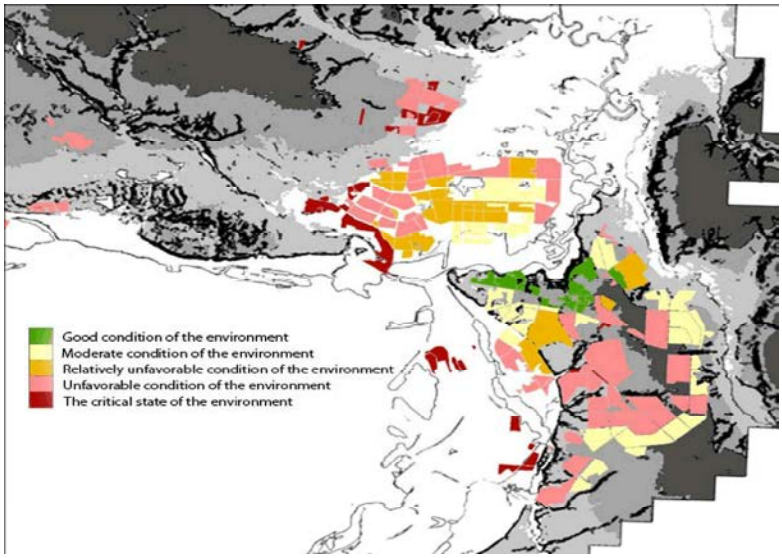

Fig. 4: The environmental condition of house with the urban landscapes scheme of Kazan city zoning

features. It is worth emphasizing that a great number of urban landscape units imposes its own specific restrictions.

Another advantage is the opportunity to generalize diverse information starting from the content of detrimental compounds in soil layer and content of plant associations up to morbidity and mortality which makes it possible to compare various factors and discover cause-and-effect relations between events. Thus, analyzing spatial distribution of indexes one can make conclusions and provide further recommendations for selection of the most beneficial residential territories of the city with respect to environmental conditions and optimal expenses on residential real estate property units. As a result, we believe to having obtained a powerful evaluation tool for complex features of urban systems which, if applied, will allow to make effective decisions aimed at constant development upkeep of the city of Kazan.

One of major results of our work is the conclusion regarding applicability and high-level importance of methods of ANN for construction of integral environmental and economic classification maps of residential real estate. According to methodology applied within the work one can perform a wide spectrum of activities in the sphere of nature protection and rational natural resources management.

CONCLUSIONS

The developed model of the restored landscapes represents the city territory as a system of geomorphologically homogenous terrains. The analysis of exogenous geodynamics helps to identify potentially adverse exogenous processes [16, 17, 21, 22]. The obtained in the result of the analysis SOM-based landscape classification map allows for the preliminary (without regard of the biotic component) zoning of territory for certain forms of economic activity. The map identifies the elements of a natural drainage system and allows for the determination of the direction of migration of material flows, including those containing contaminants. The results can be used in the analyzing of informal arrangement of a territory, which is necessary for the adjustment of visual properties of a landscape by planning methods.

Field research results have made it possible to conclude of fairly correct and adequate zoning and identification of large geo-systems in Kazan. Sometimes, while supervising the work of the machine, we wondered how this "stupid mechanism" with a much lower level of intellect than, say, a threadworm has, correctly determined the borders of geo-systems, carried out classification of space, singles out certain sections of land. Most likely, cities and other localities with rougher relief are more suitable for the application of the discussed SOM-based zoning method and one can expect the results of à higher practical relevance there. The very fact of successful application of the given approach, even in specific landscape conditions of the Volga-river valley, witnessed a high potential of its application in other territories. The accomplished project is a starting point for all subsequent projects to do with the ecological-geographical mapping in the city of Kazan. Following relevant checks and processing of the received results, we will be able to proceed to the creation of maps of urban landscape and functional zoning of the city territory, as well as development of forecast and recommendation maps which would contribute to the improvement of the city ecology (determination of the "ecological potential" of territories, justification of the "green main structure", etc).

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