Features of processing of measuring information for an assessment of human ecological wellbeing

O E Bezborodova, O N Bodin, A I Gerasimov, A V Svetlov and B V Chuvykin

Penza state University, 40, Krasnaya str., Penza, 440026, Russia

E-mail: oxana243@yandex.ru

Abstract. The connection between the state of the territorial technosphere and the ecological well-being of man is obvious. Modern research is aimed at studying the effect of pollutants on individual natural systems and do not take into account their complex effects. The assessment is carried out according to individual parameters, not combined into generalizing indicators characterizing the state of the territorial technosphere as a whole and not taking into account the contribution of each. A method for processing measurement information is proposed, which makes it possible to evaluate the contribution of each impact to the final coagulation index. This index characterizes the state of the territorial technosphere taking into account the current aspects and the analyzed criteria and allows, using the method of hierarchy analysis, to determine the weighting coefficients for each aspect. A feature of the proposed method implementation is the lack of subjectivity in the ranking of the analyzed criteria due to the use of not subjective expert assessments, but quantitative values enshrined in regulatory legal acts. The results of such an analysis are important for setting priorities for the implementation of environmental measures and ensuring the ecological well-being of man.

1. Introduction

Today the need for control and evaluation of the condition of the territorial technosphere (TT) as a complex of subsystems (SSs) on different levels, for example biosphere, the society and technogenic [1], is not in doubt. The authors see the evaluation of the danger level of the modified biosphere to the normal human life as the TT and its subordinate SSs condition evaluation. In accordance with [2], the environmental situation is ranked in ascending order of environmental ill-being in the following way: relatively satisfactory; precarious; critical; crisis; emergency. The following criteria form the basis of this classification: condition of the environment: biosphere, health, integrity of natural ecosystems.

There are two kinds of influences of the biosphere: the safe one that does not endanger safety or health; and the dangerous influence that can result in diseases or even death. Consequently, biosphere quality monitoring is essential for health protection of the population and SSs that influence it. The condition of TT as a multi-parameter object (MPO) can be evaluated through the SS aspects that influence it. The authors understand by the term 'aspect' the result of the SS work, its products and services that can interact with biosphere and change its condition. Chemical polluting substances and compounds (PS), energetic impact (noise, electromagnetic and ionizing radiation) can be considered as aspects. The intensity of the aspects today is extremely high. The impact of each of them can be lower than the permissible value (PV), but their synergetic effect can be considerable. The PS are proved to exert synergetic effect, for example, acetone and phenol, sulfurous dioxide and phenol, sulfurous dioxide and hydrogen sulphide. This is why in order to assess the condition of TT, it is essential to enter
parameters that take into account their synergetic interaction in biosphere rather than just their individual PVs. Such impact today is taken into account only when setting PS environmental standards for biosphere SS (atmosphere, hydrosphere, lithosphere), which does not allow to comprehensively assess the impact of the transformed biosphere on human beings.

2. Problem statement
The overview of control methods and indicators within the comprehensive assessment of natural MPOs is given in [3]. The work presents the analysis and classification of natural MPO comprehensive assessment indicators and lists the contradictions and disadvantages of existing comprehensive assessment concepts. It is mentioned in particular that the assessment is carried out either by individual biosphere SS, or by individual environmental objects.

A number of papers [4, 5] use summarising coefficients for every studied biosphere SS, or quality indexes, that show its condition. When individual parameters are united into the integrated index, every one of them is given weight corresponding to the PS relevance (class of danger in the environment, emission size).

The works [6, 7] have one MPO characterise a number of indexes, which makes it difficult to make a definite decision. This is why it is obvious that for implementation purposes it is essential to develop and introduce new methods of deeper information phasing out that provide for comprehensive man-made impact. It is feasible to develop such methods both for phasing out a group of parameters characterising TT and for index systems showing the condition of a studied object through parameters that are common for various MPOs.

The works [8, 9] show the examples. They list techniques for comprehensive monitoring of MPO condition, processes and systems based on homogenous measuring information.

These techniques have the following disadvantages: considerable time needed to record changes in MPO condition based on deviations from its parameters from the permissible values; it is impossible to use in case of parallel emergencies at more than one structural element; there is no simultaneous display of results of tolerance evaluation for every one of the diverse controlled MPO parameters, which results in insufficient accuracy of the evaluation of MPO condition. In its turn, insufficient accuracy MPO assessment results in incorrect selection of steering impacts on the object's parameters. The analysis showed an almost complete lack of theoretical and practical material with comprehensive research and multi-parameter analysis and TT assessment.

3. Theoretical part
The authors propose a new method of information processing (measuring information, laws and regulation, etc.) for the purposes of TT assessment. The developed method involves an algorithm shown in figure 1.

The method involves a hierarchical TT map, collection of information on threshold values for the analysed criteria (AC) for every environmental aspect (EA), AC calculation, AC contribution based weight coefficients (WC), representation (transformation) of AC values as a resulting index (RI), comprehensive monitoring of environmental prosperity based on the RI. TT is a system that can be divided by SSs based on certain features. In its turn, these SSs include smaller SSs on the same level. If we continue the division, we will have SS of a lower level. Such a division is called a hierarchy.

The system hierarchy is a subordination structure, or connections between SSs with different weight. The number of levels, number of SSs on every level can be different, but SS in one system should perform all the functions within this system.

Hierarchical structure of the system (HSS) (figure 2) is a graphic representation of the system in the form of a reversed tree where every SS depends on one or more SS situated higher. The tree structure of the hierarchy is the simplest to analyse and implement. It is simple to identify hierarchical levels in it: SS on n levels, their aspects affected by them and criteria that characterise these aspects. The top of the hierarchy in HSS is the main goal or problem that needs thorough research; elements on lower levels, group of miscellaneous criteria; their values affect the achievement of the goal (solution to the problem);
elements on intermediate levels correspond to the aspects that connect the goal (solution to the problem) with the criteria.

![Diagram of hierarchy](image)

**Figure 1.** Environmental prosperity assessment algorithm.

![Diagram of hierarchical structural map](image)

**Figure 2.** Hierarchical structural map of human environmental prosperity.

After the hierarchy is developed, you should set the priority (relevance) of criteria and aspects in the structure of the system and SSs. Priorities are the weight coefficients of elements on every level. The higher the priority, the more relevant is the corresponding aspect or criteria.

The hierarchical structure of TT is based on the assumption that TT can be divided into SSs on several
interconnected levels. Every SS is influenced by neighbouring SSs and influences them. This influence is described with the help of aspects, in this case with EAs that are the results of the operation of SSs that interact with SS biosphere and change its condition. The influence of EAs on SS biosphere is evaluated using miscellaneous ACs that are different by their origin (physical, chemical, biological, etc.), but are capable of synergy. A list of necessary ACs is drawn for every EA, and all ACs must be sufficient to describe the condition of the biosphere. Biosphere, man-made environment and humanity as a part of the society are the first level SS in TT. In order to assess the danger that the transformed biosphere poses for the normal life of people, we analyse SSs on the second level: atmosphere, hydrosphere and lithosphere using the total of ACs and EAs.

The formal description of human environmental prosperity HSS allow to see structural connections within the system as a formula helping to consider the impact of SSs on humans either one by one, or as a whole:

\[
H_EW = H_EW^A \cup H_EW^H \cup H_EW^L. \tag{1}
\]

The description of the impact for every analysed SS is done using the total of EAs and ACs and the following formulas:

\[
H_EW^A = A \cap (EA_1^A \cup ... \cup EA_k^A) \cap (AC_1^A \cup ... \cup AC_m^A), \tag{2}
\]

\[
H_EW^H = A \cap (EA_1^H \cup ... \cup EA_k^H) \cap (AC_1^H \cup ... \cup AC_m^H), \tag{3}
\]

\[
H_EW^L = A \cap (EA_1^L \cup ... \cup EA_k^L) \cap (AC_1^L \cup ... \cup AC_m^L), \tag{4}
\]

where \(H_EW\) is the general human environmental prosperity; \(A\) is atmosphere SS; \(H\) is hydrosphere SS; \(L\) is lithosphere SS; \(EA_k\) – environmental aspect; \(AC_m\) – analysed criteria.

The result of the hierarchical analysis is a list of ACs that can be divided into three groups by their impact on SSs: ACs that when they grow, the condition of SS improves (the minimal permissible value is standardized, for example, the percentage of oxygen in water), ACs that when they grow, the condition of SS deteriorates (the maximum permissible value is standardized, for example, the percentage of PS in the medium).

In order to assess EA based on norms and regulations, we calculate the quantitative characteristics of ACs that describe the impact of the analysed EA on humans, environment and its relations to other EAs and set threshold values.

As ACs are parameters with different measuring units, they must be calculated into dimensionless units for further analysis and comparison. Let us introduce the term "compliance to permissible levels\(\delta\)," or a condition and its parameter that help to assess the compliance to the requirements of Laws and Statutory Instruments. Permissible value compliance parameters for every AC group is set in the following way.

For ACs that are standardized by:

- minimal permissible values:
  \[
  \delta_m = C_{m,\text{min PV}} / C_{m,\text{act}} \tag{5}
  \]

- maximum permissible values:
  \[
  \delta_m = C_{m,\text{act}} / C_{m,\text{max PV}} \tag{6}
  \]

where \(C_{m,\text{act}}\) is the measured and calculated value of AC; \(C_{m,\text{min PV}}\) is the value of the lower threshold of AC for minimum permissible value standardizing; \(C_{m,\text{max PV}}\) is the value of the upper threshold of AC for maximum permissible value standardizing under LSI or other requirements. Based on formulas (5) and (6), if a compliance feature is \(\delta_m \geq 1\), then the actual value of the AC parameter exceeds the standard, if a compliance feature is \(\delta_m < 1\), then the actual AC parameter is within the norm. The graphic representation of the compliance features for various ACs is shown in figure 3.
We can break the «curse of dimensionality» with the help of the formulas (5) and (6) that allow to compare EAs of different origins against PVs, but not to take into account its physical and chemical aspects. To do that we identify the relevance of every EA in the form of a weight coefficient (WC) using the hierarchy analysis method (HAM). HAM is efficient for MPO assessment, when the number of AC exceeds 5 \((m > 5)\). The point of HAM with regards to the assessment of TT is the following. There is a goal to assess TT at the moment and the total EA and AC that characterize this condition.

For every \(k\)th EA, AC values calculated using the formulas (5) and (6) are compared to each other in pairs, and we calculate the relative relevance of every AC in the pair:

\[
a_{ij}^m = \frac{a_i^m}{a_j^m}
\]

where \(a_i^m\) is AC values in the matrix line of \(n\)-th level; \(a_j^m\) is AC values in the matrix column of \(n\)-th level.

The results are represented in the form of a matrix of \(n\)-th level. The elements of such a matrix are the coefficients of pair-by-pair comparison of the values of the \(m\)-th AC, with \(i\) being the number of AC in a matrix line and \(j\) being the number in a matrix column:

\[
A_{kn} = \begin{bmatrix}
1 & a_{12}^m & \cdots & a_{1j}^m \\
1/a_{21}^m & 1 & \cdots & a_{2j}^m \\
\rotatebox{90}{$\vdots$} & \rotatebox{90}{$\vdots$} & \ddots & \rotatebox{90}{$\vdots$} \\
1/a_{jn}^m & 1/a_{2j}^m & \cdots & 1
\end{bmatrix}
\]

Let us calculate the geometric mean for every matrix line using the following formula:

\[
B_{i}^m = \sqrt[n]{\prod_{k=1}^{n} a_{ij}^m},
\]

then we sum it up:

\[
B_{\Sigma}^m = \sum_{i=1}^{k} B_{i}^m.
\]

Then we calculate weight coefficients using the \(m\)-th AC:

\[
W_i^m = \frac{B_i^m}{B_{\Sigma}^m}.
\]

Similarly, using pair-by-pair comparison we calculate and make matrices for every AC of \(n+1\) WC
values and then, on this basis, we establish how well every WC corresponds to every AC. On the basis of the calculated WC, we make a matrix of \( n+1 \) level where for every EA we put WC that have been calculated for every AC.

We calculate the WC arithmetical mean by lines and we calculate WC EA for the purposes of analysis:

\[
W_k = \frac{\sum_{i=1}^{m} w_m}{m}.
\]

Further, taking into account the WC for every AC, we calculate the contribution of every AC into the current condition of TT using the resulting index \( \Delta \):

\[
\Delta = \sqrt{\sum_{i=1}^{k} W_k \cdot \delta_i^2}.
\]

The assessment of human environmental prosperity on the basis of HSS is done using the scale shown in [2] for HSS-based human environmental prosperity calculated using the formulas (5) – (13) (table 1).

| SS/condition | satisfactory | crisis |
|--------------|--------------|--------|
| people and their environmental prosperity | quality description | there is no threat to the life and health of the public | there is a threat to the life and health of the public |
| HSS | 0 - 1 | more than 1 |

### 4. Practical significance, suggestions and results of implementation

An assessment was conducted using the proposed methodology of human environmental prosperity in TT with an industrial company that is under comprehensive monitoring. The percentage of ammonia, hydrogen chloride, acetic acid in the air in a community and the level of noise in proximity to residential construction. Actual AC values have been established for every EA, and based on the LSI data, the PVs for air in a community have been set in table 2. The values of the upper level for all AC are established on the level of 70% from PVs (table 2).

| AC/EAs | noise \((X_1)\) | ammonia \((X_2)\) | hydrogen chloride \((X_3)\) | acetic acid \((X_4)\) |
|--------|-----------------|-----------------|-----------------|-----------------|
| actual AC values in the medium, \( C_{m\text{ act}} \), (dBA*, mg/m^3) | 54* | 0.16** | 0.05** | 0.07** |
| permissible AC values in the medium (PL*, PC average daily **), \( C_{m\ PV} \), (dBA*, mg/m^3)** | 50* | 0.04** | 0.02** | 0.06** |
| \( \delta_m \) class (labour conditions*, PS danger class in the medium**, (I, II, III, IV)), \( K_k \) | 1.08 | 4 | 2.5 | 1.17 |
| AC upper threshold, \( C_{m\ max PV} \), (dBA*, mg/m^3** | 35 | 0.028 | 0.014 | 0.042 |
| AC lower threshold, \( C_{m\ min PV} \), (dBA*, mg/m^3** | 0 | 0 | 0 | 0 |

Then using the formula (13), we calculate HSS

\[
\Delta = \sqrt{0.0975 \cdot 1.08^2 + 0.725 \cdot 4^2 + 0.08 \cdot 2.5^2 + 0.098 \cdot 1.17^2} = 3.51
\]
The calculated WC and HSS allow us to conclude that the relevance of EAs is established in the following way: ammonia is the most dangerous substance (and in the ascending order of danger), acetic acid, noise, hydrogen chloride. On the basis of the data from Tables 2 and in accordance with the formulas (5) and (6), we establish the compliance values $\delta_i$ for every AC (table 3). We use the formulas (5), (6), (9) – (11) and make matrices of the 1st level for AC-1 «Compliance with permissible values» (table 4). AC-2 «Class (labour conditions, PS danger in the medium (I, II, III, IV))» (table 5). Then on the basis of table 4 and 5, we fill in «The Final Matrix of the 2nd level» and using the formula (12), we calculate WCs for every EA (table 6).

| Table 3. Calculations. |
|------------------------|
| AC | noise ($X_1$) | ammonia ($X_2$) | hydrochloric acid ($X_3$) | acetic acid ($X_4$) |
| $W_i^1$ | 0.13 | 0.53 | 0.31 | 0.03 |
| $W_i^2$ | 0.19 | 0.59 | 0.03 | 0.19 |
| $W_k$ | 0.16 | 0.56 | 0.17 | 0.11 |
| WC$_{prior}$ | 3 | 1 | 2 | 4 |

| Table 4. Calculation for AC-1 Compliance feature. |
|------------------------|
| AC | $\delta_1$ | $\delta_2$ | $\delta_3$ | $\delta_4$ | $B_i^1$ | $W_i^1$ |
| $\delta_1$ | 1 | 0.2 | 0.4 | 0.9 | 0.02 | 0.00 |
| $\delta_2$ | 3.7 | 1 | 1.6 | 3.4 | 5.06 | 0.86 |
| $\delta_3$ | 2.3 | 0.6 | 2.1 | 4 | 0.78 | 0.13 |
| $\delta_4$ | 1.0 | 0.2 | 0.4 | 1 | 0.03 | 0.00 |
| $B_{\Sigma 1}$ | 5.90 | 1 |

| Table 5. The calculations for AC-2 Class. |
|------------------------|
| AC | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $B_i^2$ | $W_i^2$ |
| $K_1$ | 1 | 0.75 | 1.5 | 1 | 0.28 | 0.19 |
| $K_2$ | 1.33 | 1 | 2 | 1.33 | 0.88 | 0.59 |
| $K_3$ | 0.66 | 0.5 | 1 | 0.66 | 0.05 | 0.03 |
| $K_4$ | 1 | 0.75 | 1.5 | 1 | 0.28 | 0.19 |
| $B_{\Sigma 2}$ | 1.49 | 1 |

| Table 6. Final Matrix of the 2nd level. |
|------------------------|
| EA/WC | $W_i^1$ | $W_i^2$ | $W_k$ | WC$_{prior}$ |
| $X_1$ | 0.005 | 0.19 | 0.0975 | 3 |
| $X_2$ | 0.86 | 0.59 | 0.725 | 1 |
| $X_3$ | 0.13 | 0.03 | 0.08 | 4 |
| $X_4$ | 0.006 | 0.19 | 0.098 | 2 |
| $\sum$ | 1 | 1 | 1 | - |

When priorities are set for the development, funding and implementation of measures aimed at ensuring human environmental prosperity, it is essential to focus on the sources of ammonia emissions.

5. Conclusion

To sum up, the proposed method of data processing (measuring information, laws and regulation, etc.) for the purposes of TT assessment using a group of environmental aspects and criteria characterizing them, and based on resulting index to assess human environmental prosperity; based on the hierarchy analysis method to identify the most important environmental aspects for environmental protection efforts.

References

[1] Bezborodova O 2018 IOP Conf. Ser.: Mater. Sci. Eng. 451 012189 doi:10.1088/1757-899X/451/1/012189

[2] Methodology «Criteria for assessing the environmental situation of territories to identify areas of environmental emergency and environmental disaster zones», approved Ministry of natural
resources of the RF

[3] Dmitriev V V 2009 Determination of the integral indicator of the state of a natural object as a complex system Society 4 146-65

[4] Shull D R, Smith Z M and Selckmann G M 2019 Development of a benthic multimetric index for large semi-recoverable rivers in the Mid-Atlantic region of the United States Environ Monitoring and Assess 191(22) Retrieved from https://doi.org/10.1007/s10661-018-7153-x

[5] Sarupria M, Manjare S D and Girap M 2019 Environmental impact assessment studies for the mining industry in Goa, India, using a new approach Environ Monitoring and Assess 191(18) Retrieved from https://doi.org/10.1007/s10661-018-7135-z

[6] Emelyanova V P, Danilova G N and Kolesnikova T Ch 1982 Review of methods of surface water quality assessment by hydrochemical parameters Hydrochemical materials 81 121-31

[7] Pinigin M A 1986 On the concept of «character of combined action» as the basis of hygienic assessment Hygiene and sanitation 1 48–50

[8] Djundikov E T 2011 Method for integrated control of state of multiparameter object based on different information Pat 2459245 RF vol 23 (Moscow: Rospatent)

[9] Belov A N 2015 Complex monitoring of state of dynamic objects and systems Pat 2574083 RF vol 26 (Moscow: Rospatent)