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Mathematical modeling of environmental management in urban natural-production systems

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Abstract. This article examines the problem of environmental pollution in urbanized territories of natural-social-production systems. A new approach is proposed for applying the fundamentals of control theory in the system of environmental management and environmental monitoring. The paper presents factors influencing the process of human management of the natural environment and ecological processes in urbanized territories of natural-social-production systems. The application of control theory principles in geoecology allows for a fresh perspective on the processes of human management of the natural environment, as well as the development of an interdisciplinary terminological apparatus for communication between specialists from different specific fields of knowledge. Approaches for improving environmental management of polluted natural urbanized territories are formulated.

1 Introduction

The problem of environmental pollution, deterioration of its quality, and exceeding the maximum permissible concentrations of pollutants in urbanized areas is increasingly noted in megacities. Cases of increased morbidity among the population are recorded, attributed to these trends in environmental pollution and, consequently, the low quality of environmental process management. Examining the aspect of natural environment management and its resources, we turn to environmental management as one of the disciplines. As I.S. Maslennikov, L.M. Kuznetsov, and V.N. Pshenin note, the ecological situation in the country is deteriorating, environmental degradation is occurring, resulting in increased morbidity of the population [1-5]. Hence, the goals of environmental management are to achieve the desired state of the environment and minimize ecological disasters [6].

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The authors previously highlighted similar environmental pollution problems in our articles on the Bogorodsky district (former Noginsky district) of the Moscow region [7]. It was also identified that population health is an indicator of environmental quality. Highly urbanized territories are characterized by increased population density, high building density, and active interaction between various natural clusters: natural, social, and industrial. At the same time, technological progress significantly integrates into the environment and affects it. The quality of environmental management must constantly improve. This applies not only to urbanized megacities but also to small town territories.

The urban settlements of the Moscow agglomeration in this case include: Noginsk, Elektrostal, Elektrougli, and Staraya Kupavna. Rural settlements include Bunkovskoye, Borovkovo, and Vorovskogo. Environmental pollution problems were previously examined and the sustainability of the natural complex in small towns of the Bogorodsky district of the Moscow region was assessed. Some tools for improving environmental quality management were found and investigated in the socio-economic development programs of the observed areas. These programs contain subprograms on "ecology and environment," as well as the amounts spent on financing and funding sources for these programs.

The situation in environmental management is complicated in some small town territories by the presence of specially protected areas, which are subject to different environmental protection requirements. In general, to apply the fundamentals of control theory in the environmental management system, all components of natural-social-production systems in urbanized territories of large and small cities, as well as urban and rural settlements, must be studied. This task will be performed in stages. In the first stage, indicators of the ecological state of the environment in urban and rural areas will be identified. Environmental factors affecting the environmental management process will be ranked. Scenarios and tools for improving the sustainability of the studied territories will also be proposed.

The information base included reports from the Ministry of Natural Resources and Ecology of the Russian Federation, federal executive bodies responsible for developing state policy and legal regulation in the field of study, use, reproduction, and protection of natural resources. Reports from various departments of State Policy and Regulation were used. Additionally, the system of state standards (GOSTs), sanitary norms and rules (SanPiN 2.1.4.1175-02), hygienic standards (GN 2.1.5.1215-03), comparison of maximum permissible concentrations in the atmosphere, hydrosphere, and soils, Federal laws in the field of environmental protection, and other regulatory legal acts were utilized. It is also worth noting that cybernetics deals with management issues, information transfer, communication methods, and control models in various systems, living and non-living, with feedback [7].

An attempt was made to analyze the management structure of the Ministry of Natural Resources and Ecology, as well as subordinate services and agencies: the Federal Service for Hydrometeorology and Monitoring, the Federal Water Resources Agency, the Federal Agency for Subsoil Use, and the Federal Service for Supervision of Natural Resources. The air pollution index was not considered, as it was believed to be insignificant in the generalized assessment of natural clusters.

2 Materials and methods

Let us consider the main categories of control theory fundamentals and environmental management. Control is an informational process, as well as an algorithmic one. As evident from the definition of the concept of "control," its scope is very broad. The scope of a concept is the range of objects to which the given concept applies [8].

Table 1. Basic concepts of management theory and environmental management.

No	Basic concepts of management theory
1	Subject of control
2	Object of control
3	Direct connection
4	Feedback
5	Environment
6	Vector of goals
7	Vector of current state
8	Error vector
9	Complete control function
10	Target control function
11	Structural control method
12	Unstructured control method
13	Combined control method
14	Stability by predictability
15	Probabilistic predeterminations (mathematical expectations)
16	Balancing control mode
17	Maneuvers
18	Autosynchronization

Now, we will analyze this control scheme from an ecological perspective, regarding a system we will call "Human - Natural (surrounding) environment (Ecological processes)". Preliminarily, the control function will look as follows:

- The vector of geoecology goals can be defined as: reducing the negative impact of human anthropogenic activities on the natural environment and of the natural environment on humans.
- The vector of the current state: continuing negative impact of human anthropogenic activities on the natural environment and of the natural environment on humans.
- The object of control: Nature
- The subject of control: Human
- Environment: The environment also participates in the control process. It is necessary to note that the environment, through feedback loops, also affects the subject of control.

Important: to maximally identify these factors, prioritize them in the vector of goals, and develop a target control function in relation to them (factors).

- Direct connection: The impact of Human (subject of control) on the Natural environment, ecological processes (object of control). That is, any anthropogenic impacts of human activities on the "Natural environment".
- Feedback: The impact of the natural environment on humans, including negative impacts. Transmission of information about the state of the Natural environment (as the object of control) to Human (as the subject of control) through feedback loops.
- Error vector (deviation assessment): continuing negative impact of human anthropogenic activities on the natural environment and of the natural environment on humans.

In "Human - Natural environment (ecological processes)", there is an apparent gradual (and possibly complete) loss of stability in terms of predictability by the subject of control (Human) of the object of control (see the error vector point above).

Thus, we have determined that the cause of loss of control stability in the "Human - Natural environment" system lies in:

1. The full control function
2. The environment
3. The subject of control

Let's examine the role of the "Environment" in the FCF (Full Control Function). Based on the general control scheme, if we look carefully and analyze, it is evident that the "Environment", through direct and feedback connections, acts as a subject of control in relation to humans. This is a crucial point in understanding control processes.

When considering the structures of information-algorithmic support of different biological species, any multicellular biological species can be assigned to one of two categories:

- Species in which the information-algorithmic support of adult individuals' behavior is fully programmed genetically (genecode) (such as plants, mollusks, coelenterates, insects) - it is transmitted in a ready-to-use form from generation to generation;
- Species in which the information-algorithmic behavior of adult individuals includes two components:
- Genetically determined (genecode), which (as in the first case) is transmitted in a ready-to-use form from generation to generation;
- Individually developed by the individual in the process of interaction with the environment throughout its life (human) - non-genetic information.

Culture is understood as the entire set of genetically non-inherited information in a ready-to-use form, which is transmitted from older generations to younger ones based on social organization [9].

Humans, at various periods of life, must receive and master a certain set of information for their normal development. Almost all information-algorithmic support for a newborn infant's behavior consists of innate instincts and reflexes (genetic information). Then, they begin to build their behavior based on what they could adopt from the environment. Non-genetic information (environment) begins to condition their behavior. (Example of the "Mowgli effect". A child who has not received a certain set of information support in time may remain underdeveloped forever, i.e., genetic information will be insufficient to develop their potential).

Over time, the frequency of technology updates has increased. Currently, several generations of technology change within the lifetime of one generation. During a person's lifetime, multiple changes occur in the world around them (changes in the information state of society). There is an increase in the significance of the influence of the non-genetic module on human behavior over the genetic one. People have to constantly master and update new knowledge and skills.

Human behavior has become more determined by the non-genetic module. This phenomenon has been termed the change in the ratio of frequencies of genetic and non-genetic information.

Culture is the carrier of another type of behavioral information (besides instincts, unconditioned and conditioned reflexes) - socially conditioned, which each person receives from the information environment of society [10].

In the new information state, the cultural module (non-genetic) has a predominant impact on human behavior, which is the Subject of control in our scheme. It is necessary to understand that "order from chaos" will not form by itself, the bifurcation point will not occur on its own, and the system will not transition to another state by itself. Often, we can observe a situation where, when communicating, specialists from different professional profiles do not understand each other. At the same time, in Science, the process of specialization has gone so far that not only representatives of different sciences cannot understand each other, but even representatives of different sections of the same science lose mutual understanding.

A uniform description of heterogeneous processes involving control theory allows finding a common language with specialists from various fields and directions: i.e., the conceptual and terminological apparatus of a sufficiently general control theory is a means of interdisciplinary communication between specialists from different particular branches of knowledge and activity.

It is necessary to develop an information module of ecological ideology and introduce it into the process of autosynchronization of the supersystem (which will be discussed further). The supersystem can include human society (both humanity as a whole and any part of humanity - the population of a country, region, city, etc.) The supersystem consists of many elements, with:

1. All elements of the supersystem are analogous to each other (i.e., similar to each other).
2. Each of the elements is capable of remembering information passing through it probabilistically. "Probabilistically" means that some element will remember everything that another element transmitted to it; 100%. But it may also be that some element will remember something and not remember something else, or not remember anything at all.
3. Each of the elements is capable of transmitting this received information to other elements, also probabilistically.
4. The behavior of all elements is determined by their internal information state.
5. All elements are self-managed based on the information stored in their memory. That is, what is "embedded" in the element is what it can do.
6. Each of the elements can be controlled externally, as all elements can accept information into their memory.
7. Each element can control other elements, as all elements can output information from their memory to other elements.

Circular addressless passage of an information module with specific content in the environment will lead to the following: system elements will become oriented towards the corresponding vector of goals indicated by the information module, in accordance with the above-described processes of the supersystem [10].

It follows that if you want to change something in the behavior of the supersystem, you must first create the appropriate information. The corresponding information can include information of an ecological nature. That is, by creating an information block to solve environmental problems and manage these processes, we can use the described process of the supersystem based on structural and non-structural control.

An additional mechanism for managing ecological processes, through non-structural control methods, can be based on and built on the use of autosynchronization.

3 Results and discussion

To initiate and implement the process of auto-synchronization of ecological processes, the following is necessary:

- A set of elements should possess (at least partially) identical (similar) informational states.
- They should be in conditions that allow for information exchange between elements (even if non-addressed, circulatory).
- The response speed of these elements to the passage of information through them (with their help) should be sufficiently high.

Thus, if information, such as ecological ideology, is distributed non-addressably among the elements of a supersystem, the behavior of the system's elements will begin to change,

probabilistically predetermined, according to the information module circulating in the system.

"Probabilistically predetermined" can be considered from the perspective of Gaussian law, and the mathematical expectation of individuals' behavior in the system under the influence of information with specific content can be determined. Gaussian law, or the law of normal distribution, plays an exceptionally important role in probability theory. The feature that distinguishes it from other laws is that it is a limiting law to which other distribution laws approach under frequently encountered typical conditions [11]. The behavior of many quantities and processes occurring in nature obeys the law of normal distribution [12]. The mathematical law of normal distribution, or Gaussian law - the probability distribution - is applied in many fields: physics, statistics, modeling of socio-economic processes, etc. (m - mathematical expectation), depending on the content of the information module. Thus, the probability of predetermined behavior of individuals can be foreseen, and based on Gaussian law and control theory, it is possible to predict the behavior of the majority, namely approximately 80% of people.

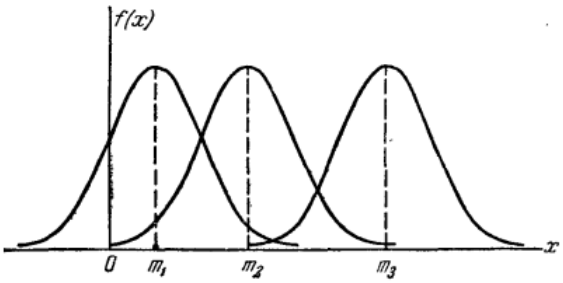

Fig. 1. Gaussinians: m_1 m_2 m_3 – mathematical expectation.

The control function of the ecological system "Human - Natural (surrounding) environment," when compiled into a table for greater clarity, appears as shown in Table 2.

Table 2. Fundamentals of environmental management.

Stages of environmental management	**Contents of environmental management**
Vector of goals in relation to the control object	Reduction of the negative impact of human anthropogenic activity on the natural environment and the environment on humans. Determination of stability by predictability of the behavior of an object under the control influence of the subject of control (human), i.e. identification of the maximum possible mathematical expectations of the behavior of an object under the control influence.
Vector of goals in relation to the subject of management	Creation of a common management language between specialists of different profiles based on management theory, as a means of interdisciplinary communication between specialists of different fields of knowledge and activity; Control (observation) of the behavior of the elements of the supersystem (Gaussian mixing). Recognition of new factors influencing the subject of management Adjustment of goal vectors, in cases of decreased management quality (error vector analysis)

Vector of goals in relation to the natural environment	Creation of an information module (ecological ideology) and circular distribution of this module between the elements of the supersystem; Creation of a chronological order structure concerning ecological processes and their relationship over time.
Error vector	Control parameters monitoring: deviation of the actual process prescribed by the goal vector from the ideal control mode. Control (observation) of the behavior of the elements of the supersystem (Gaussian mixing).
Control methods	Unstructured, structured, combined, mechanism of auto-synchronization of supersystems.
Implementation mechanism	Unstructured management of ecological processes. The mechanism of autosynchronization in supersystems.

4 Conclusion

The application of control theory fundamentals and mathematical apparatus in environmental management allows for improving the quality of management of ecological processes and environmental conditions, as well as enhancing the identification of new factors influencing the process of environmental pollution. It enables the development of a common terminological apparatus as a means of interdisciplinary communication among specialists from various specific fields of knowledge and activity. Population health, serving as an indicator of the ecological situation in urbanized territories of megacities (natural-technical systems), also adheres to the laws of control theory and is interconnected with it. The resulting development can be utilized in the foundations of ecological safety in Russia and other countries. Additionally, it can be applied in educational programs on geoecology, nature management, environmental management, ecological cybernetics, and in areas of knowledge and spheres of human activity related to the managerial aspect.

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