The use of the Monte Carlo method for predicting environmental risk in construction zones

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Abstract. The article analyzes the problem of determining environmental risk. The author took into account the features of natural landscapes when choosing a model of environmental risk in order to predict the level of interaction of the construction project with the environment. The matrix of construction zones distributions and the risk of environmental vulnerability are compiled on the bases of the study of the anthropogenic impact parameters on natural landscapes. Monte Carlo simulation method allows predicting the process of techno genesis relative to the natural environment within the limits of confidence interval. The industrial territories of the Far North and the regions equated to them are characterized by the highest probability and level of risk, as well as vulnerability. The impact of techno genesis on all four components of the environment (atmospheric air, hydrosphere, lithosphere and biosphere) in all areas of construction work normalization will continue to increase. This is indicated by trend graphs of the predicted values of anthropogenic impact within the industrial and residential zones. The quantitative characteristic of possible ecosystem “failures” as a result of anthropogenic interference is analyzed using a point scale. The worst-case scenario can be defined as post-catastrophic (ultra-high risk, emergency measures in emergency situations, score 26-30). The reliability of the simulated forecast is confirmed by the anthropogenic accident in Norilsk in June 2020, the largest and most unprecedented in the history of the Arctic.

1. Introduction
The study of environmental risk and its prevention is an extremely important task. According to the guiding technical standards both Russian and foreign - GOST R 51901.1-2002 (Risk management. Risk analysis of technological systems); “Methodological foundations for hazard analysis and risk assessment of accidents at hazardous production facilities” (2016), ASTM E2590-2015 (Standard guide for conducting hazard analysis-critical control point (HACCP) Evaluations), SAE/TP 2008-01-2228-2008 (The art of conducting a safety risk analysis on in-service problems) – in risk assessment, it is necessary to highlight the frequency and consequences of a particular hazard. The risk study procedure is understood as a probabilistic risk analysis. In the Law “On Environmental Protection” N 7-FZ (as amended on December 27, 2019), environmental risk is nothing but the likelihood of an adverse event with consequences negatively affecting the natural environment, and the event itself has both a natural and a man-made character in the form of an emergency, accident, etc. According to GOST R 58771-2019 (Risk management. Risk assessment technologies), risk is understood as the consequences of some uncertainty aimed at ensuring that well-grounding decisions and actions are taken (2019). Indeed, uncertainty in the broad sense can encompass both the typification of its
manifestations and the absence of any knowledge about it, unpredictability as such, which can make any human knowledge powerless and which is perceived by the mind as something threatening its well-being [1-6]. That is why the technology of risk assessment is so relevant in order to ensure its acceptable level in the construction industry [7]. GOST R 51898-2002 (Safety aspects. Guidelines for their inclusion in standards) requires risk to be considered acceptable when it comes to an optimal balance of safety and requirements and, as a means of achieving it, follow an iterative process of assessing and reducing expected damage [8].

Assessing the process of construction facilities erection, factors (internal and external, objective and subjective) of environmental risk can be reduced to three large groups: natural, man-made and social [9]. Further, the risks can be structured as follows: natural-ecological, technical-ecological, risks of sustained man-made and catastrophic impacts, social-ecological, environmental-normative, ecological-political, ecological-economic [10]. The author’s task is to analyze the concept of environmental risk in the framework of the ecological balance of the “erection-human-being-natural environment” system and consider the problem of determining environmental risk fields (ERF).

2. Materials and Methods
The analysis of the concept of “environmental risk” is based on the identification of system processes. To create a conceptual model, a functional approach is applied that provides the basis for the synthesis of system components. This approach makes it possible to model each nodal component of the “erection-human-being-natural environment” system and integrate them into a single complex according to the structure of the conceptual model [11-12]. The author uses Monte Carlo simulation, which generates random processes with specified parameters. Randomly selected changes are generated by repeated analysis of the input data: the uncertainty of some indicators and the variability of others. The Monte Carlo method allows you to analyze the distribution of the desired value under conditions of an almost unlimited number of factors that can affect the risk assessment of a particular scenario of the project, as well as through an unlimited number of possible scenarios. When constructing a mathematical model, parameters (deterministic values) and variables (random numbers) are chosen. After each new simulation, during which the values of the variables are selected by the method of generating random numbers from certain probability ranges, the original mathematical model is recalculated. You can create and analyze thousands of alternative scenarios and quantify the level of risk for each particular scenario. Simulation results are used for subsequent study of the probability distribution over the uncertain variables of the model and the calculation of optimal risk indicators. Subsequent sensitivity analysis through rank correlation of relationships between distributions and forecast indicates key factors responsible for changing the results. The sensitivity graph displays these relationships as correlation coefficients or as percentage values. The above listed assumptions have the greatest impact on the resulting indicator, while the direction of the bar indicates a direct or inverse relationship [13]. Thus, iterative stochastic modeling based on given characteristics and sensitivity analysis help to focus on the most important factors of the model and take them into account when determining the probability of damage or benefit [14-15].

If the totality of methods allows, by assessing the risk, identifying hazards, making recommendations for managing and reducing the threat to the consequences of extreme processes and phenomena dangerous to human life and the ecosystem as a whole, then it can be used as a risk analysis toolkit [16].

3. Results
Typically, the multidimensional nature of the impact on environmental components should be considered for construction. At the same time, the same factor can have both a negative (increasing risk) and a positive (reducing risk) impact on the ecosystem. So, toughening environmental requirements may increase the risk of construction due to the expense of funds for the purchase of scientific and technological innovations that reduce production costs, but changing the regional environmental situation can significantly reduce the risks of competition from competitors who could
not cope with the development of new technology. It is important that the risk associated with possible
damage due to the probability of the occurrence of a risky event remains within the normalized
acceptable value. Otherwise, in the presence of long-term negative impacts on the natural
environment, permissible norms (direct and indirect actions) may be violated, which will lead to
significant imbalances that cause degradation of the ecological balance in the direction of uncertain
states. Say, the impact of the elemental forces of nature and the climate on the production process of
the region can lead to an unpredictable risk.

Riskology helps to make a decision, taking into account the uncertainty, to choose the best option
for the implementation of the construction project. A number of researchers believe that “risk” is the
probability of an event and its negative consequences. It requires evaluation and is associated with the
expectations and decisions of the subject and exists in the proper sense only in relation to human
activity. We may say that risk is a necessary element of any project and reflects the decisions of
project participants at different time intervals in order to avoid the risk of degradation processes in the
future. Although the forecast always remains insufficient, it certainly determines construction activity
as a key anthropogenic factor. Moreover, risk-free activity is more likely a fiction than a reality. It
should be added that risk is the probability of loss. In another case, it is the value of possible losses.
The risk is the correspondence between probability and dimension of loss. The risk can be considered
as a variation in the distribution of possible negative consequences relative to a certain set base value;
thought through linear relationship between variation and expected value (mathematical expectation)
of the dispersion of all possible outcomes. The risk is determined by the following factors: a risk
event, the probability of its occurrence and the size of the possible damage [17].

It is important to note that the risk is mainly compared with the danger that can harm not only the
economic activities of people, but also the environment. Due to both natural and man-made factors,
the risk depends on the complexity of the situation. In one case, it is identified with minor
consequences and requires decisions in accordance with established rules and procedures. In another
case, in conditions of high uncertainty and little experience, risk becomes the subject of the search for
non-traditional technologies for its assessment. In this regard, its anthropocentric character, i.e. the
study of risk outcomes makes sense only within the framework of a single nature-human-being
system. There is nothing surprising here: in its quantitative measure, the risk is defined as the product
of the studied hazard factor and the size of the damage caused to human activities or the environment
from the point of view of their safety [18].

Various kinds of risks cause both material and human losses. As for the concept of “environmental
risk”, its anthropocentric characterization is obvious: risk is interpreted as the probable value of losses
due to negative technological impact on the environment, as the probability of initiating such
anthropogenic changes (intentional or accidental; gradual or catastrophic) in nature and society at
which the structure and functioning of the natural-technical systems themselves as a major factor in
ensuring environmental safety is changing. On the other hand, we must not forget that the likelihood
of accidents and other risk events are associated with special environmental conditions (biological,
hydrological, geological, climatic, seismic, etc.) that “program” the unpredictable negative
consequences: natural, natural-technological, man-made disasters. At its core, environmental risk is a
natural and man-made phenomenon [19].

Risk assessment is a multi-element process produced by external exposure under certain
circumstances that caused an adverse effect on the human body and ecosystem. Risk is often
characterized by a reference to potential events and consequences, or a combination thereof, often
expressed as a combination of the consequences of an event (including a change in circumstances) and
the associated probability of occurrence. We can say that in general, risk analytics is quite well
developed. However, it remains a matter of contention because goals and risk management are
determined by uncertainty [20].

The impact of uncertainty on risk is recognized in almost all international standards. So, the
International Organization for Standardization (ISO) defines risk as the impact of uncertainty on goals;
as a positive or negative deviation from what is expected at different levels and in various aspects of
human activity. In ISO 31000: 2009 (Risk Management: Principles and Guidelines), “uncertainty” is understood as a situation characterized by a lack of information related to understanding of an event, its consequences or probability. For example, when identifying sources of risk, events, their causes and possible consequences, many questions arise, since the source of risk can be tangible or intangible, the risk event itself may not happen, sometimes it can consist of several events, sometimes its development may result in “incident” or “accident”. The same applies to the consequences of a risk event. These consequences can be definite or uncertain, have a positive or negative impact on the goals, expressed qualitatively or quantitatively. In addition, the initial consequences may be intensified by effects that cause influence. All this, on the one hand, complicates the study of the likelihood of risk, on the other hand, allows you to search and use new approaches to determining (objectively or subjectively, qualitatively or quantitatively) what is interpreted as a risk event. In such standards as IEC / FDIS 31010 (Risk Management - Risk Assessment Techniques), ISO / IEC 31010: 2009 (Risk Management - Risk Assessment Techniques), ERM / COSO (Enterprise Risk Management - Integrated Framework), as well as the rules of the US EPA (Hazardous Waste Identification Rule Frameworks), US EPA (Total Risk Integrated Methodology System), EOSCA (Chemical Hazard Assessment and Risk Management), and many others, the risk is understood from the attitude to uncertainty (“measure of uncertainty”, “some impact under conditions of uncertainty”, “credibility of damage”, “the uncertainty of the implementation of a certain negative event”, etc.), which indicates the strive of specialists to understand the problem of the probabilistic distribution of damage and thereby exclude additional losses or shortfalls in the planned revenues due to the need to provide adequate environmental protection.

Thus, the uncertainty that cannot be estimated cannot be eliminated, but it is exactly the source of not only predictable damage, but additional income in a risky situation. According to many scientists, an assessment of the extent of potential hazardous effects on the environment and human health should be based on an understanding of risk in connection with an analysis of the uncertainty of expected events, most often leading any damage [21-22]. To assess any risk in comparison with some acceptable one is possible only if the regulated boundaries of anthropogenic changes are taken into account. In this case, maintaining the equilibrium state of the ecosystem subjected to the harmful impacts is the goal of risk assessment. From the point of view of environmental safety, the Monte Carlo (MC) method seems to be the most important and effective for an adequate quantitative assessment of uncertainty.

The concept of climatic comfort of territories is important for assessment of environmental risk in construction, since the issue of extremeness or comfort of the environment is a key one with respect to ensuring environmental safety of industrial, civil and other construction projects for the life of population, taking into account the determining role of the natural environment. Since the construction territories vary significantly in a number of parameters, it becomes necessary, among other things, to first of all evaluate the economic feasibility of costs in order to minimize them. On the one hand, climatic conditions determine the activities of the population and the level of resource potential involved in construction, on the other hand, the economic component of a given territory determines the standard of living of people, the departmental structure of the economy with employment of people, their income and expenses and wage differentiation and etc. It is worth emphasizing that at present, we are talking about the priority of the economic vector of development over the natural resource potential of territories. Their comfort or extremeness is determined mainly due to the cultural, innovative, intellectual level, multifaceted needs for the comprehensive development of the individual, advanced forms of social differentiation of the population, etc. Hence, the degree of quality and comfort of the human environment is an important factor in making the decision to start construction. In regions that are extreme for living, the environmental risk will be insignificant, since in such areas the opportunities for adaptation of immigrants will be lower and the environmental resistance to anthropogenic impact will not be exhausted. On the contrary, in comfortable living areas of the population, construction costs will be initially higher and environmental risk will be higher due to high mandatory sanitary and environmental measures. In comfortable places, methods of artificial
The degree of pollution risk by harmful substances depends on the vulnerability of the environment (the more vulnerable the ecosystem, the higher the risk of negative impact) [24]. Risk value is a function related to the severity of the risk ($r$) and the vulnerability ($v$) of the recipient. This dependence is reflected in the following matrix, for which the probability of a dangerous event has the following form (Table 1):

$$P = \{p_1, p_2, p_3, p_4, p_5\},$$

(1)

where $p_1$ is practically excluded; $p_2$ – unlikely; $p_3$ – probably; $p_4$ – possibly; $p_5$ – inevitably; risk values have the following form:

$$R = \{r_1, r_2, r_3, r_4, r_5\},$$

(2)

where $r_1$ is an acceptable insignificant risk (we are talking about a high level of stability, score: 1-3); $r_2$ – acceptable low risk (no measures are required, but the situation must be controlled so that the risk is manageable, score: 7-9); $r_3$ – acceptable average risk (measures to reduce risk are required, more accurate calculations of the probability of a dangerous event are relevant, score: 4-6); $r_4$ – high risk (the risk has serious consequences, urgent intervention in industrial development is necessary to ensure safety measures, score: 10-16); $r_5$ – catastrophic (the risk is too high, it must be reduced by eliminating the sources of hazards or by controlling the ratio of the number of hazards and risk objects, score: 17–25).

**Table 1. Environmental Distribution Matrix.**

|   | $r_3$ | $r_4$ | $r_5$ | $r_5$ | $r_5$ |
|---|---|---|---|---|---|
| $p_5$ |   |   |   |   |   |
| $p_4$ | $r_2$ | $r_3$ | $r_4$ | $r_4$ | $r_5$ |
| $p_3$ | $r_1$ | $r_2$ | $r_3$ | $r_4$ | $r_4$ |
| $p_2$ | $r_1$ | $r_1$ | $r_2$ | $r_3$ | $r_4$ |
| $p_1$ | $r_1$ | $r_1$ | $r_1$ | $r_2$ | $r_3$ |

Distribution of environmental risk by zones can be described as a sequence of levels of environmental risk between regions and domains of each region. Based on the mathematical expression of regional environmental risk, the degree of risk caused by environmental pollution depends on the following factors: (1) ERF intensity; (2) environmental vulnerability in the disaster area. Sudden environmental pollution incidents have become more frequent. Risk increases when the ecological environment becomes more vulnerable. The combined effect of these two aspects (hazard index and vulnerability) determines the level and priority of environmental pollution risk among numerous hazards, which allows zoning of environmental risk.

The risk intensity can be calculated for each part of the ERF by adding together the product of the probabilities of different pollutants (the number of cases of pollution is calculated) and the specific
risk intensities for a given type of pollution (specific risk intensity is defined as the ratio of the measured concentration to a known standard concentration). The risk intensity, or risk quotient, is calculated using the formula:

\[ RQ = \frac{PEC}{BMC} \]  

where \( PEC \) – predicted environmental concentration), \( BMC \) – benchmark or maximum permissible concentration).

\( RQ \) is an environmental hazard index of environmental pollutants and can be considered a level of the severity of the risk. The higher is the \( RQ \) value, the higher is the likelihood of environmental risk. When \( RQ > 1 \), adverse environmental effects can be expected.

The risk concept always contains two aspects: the frequency of a dangerous event and its consequences. Therefore we determine the risk by the formula:

\[ R = P \times C \]  

where \( P \) is the probability of the event, and \( C \) is the degree of danger of the consequences.

Considering the uncertainty of \( C \) in regional environmental risk, we find \( C \) as the product of \( RQ \) – hazard index and \( V \) – vulnerability of risk receptors:

\[ R = P(RQ \times V) \]  

Knowing the value of the hazard index and the vulnerability value of the risk object (integer arbitrary units from 0 to 10 are used), by multiplying them, you can also calculate the level of adverse situation. The product of the degree of adverseness and the probability of an adverse event (accident) allows you to quantify the risk. Risk (\( R \)) can be quantified by the formula:

\[ R = P(C > C_{\text{standard}}) = \int_{C_{\text{standard}}}^{\infty} f_C(C) dC \]  

where \( C \) is the pollutant concentration, \( C_{\text{standard}} \) is the standard, regulatory concentration of pollutant. The ecological state of objects is classified according to the results obtained (Table 2).

**Table 2.** Criteria of the ecological state of natural objects.

| Ecological state  | Index | Criteria for evaluation  |
|-------------------|-------|--------------------------|
| Satisfactory      | 1     | \( C < \text{BMC} \)     |
| Tense             | 2     | \( 1 \text{BMC} < C < 10 \text{BMC} \) |
| Critical          | 3     | \( 10 \text{BMC} < C < 30 \text{BMC} \) |
| Crisis            | 4     | \( 30 \text{BMC} < C < 50 \text{BMC} \) |
| Catastrophic      | 5     | \( C > 50 \text{BMC} \)   |

According to scientists, in particular, A.L. Bolsherotov, the degree of the construction site’s influence on the ecosystem depends on its place of location. In this regard, it is necessary to take into account the state of the environmental background at the construction site of the facility, the value of the environmental reserve and environmental safety threshold. It makes sense to give a table of calculation of the environmental safety of the construction site for natural and artificial ecosystems (Table 3) [25].

The table shows that the environmental costs in their structure for different types of ecosystems will be fundamentally different. Thus, the value of the biotope as a “living substance” is of key importance for the natural ecosystem, while for artificial ecosystems only humans have a value that ensures the equilibrium state of the environment within the framework of regulated environmental tolerance. It should be noted that the main purpose of environmental risk assessment is the identification of hazards, analysis of the intensity of occurrence of risk situations, calculation of possible damage. Therefore, the table under consideration could be supplemented with the following important data on the development of the natural environment: the duration of periods with different air temperatures; astronomical duration of day and night; climate features (continental, etc.); wind
speed; moisture content of the territory (vegetation index); state of atmospheric pressure; number of days of heating; soil and water self-cleaning potential; the nature of the biota; parameters of seismicity, permafrost; the likelihood of floods, mudflows, avalanches, conditions for the manifestation of diseases; identification of pathology in different population groups; factors that hinder or contribute to the recovery of people; the impact of climate discomfort on public health in correlation with mortality and morbidity, etc. According to V.G. Loginov et al., to identify the comfort of the region, zonal (we are talking about the climate severity index – the Bodman index; average annual air temperature; average temperature of the coldest month, etc.) and azonal (about the swaminess of the territory; air humidity, etc.) factors should be considered [26].

Table 3. Characterization of environmental construction safety data for different ecosystems.

| Data type          | Unit, data, necessary for calculations | Ecosystem type |
|--------------------|---------------------------------------|----------------|
|                    |                                       | Natural        |
| Ecosystem          | Configuration                         | Yes            |
|                    | Area, km²                             | Yes            |
|                    | Geographical position                 | Yes            |
|                    | Surrounding ecosystems                | Yes            |
| Biotope            | Configuration                         | Yes            |
|                    | Area, km²                             | Yes            |
|                    | Geographical position                 | Yes            |
|                    | Surrounding biotopes                  | Yes            |
| Biocenosis         | The main types of living animals,     | Yes            |
|                    | birds                                 | Yes            |
| Location of the construction facility | Location in the ecosystem             | No             |
| Polluting factors  | Atmosphere                            | Yes            |
|                    | Hydrosphere                           | Yes            |
|                    | Lithosphere                           | Yes            |
|                    | Valiosphere                           | No             |
|                    | Noise                                 | Yes            |
|                    | Heat                                  | Yes            |
|                    | Light                                 | Yes            |
|                    | Video pollution                       | Yes            |
| Affecting factors  | The quality of life                   | No             |
|                    | Somatic health                        | Yes            |
|                    | Psychosomatic health                  | No             |
|                    | Biotope                               | No             |
|                    | Biocenosis                            | Yes            |

Further, in order to obtain an integral indicator for the classification of various territories according to the comfort of living of the population, a five-point rating scale is used. The following areas are emphasized: 1) favorable (e.g., Krasnodar, Stavropol area); 2) relatively comfortable (Western and Central Russia, Volga region); 3) unfavorable (North of the European part of the country, south of Western and Eastern Siberia, Khabarovsk Territory, as well as Primorsky area); 4) uncomfortable
(e.g., Krasnoyarsk Territory, Komi Republic) and 5) extreme, i.e. extremely unfavorable (17 northern territories, regions and republics, as well as 6 autonomous districts, for example, Chukotka) [26].

Obviously, the bulk of the country’s territory in the permafrost zone (79.5%), without any doubt, can be described as uncomfortable for living. Let’s recall that 65% of the country’s territory is areas of the Far North and equated with them. 60% of the land lies north of the 60th parallel, with 20% of them located beyond the Arctic Circle. 53% of the planetary zone of the North and 80% of its population belongs to Russia. As already noted, the construction industry in the North needs large investments to create a socio-economic infrastructure, so the cost of creating the appropriate construction projects will significantly exceed (10-12 times) the costs in regions that are comfortable for living.

Due to the fact that in uncomfortable and extreme areas there are no normal living conditions, specialized life support systems and a high level of health care, the creation of an artificial environment and ensuring a high standard of living will be associated with increased environmental risk, although, at first glance, the environmental risk of construction is these territories should be several orders of magnitude lower. However, it is not like this. In disadvantaged areas (with an assessment of 3 points on a five-point scale), construction costs will be 15-20% higher, in uncomfortable (4 points) already 100-120%, and in extreme (5 points) – 120-250%. Here, the environmental damage from construction is high due to the fact that a number of environmental factors would have critical values for health and life. In addition, the artificial environment must be reliably isolated from the natural, which is likely to require significant financial subsidies and budgetary injections. It should be remembered that here the concentration of construction projects is one of the main reasons for the negative impact on the environment, giving to this risk assessment model additional aspects of distribution (Figure 1).

Figure 1. Integral indicator for the classification of various territories by the comfort of living (source: E.B. Lopatina & O.R. Nazarevskiy. Otsenka prirodnykh usloviy zhizni naseleniya. Moskva: Nauka, 1972).

Nevertheless, the assessment of environmental risk is problematic, since in its calculation it is based on an assessment of the predominantly economic equivalent of damage. So, according to the “Methodological fundamentals for conducting hazard analysis and risk assessment of accidents at hazardous production facilities” (2016), environmental damage is estimated by the sum of losses from each type of environmental pollution according to the formula:

\[ C = EC_A + EC_G + EC_L + EC_B + EC_W, \]

where \( EC_A \) is the compensation for damage from air pollution; \( EC_G \) – for damage from pollution of water bodies (hydroosphere); \( EC_L \) – for damage from soil pollution (lithosphere); \( EC_B \) – for damage from biosphere pollution; \( EC_W \) – for damage caused to the territory by construction waste.
4. Discussion

An analysis of “pure” environmental risk suggests slightly different grounds. From the author’s point of view, it is the classification of different territories according to the comfort of living of the population that could simultaneously serve as a matrix for identifying ERF. Distribution of groups of territories by zones correlated with risks of various types is in full agreement with the definition of natural risk as a result of the combined impact of techno genesis on the ecosystem. It also meets current trends in developing resource-saving technologies and “green” construction technologies to create an environmentally friendly “circuit”.

We emphasize once again that when choosing a model of environmental risk in order to predict the level of interaction of a construction project with the environment, one cannot ignore the features of natural landscapes. Not all technical standards take into account the zonal principle for standardizing requirements in which the criteria for anthropogenic impact on the ecosystem would be clearly formulated as part of a “green” development strategy [27]. The presence of such a quantitatively determined classification of indicators of anthropogenic impact on natural landscapes would help to establish the main restrictions on construction conditions in natural places, especially vulnerable to techno genesis. In order to identify environmental groups for a specific area of construction and industrial development in general, with a certain level of anthropogenic impact, we will try to formulate criteria for estimation of the natural topography on the basis of scores.

Analysis of the degree of anthropogenic impact on the ecosystem implies the following types of zoning:

1) the landscape is predominantly artificial, containing in its subsoil natural minerals and being under the constant influence of techno genesis \( (L_1) \), it must be provided with reliable constructions and structures with increased requirements for their use, the restoration of anthropogenic reliefs, disturbed lands and the restoration of full biocenoses;

2) the landscape is partially artificial (including the lands of the forest and water resources), which serves to obtain agricultural and other products \( (L_2) \), must meet the criteria for rational, technologically and economically competent use, a development strategy with mandatory environmental restoration of disturbed development zones;

3) the landscape is completely natural and at the same time unsuitable or completely unsuitable for farming or creating a recreation zone that does not contain minerals \( (L_3) \) should be considered as optimal for industrial and civil development, only if the level of influence of anthropogenic factors, say, new explosive plants, to the ecosystem corresponds to the adaptive capabilities of a particular natural complex, and the higher are the reserves of natural restoration and the more effective the methods of artificially preserving of the natural environment, the faster the already modified and partially artificial ecosystem will reach its initial equilibrium state;

4) the landscape is partially natural with a high recreational potential \( (L_4) \), the safety of which should be provided with engineering means, biological reclamation, maintaining plant communities, a reduced load on the soil-plant complex, regular maintenance of garden and park plantings;

5) the landscape is completely natural, undisturbed and not included in the scope of any anthropogenic impact and development \( (L_5) \), should be preserved as a specially protected natural area with significant coverage in order to maintain ecological balance and stability of climatic conditions in the region and the country as a whole [28-29].

These types of landscape restrictions for construction suggest the following gradation in the use of territories (it should “remove” the purely economic territorial division of the country into 12 zones, highlighting the “horizontal” division into 3 zones, based on the principles of reduced environmental risk (although danger and damage, as considered by Aronson et al. [30] are meant in any relation to the natural environment, potentially present to an undetermined degree): areas of the Far North and equated with them \( (R_1) \); the central and southern regions of the European part of the country, the south
of Western and Eastern Siberia, the Khabarovsk Region, as well as the Primorsky Region ($R_2$); mountainous areas ($R_3$).

At first glance, the ecological matrix of the correspondence of construction zones to various natural landscapes should take the following form, where $p$ is the probability of risk, $r$ is the degree of risk, $v$ is the vulnerability of the ecosystem (Table 4):

**Table 4.** Matrix of the distribution of construction zones and the risk of environmental vulnerability.

| Region Index | Environmental group index for natural landscapes |
|--------------|-------------------------------------------------|
|              | L1      | L2      | L3      | L4      | L5      |
| $p_1 R_1$    | $R_1 L_1$ | $R_1 L_2$ | $R_1 L_3$ | $R_1 L_4$ | $R_1 L_5$ |
| $p_2 R_2$    | $R_2 L_1$ | $R_2 L_2$ | $R_2 L_3$ | $R_2 L_4$ | $R_2 L_5$ |
| $p_3 R_3$    | $R_3 L_1$ | $R_3 L_2$ | $R_3 L_3$ | $R_3 L_4$ | $R_3 L_5$ |
| $v_1$        | $v_2$   | $v_3$   | $v_4$   | $v_5$   |          |

At the first approximation, it seems that the undisturbed zones ($L_s$) of all 3 regions ($R_1, R_2, R_3$) are highly vulnerable to techno genesis and are characterized by a high risk of violating the permissible level of anthropogenic impact and transforming them into anthropogenic disturbed territories with subsequent degradation of landscape stability. The highest probability and degree of risk, as well as vulnerability, are those of the Far North and the regions equated to them.

The dynamics of changes in the area of the land fund of the Russian Federation was discussed for further development of the distribution matrix of construction zones and its indicators. Industrial lands, occupying only 1% of the country's territory, cause an increase in the area of anthropogenically transformed ecosystems (up to 45%) and a significant reduction in the area of natural ecosystems (55%). This important circumstance should be connected with understanding and forecast of anthropogenic changes in natural landscapes. Although the zoning map (Figure 1) reflects the real distribution of the probability of environmental pollution risk during construction, nevertheless, linking the matrix regions $R_1, R_2, R_3$ to Rosreestr data allows you to find out the land area, specify the structure of zones within the regions under consideration, and understand what are the factors of anthropogenic impact, establish their nomenclature and degree of impact (Table 5).

**Table 5.** Changes in the area of the land fund of the Russian Federation (source: Rosreestr data).

| Land category                              | Land area by years, million ha /% 2010 | 2018 |
|--------------------------------------------|---------------------------------------|------|
| Agricultural land                          | 393.4                                 | 382.5 | 22.4% |
| Land settlements                           | 19.6                                  | 20.5  | 1.2%  |
| Land of industry, transport, communication, radio broadcasting, television, computer science, space support, power economy, defense and other special purposes | 16.8                                  | 17.5  | 1.0%  |
| Lands of specially protected areas and objects | 34.9                                  | 49.6  | 2.9%  |
| Forest land                                | 1115.8                                | 1125.8 | 65.7% |
| Land of the water resource                 | 28                                    | 28.1  | 1.6%  |
| Land stock                                 | 101.3                                 | 88.5  | 5.2%  |
| Total land                                 | 1709.8                                | 1712.5 | 100%  |

Next, the significance of anthropogenic impacts on the natural components $A$ (atmospheric air), $G$ (hydrosphere), $L$ (lithosphere) and $B$ (biosphere) was determined relative to each of the categories of lands, and, accordingly, landscape zones $L_1$, $L_2$, $L_3$, $L_4$, $L_5$. For this purpose, the level of anthropogenic...
impact was specified as a characteristic of an artificial or natural object. The results of a study of the effect of techno genesis on the properties of the natural environment are presented in Table 6 [31]:

**Table 6. Anthropogenic impact on the components of the environment.**

| Kind and character anthropogenic impact of artificial object | Character of impact | Environmental vulnerability rate | Totally |
|-----------------------------------------------------------|---------------------|----------------------------------|---------|
|                                                           |                     | A      | G     | L     | B     |
| Mechanical                                               | short-term          | 0.23   | 0.15  | 0.28  | 0.05  | 0.71  |
| $L_1$ Objects of industry, transport, communication,     | long-term           | 0.34   | 0.2   | 0.34  | 0.18  | 1.06  |
| radio broadcasting, television, computer science, space  | short-term          | 0.18   | 0.25  | 0.14  | 0.08  | 0.65  |
| support, defense and other special purposes on            | long-term           | 0.37   | 0.4   | 0.21  | 0.22  | 1.2   |
| industrial lands                                         | short-term          | 0.12   | 0.05  | 0.28  | 0.31  | 0.76  |
| Electromagnetic                                          | long-term           | 0.12   | 0.2   | 0.26  | 0.23  | 0.81  |
| **Totally**                                              |                     | 10.65  | 1.75  | 2.07  | 1.73  | 16.2  |
| Mechanical                                               | short-term          | 0.15   | 0.1   | 0.21  | 0.03  | 0.49  |
| $L_2$ Housing and civil facilities on unsuitable (        | long-term           | 0.21   | 0.15  | 0.27  | 0.09  | 0.72  |
| residential) lands                                       | short-term          | 0.07   | 0.11  | 0.1   | 0.04  | 0.32  |
| Thermal                                                  | long-term           | 0.14   | 0.2   | 0.17  | 0.12  | 0.63  |
| Biochemical                                              | short-term          | 0.08   | 0.04  | 0.21  | 0.23  | 0.56  |
| Electromagnetic                                          | long-term           | 0.12   | 0.16  | 0.25  | 0.31  | 0.84  |
| **Totally**                                              |                     | 0.92   | 0.86  | 1.5   | 1.03  | 4.31  |
| Mechanical                                               | short-term          | 0.41   | 0.33  | 0.9   | 0.6   | 2.24  |

An assessment of the level of impact of techno genesis allows us to make an important conclusion: the initial matrix of the distribution of construction zones and the risk of vulnerability of the environment (Table 4) needs significant correction. According to Table 6, the largest integral coefficient of environmental vulnerability is inherent in the elements of the environment in industrial landscapes of all three zones $R_1, R_2, R_3$ (the total value is 16.2). In residential landscapes, the coefficient of vulnerability is lower by several orders of magnitude and in agricultural landscapes, lands of protected areas and in regions with undisturbed landscapes it is even lower: the sensitivity of
natural components has minimal values. At the same time, the matrix of distributions of construction zones and the risk of vulnerability of the environment takes the following form (Table 7):

**Table 7.** Adjusted matrix of distributions of construction zones and environmental vulnerability risk.

| Region Index | Environmental group index for natural landscapes |
|--------------|-----------------------------------------------|
|              | L5 | L4 | L3 | L2 | L1 |
| p3 R1        |   |   |   |   |   |
| r3           | R1L5 | R1L4 | R1L3 | R1L2 | R1L1 |
| p2 R2        |   |   |   |   |   |
| r2           | R2L5 | R2L4 | R2L3 | R2L2 | R2L1 |
| p1 R3        |   |   |   |   |   |
| r1           | R3L5 | R3L4 | R3L3 | R3L2 | R3L1 |

According to the corrected matrix, industrial territories of the Far North and the regions equated to them are characterized by the highest probabilities and risk level, as well as vulnerability. On the contrary, undisturbed landscapes as valuable objects of ecological balance in the region and the country are, of course, vulnerable to anthropogenic interference, but their ecological importance implies uncompromising and significant reduction of environmental risk, especially in industrial and residential areas. The framework of natural landscapes cannot be preserved at high and catastrophic risks of environmental hazard in all three regions on R1, R2, R3. To assess any risk in comparison with some acceptable one is possible only when taking into account the regulated boundaries of anthropogenic changes. Therefore, by analyzing the gradation of construction zones, we can distinguish the following 4 classes of standardization of construction work (under conditions of anthropogenic impact on the ecosystem):

1) acceptable risk zone – R1L5, R2L5, R3L5 with low vulnerability of natural components and low risk, score: 1-3;
2) risk warning zone – R1L2, R2L2, R3L2 with medium vulnerability and acceptable risk, requiring to keep the situation under control and more accurately calculate the probability of a dangerous event, score: 4-9;
3) risk reduction zone – R1L3, R2L3 with high vulnerability, the risk is high, urgent intervention in industrial development is necessary to ensure safety measures, score: 10-16;
4) unacceptable risk zone – R1L2, R1L1, R3L2 with catastrophic vulnerability, the risk is too high, urgent measures to eliminate anthropogenic hazard, score: 17-25.

The proposed classification takes into account the real environmental risk of the construction of both an individual facility and their complexes.

The MC method may be considered the most effective method for quantifying uncertainties [32]. After modeling the scenarios with lognormal assumptions using this stochastic approach, we obtain some of the most sensitive scenarios of anthropogenic impact on the components of the environment in the industrial and residential areas (Table 8).

After the simulation is completed, trend graphs are built for the predicted values of the anthropogenic impact within the industrial and residential zones (Figure 2-3).

As can be seen from the data obtained using the MC method, the effect of techno genesis on all four environmental components in the considered zones will continue to increase. The worst-case scenario can be defined as post-catastrophic (ultra-high risk, emergency measures in emergency
situations, score 26-30). Man-made accident in Norilsk, the largest in the Arctic, shows the reliability of the simulated forecast. As for the anthropogenic impact on nature in the landscape zones L3, L4, and L5, it will only increase, since with an increase in the standard deviation (up to 0.05; 0.03; 0.02, respectively), the vulnerability coefficient of the ecosystem as a risk factor increases.

**Table 8.** Scenarios of anthropogenic impact on environmental components.

| Scenarios                  | The value of the coefficient of environmental vulnerability for zones |
|----------------------------|---------------------------------------------------------------------|
|                            | industrial | agricultural |
| The best (minimum value)   | 17.45      | 4.42         |
| Expected                   | 17.89      | 4.46         |
| The worst (maximum value)  | 19.82      | 4.60         |
| Standard deviation         | 0.43       | 0.03         |

**Figure 2.** Graph of the trend growth of anthropogenic impact on ecosystem components in the industrial zone.

**Figure 3.** Graph of the trend growth of anthropogenic impact on ecosystem components in the industrial zone.

5. **Conclusions**

Thus, the concept of ERF means the relationship between territories that include a certain number of natural components and characterize them as “risk situations”. When choosing a model of environmental risk in order to predict the level of interaction of the construction object with the environment, it is necessary to take into account the features of natural landscapes. The adjusted matrix of the distribution of construction zones and ecosystem vulnerability risk based on the study of the parameters of anthropogenic impact on the components of the environment allowed us to correlate
the index of regions (regions) and the index of ecological groups for natural landscapes. Data from Rosreestr was used to specify the ecological zoning. MC modeling allows predicting the process of techno genesis relative to the natural environment in confident limits. Industrial territories of the Far North and regions equated to them are characterized by the highest probability and level of risk, as well as vulnerability. The impact of techno genesis on all four environmental components in the zones under consideration will continue to increase.

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