About Two Model Approaches to Study of Sustainable Development

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Abstract. The concepts of "Stability" and "Sustainable Development" from a model point of view are considered. Two approaches to the study of sustainable development based on the Verhulst equation are analyzed. The analytical solution of the Verhulst equation corresponds to the “order” in the system. However, taking into account small “white noise” type disturbances in the system either consideration with a discrete change in time for certain values of the coefficients of the Verhulst equation, “chaos” may appear in the system.

Introduction

A characteristic feature of recent studies is the expression of interest in complex problems, which include consideration of the economic, social and environmental aspects in their complex interweaving and mutual influence. One of the most urgent tasks is a quantitative assessment of the effects of human impact, the study of trends in the development of natural systems. Currently, under the auspices of the UN, all states are developing a sustainable development strategy. Currently, “Sustainable development” is a priority research topic of all departments of Moscow State University named after M.V. Lomonosov. Due to the fact that there is no clear and unambiguous understanding of this term, each department finds its own problems and tries to solve them. The concept of sustainable development [2,8,9,10,18,24] is closely intertwined with the concept of "stability". The concept of sustainable development is associated with the “order” and “dynamic chaos” in natural systems [18,21].

Environmental, economic, social and political issues [3,4,5,6,7,11] are included in the concept of "sustainable development".

Criteria and Indices of Sustainable Development of Natural Model Systems

Sustainability is a fundamental concept about the development of natural complexes. This problem is extremely urgent due to the strong anthropogenic impact on ecosystems and the need to assess the effects of anthropogenic impacts on natural complexes. When analyzing sustainable development, a common for all approaches is the presence of a natural ecosystem with a certain structure and the presence of impacts, both natural and anthropogenic in nature, seeking either to remove the ecosystem from certain areas considered sustainable, or to affect ecosystem parameters, thereby changing the structure of the latter, which also corresponds to the instability of the ecosystem [1]. Based on these ideas, we formulate the qualitative concept of “ecosystem stability”. Let us call the stability of an ecosystem exposed to impacts, its ability to maintain internal structural relationships and to be within the same steady state area.

When studying the problem of ecosystem stability, it is advisable to distinguish two assessments of stability. To quantify the stability of natural ecosystems at a fixed point in time without considering the effects of specific disturbances acting on the ecosystem, it is proposed to use the concept of “stability index” of ecosystems [26]. In those cases when it is required to assess the stability of ecosystems at a certain time interval in relation to a specific type of disturbance, it is proposed to use...
the term “stability criterion” of ecosystems [16,17,26]. An ecosystem may be resistant to some classes of disturbances and unstable to other classes [19,22,25].

Model studies of the sustainable development of natural systems of all three levels consider different approaches [14,15]. One approach is to build models of natural ecosystems using differential equations and study the stability of such model systems to various perturbations [12,20,23]. Another approach is to find a characteristic in the system that is responsible for sustainable development. Indices and indicators are representatives of this approach. Dynamic processes in these systems are described by deterministic differential equations. In this region, even small perturbations in the system can lead to large consequences. Modes that are sensitive to initial conditions are called strange attractors.

**Two Approaches to the Study of the Verhulst Equation**

Ecological studies often use the Verhulst equation. Although this equation is non-linear, it may be integrated in quadrature. Verhulst equation is the simplest form for describing dynamic curves; nevertheless, ideas for constructing a logistic curve underlie models at all levels: local, regional, and global. The solution to this equation is a logistic curve.

The Verhulst equation with constant coefficients, considered from the point of view of order and chaos, is a representative illustration of order in natural systems. In reality, the environmental parameters included in the Verhulst equation are not constant values, but change over time. Accounting for changes in the parameters of the Verhulst equation leads to far-reaching consequences, more accurately reflecting the real situation. Impacts on ecosystems strongly affect the coefficients of the Verhulst equation. Two cases of the Verhulst equation were investigated. In the first case, a mathematical model of the functioning of the ecosystem in the form of differential equations is compiled and the influence of perturbations on the dynamics of the development of this system is investigated. Instead of taking into account the variation of the system parameters, it is considered that the system as a whole is exposed to small (by absolute value), but constantly acting disturbances. This approach is implemented for the case of studying the effect of small random perturbations on the stability of the states of natural ecosystems. In [13,23,25], it was shown that the stability of the state of the system described by the Verhulst curve to “white noise” type perturbations is determined by a nonlinear ratio of the coefficients included in the Verhulst equation. In these works, it is shown how small but constantly acting perturbations can “shake” and even lead to the death of a very stable (when there are no perturbations) system.

Verhulst equation, being a nonlinear differential equation, has an analytical solution. In the overwhelming majority, the solution of nonlinear differential equations is found using numerical methods. With the help of numerical methods, the discrete Verhulst equation was investigated. The paradox of the research result is that the analytical solution always has a limiting value, which corresponds to the “order” in the system, and with a discrete change in time, with certain values of the logistic equation coefficients, various development scenarios are possible, including scenarios in which the limit value is exceeded that corresponds to the appearance of “chaos” in the system.

**Summary**

Currently, there are many approaches to the model study of the sustainable development of natural systems. There is no unambiguous approach to working out a criterion for sustainable development and, apparently, it will not be found. Researchers use different mathematical tools to obtain criteria and apply it to determine sustainable development. Two approaches to the study of the Verhulst equation are considered, each of which can lead to unstable development.

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