Concept of integrated monitoring of territorial technosphere state

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Abstract. To ensure the safe operation of a local technosphere, a concept of comprehensive monitoring aimed at predicting, identification, analysis, and assessment of anthropogenic threats to society is needed. This paper puts forth a concept of comprehensive monitoring of a local technosphere based on a quantitative assessment of a multivariate object, including the problem, tasks, methods, and algorithms that ensure its implementation. The author substantiates the necessity to develop this concept given the importance of anthropogenic threats to society. An algorithm for comprehensive monitoring of a local technosphere has been developed. Within the framework of this concept, a method of compression of information linked to the state of a multivariate object was justified and proposed. Introduction of an overall index of multivariate information compression was justified, and method of its assessment was proposed. An approach to assessing the state of objects of a local technosphere using a combination of parameters, taking into account the weighting factors, has been proposed.

1. Introduction
The relevance of forming a comprehensive monitoring system (MS) of a territorial (local) technosphere (LT) is associated with general trends in ensuring the security of a country. The most important of these trends are: forecasting, identifying, analyzing, and assessing security threats, organizing prevention activities, and continuously improving the security system.

Generally speaking, LT MS is viewed as a type of management activity and consists in accumulating information regarding territorial (local) technosphere objects (LTO) aimed at evaluating their condition and predicting the trends in their development. This information is then used by decision-makers (DM) to take action. In order to complete this objective, it is necessary to develop an LT MS concept aimed at organizing a unified system of parameters characterizing each LTO and the entire LT, ensuring the completeness and reliability of such data, developing scientific approaches to forecasting and preventing emergencies, as well as methodological and analytical tools for assessing the status of LTOs based on common criteria and methods of analysis.

With that in mind, comprehensive monitoring of LT status should consist of scientifically proven study methods which would include surveillance, evaluation, and forecasting of changes in LTO status as a result of their interaction, as well as meeting the demand of DMs in this information in order to prevent and/or mitigate emergencies.
2. Relevance, scientific significance of the issue with a brief review of literature

Various countries of the world are constantly monitoring environmental objects, which indicates the relevance of this topic. However, most of the studies are directed towards a specific component of the biosphere, that is, atmosphere, hydrosphere, or lithosphere [1-6]. These studies are often aimed at analyzing local problems according to one or several parameters, and migration of pollutants is not taken into account [7]. In the course of the research, the dependences of the intensity of anthropogenic impact on the environment or the object are established according to the legal quality criteria (maximum permissible concentrations, levels, impacts, etc.) and do not take into account their mutual influence (compensation or synergistic effect).

In studies [8-14], generalized factors such as quality indexes are used for each component of the biosphere. These indexes reflect the state of the biosphere. When combining specific parameters into a generalized factor, each of these parameters is assigned a weight corresponding to the significance of the pollutant (hazard class in the environment, buildup volume).

In studies [15,16], one multivariate LTO is characterized by several indexes, which would render the decision-making process complex. Therefore, it is obvious that for practical application it is necessary to develop and introduce new methods of deeper compression of information, taking into account the overall anthropogenic impact. It is also reasonable to develop methods both to compress a sum of parameters characterizing LTOs and for indexes reflecting the status of a studied object through parameters which are common for various LTOs.

The examples of such studies are [17,18]. Authors of these studies have proposed methods for comprehensive monitoring of the state of dynamic multivariate objects (DMO), processes, and systems according to heterogeneous measurement data.

The disadvantages of these methods are the considerable time spent on registering changes in DMO status due to deviations of its parameters from tolerance values, failure to use these methods when an emergency occurs in more than one structural element, absence of simultaneous display of the results of estimated tolerance values for each of the entire set of heterogeneous DMO parameters, which leads to a lack of accuracy in assessing the status of DMO. In turn, the lack of accuracy in estimating DMO status leads to an incorrect selection of control actions on object parameters.

The analysis showed an almost complete absence of theoretical and practical material containing comprehensive studies and multivariate analysis of LT status.

3. Formulation of the problem

CM of LT status is needed to create a scientifically based approach to organizing and conducting a comprehensive study of LTOs. This approach involves the stages of observation (measurement), processing, analysis, evaluation, and prediction of changes in LTO status when interacting with each other, as well as provides for the need of decision makers for reliable and timely information to prevent and/or mitigate the consequences of emergencies.

To date, there are separate systems for monitoring objects of different origin. These systems employ different approaches, methods, and controlled parameters. In addition, such systems are divided between various departments, and it is not possible to quickly and effectively combine the results of their performance.

CM system for LT status based on a scientifically proven concept will allow to combine heterogeneous multivariate data characterizing each LTO and will provide a unique LT evaluation and management tool.

4. Theoretical part

Modern control systems implemented using computer technology have made it possible to perform data mining. The objective of data mining is to establish patterns that characterize the object being analyzed.

To analyze LT status, it is necessary to determine which parameters should be selected for monitoring and to identify factors that have a significant impact on their values. In order to make such
analysis more effective, it is necessary to carry out integral assessments and comparisons based on a large number of parameters. Methods of multi-criteria evaluation and visualization of DMO are suggested in [19,20].

Since it is not simple to evaluate an entire sum of parameters characterizing LT in general according to a large number of criteria, it is more reasonable to use various indicators or status indexes for LTOs. These are sustainable (balanced) development indexes or indicators. In our case, the overall compression index (OCI) is a result of compressing a sum of parameters and criteria of their evaluation characterizing LT. These procedures can be carried out according to various methods. The main feature of the use of OCI is the unification of rules and attributes of assessing the compliance of OCIs with acceptable values.

When accumulating and preparing data for defining OCIs, one may experience problems related to:

- obtaining information on LT status by carrying out time-consuming measurements, since it leads to the emergence of a number of subjective and objective reasons for data gaps to appear;
- the fact that the same external manifestations of deviations from normal OCI values may be due to various internal processes taking place in an LT, which leads to a significant ambiguity of the results and conclusions.

Thus, during data mining it is necessary to find structure in it and to identify patterns of interest that help to control the LT status.

In order to organize data mining on the LT status, it is important to solve a number of problems related to the modeling and identification of patterns in the measured data. These objectives have a number of common features. First, the input data for the analysis are the results of measurements reflecting the stochastic process. Second, this data has a multidimensional structure. Third, the data may be heterogeneous or may contain gaps. In some cases, it is necessary not only to solve the direct problem, for example, to find the dependence of the LT status on the parameters of impact on it, as well as the inverse.

To do this, we need a concept of CM of LT status. Its scheme is shown in Figure 1.

![Figure 1. A concept of comprehensive monitoring of a LT.](image-url)
Figure 2. Algorithm of CM of LT status.

5. Practical significance, suggestions and results of implementation, the results of experimental studies

LT status as a result of implementing CM system is evaluated according to the algorithm shown in Figure 2.

A set of parameters characterizing an LTO and intended to be used to assess its status is preselected. Each of the selected parameters should be necessary, and all parameters together should be sufficient to describe the status of an LTO in question.

In this combination, there may be parameters an increase in the values of which leads to an improvement of LTO status (a minimum permissible value is normalized; for example, the oxygen content in water); parameters an increase in the values of which leads to its deterioration (a maximum permissible value is normalized; for example, chemical impurities content in the environment); as well as parameters, the critical values of which divide the scale of parameter changes into two or more intervals with opposite properties of the effect of the parameter on an LTO (for example, temperature estimated by a range of values).

In order to accumulate information, stationary and mobile sensors which help to obtain data on LTO status in short order are used.

Results of LTO monitoring are transferred to the data processing center and are transformed into OCIs.

This transformation is proposed to be carried out in such a manner that the best conditions for each parameter (deviation from the maximum permissible value is zero) correspond to the value "0", and the worst (the deviation from the maximum permissible value is maximum) correspond to "1". Let us also set minimum ($x_{\text{min}}$) and maximum ($x_{\text{max}}$) values for parameters.

We use the following formula for parameters normalized according to the minimum permissible value:
where \( q_i \) is a transformed parameter value; \( x_i \) is a current value of a measured parameter; \( x_{\text{min}} \) is the minimum (background, permissible, safe, threshold etc.) parameter value; \( x_{\text{max}} \) is the maximum parameter value.

We use the following formula for parameters normalized according to the maximum permissible value:

\[
q_i(x_i) = \begin{cases} 
0, & \text{if } x_i \leq x_{\text{min}} \\
\left( \frac{x_{\text{max}} - x_i}{x_{\text{max}} - x_{\text{min}}} \right), & \text{if } x_{\text{min}} < x_i \leq x_{\text{max}} \\
1, & \text{if } x_i > x_{\text{max}} 
\end{cases}
\]  

(1)

Range of changes in \( q_i \) always fluctuates between 0 and 1. Thus, the initial parameters in various units of measurement are converted into the dimensionless ones. After that, compression is carried out and OCIs characterizing the LTO status are obtained. We get \( Q_{\text{max}} \) and \( Q_{\text{min}} \) from the obtained values.

Compression of set parameters into an OCI \( Q(q, p) \) is made in such a way so that it depends not only on \( q_i \), but also on weighted factors \( p_i \), the sum of which per an OCI is 1 (\( 0 \leq p_i \leq 1 \)). Values of weighted factors \( p_i \) are chosen in accordance with the magnitude of parameter impact on an LTO (taking into account the hazard class in the environment, the DLS, or the actual formation volume).

To obtain OCIs, we use linear compression of parameters

\[
Q = \sum_{i=1}^{n} q_i \cdot p_i,
\]  

(3)

where \( n \) is the number of measured parameters.

Then, using (4) and (5) we determine the upper and lower limits (\( Q_i^l \)) for each OCI, thus obtaining a scale of LTO statuses, with weighted factors of each measured parameter taken into consideration.

To determine OCI threshold values combining the parameters normalized by the minimum permissible value, we use the formula:

\[
Q_i^l(q, p) = \begin{cases} 
0, & \text{if } Q_i \leq Q_{\text{min}} \\
\left( \frac{Q_i - Q_{\text{min}}}{Q_{\text{max}} - Q_{\text{min}}} \right), & \text{if } Q_{\text{min}} < Q_i \leq Q_{\text{max}} \\
1, & \text{if } Q_i > Q_{\text{max}} 
\end{cases}
\]  

(4)

To determine OCI threshold values combining the parameters normalized by the maximum permissible value, we use the formula:

\[
Q_i^l(q, p) = \begin{cases} 
1, & \text{if } Q_i \leq Q_{\text{min}} \\
\left( \frac{Q_i - Q_{\text{min}}}{Q_{\text{max}} - Q_{\text{min}}} \right), & \text{if } Q_{\text{min}} < Q_i \leq Q_{\text{max}} \\
0, & \text{if } Q_i > Q_{\text{max}} 
\end{cases}
\]  

(5)

Based on the calculated values of OCIs, a special status scale is built. This scale is used to determine the status of an LTO at a given time (see Figure 3).
Figure 3. Results of analysis of LTO status.

Thus, Figure 3 shows the results of analysis of LTO status according to OCIs characterizing the status of atmosphere (OCI$_{atm}$), hydrosphere (OCI$_{hydr}$), and lithosphere (OCI$_{lith}$). Furthermore, a threshold value OCI$_{threshold}$, which combines the parameters normalized according to the minimum permissible value has been singled out. Thus, all points that are outside of the threshold zone indicate that an LTO is in a troubled state, and intervention by decision makers is needed.

6. Conclusion

The proposed concept of comprehensive monitoring of TO status can be widely used in monitoring studies to solve the problems of sustainable development of regions, as it allows to evaluate any number of objects by setting specific set of parameters and criteria for their assessment for each object. The use of OCIs simplifies the way the output data is shown and allows for quicker decision-making in case of emergencies.

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