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ARTICLE

Some Approaches to Measuring Environmental Safety

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ABSTRACT

The article is devoted to the measurement of environmental safety. The differentiation between the methodological concepts of safety and danger is carried out. The requirements for measures of environmental safety are substantiated. The correlation between safety and development, safety and danger is revealed. A quantitative approach to the environmental safety assessment is proposed. The objectives of environmental safety as a science and practical activity, along with the criteria for achieving these objectives, are substantiated. In the article, life expectancy is analyzed as an indicator of environmental safety as well as its dependence on other state development priorities, such as the costs of giving birth and raising children, supporting pregnant and lactating mothers, caring for pensioners, costs of ensuring industrial and transport safety, etc. It is substantiated that the mortality rate of the population at different ages, from different reasons, in different conditions, will represent the state of safety in a given place. The article considers the indicators that determine the quality (state) of the environment as the maximum permissible environmental load and the degree of proximity of the ecosystem state to the border of its sustainability. The possibilities and advantages of using the assessment of the photosynthetic organisms' state as the indicator of environmental safety are substantiated.

Keywords: Environmental Safety; Safety Level; Safety Criteria; Basic Values; Life Expectancy; Integral Indicators; Photosynthetic Organisms

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1. Introduction

By the end of the 70s, the danger assessment in the scientific world of almost all countries came to the standard measure based on risk. But in the case of safety assessment, such a standard measure has not been found yet. Moreover, many people evaluate safety in terms of danger, which is a methodological error.

Danger and safety are the attributes of different objects. Danger is an attribute that characterizes the habitat (location) in which the object of research is located, where it originates, develops, multiplies and dies. This environment has certain physical and chemical characteristics, a certain biological environment (the entire set of organisms surrounding the object and their interaction and influence on the object, both positive and negative). And safety is an attribute of a protected object that characterizes how much the object is protected from negative environmental influences, how much the object can withstand changes in the physical and chemical characteristics of the environment (temperature, pH, redox potential, pressure and other changes), the level of protection from the influence of other organisms (from being eaten by predators, from the penetration of bacteria, from the attack of viruses, etc.) and from natural disasters.

Thus, safety and danger are two interrelated but independent attributes that allow the fundamental existence of a high level of safety at a high level of danger and vice versa. Both attributes characterize both natural and social development.

Danger is a natural attribute of all processes, phenomena and objects with potential or kinetic energy, chemical or biological activity, and is determined by their physical, chemical, biological or social nature. In any conditions, with a certain degree of probability, a dangerous factor can represent one or another real danger to human life and health, enterprises and territories, ecosystems or individual living organisms. That is, for all socio-biological systems, there are no (and can't be) conditions in which danger is completely absent. Danger is a natural and integral attribute of life.

2. Research Philosophy

The problem of ensuring human safety and the safety of the environment is a multi-criteria problem that requires taking into account numerous factors, circumstances, conditions and parameters, often competing and contradictory, for its correct solution. They can have different scales and significance, appear and act in different ways in time. There are certain laws governing the interaction of people and the environment, which unfortunately have not been sufficiently studied yet.

Ensuring environmental safety must be considered as a kind of management. If environmental safety management is carried out at the level of a country, region, district or city, then we are talking about state or municipal management, and if environmental safety management is at the level of an organization or territorial complex, then it is a type of production management. Any management, including ensuring safety, requires resources for its implementation: financial, material, human and time. However, most of the material resources on Earth have their natural limits, and human and time resources are always limited. That's why the vital interests of a country or organization lie in the rational use of resources. That is, while ensuring safety and development at the same time, it is necessary to know exactly what the existing safety level is at the moment and what the value of danger is.

The management problem is to ensure that the costs of danger reduction are consistent with the benefits of increasing the level of safety and are adequate to the value of the danger, ensuring the balance between costs, benefits and the value of danger. In the absence of accurate quantitative safety level estimates, the balance between safety and development is often imbalanced. An unjustified increase in safety is detrimental to development when resources are spent on unjustified objectives, falsely assessed as having high danger. Conversely, underestimating the danger can lead to significant damage to the individual enterprise, organization, territory, and even the whole country. Therefore, accurate safety and danger assessment is vital both at the country level and at the level of organization or enterprise.

3. Research Methodology

Over the past 30 years, risk has been used as a standard "scale" in world science to quantitatively measure the degree of danger. According to the SRA (Society for Risk Analysis, USA)[1,2], risk is known as: "The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment; estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred".

Risk is usually a combination of three indicators:

- The probability of occurrence (frequency of occurrence) of an adverse event (for example, more frequent cases of diseases or injuries of a certain kind);
- The consequences of an adverse event (the amount of damage from the impact of a dangerous factor);
- Uncertainty in assessing both the probability and the value of the consequences.

As for safety, there is still no standard "scale" for quantitative measurement of environmental safety. That is a direct consequence of the insufficient development of the very environmental safety concept. The concept of environmental safety should be based on the following methodology, which includes:

- Teleology (objective-setting) of environmental safety, which ensures the identification of objectives at various levels, their structuring, and interconnection (correct identification of objectives predetermines the effectiveness of both policy and strategy);
- Development of an environmental safety implementation strategy;
- Postulation of the basic environmental safety principles;
- Determination of indicators of environmental safety objective achievement (by what signs the progress towards objectives can be measured);
- Development of the measure of environmental safety objective achievement, determining the criteria for assessing the effectiveness of objective achievement;
- Development of decision-making principles in the implementation of environmental safety objectives;
- Development of principles for identifying the wrong decisions in the implementation of environmental safety objectives.

The correct identification of environmental safety objectives predetermines the effectiveness of the entire methodology. This will help in developing the principles of ensuring environmental safety and answer a number of questions: What levels of environmental safety can be considered acceptable? What means of ensuring environmental safety should be considered the most effective? How to select them and create a system for ensuring environmental safety, taking into account available opportunities, developing plans, programs, projects, etc.?

The more clearly the environmental safety objectives are identified, the easier it will be to determine the strict criteria for achieving these objectives, and the more strictly quantitative indicators of the minimum necessary environmental safety (adequate to a certain level of danger), optimal environmental safety (based on certain criteria of optimality), and reasonably achievable environmental safety will be determined. The term "reasonably achievable environmental safety" means the level of safety, exceeding which is not economically justified, because the society does not have the resources to further improve safety at a given socio-economic level of development and the attraction of additional resources will seriously slow down the socio-economic development.

In our opinion, one of the most successful formulations of the environmental safety objectives was presented in the Russian Federation Bill "About Environmental Safety". The Russian Federation State Duma (Russian Parliament) adopted the bill in 1996, and it was approved by the Federation Council (Russian Senate), but not signed by President of the Russian Federation B.N. Yeltsin [3]. The objective of environmental safety was very well defined in this bill: "The objective of environmental safety is to protect human life, health and living conditions, to protect society, its material and spiritual values, and the environment, including atmospheric air and outer space, water, subsurface, land and forest resources, soils, landscapes, flora and fauna from threats posed by the impact on the environment."

Over more than the next 30 years, the law was never adopted. However, on April 19, 2017, the Strategy of the Environmental Safety of the Russian Federation for the period up to 2025 was approved by the Decree of the President of the Russian Federation No. 176 [4]. This document does not clarify or develop the theory of environmental safety, but the state policy in this practical area of activity is defined as follows: "The objectives of state policy in the field of environmental safety are the preservation and restoration of the environment, ensuring the quality of the environment necessary for a favorable human life and sustainable development of the economy, eliminating the accumulated damage to the environment due to economic and other activities in the context of increasing economic activity and global climate change."

The immediately evident fact is that the preservation and restoration of the environment and ensuring the quality of the environment are in the first place and the protection of human life and health is generally absent in the definition. That means that objective-setting and the setting of priorities, originally defined in the bill of the Russian Federation "About Environmental Safety", have been fundamentally changed.

Nevertheless, we assume that the main objectives of environmental safety (as a science and practical activity) should be considered as the following: 1) protection of human life, health and living conditions and 2) protection, preservation and restoration of the environment. Albert Einstein noted: "The life of the individual has meaning only insofar as it aids in making the life of every living thing nobler and more beautiful. Life is sacred, that is to say, it is the supreme value, to which all other values are subordinate"[5]. Academician Valery Alekseevich Legasov has repeatedly emphasized that a person's life should be a measure of safety. Thus, from the view of teleology, we are able to identify the environmental safety objectives, as was done in the unapproved bill.

The next step should be to determine the criteria needed to evaluate the degree of objective achievement. These criteria depend on what scale of measurement we will use to determine the achievement of objectives. And this, in turn, will determine what should be the measure of environmental safety. First of all, it is necessary to determine what criteria this measure should satisfy. Of course, it must meet the following basic criteria: it must be clear, expressive, clearly understood by all specialists, and not abstract. The criteria should be based on available and reliable statistics, and not on the conclusions of experts (often very unreliable). It should be more objective and less influenced by the current socio-economic policy than most socio-economic indicators (Goodhart's law[6]).

4. Scales and Measures of Environmental Safety Measurement

If we identify that the most important environmental safety objective is the protection of human life, health and living conditions, then the measurement scale we will use to determine the achievement of these objectives should represent the measure of human life, closely related to his health and living conditions. Striving to prolong human life in a good state of health as long as possible would be quite logical, and based on this state, to define a measure of safety as the life expectancy in a state of good health. The longer the life expectancy in a state of good health for both an individual and a certain population (who are in certain conditions and in a certain territory), the higher the level of safety for this person and for this certain population.

For several decades, the United Nations (UN) has been widely using a socio-economic indicator that fully represents the state of safety from the point of view we have formulated. This indicator is "life expectancy"—the expectancy of life at a certain age. Life expectancy at birth is defined as "the cumulative measure of all deaths in a population that is little affected by any age and sex pyramid structure, fertility pattern, or migration history" in UN international organizations like the World Health Organization (WHO). It is one of the most effective indicators of the population's standard of living in terms of health. It characterizes apparently the most important objective of development—the most important value that determines the gist of development. Philosophers have argued that life is the measure of all things since ancient times. This is the *mensura vitae* (life is the measure) principle. Life expectancy is an integral indicator of the society and civilization development and has a clear dependence not only on the available health care quality and the level of medicine development, but also on living standards, the quality of services provided to the population, and the state of the environment.

But this or that estimate of safety will only make sense when we clearly determine what level of safety in given specific conditions can be considered to be "safe" and, in general, what level of safety will be necessary and sufficient and why. The safety level is not an absolute concept, but a relative one, and safety criteria should play a key role in its determination.

The safety criteria should clearly determine how close we are to the identified safety objective. Hence, it is clear that for each safety objective, there should be its own scale of measurement and its own units of measurement on this scale. There should also be criteria by which one can judge how close a given safety level is to the identified safety objective and the level of necessary and sufficient safety. Such an approach will require a complete remake of the entire existing safety methodology and a transition from qualitative to quantitative assessments.

Thus, having chosen life expectancy as a safety measurement scale, we ought to determine the criteria for the level of safety that can be considered "safe" in modern civilization conditions. The level of safety which will be necessary and sufficient should be considered with our core value system in mind (what we consider important and why).

Such criteria will inevitably depend on how highly we value human life and health and what costs society and the state are willing to bear in order to preserve and prolong human life and health. The attitude to these values is represented in the state development priorities, in the costs of giving birth and raising children, support for pregnant and lactating mothers, care for pensioners (the size of pensions, their indexation, retirement age), the cost of ensuring industrial and transport safety, state expenditures on obtaining primary, secondary, and higher education for its citizens, state expenditures on science development, and much more. One of the indicators of this approach is the ratio of gross national product (GNP) (with purchasing power parity (PPP) per person taken into account) to the value of life expectancy. This ratio reflects the share of the country's resources spent on maintaining the basic values of modern civilization and the effectiveness of the country's leadership in achieving objectives. The mortality rate of the population at different ages, from different reasons, in different territories, industries and conditions will represent the state of safety in a given place, at a given time. By comparing this mortality rate with the mortality in the conditions that society currently considers "normal," it will be possible to determine the necessary safety criteria. Data on life expectancy and age-specific mortality rates across various countries make it possible to determine which country is safer to be born in, which is safer to work in, and which is safer to grow old in.

If the environmental safety objective is identified as the preservation and restoration of the environment, then the measurement scale on which we are able to determine the achievement of these objectives should represent a measure closely related to the environment's state.

If the quality (state) of the environment is chosen as the safety objective, then the indicators that determine the quality (state) of the environment (such as the maximum permissible environmental load) can be used as safety measurement units. Thus, each safety objective has its own measurement scale, which determines the degree of the objective's achievement.

Based on a set of scales for safety objectives achievement, the methodology allows for the development of a speculative scale for the integral level of organization, territory, region or even the whole country's safety. Such an approach is based on weight coefficients that determine the value of each safety objective weight using expert judgment (preferably the Delphi method).

Weights are determined based on the importance of certain objectives. It is necessary to bear in mind that if the value of the estimate on the scale of a separate "type" of safety is based on the degree of progress towards a certain objective, it can be expressed both quantitatively and expertly (for example, estimates expressed in points), but the estimates of integral safety are always speculative. It means that the integral estimate shows that one value (for example, 80) is greater than another (for example, 40), but does not show how much (in particular, one cannot say that one is twice as large as the other).

Such estimates of the integral safety level make it possible to rank different safety objects by safety level in order to compare different types of safety and to determine the priorities for ensuring their safety. It is possible to develop a scale for determining both the different types of safety and the integral estimates of safety, in which only quantitative numbers will be used, and this scale will not be speculative. For example, if the main criterion of the effectiveness of safety measures is considered as the value of the prevented damage, then it is more methodologically correct to use damage to determine the main categories of the safety theory [7].

The quantitative characteristic of the safety degree of ecosystems at the current level of scientific knowledge includes, in particular, the degree of proximity of the ecosystem state to the border of its sustainability (to the bifurcation point), where the predictability of changes of the ecosystem in response to external influence is uncertain. In some countries, such an assessment of the ecosystem state has been used for several decades to determine the quantitative values of the maximum permissible environmental loads (MPEL). MPEL should guarantee the absence of instability and un-predictability in the environmental system state. In some countries the level of impact on the ecosystem (i.e., MPEL) should not exceed the level at which 5% of the species of the ecosystem may be affected [8].

5. Our Vision for Assessing the Environmental Safety State

In our opinion, the methodology of environmental safety assessment in terms of biodiversity that is currently widely used in international practice (for example, in the Netherlands and many other countries of the world) is incorrect, extremely inaccurate, and poorly applicable in practice due to its significant labor input and the impossibility of applying this methodology for computer modeling. In addition, biodiversity assessment cannot be monitored in real time. The use of integral indicators, mentioned by Odum and Barrett, may be much more promising [9].

From our point of view, the most promising indicators of environmental safety will be indicators of the photosynthetic organisms' (phototrophs) state [10,11]. Phototrophs are the most suitable integral indicators for the following reasons:

1. Phototrophs are practically the only source of energy for almost all other organisms on Earth, since only they are able to convert the energy of sunlight into electrochemical energy and accumulate it in high-energy products.
2. Phototrophs are the only source of oxygen for all living things, and their vital activity determines the composition of the modern atmosphere of the planet almost completely.
3. Phototrophs are practically the only food source on Earth for all other organisms and are the first to react to all changes in the environment
4. Phototrophs are the first link in the food chain and therefore the most sensitive: their change affects all other organisms.
5. Phototrophs have the highest light absorption coefficient (extinction) in the organic compounds world due to the unique physicochemical structure of chlorophyll (or bacteriochlorophyll) molecules. This property allows monitoring their condition using highly sensitive laser spectrometers (non-destructive testing methods) at a distance and without any damage: on native and intact organisms (*in vivo*).
6. Such control is easy to carry (for monitoring purposes too) out in automatic mode. It has a high efficiency of obtaining information because the time of spectrum registration on a modern spectrophotometer is only a few minutes.
7. The obtained spectral information is easily digitized (if it is not originally presented in digital format) and entered into the computer memory. It is a necessary condition for storing a large amount of information. The results of computer processing of spectral information from such studies can be easily stored on any computer storage media, which makes it possible to form spectral information databases.

In the process of assessing environmental safety based on the state of biota, the assessment of the photosynthetic organisms' state is decisive for assessing all life on Earth, since they are the first and most sensitive link in the food chain and the main source of biomass, energy and oxygen for all other organisms. The state of the entire ecosystem and its dynamic resistance to anthropogenic changes in the environment depend on the state of photosynthetic organisms, since they determine the nutritional conditions for all other links in the ecosystem. They also determine the composition of the atmospheric air, which in turn determines all the life conditions for all living things on our planet.

With the help of accurate phototroph state assessment, one can analyze the state of the entire ecosystem with a high degree of confidence. That's why the assessment of the photosynthetic organisms' state is so important for the development of the entire environmental safety system. Such a concept of phototrophs was created by the great Russian scientist Clement Arkadevich Timiriazeff (1843–1920), Foreign Member of the Royal Society (UK), whose views were much ahead of their time [12].

Currently, there are many methods that can be used to assess the phototroph state as the integral indicators of the state of the biota and the entire biosphere. They include the assessment of chlorophyll fluorescence as an indicator of photosynthesis efficiency; lichen indication (a method of bioindication of air pollution using lichens); bryoindication (a method of bioindication of ground cover chemical contamination using mosses); bioindication based on the assessment of the electric potential of the leaves of trees and shrubs; bioindication based on radial growth of trees monitoring; the Kirlian method of bioindication (based on the pattern that "any living object placed in a field of high-frequency current gave a glow on the camera roll, the nature of which depended on the state of the object being photographed" according to the author) and many other methods of bioindication. Particular emphasis should be placed on the Kirlian bioindication method.

6. Environmental Safety State Assessment Using the Kirlian Method

The phenomenon of luminescence (glow) of objects exposed to a high-voltage, high-frequency electromagnetic field was studied by S.D. Kirlian and V.K. Kirlian [13]. The glow was characterized by a color palette: its shape, chromatic composition, and dynamic evolution were found to reflect the state of the test object, with distinct color properties observed for living and non-living objects. Furthermore, for living objects, the glow characteristics were shown to correlate with their "health" state. Kirlian proposed a method and developed a corresponding device, which allowed studying this phenomenon [14]. The device was subsequently modified on multiple occasions. The method was later designated as gas discharge visualization (GDV) bioelectrography [15]. Following publications by American scientists, the method became known as Kirlianography [16]. Originating in Russia, Kirlianography has gained widespread international adoption in over 60 countries, including the USA, Canada, Mexico, Brazil, Argentina, Portugal, Spain, Germany, the UK, Denmark, France, Finland, Japan, New Zealand, Bulgaria, Romania, Poland, the Czech Republic, Kazakhstan, Lithuania, Estonia, Belarus and Ukraine [17,18]. A particularly large number of articles have been published by scientists from India [19–23] and China [24].

Given that S.D. Kirlian had demonstrated the dependence of luminescence on the psychophysiological state of human subjects. The medical community was the first to express interest in the application of this method, notably including Peter Mandel [25]. Mandel's outstanding contribution lies in the fact that he was the first to discover the connection between Kirlian images and Voll's electroacupuncture method, and subsequently developed the connection into a scientific methodology, which he subsequently verified and proved in practice.

The diagnostic methodology developed by P. Mandel, based on the analysis of various forms of Kirlian radiation coronas, followed by sectoral study of the corona (visually resembling an aura), is now used worldwide [18,26–29]. Currently available hardware systems perform mathematical processing of the acquired images, enabling both express diagnostics and long-term monitoring of the individual's overall psychosomatic state, as well as the energy state of their internal organs. He also proposed a diagnostic chart based on the glow emitted by the fingers and toes.

Mandel also developed a special device for recording the glow onto photographic paper, which was manufactured until 2005. In subsequent years, he expanded his system and supplemented it with the concept of circular energy flows within the body. He hypothesized that the parameters of finger glow are related to the current state of the acupuncture channel, the starting or ending points of which are located on this finger. Mandel compiled his reference tables based on acupuncture meridians. In 1996, the International Institute of Esogetic Medicine was established in Switzerland [30].

Currently, research institutes and clinics operating under his guidance are active in Germany, Switzerland, Austria, and the Netherlands, where further bioenergetic research on humans is being conducted, and methods of energetic correction and therapy are being developed and clinically tested [31].

The gas discharge visualization method currently in use has a number of significant drawbacks that seriously complicate its application for assessing environmental safety state:

- Insufficient systematic clinical research with statistical data collection across various physiological conditions, types of pathologies, vital dysfunctions, etc.;
- Limited theoretical substantiation of the interaction between gas discharge and biological objects;
- Difficulties in reproducing published data due to the lack of standardized methodological protocols and reference technical equipment [31,32];
- Absence of a basis for statistical data comparison owing to the complexity of quantitative image processing;
- Lack of standardization of research methods;
- Method inconvenience for everyday use due to reliance on image processing and darkened rooms.

Moreover, studies examining the spectral characteristics of the luminescence across different states of the object remain practically nonexistent.

However, the rapid advancements in modern science inspire confidence that the synergistic integration of spectral analysis, advanced image processing, and artificial intelligence will make it possible to develop a universal approach to environmental safety assessment—the one that operates at an entirely new level [33,34].

7. Conclusions

The problem of environmental safety assessment, the one that would provide precise information on both the human safety state and the environmental state, will remain relevant for a long time. Current approaches to such assessment do not fully satisfy the scientific community. Nevertheless, the capabilities of modern science inspire confidence that we will gradually approach a solution to this problem, to one degree or another. In any case, any attempts to move closer to solving the problem should be supported and further developed. This article represents our small contribution to this endeavor.

It is important to remember that no expert is omniscient, no organization is omnipotent, and no judgment is final.

Author Contributions

Both authors contributed equally to the conception, design, data collection, analysis, and writing of this study. Both authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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