ATLANTIS PRESS
Advances in Social Science, Education and Humanities Research, volume 392
Ecological-Socio-Economic Systems: Models of Competition and Cooperation (ESES 2019)

Territorial System Analysis and Modeling of the Socio-Ecological Processes of Natural Resource Management (On the Example of Ethnic Geosystems of Southern Trans-Urals and the Soil Cover of the City of Kurgan)

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***Abstract*— System approach to scientific research is the principle and direction of cognitive and practical activity which is based on systemic reflections of reality and on the processes of considering different objects as systems. System analysis (SA) is a methodology for understanding the world and solving emerging problems, including territorial ones. There are many techniques of SA: set-theoretic, diagnostic, monitoring, matrix, graphic, fractal, model, etc. SA is universal, transdisciplinary and interdisciplinary. Currently, new approaches to the study of social systems in terms of interaction of social, ethnic, economic, ecological systems, the so-called "soft and hard" system methodologies (W. Churchman, P. Checkland and others). The world is problematic, so, system models being a kind of intellectual construct and tool should be maximally focused on human, on achieving harmony and sustainable development. There is a certain hierarchy of models: mathematical, economic, informational, imitational, conceptual, etc. Let us turn our attention to some of them on the example of the Trans-Urals.**

Keywords—system approach, system analysis, modeling of socio-ecological systems.

I. Introduction

System analysis (SA) is a methodology for understanding the world and solving emerging problems, including territorial ones. In the framework of system analysis, many methods are used: set-theoretic, diagnostic, monitoring, matrix, graphical, fractal, model, etc. Currently, system analysis is universal, subdisciplinary and interdisciplinary due to the development and implementation of new approaches to the investigation of social systems in terms of interactions of social, ethnic, economic, ecological systems, the so-called "soft and hard" system methodologies (W. Churchman, P. Checkland and others). Versatility, diversity and ambiguity of the modern world, its problematic nature requires using system models which are a kind of intellectual construct and a tool focused as much as possible on human, on achieving harmony and sustainable development [1, 2]. There is a certain hierarchy of models: mathematical, economic, informational, imitation, conceptual, etc. In our article we show the possibility of using system models for considering some aspects in the framework of territorial system analysis and modeling of social and environmental processes (by the example of Southern Trans-Urals and the city of Kurgan).

Goals of study. 1) Development and use of the pendulum model of the distribution of geographical conditions of ethnosocial and environmental territorial organization of the space of Russians as a factor in cultural identity and sustainable development of society.

2) Development and demonstration of a mathematical model of urban economy by the example of the mathematical model of soil safety environmental assessment in the city of Kurgan.

The objects of study are geographical factors of the ethnosocial and environmental territorial organization of the Russian space and soil cover of some zones of the city of Kurgan.

II. Methods and materials

Research Methods. This article is based on the results of experimental studies and their interpretation in the framework of scientific theories using methods of normative, structural-functional, comparative and statistical analysis, mathematical modeling and forecasting. This study was performed using a number of conceptual models: a pendulum model of EGS development where external factors and conditions and ethnic constants – archetypes of the ethnos – closely interact (development binomials – the principle of binary). Black box mathematical model based on the results of correlation analysis with the construction of an ecological and geographical map of the ecological condition of the soils of Kurgan was developed. Two methods were used to assess the fractal dimension by the density of urban area: the grid method and the concentric circle method.

Methods for assessing the quality of urban soils: 1) Method for assessing MPC (maximum permissible

concentrations of chemicals) that allows evaluating soil chemical composition [3]. 2) Method for assessing TAC that helps to define the level of soil contamination [3]. Development of the soil map in two layouts – with natural and man-made condition. Man-made component reflects the current state of the soil cover of the city of Kurgan.

Combining the imperatives of security with sustainable development of society creates a single system and provides an opportunity for a comprehensive study of social and environmental problems [4]. Moreover, according to M.V. Rosinskaya – and rightly so – the solution of environmental problems should be predetermining and reflect the results of political, social and economic transformations in modern international society, including Russian one [4].

The study included two blocks: 1) showing the evolutionary and historical development of natural resource management in the Ural region, 2) assessing the results of urban settlement and the environmental safety of soils in urban areas of the modern city of Kurgan. Therefore, a system approach to this problem was used as a theoretical basis for this study which allowed developing a theoretical justification of the changes in urban soils in the process of their development at the regional level (by the example of the city of Kurgan).

III. Literature review

Many scientific works are devoted to environmental, economic and social problems of nowadays, among these the works of E. Buchwald, Yu. Gladky, A. Granberg, V. Ignatov, Yu. Kolesnikov, D. Lvov, A. Shvetsov should be mentioned.

In the works of T. Akimova, D. Galtung, H. Daily, D. Pierce, R. Repetto, A. Cheshev, A. Shevchuk, and others, economic approaches to environmental quality management are studied.

In the works of E. Girusov, V. Danilov-Danilyan, N. Reimers, A. Ursul, the most problematic issues of the connection of environmental safety and economic efficiency in the course of functioning of urban economic systems are studied.

Investigation of fractal method and its practical use is carried out by D. B. Gelashvili, D. I. Iudin, G.S. Rosenberg, V.N. Yakimov, L.A. Solntsev (they are studying fractals and multifractals in the terms of bioecology) [5, 6]; Yu.V. Pavlov considers the use of fractals as a tool for spatial planning [7]; publications on the subject appear in foreign journals (M. Batty, P. Longley, G. Trentin, C F. Marcos, and others) [8, 9].

IV. Results

Existing territorial structures of the region are the "triggers" of social and environmental processes; due to the interaction of latter they can be more or less successful. We used in our study integral system analysis (based on ethnic and psychological, innovation-synergetic, cultural, spatio-temporal methods) of the co-evolution of Trans-Urals ethnic groups.

One of the authors of this article proposed and tested an ethno-geosystemic territorial analysis of the evolution of natural resource management and of interaction between ethnic groups in Southern Trans-Ural ethno-contact area. Southern forest-steppe Trans-Urals is located on the border of forest and steppe. This territory was the place of interaction of many ethnic communities: Finno-Ugric tribes and Sargats, Turks and Slavs. Here the relationships between both hunters and traders, and nomadic cattle herders and farmers were established. In the process of regular interactions, a peculiar Turkic-Slavic ethno-contact area developed [10] which can be called an ethno-geosystem. If ethnic geosystem (EGS) is understood as stable ethnic communities of people formed in the course of joint development of the territory: living, economy and natural resource management, then it can be considered that it was formed in the process of interaction of ethno-geosystems resulting in integral territorial formation at the territory of Southern Trans-Urals. Present-day society can be regarded as a global EGS which is based on the evolution of territorial systems of natural resource management and management of ethnic communities. At the same time, ethnic culture, as an integrating one, connects the territorial community and protects it from decay. Stable cultural positions of the ethnos that are of archetypal nature are the components of its structure. Ethnic mentality can be figuratively represented in the form of a "top". Around the "spinning" circle there is the central zone of culture, the picture of the world and the code of human behavior crystallize, ethnic constants (archetypes, i.e. collective unconscious) make up its "stem".

If we consider a set of "opposing factors of EGS in the context of a particular institutional environment as binomials of development, then the basis for the development of ethnic groups will be life support and adaptation processes associated with the development of territory (natural resource management and restoration)", as well as socio-economic, military-protective and others factors. Based on this, according to our assumption, they should be considered the foundations of innovation-transformational development processes. This assumption was proved in the course of analyzing the evolution of forest-steppe EGSs. Their theoretical basis included the laws of unity and struggle of opposites put across by Hegel as applied to natural, social, economic and other forms of matter movement. In accordance with synergistic patterns discovered in the 20th century, the development process is activated and is guided by the pulsation of "binary" structures.

This pulsation is characterized by a combination of directed rhythmic changes that can conditionally be represented as the main vectors ("leading" subsystems): 1) cultural (C) – religious (R); 2) administrative (A) – political (P); 3) social (S) – economic (E); 4) military (M) – defensive (D), etc. Connections between these subsystems can be both mutually generating and mutually overcoming. During each particular period of territory development, certain institutional factors will prevail. Thus, EGS can be "divided" into system "binomials" of the following types, with an advantage of one or another factor depending on its "strength" during one or another temporary development period:

C - >R - - C> R - < C – - R >

A - >P - - A> P - <A – - P >

S - >E - - S > E - < S – - E >

M - > D - -M > D – < M – - D >

Based on P. Curie's principle "symmetry of causes forms the symmetry of consequences", we can assume that in such systems, the sequence of their structure is determined by the direction of movement of ethnic groups. Moreover, the

symmetry of structure laws creates the symmetry of movement laws and vice versa. Using this physical principle as applied to EGS, it can be assumed that their evolution occurs in ethno-contact areas. This line will be a reflection of the symmetry of the interconnections of ethnic communities, their natural resource management and restoration, and other vectors of development in a jointly developed territory.

This interpretation can be graphically represented by the conditional volumetric (3 D) simultaneous movement of several pendulums – binomials – in intersecting planes (defined by letters above) which are freely suspended on the "stem" of ethnic constants. The range of fluctuations of more than 180 degrees can turn the pendulum around the mounting point but it still firmly holds on to its ethnic stem (Figure 1).

Thus, the evolution of EGS should be considered as a set of changes closely related by innovation-synergetic cycles of the ways of life of ethnic communities. Proceeding from this, it can be concluded that during the period of archaeological natural resource management in Southern Trans-Urals, the general line of EGS evolution was determined by military and economy binomials. There is no doubt that this is a conditional model, since ethnic development cannot coincide with physical phenomena: gravitational, mechanical, wave, etc.

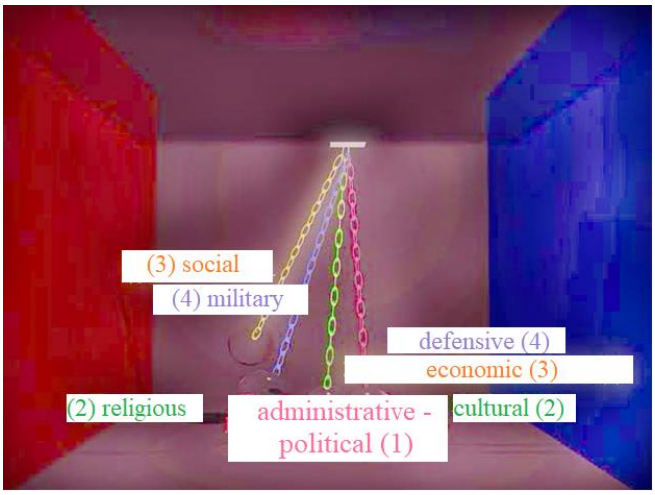

Fig. 1. Pendulum model of EGS development

At the same time, such model made it possible to reveal many causal relationships of territorial evolution as a whole. The interaction of EGSs occurs in a complex, unbalanced, autonomously fluctuating system.

Such complex motions in a nonlinear oscillator create a set of undamped oscillations. Their ability for continuous autonomy is supported by external sources of a nonlinear dissipative system. This movement results in the emergence of self-similar systems (fractals) in large numbers. Each set has its own rule of self-similarity determined by the properties of integral EGS. The evolution of EGS is always associated with searching for the best way of its adaptation to external conditions. The result of such adaptation is the emergence of new forms of adaptation and the disappearance of old ones.

Leading mechanism for EGS evolution is the change in the economic and cultural types of ethnic groups and natural resource management technologies followed by social institutions. The principle of opposites or "binary" (pendulums) is constant; it is "refracted" through ethnic constants (archetypes) of an ethnic group (ethnic "spinning top").

We used fractal measurements of the urban territorial-planning structure by the example of the Kurgan to assess the area of the territory of the urban settlement (Kurgan) and its difference from the perfect one.

In a two-dimensional image, the fractality of the planning structure of the city within linear and planar spaces varies from high values where urban structure is homogeneous and completely filled to low ones indicating fragmentation in the structure of urban design. It is characterized by the inclusion in urban territory of undeveloped arears or areas with any restrictions.

Assessment of the density of Kurgan urban area using grid method allowed concluding that urban development is quite irregular (Figure 2).

Fig. 2. Map of the city of Kurgan. Dimension determination by coverage method (by square counting)

Using the method of concentric circles gives a more specific characteristic of the fractal dimension of urban design.

On the map of the city in the form of concentric circles, with a start point in its center, the center of the city with central administrative buildings and cultural institutions is represented. In this circle with a radius of 1 km, territory is fully built up, with no fragmentation; park zones and industrial zones are included in building system.

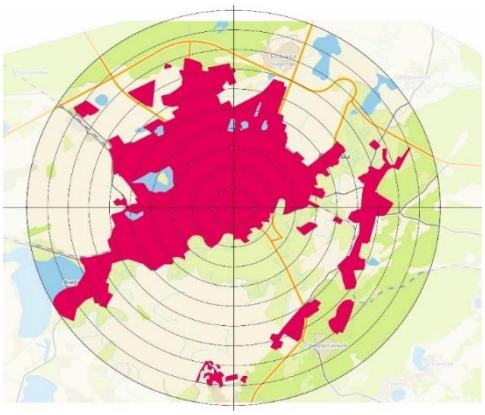

Fig. 3. Built-up territory of the city of Kurgan (within a radius of 10 km). Determination of fractal dimension by the method of concentric circles

However, from the second circle one can see fragmentation –building does not completely fill this circle; in

this part of the city there are territories for prospective development and the garden plots (Figure 3).

To extend the safety assessment of built-up urban areas and zones planned for development, soil samples were taken on the basis of general development plan of urban territory: 1) residential zone (residential buildings in the western part); 2) industrial zone – within the boundaries of the sanitary zone of the industrial enterprise; 3) transport zone (near the railway); 4) zone of perspective residential development (northern part of the city); 5) the territory of childcare facilities which are considered as high-risk facilities within the framework of the general development plan of the city – kindergartens under construction and design – in the eastern and western parts of the city; 6) zone of garden plots.

The development of a mathematical model based on the results of the correlation analysis of used parameters is shown in the article by the example of soil environmental safety model of Kurgan [11]. Quality and environmental safety of urban soils is an urgent problem of urban development.

Under urban soils (soils of urban settlements), according to the developers of this type of soil, we should understand anthropogenically altered soils with the surface layer created as a result of different types of anthropogenic activity. The thickness of these soils is not more than 50 cm, they are created artificially in the process of adding soil for burying and mixing materials of urban origin, including construction and household waste [12-14].

Based on a correlation analysis of the results of laboratory studies, the authors of this article developed a black box model of urban soil safety which resulted in the technology of its assessment. A specific feature of this approach is the creation of a comprehensive soil assessment that shows the degree of the correspondence of their actual condition to the environmental requirements for their development and use in the interests of urban settlement [15].

Natural soils of Kurgan urban territory are covered with a "soil cushion" created, inter alia, by various debris with the addition of humus and dust deposited during the period of city's existence. At the moment, even before building and in the course of it, the degradation of natural soils is often detected during urban planning in undeveloped territories. It is caused by soil disturbance occurred already during the planning process. Construction work only accelerates this process.

The following factors should be mentioned as the main limiting ones for the degradation of urban soils of the Kurgan territory.

1) Man-made soil pollution as a result of accumulation of heavy metal emissions, primarily – lead ones, although their amount per year currently tends to decrease;

2) with regard to emissions of vehicles, their gross emissions in Kurgan city have a trend to increase;

3) municipal waste is a special problem of the city of Kurgan. Severe soil pollution in existing industrial zones and in places of their creation is observed due to the ingress of waste (copper, arsenic compounds, nitrogen and sulfur oxides and other substances) into the soil. The "leaders" in the terms of environmental load degree are (in terms of their contribution to pollution) energy producers – OAO "Kurgan Generating Company"; city's engineering complex and transport system are in second place.

Obtained research results revealed the accumulation in the soils of urban areas of an excessive content of heavy metals (iron, copper, lead, etc.). They, accumulating in the soil, have both direct (toxic) and an indirect effect on all living things (vegetation, animals), and worsen the state of human health. Their action can be delayed both in space and in time. Thus, using of leaded gasoline containing lead by motor vehicles for many decades led to the accumulation of its compounds in the soil. These compounds currently take part in the biological cycle of the city and through the biological system of plants, are accumulated in the leaves of vegetation, for example, on highways, parking lots what leads to lead entry into the soil from decaying residues and its spread throughout the territory.

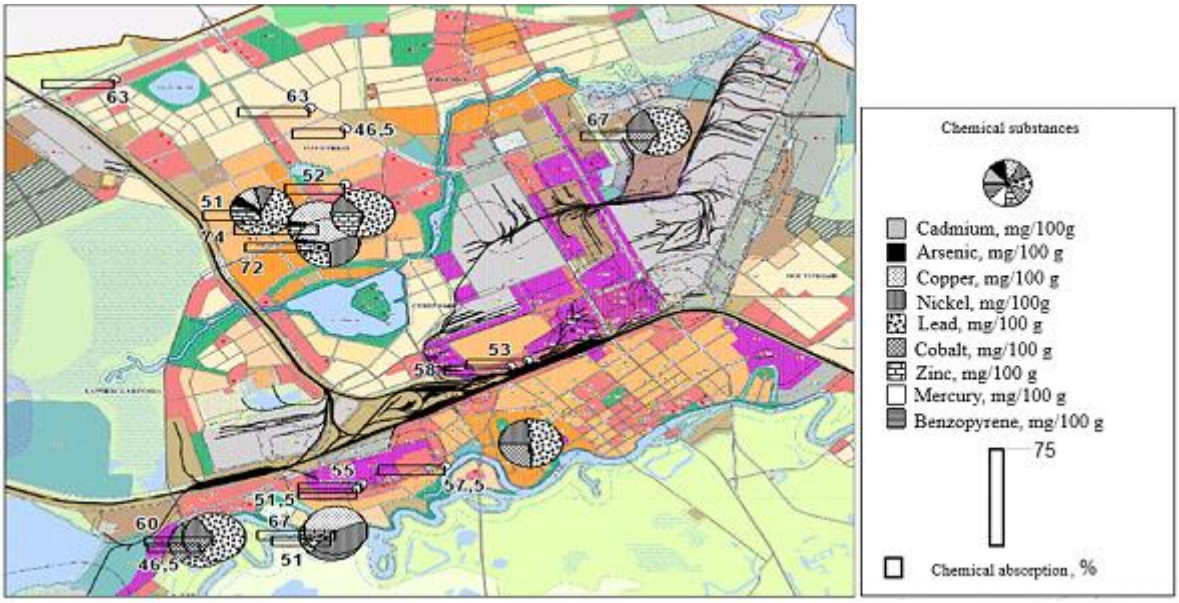

Fig. 4. Map of soil toxicity in some areas of the city of Kurgan

In the process of assessing the environmental safety of soils as the environment of the territory of Kurgan city, the following conclusions were drawn (Figure 4):

- in the urban soils of Kurgan increased concentration of heavy metals was found, especially in the upper horizons (up to 15 cm), sometimes several times higher than the baseline;

- over several decades, the area of gradually degrading and becoming environmentally hazardous urban soils heavily contaminated with heavy metals has increased and already covers territories not yet built up by urban new buildings;

- the most significant factors of pollution and degradation of urban soils are transport, industry and energy;

- in new residential areas of micro districts currently under construction, motor vehicles are of particular importance, including that for personal use, which account for up to 90% of all emissions into the air, and from it into the soil.

The soils under consideration are urban ones, mostly artificial and low-fertile, with low humus content, saline with a neutral or alkaline reaction. Due to the existing conditions, phosphorus and its salts, including these of heavy metals, contained in them are inactive and can accumulate in the soils of courtyards, parks, squares, and other public territories in large quantities, worsening the quality of the urban environment and threatening the life and health of the population.

V. Conclusion

1. Modern system analysis based on the use of set-theoretic, diagnostic, monitoring, matrix, graphical, fractal, model and other methods such as the methodology of understanding the world allows finding solutions to emerging problems, including territorial ones such as Southern Trans-Urals, the city of Kurgan.

2. System analysis with its universal, supra-disciplinary and interdisciplinary nature allows considering the history of formation and the structure of social system of Southern Trans-Urals in terms of interaction of social, ethnic, economic, ecological systems.

3. Fractal analysis of the city of Kurgan allowed considering the features of the current condition of the developed natural resources management territory. Using GIS technologies helped to evaluate the soil cover of the city occupied by buildings and of undeveloped but already affected territory.

4. In general, system analysis gives the possibility of using system models of socio-environmental processes shown by the example of Southern Trans-Urals and the city of Kurgan.

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