Generalized assessment of region environmental state based on mathematico-cartographic modeling with GIS

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Abstract. The developed methodology features an uneven distribution of indicator parameters in classes, based on principles of regulation and ecological laws. The problem is solved by the innovative method of mathematico-cartographic modeling, based on GIS-technology using the Geostatistical Analysis ArcGIS. All models are tested according to the Belogurov's RR-criterion of model suitability. Among the many logistic functions, the one for which the rules for the allocation of 5 classes are established, is selected. Mathematical analysis of the expression for the logistic curve made it possible to propose the new authors expression for its description. It contains such parameters as the values of the middle and width of the increasing section of this curve and its maximum value. This set is more visible and convenient for assessing the environmental state. It also corresponds to the typical pollution levels accepted by the Hydro meteorological Service: high and extremely high pollution levels. The maximum efforts and means to improve on the environmental state will be devoted to the first signs of high pollution, preventing the transition from class 2 to class 3. A well-reasoned concept of creating systems for monitoring dangerous trends and managing enterprises in accordance with mining safety conditions has been developed.

1 Introduction

From the Concept of Sustainable Development adopted in 2015 by the UN General Assembly, which contains 17 goals and almost 170 related tasks [1] here we consider the task of assessing the generalized assessment of regions environmental state, which, using the Methodology developed in article [2], can be solved by each of the 193 countries, signed the UN Resolution, and which should contribute to the best of their ability.

This task is solved in accordance with the UNESCO regulations formulated for various regions of the world [3].

The number of classes over the entire range of indicators and the characteristics of each class are formulated in the Water Framework Directive No2000/60/EC, 2000 [4].

The governing body of UNESCO, the Board of Governors, consisting of representatives (experts) of 58 countries, has been meeting annually since 1972 and reviews the annual State Report on the state and protection of the environment from each country. The rules for
compiling each State Report are strictly regulated by international documents and national legislation. These normative documents provide for mandatory public participation in the discussion of the State Report. The methodological basis of the competence of independent experts is not regulated.

General purpose of the work: Transformation of the proposed methodology in the direction of developing methods, algorithms, tools for solving real environment problems

Work tasks:
1. Based on the mathematical properties of the logistic function, formulate rules for determining the boundaries between each of the 5 classes of the type "1 - excellent; 2 - good; 3 - satisfactory; 4 = bad; 5 - very bad."
2. To develop examples of optimizing the solution for a generalized assessment of the state of the atmosphere, hydrosphere and lithosphere.
3. Determine the features and properties of mathematically-cartographic models (MC-models), the criterion for the suitability of these models for forecasting time series, GIS technologies and tools for their application.

2 Manuscript preparation

2.1 Theoretical analysis and normative justifications

Two fundamentally different approaches to the assessment can be identified. The first is an expert one, in which a group of experts based on the study of the plurality of source data, finds a common solution to the problem. An example of such an approach is the Canadian GLASOD system [5], which contains a database with generalized assessments of soil degradation worldwide. Examples of these are environmental impact assessment and biological productivity of land in the "global" acres" of the International Fund for the WWF wildlife [6].

This approach, based on Ecology theories, laws, rules, principles and hypotheses by [7], should include generalized methods and indicators are usually not commonly recognized and have no regulatory support which is required to establish the boundaries between the acceptable classes and the catastrophic conditions [2].

Among all logistic function, usually interpreted as “growth function”, the most convenient for our purposes [8] is presented in terms of the age development of a person and contains the required 5 classes of the type “childhood - youth - maturity - old age - decrepitude”.

The article by Korean authors [9], which demonstrating the success of innovative approaches for a generalized assessments on example of one from river basins in Korea. Here, the transition from water quality indices to chemical pollution index (CPI) is used, and most importantly, index of biotic integrity (IBI) what developed in the [10]. As a result, a comprehensive assessment was obtained, which takes into account many types of anthropogenic disturbances, including eutrophication, acidification, chemical pollution, flow regulation, physical habitat alteration and fragmentation, human exploitation, and introduced species). Finally proven, that the assessment of river health is an important, and perhaps the main direction in the study of the fresh water.

2.2 Logistic function

The logistic function finds applications in a range of fields, including biology, especially ecology, biomathematics, chemistry, demography, economics, etc.
The author is convinced [2], that the logistic function suitably reflects the causal relationship "impact - response" in a variety of areas. The logistic curve is a mathematical model that is used to describe the change in time of the main parameter during the development of the system in accordance with the law of S-shaped development.

The presented material was initiated by Dmitry Kucheryavy's report at the "TRIZ Future 2007" conference /1/. In this report, the following analytical expression for the logistic curve was proposed.

\[ N(t) = \frac{M}{1 + e^{-a \times t - b}} \]  

(1)

where M determines the maximum value of the logistic curve, "a" and "b" determine the position of the curve along the abscissa axis and the width of the middle section of the curve.

The presented expression for the logistic curve is rather inconvenient for practical application, it primarily refers to the parameters "a" and "b".

First, these parameters are only indirectly related to the position of the curve on the abscissa axis.

Secondly, the parameter "a" has the inverse dimension of time, and the parameter "c" is dimensionless, it is more convenient to have the time dimension of that and the second parameter.

Thirdly, the position of the curve on the abscissa axis and its width depend on both parameters.

It is proposed to transform the expression with an exponent to a more convenient, from the point of view of practical application, form.

Let's plot the graph of this function and show the values of the GPP on it (Figure 1).

![Fig. 1. Graph of the logistic curve.](image)

Using the standard approach, we divide the S-curve into three characteristic sections. The first gentle section is the stage of "childhood" (the stage of "using" the newly born system in its environment); second fast-growing – stage of "maturity" (stage of rapid growth and use of available resources); the third, again gentle, is the stage of "old age" (the stage of exhaustion of system resources).

Parameters a and b of function (1) do not uniquely define the boundaries of these stages. Let's try to find such parameters that will do this. To do this, we will find the middle of the "maturity" interval and its boundary by studying the function (1) with the parameters M=10, a=0.6, b=-10 (the parameters are chosen based on the fact that the boundaries of the plots are clearly visible on the graph of this function). The graph of the function is shown in Figure 2.
As can be seen from the graph, the middle of the "maturity" interval is the point of transition of the function from the interval of concavity to the interval of convexity. To find the value of this point, we find the roots of the second derivative of the function under study. The second derivative formula has the form (2), its graph is shown in Figure 3.

\[
F(x, M, a, b) := M \cdot a^2 \cdot \exp(-a \cdot x - b) \cdot \frac{\exp(-a x - b)}{(1 + \exp(-a x - b))}
\]  

(2)

The root of function (3) with respect to x is equal to \(-\frac{b}{a}\). Thus, the point \(-\frac{b}{a}\) determines the position of the middle of the "maturity" interval. Let us denote the parameter responsible for the middle of the "maturity" interval by S.

\[
C = -\frac{b}{a}
\]  

(3)

Let's determine the boundaries of the "maturity" interval. Let's assume that the boundaries are those points where the tangent has an angle of inclination to the abscissa axis of 45 °. To find these points, we solve equation (4).

\[
F(x, M, a, b) = \tan \frac{\pi}{4}
\]  

(4)

The solution of this equation for \(M=10, a=0.6, b=-10\) has the following form:

\[
x_1 := 14.471736838458638819
\]

\[
x_2 := 18.86159649487469451
\]

Let's plot the points corresponding to the obtained solution on the graph of the function (Figure 4).
As can be seen from the graph, the found points are too close to the middle of the "maturity" interval, therefore, they do not fit. Most likely, the required boundaries are in the intervals [10, 13] and [20, 23].

Let's continue the study of the function. We will conduct a visual analysis of the graphs of the third and subsequent derivative functions. Figures 5-6 show graphs of the third and fourth derivative functions, respectively.

As can be seen from the graphs, there are no special points in the third derivative in the investigated intervals, but local extrema can be observed in the fourth derivative. To find them, you need to find the roots of the fifth derivative, but we DON'T NEED THIS.

**Conclusion**

The analysis of the expression for the logistic curve made it possible to propose an expression for its description, which contains, as parameters, the values of the middle and width of the increasing section of this curve and its maximum value. This set of parameters is more visible and convenient for analyzing the development of the system. In addition, the points of transitions from stage to stage are determined, which are equal to 4.1% and 95.9% of the maximum value of the curve, respectively.

### 2.3 Developing new standards in surface water

Among approaches to the development of standards for surface water, it is necessary to note works by A.E. Vasyukov et al.

They are the end result [11] about Environmentally friendly conductometric method for spring water; and also [12] - statico-dynamic approach to spring water estimation.

Statically-dynamic approach to estimation of spring water was also considered in two papers, but in work [13] - for mineralization stability, and in [14] – for hardness cation content.
It should be noted that the point equal to 4.1% of the maximum value of the Logistic curve does not remain stable when changing hydrochemical standards. This makes it impossible to use the derivation of section 2.2 in this situation.

It should be noted that there are only 2 articles where my work [2] was referenced. They include: [15] and [47] in ref. Although there are only two of these works, both authors contributed to our research direction. Works by A.E. Vasyukova is discussed above, the contribution of VS Koloskov is discussed in the EMERGENCY section.

2.4 Increasing the efficiency of generalized assessments: innovative approaches, methods, models

2.4.1 Application of the pollution coefficient to assess the state of water bodies.

Among the all chemical pollution indicators (CPI), that given in the article [9], there is no pollution coefficient KZ by [16]. The KZ differs from each of these CPI in that it is not a straight line. KZ is a broken line, where small changes in pollutant concentrations near the standard norm do not have any-any effect on the value of KZ. But after that, the KZ value grows as fast as the linearization of the widest (growth) part of the S-shaped logistic curve dictates to it. That is why the KZ is an unique generalized assessment, which is fundamentally different from all other CPIs in the world.

This zone of insensitivity near the standard norms increased the accuracy of the estimation so much that it allowed us [18] to check the reliability of the initial data even during the modeling process.

2.4.2 GIS-technology using for state assessment of lithosphere and atmosphere

The best GIS technology used in [17] for modeling Water-Soil systems is the ArcSWAT program, where watershed area can be considered as a habitat of aquatic ecosystems.

The work [19] could not take place at all because the Atmospheric Pollution Index (Russian Hydrometeorological Service) had too high errors. And only his replacement on the KZ (transformed to atmospheric standards) allowed the student Alexander Ivakhnenko to defend his graduation project perfectly well.

In article [20] was an assessment of soil degradation by means of GIS.

2.4.3 Non-timber use of forests

In the article [22] is demonstrated that the top region of using forests for the sake of health is Bashkortostan which is the only populated region in Russia with no COVID-19-related incidence rate (official statistics as of November 2021).

The fact that there are only two regions out of 84 subjects of the Russian Federation cannot be a coincidence. Yakutia is a country of reindeer herders roaming the undisturbed civilization of the tundra, just like Bashkortostan, which has been supplying Europe with the famous Bashkir honey since tsarist times. to grows of human heals and to replenish the family budget.

Systematic and massive communication with nature is not only crucial for natural immunity and human health, but also of great economic importance [23]: Economics of production in forestry and the forest industry. The main provisions of this fundamental book are cited below.

Of particular importance are non-timber forest resources, the use of forests for the purposes of hunting, gathering nuts, berries, and, of course, mushrooms (including the especially valuable white mushroom, rydjik, etc.), as well as other types of forest use.
According to calculations, the biological reserve of the main types of berries (cranberries, lingberries, blueberries) is more than 7 million tons, of pine nuts more than 1 million tons, of mushrooms about 4.3 million tons: according to expert estimates, it is worth tens of billions of dollars annually.

Of the wild nut-bearing species, cedar is the most important. Cedar forests occupy about 40 million hectares in the Russian Federation. Cedar (Siberian cedar pine) is the most important forest-forming species of the West Siberian, East Siberian and Far Eastern taiga.

2.4.4 Conclusion on section 2

Analysis of the expression for the logistic curve made it possible to propose a special expression for its description. It contains such parameters as the values of the middle and width of the increasing section of this curve and its maximum value. This set is more visible and convenient for assessing the environmental state. It also corresponds to the typical pollution levels accepted by the Hydro meteorological Service: high and extremely high. These 2 levels, (they usually correspond to 30 and 100 standard norms. the transition points from stage 2 (good) to stage 3 (satisfactory) are determined.

3 Management, control and monitoring under sustainable development. emergency

3.1 Environmental Management

The ecological crisis caused by the contradictions between the limited resources of the Earth (biological and mineral) and the rapid growth of needs in modern civilization dictates the need to find ways to eliminate these fundamental contradictions. Offer a solution to the problem by changing the paradigm of integrated development of subsoil through the creation and application of nature-like mining technologies [34]. At the Honored Ecologist of Russia I.V. Zenkov et al. disturbed land reclamation technology and is successfully implementing it here and abroad [35].

The first author’s work that fully corresponds to this new, nature-like paradigm of K.N., Trubetskoy, is a multidisciplinary article [32]. Hear the innovation mathematico-cartographic models and modern GIS technologies are used for its implementation in the Environmental state assessment space.

To check the suitability of these MC-models, the author's criterion [31] should be used. Now this is the only universal criterion that corresponds to the fundamental Idea of Academician Kolmogorov [33] about the information content of the model with respect to the real object of arbitrary statistical nature.

They are works [28] about Evolution of the Concept of Self-Organization; [29], [30] about Investment portfolio management from cybernetic point; [30] about Prediction of the Air Pollution; and also 2 authors articles [36] and Belogurov, Denisova, 2023.

3.2 Safety-conscious management

Scientists of the Kola Science Centre of the Russian Academy of Sciences, KSC RAS (Apatite, Murmansk region, Russia) are leaders in the development of innovative projects in mining and their implementation in Russian Arctic. Currently, their basic directions are defined in the work [38] Digital past, present, and future of mining industry. And by Lukichev at al. in 2021: Digital tools for underground mine planning; in 2020 about. Temporal approach to modeling objects.
There are 2 works by [41, 42] and other works with Nagovitsyn: [40] (Digital Twin of Solid Mineral Deposit) and [43] (Structure of Integrated Stability Monitoring in Open Pit Mining).

It should be noted work [45] about the stress distribution; and also [46] on development of an express-method to control damages in underground mining excavations under rockburst hazardous conditions.

3.3 Emergency

Developed [47] criterion takes into account both interrelations between elements of natural surrounding (including species from different trophic levels) and result of impact an environmentally dangerous object on these species. Implementation the new ecological reserve criterion makes the method of territories' environmental condition assessment applicable for assessment dangerous impacts same as for operative environmental safety control.

On the environmental safety direction there are works with Leonid Pisnia, 2020 (about environmental safety of solid household waste handling processes) and. 2022 (Information-Analytical System of environmental safety assessment), and papers by Strelnikova, Serikova and al. (2021) about elastic properties clarification of three-dimensional nanocomposites, with K. Degtyarev (2022) for the liquid hydrocarbon storage and with L. Pisnia (2022) - for Oil Storage Systems.

They are also 2 authors works [53] and [54].

4 Conclusions

And in conclusion, I want to quote a phrase that I used to say to students before the first GIS technology test, urging them to make their first real map. And they did it with joy and creativity.

The great Aristotle in his famous "Metaphysics" wrote: "Investigating the truth is difficult in one respect, easy in another. This is evident from the fact that no one can achieve it properly, but also does not suffer complete failure, and everyone says something about nature and one after another, it is true, adds nothing or little to the truth, but when all this is added up, it turns out A significant amount" Quoting this from my article with students [37], I want to say to you, the reader: dare, create, do not be afraid - nothing is lost in vain. Thus said Aristotle.

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