ENVIRONMENTAL SUSTAINABILITY AS AN INDICATOR OF RELIABILITY OF ECOSYSTEMS

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The intensive flow of pollutants into ecosystems leads to their structural and functional changes. In such anthropogenically transformed ecosystems, the mechanisms of balanced functioning are disrupted, which leads to a loss of ecological sustainability. The paper examines the issue of the established response of the biotic component of the ecosystem to the impact of anthropogenic pollutants. It is proved that the biotic component of ecosystems is a reliable indicator of their sustainability. It is noted that the study of the levels of reactions of living organisms in ecosystems and their thresholds to the harmful effects of anthropogenic pollutants allows developing the approach for assessing the level of their environmental sustainability. The authors have proposed the approach for assessing the sustainability of ecosystems based on studies of the viability of their biotic component. The results of the research have shown that the biotic component of ecosystems allows to reliably reflect the level of their sustainability as an informative indicator of their ecological reliability. The paper demonstrates that the assessing ecological sustainability of anthropogenically loaded ecosystems is a highly informative indicator of determining the level of their ecological reliability and can be successfully applied for managing ecological reliability of such anthropogenically loaded ecosystems.

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Introduction

The rapid increase of anthropogenic pollutants in the environment inevitably leads to uncontrolled changes in the natural environment, which result in the loss of ecological sustainability of ecosystems and, accordingly, their reliability.

To date, there are still urgent questions about the distribution and redistribution of anthropogenic pollutants in ecological systems and the response of living organisms to harmful effects of pollutants. These issues are extremely relevant, as they determine the state and dynamics of pollution of natural ecosystems, and, accordingly, the level of their environmental sustainability. In addition, the study of environmental sustainability assessment and ecosystem reliability management to some extent contributes to solving the problem of survival and viability of human civilisation on the resource-limited planet Earth (Azarov et al., 2017).

Ecosystems in some way are the basis structures of life on our planet. They are the main natural units of the Earth's biosphere. With the growing anthropogenic impact on the environment, there is a need to develop an approach for assessing the sustainability of ecosystems to ensure their environmental reliability.

The purpose of the study is to develop the approach for assessing the sustainability of ecosystems and improve the management of ecosystem's reliability.

Assessment of the reliability of ecological systems is reduced to assessing the extent to which the structural elements of ecosystems function in a mutually consistent manner. And to determine under what conditions reversible or irreversible changes in ecological systems can be triggered, which can lead to structural and functional changes that result in a loss of ecosystems' ability to regenerate themselves and, consequently, to a loss of their environmental sustainability (Madzhd, 2024).

Materials and Methods

The mechanism of pollutant redistribution in ecological systems was studied based on the analysis of the statistical characteristics of the physical process leading to 'sudden' and 'random' failures (according to Poisson's law) by means of probabilistic and physical modelling of ecosystems' stability. The statistical processing of the research results was carried out by the methods of variation statistics according to the generally accepted methodology using the standard package of applied statistical programmes 'Microsoft Office Excel' and 'Statistica 5.0 for Windows'. The Student's t-test was used to assess the significance of the results. The formula for calculating the t-test:

$$t = \sqrt{\frac{r\sqrt{n-2}}{\sqrt{1-r^2}}} \tag{1}$$

where r is the correlation coefficient; n is the number of levels of the dynamics series under consideration.

The density of the statistical relationship was estimated by calculating the Bravier-Pearson linear correlation coefficients:

$$r_{xy} = \frac{\sum_{i=1}^{N}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{N}(X_i - \overline{X})^2 \sum_{i=1}^{N}(Y_i - \overline{Y})^2}} \tag{2}$$

where r_{xy} is the linear correlation coefficient, which allows to emphasise the density (close linear relationship) of random variables between two samples, provided that: $r_{xy} = 0$ – no linear relationship; $r_{xy} = +1$ – linear relationship is present; $/r_{xy}/ = -1$ – negative linear, inverse, functional relationship.

Methods for assessing environmental sustainability include:

modelling methods:

- statistical modelling methods;
- methods of simulation modelling;

forecasting methods:

- forecasting methods based on research of physical processes;
- methods of forecasting based on pattern recognition;
- methods of analytical forecasting;
- methods of probabilistic forecasting;

calculation and experimental methods:

- methods of normal tests;
- methods of reduced tests;
- methods of forced testing;

methods of a priori calculation:

- methods of refined a priori calculation;
- methods of approximate a priori calculation.

Results and Discussion

Natural ecosystems belong to the class of complex systems. Their peculiarity is determined by the existence of a significant number of links between individual structural units and the presence of many structural components.

All ecosystems include their structural elements and subsystems, which are interconnected by structural and functional links (Isaenko et al., 2019). Since ecosystems are hierarchical, their structure is presented as a set of subsystems of different levels arranged in a gradual manner. In general, the structure of an ecosystem is represented by numerous links and elements that are crucial for ensuring energy and information exchange not only within the ecosystem itself, but also between it and the external environment (Turevych, et al., 2021)

Natural ecosystems are complex multifunctional systems whose functions are hierarchically distributed in the following sequence (Ogmundarson, 2020):

- passive existence (the basis for a higher-order system);
- servicing a higher-order system;
- opposition to other systems (survival);
- absorption of other systems;
- transformation of other systems.

Changes in ecosystem states are usually accompanied by their structural and functional restructuring, which occurs in a ‘jerk’ manner. This is due to the fact that compensatory mechanisms of self-regulation are no longer able to keep the ecosystem in the same state, and in the new state it already loses its stability due to radical restructuring of the structure and loss of functional properties (Lapan et al., 2019).

The choice of the direction of change in ecosystem states depends on a limited number of alternatives in order to maintain sustainability and stability. Most often, the need to choose an alternative state arises when the ecosystem enters the so-called ‘exacerbated’ mode of functioning, which may result in natural accidents, crises, and disasters. A crisis in ecosystems should be seen as a phenomenon that indicates the need for the ecosystem to adapt to external or internal conditions that have changed significantly. A crisis is characterised by the preservation of the most important characteristics of ecosystems and minor damage. However, the emergence of crises should be regarded as evidence of the need for a certain renewal of the ecosystem. The occurrence of a disaster in an ecosystem is usually accompanied by a significant and rather sharp change in the ecosystem's integral indicators due to the transformation and radical restructuring of its morphology and structure. More radical changes, which usually lead to ecosystem destruction, are observed during cataclysms (Matveeva, 2018).

Ecosystems have a clear hierarchical organisation in which each element performs its own function. Therefore, in the functioning of ecosystems, the desire of a system of living organisms for self-preservation is extremely important, which is impossible without self-reproduction and self-improvement, since the key feature of ecosystem reliability is its environmental sustainability.

Ecological systems are very complex systems. Due to the significance of the functions they perform, the leading place is given to the subsystem of living organisms. They, in comparison with other structural elements, directly affect environmental sustainability and thus, they are directly responsible for the environmental reliability of ecosystems.

The state of the biotic component of ecosystems should be considered as a universal means of assessing environmental sustainability of ecosystems. If the biota is sufficiently stable, it is able to perform two of the most important functions in the ecosystem that ensure its environmental sustainability:

- conservation and maintenance;
- accumulate and maintain biomass (Madzhd et al., 2017).

These functions of the biota allow ecosystems to ensure their survival, even in stressful situations of anthropogenic impacts. Due to the implementation of these functions by the biota, ecosystems are capable of self-healing and rapid self-regeneration. Obviously, a high parameter of ecosystem reliability does not yet provide optimal conditions for biota to perform its functions, but it undoubtedly guarantees its survival in anthropogenically loaded habitats (Morelli, 2022).

When it comes to the reliability of anthropogenically loaded ecosystems, it is customary to distinguish two main types of them: a sequential system and a parallel system. Anthropogenically loaded ecosystems should be considered reliable ecosystems if they have a probability of failure-free existence of their components in the range from 0 to 1. Natural ecosystems, on the other hand, due to the complexity and diversity of their structural and functional properties, are much more reliable than anthropogenic systems. This is due to the much longer period of existence of more perfect natural systems compared to those created by humans (Azarov et al., 2019).

Ecosystems have certain limits within which they are able to compensate the negative impact of pollutants. The setting of impact limits is based on sub-threshold concentrations of pollutants at which there is no noticeable deviation or change in the functional state of the ecosystem and the response of the biotic component.

Living organisms are able to tolerate certain amounts of hazardous and harmful effects of pollutants without obvious harm (Figure 1). The level below which ‘painful’ reactions in ecosystem elements are not observed is indicated as a threshold. With a large number and high concentration of pollutants, negative impacts on the ecosystem will occur. These impacts depend on both the concentration of pollutants, P, and the duration of exposure to the hazard, t.

The figure shows that higher levels of pollutant impact on the biotic component of ecosystems are recorded for shorter durations of exposure. Accordingly, the threshold values are higher. With a longer duration of pollutant impact on the biotic component of ecosystems, the levels of pollutant impact and threshold values will decrease accordingly.

Thus, the study of the biotic component of anthropogenically loaded ecosystems allows us to draw conclusions about their ecological sustainability, which is an informative indicator of their ecological reliability.

The ability of ecosystems to self-heal and self-regulate in the process of systemic changes accompanied by changes in the states and properties of all its components is environmental reliability. It includes: the ability to function in randomly varying environmental conditions and over time; the ability to adapt, survive, preserve and restore basic functions in changing environmental and internal conditions; resistance to changes in environmental parameters; the ability to maintain a state of homeostasis; the ability to perform physiological and biochemical functions that ensure its normal life during ontogeny in certain environmental conditions; the ability to maintain its function under different environmental conditions and different internal states.

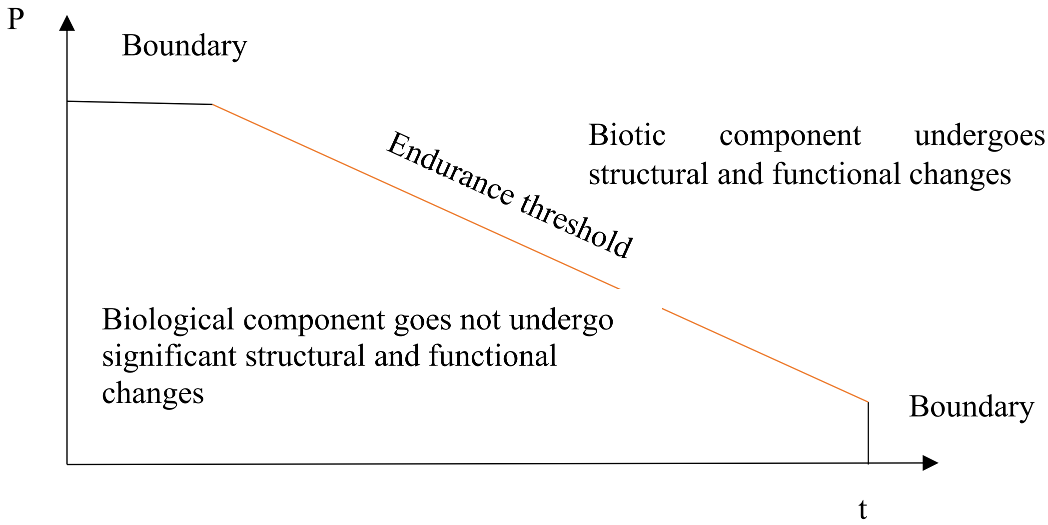

Figure 1. Dependence of reaction of biological component of ecosystem on pollutant concentration and duration of exposure

Conclusions

Continuous scientific and technological progress has inevitably led to structural and functional changes in ecosystems. In the context of increasing anthropogenic pressure on natural ecosystems, their mechanisms of balanced functioning are disrupted and there is a need to create a system for assessing the level of their ecological sustainability to the harmful effects of anthropogenic pollutants. Therefore, the authors have proposed the approach for assessing the ecological sustainability of ecosystems based on studies of the viability of their biotic component. The research has shown that the biotic component of anthropogenically loaded ecosystems allows to reliably reflect the level of their ecological sustainability, which is an informative indicator of their ecological reliability. The developed system for assessing the ecological sustainability of anthropogenically loaded ecosystems is a highly informative indicator of determining the level of their ecological reliability and can be successfully applied in the system of managing the ecological reliability of anthropogenically loaded ecosystems.

Thus, the viability of the biotic component of ecological systems is a universal means of assessing their ecological sustainability and ecological reliability. In the system of environmental management, it is the reliability of ecosystems that should be taken into account as an informative indicator for determining quantitative indicators of anthropogenic impacts on the ecosystem.

Conflict of interest

The authors state no conflict of interest.

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