Ukrainian Journal of Ecology

Ukrainian Journal of Ecology, 2020, 10(4), 218-224, doi: 10.15421/2020_191

ORIGINAL ARTICLE

Prognosis of emergencies and their impact on population and territory of Ukraine

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Received: 20.08.2020. Accepted 24.09.2020

The article presents the original statistical method to determine the possible emergencies and forecast their impact on the population and territory of Ukraine. The proposed mechanisms allow determining the emergencies despite the uncertainty and variability of influential factors and assessing the adequacy and reliability of suggested model. The presented approach could prevent the possible of emergencies and eliminate their negative consequences for the population and territories.
Key words*:* emergencies; prospective number; uncertainty; reliability; adequacy.

Introduction

Dangers and threats in the natural and technogenic spheres are realized when the characteristics of natural processes and phenomena, parameters of production and other technogenic processes reach a certain critical level and even exceed it, after which the natural or technogenic process returns to normal. This can be accompanied by destructive or other negative impact on the environment and human life, leading to a natural or technogenic disaster of varying intensity and scale – the source of an emergency, which, in its turn, causes a natural, technogenic or social emergency. Accordingly, it is important and necessary to determine the prospective number of emergencies in Ukraine in order to develop a set of measures to prevent them.

According to the research conducted by scientists in Ukraine and the world in recent years, it has been defined that there is an increasing tendency as to the number of emergencies around the world (Brushlinskiy, Klepko, 2005). Forecasting the number of natural and technogenic disasters is becoming increasingly important, given the statistics of the United Nations, which demonstrates a significant increase in material damage caused by emergencies (Global Assessment Report, 2013).

National and foreign scientists pay considerable attention to forecasting emergencies in order to prevent them. For this purpose, certain forecasting methods have been developed using information technologies (Nemtinov et al., 2016). In addition, scientists are developing scientific concepts based on mathematical methods that are used in this direction (Ivanyuta, 2017). Taking into account the comprehensive analytical data obtained during the research (Brushlinskiy, Klepko, 2005; Vostokov et al., 2012; Guha-Sapir, 2015), there is a problem of developing a reliable method for determining the prospective number of emergencies in the context of further development of appropriate measures for their prevention and elimination. Existing methods (Gorbunov et al., 2015), which have been analysed in the course of our research, need some refinement in order to increase the reliability level of future forecasts.

The paper objective is to determine the prospective number of emergencies in Ukraine based on the diagnosis of their retrospective dynamics.

To achieve this objective, the following tasks have been solved:

- substantiation of the necessity to determine the prospective number of emergencies within the territory in accordance with the possible risks of their occurrence;
- diagnostics of concepts of the emergencies risks analysis and the choice of a method for determining the prospective number of emergencies in Ukraine;
- analysis of retrospective statistical information on the number and composition of emergencies in Ukraine;
- forecasting the prospective number of emergencies in Ukraine in view of the development and implementation of rational measures that can reduce the risks of natural and technogenic character to the minimum possible level;
- assessment of the forecast reliability and adequacy concerning the prospective number of emergencies in Ukraine.

Materials and methods

Correlation-regression analysis, the essence of which is to choose the type of regression equation, calculate its parameters and establish adequacy of the theoretical dependence on actual data, has served as a mechanism for predicting the prospective number of emergencies in Ukraine and analysing the closeness of the relationship between the total number and types of

emergencies in Ukraine. Given the fact that there is a functional relationship between the factorial (year) and effective (total number of emergencies) features, the linear regression equation is built for the prediction by calculating its parameters using the least-square method.

In general, the linear equation of dual regression is as follows:

$$Y = a_0+a_1+a_x$$

where a_0 and a_1 are the parameters of the theoretical dependence that must be calculated.

The parameters of the theoretical dependence are calculated by the least-square method (table 1).

Table 1. Calculation table for determining parameters of the theoretical dependence

No	*x*	*y*	x^2	*xy*	*Y*
1	1	144	1	144	143
2	2	143	4	286	145
3	3	148	9	444	147
4	4	149	16	596	149
Total	10	584	30	1470	–

The values of parameters of the linear regression model are calculated as follows:

$$a_0 = \frac{\sum y \sum x^2 - \sum xy \sum x}{n\sum x^2 - \sum x \sum x} = \frac{584\times 30 - 1470\times 10}{4\times 30 - 10\times 10} = 141;$$

$$a_1 = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - \sum x \sum x} = \frac{4\times 1470 - 10\times 584}{4\times 30 - 10\times 10} = 2$$

Thus, the theoretical dependence of the number of emergencies in Ukraine depending on the year is as follows:

$$Y = 141+2x$$

According to the obtained dependence, we carried out the calculation of the prospective number of emergencies during 2019-2020 (table 2).

Table 2. Calculation table for determination the characteristics of the tightness and significance of the relationship between factorial and effective features

No	*x*	*y*	*Y*	$(Y-\bar{y})^2$	$(y-\bar{y})^2$	y-Y	$(y-Y)^2$
1	1	144	143	9	4	1	1
2	2	143	145	1	9	−2	4
3	3	148	147	1	4	1	1
4	4	149	149	9	9	0	0
Total	10	584	584	20	26	–	–

The criterion of adequacy and reliability of the model is the determination coefficient, which is defined according to the formula:

$$R^2 = \frac{\sum (Y-\bar{y})^2}{\sum (y-\bar{y})^2}.$$

The closer the value of the specified coefficient to one, the more adequate and reliable is the forecast.

Results

Before determining the prospective number of emergencies, it is necessary to analyze the risks of their occurrence and development because these risks are transformed into threats of occurrence and development of emergencies and subsequently into immediate emergencies. The general sequence of stages of the risk analysis of the emergencies occurrence and development is presented in fig. 1. Accordingly, as one can see in Fig. 1, the risks analysis of the emergencies on the territory is the basis for determining the prospective number of emergencies.

Nowadays, the following concepts of risk analysis of the emergencies occurrence and development are used: technical (technocratic) concept which was based on the principles of analysis of the relative frequencies of the emergencies occurrence and development indicating their probabilities. When applying this concept, the available statistical information is subject to averaging by scale, population groups and time; economic concept within which the risk analysis of the emergency occurrence and development is a part of a more general study of costs and benefits.

In this case, the risks are considered as expected loss of utility as a result of certain events or actions. The ultimate goal of using the economic concept is to allocate resources in such a way as to maximize their general public utility.
– psychological concept which aims to study individual preferences in relation to probabilities in order to explain why individuals do not develop their own opinions about the risk of the emergencies occurrence and development on the basis of averaged data; why people react according to their own perception of risks and do not account for the objective level of risks and their scientific assessment; social (cultural) concept which is based on the interpretation of the undesirable consequences of the emergencies occurrence and development from a social point of view taking into account group values and interests. It should be noted that the sociological analysis of risk links public opinion with the personal or public interests and values. The social approach assumes that the existing cultural prototypes determine the typology of opinions of certain individuals and public organizations, forcing them to adhere to some values and do not take into account others (Gorbunov et al., 2015).

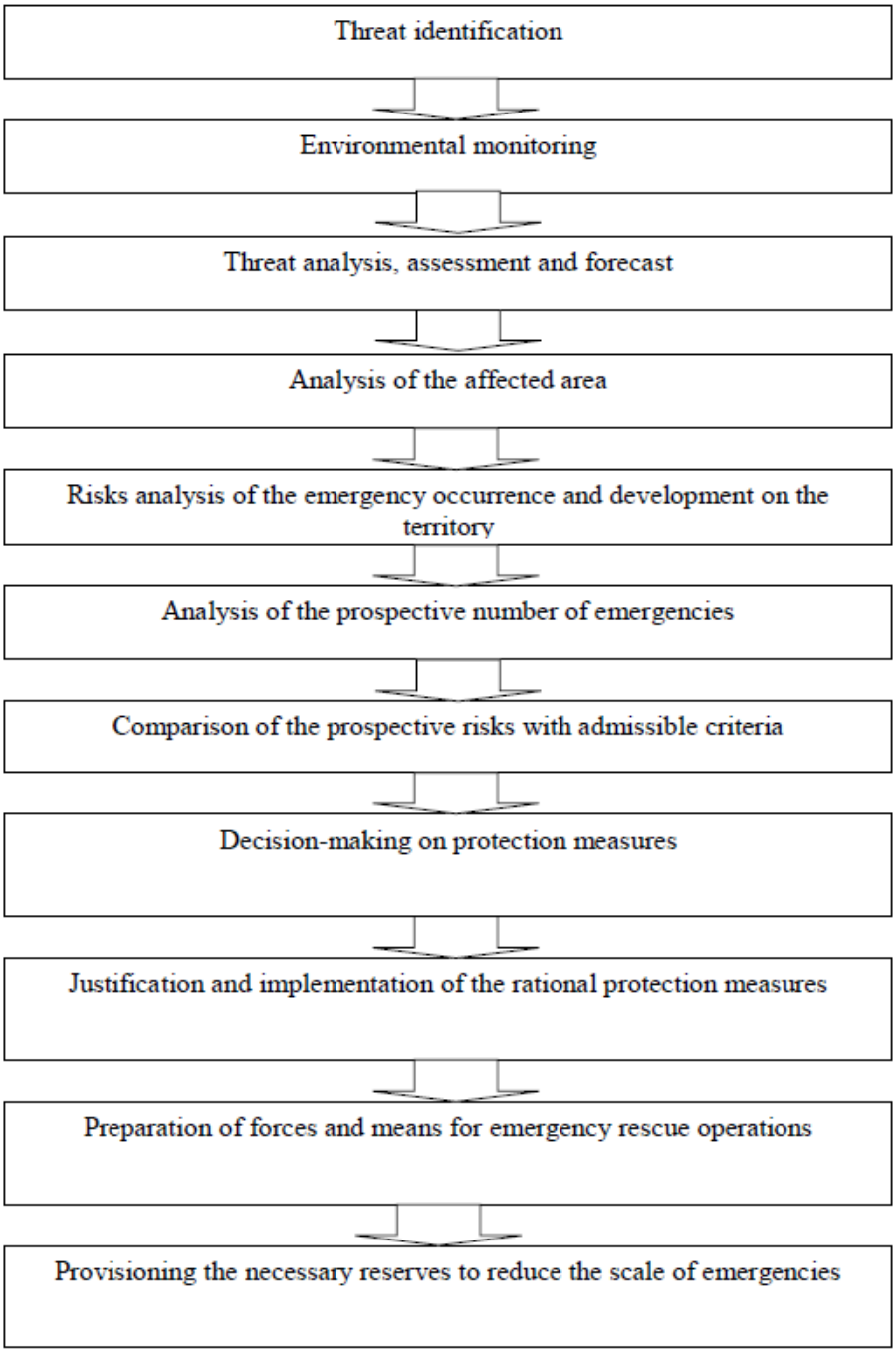

Fig. 1. The stages sequence of the risk analysis

As a part of the technocratic concept, after hazards identification (risks identification that are possible from a fundamental point of view), the assessment of their level and consequences they may cause, i.e. analysis of the probability of occurrence and development of certain events and the potential damages associated with them is carried out. The risk assessment methods are possible to be used to do this. They are traditionally divided into phenomenological, deterministic and probabilistic.
In particular, the phenomenological approach to the risks analysis of the emergencies occurrence and development is based on determining the possibility of the processes of the hazardous character, taking into account the results of the analysis of the necessary and sufficient conditions associated with certain natural laws.

The deterministic approach to the risks analysis of the emergencies occurrence and development involves the analysis of the sequence of stages of the accidents development, starting from the base event through a series of predictable stages, including failures, deformations and destruction of components, to the established final state of the system.

The probabilistic approach to the risks analysis of the emergencies occurrence and development provides both an estimation of probability of an accident occurrence and development and calculation of the relative probabilities of the possible ways of development of the hazardous processes. At the present stage, this approach is considered as one of the most promising for practical application.

The study of the risk of the emergencies occurrence and development for the population and territories using the probabilistic method makes it possible to build different approaches to the risk assessment. Depending on the available source data, the following approaches can be used:

- statistical (determination of probabilities according to available statistical data);
- theoretical and probabilistic (assessment of the risks associated with rare events, when there is almost no statistical data);
- heuristic (application of the subjective probabilities obtained through expert evaluation).

In particular, the heuristic approach is used in the process of assessing the complex risks of various hazards, when there is not only statistical information is absent, but the accuracy of mathematical models is also too low (Nemtinov et al., 2016).

The general methodical apparatus of the risks analysis of the emergencies occurrence and development is presented in fig. 2.

Accordingly, the scientific novelty of the paper is the proposition to use statistical method to determine the prospective number of emergencies by forecasting based on relevant available retrospective data within the probabilistic concept. The forecasting methods of the emergencies occurrence and development are the most advanced in relation to emergencies of a natural nature, more precisely, in relation to dangerous natural phenomena that cause such situations. In order to timely and effectively forecast and identify a dangerous natural phenomenon at the stage of its occurrence, it is necessary to establish a system of monitoring the precursors of natural disasters and catastrophes at the national level.

According to the time criterion, the methods of the scale of emergencies forecasting are divided into two groups:

– methods based on the priori assessments (which can be forecasted), obtained through the use of theoretical models and analogies;

– methods based on the posteriori assessments (assessment of the scale of the emergency development that is already taking place).

It should be noted that considering the influence of various factors on individual risk, the justification of rational measures that reduce the risks of natural and technogenic nature to the minimum possible level is carried out (Ivanyuta, 2017).

According to the statistics of The State Emergency Service of Ukraine, during 2018 there were registered 149 emergencies in Ukraine in accordance with their gradations in the National Classifier "Classifier of Emergencies" SC 019:2012.

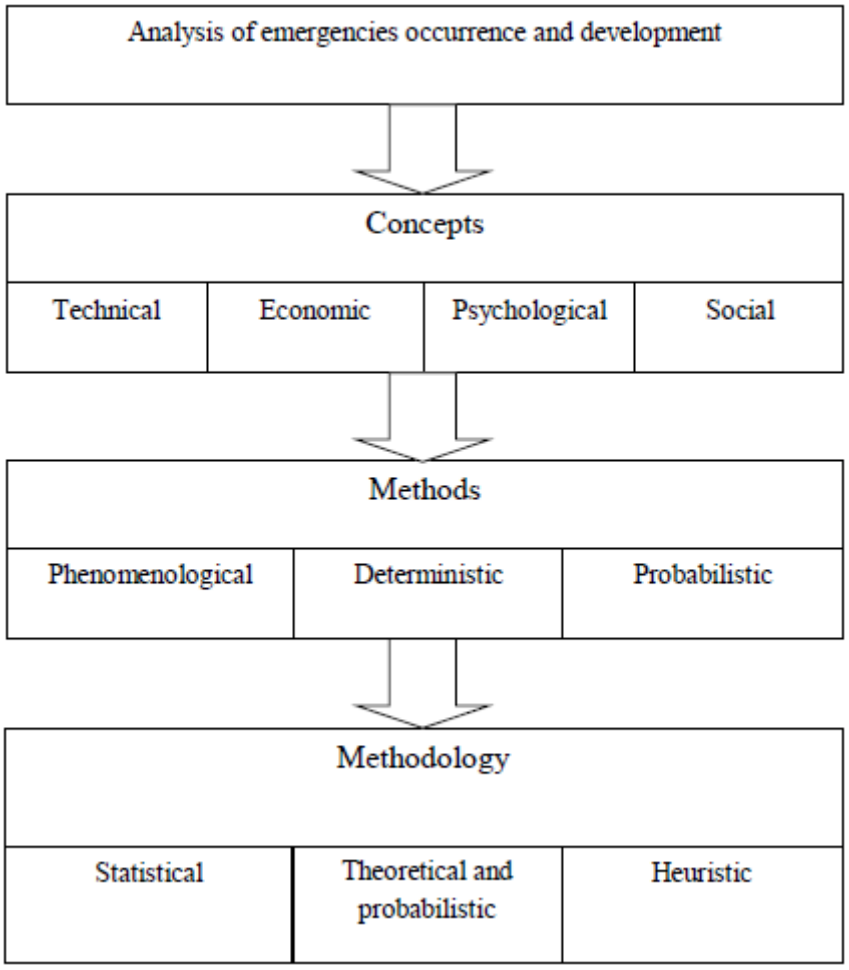

Fig. 2. Methodical scheme of the risk analysis

Thus, we calculated the emergencies distribution according to the nature of the origin. The highest number of emergencies registered in Ukraine in 2018, according to the National Classifier "Classifier of Emergencies", are of natural origin (60%). The technogenic registered emergencies are almost half as many (37%). As for social emergencies, their number accounts for about 3%. Thus, In Ukraine we counted 56 technogenic, 89 natural, and 4 social emergencies in 2018.

A total of 183 people died in these emergencies, 37 of them were children. The registered number of victims of these emergencies reached 1,856 people, including 861 children. During the first half of 2019, 69 emergencies were registered in Ukraine. We separated 21 technogenic, 47 natural, and one social emergency in Ukraine for the fisrt half of 2019.

The largest number of emergencies registered in Ukraine during the first half of 2019, according to the National Classifier "Classifier of Emergencies" are natural (68%). Technogenic emergencies take the second place again (30%). Social emergencies account for only 1.45%.

According to the statistics of The State Emergency Service of Ukraine, according to the scale of the emergencies distribution, they were distributed as follows: one state emergency, 9 regional, 64 local, and 75 facility-based emergencies.

In Ukraine in 2018 the vast majority of emergencies were registered at the facility-based level (over 50%). The local emergencies take the second place (over 40%). The distribution of emergencies according to the scale of their distribution in the forst half of 2019 was as follows: one state, 3 regional, 32 local, and 33 facility-based

In Ukraine during the first half of 2019 the vast majority of emergencies were again recorded at the facility level (over 48%). The number of local emergencies was similar (over 47%).

At the same time, if to compare the number of registered emergencies in Ukraine according to the nature of their origin in 2017 and 2018, it can be seen that the number of technogenic emergencies decreased by 11% and the number of social emergencies decreased by 50%. As for natural emergencies, in 2018 their number increased by almost 17% compared to the previous 2017 (Table 3).

Table 3. Number of emergencies registered in Ukraine in 2017-2018

Category of emergency	n (2017)	n (2018)	Absolute deviation, %	Relative deviation, %
Technogenic	63	56	−7	−11,1
Natural	77	89	12	16.6
Social	8	4	−4	−50

The number of emergencies at the regional and facility-based level in 2018 compared to the previous 2017 did not changed (table 4). The number of emergencies at the local level increased insignificantly (3%). The number of emergencies at the state level halved.

Table 4. Comparative characteristics of the number of registered emergencies in Ukraine in 2017 and 2018 according to the scale of their distribution

Emergency Level	n (2017)	n (2018)	Absolute deviation, %	Relative deviation, %
State	2	1	– 1	– 50%
Regional	9	9	0	-
Local	62	64	2	3.2
Facility-based	75	75	0	–

In general, the analysis shows that in Ukraine there are mostly cases of natural emergencies occurrence and development and their number is increasing. The number of natural emergencies evidences this trend during the first half of 2019. Thus, their number was 68%, which is 8% more than in the previous 2018. Mostly emergencies occur at the local and facility-based levels, and the number of emergencies at the local level is increasing. The analysis demonstrates the need to prevent natural emergencies, especially at the local and facility-based levels.

However, preventive measures in this context can be effective only if the risks of the emergencies occurrence and development are assessed, in particular, their prospective number is determined. There are many methods of risk assessment among which are the following: risk index, brainstorming, structured interviews, Delphi method, checklists, preliminary hazard analysis, hazard and performance studies, hazard analysis and critical control points, toxicological risk assessment, structured scenario analysis by the method of "What if?", scenario analysis, root cause analysis, analysis of types and consequences of failures, event tree analysis, cause and effect analysis, protection level analysis, decision tree analysis, human factor analysis, analysis of hidden defects, Markov analysis, Monte Carlo simulation, Bayesian analysis and Bayesian networks, FN curves, consequence and probability matrix, multicriteria decision analysis, expert methods.

In particular, among these methods such as risk index, Delphi method and decision tree analysis are most often used. Thus, the risk index is the risk measurement, its quantitative assessment, obtained by using the scores based on ordinal scales. This is a mixed method of the risk assessment.

The methodology of the risk index has the following advantages:

– can be used to rank various risks;

– allows to combine into a single score assessment of the risk level many factors that affect the risk level.
However, the methodology of the risk index has the following disadvantages:
– if the reliability of the process (model) and the original data is not properly confirmed, the results may be inaccurate. The fact that the source data is a numerical expression of the risk value can be misinterpreted and wrongly used;
– in many cases, when the risk indices are used, there is no basic model to determine the linearity or nonlinearity (e.g., logarithmic nature) of individual score scales of the risk factors or their other types, as well as a model of combining factors. In these cases, the ranking is initially unreliable and verification of its accuracy against the facts is particularly important.
The Delphi method is a procedure for reaching a credible consensus of the expert group opinions. Although the term is now widely used to refer to any form of brainstorming, an important distinguishing feature of the Delphi method, according to the original wording, is that experts express their opinions individually and anonymously, achieving access to other experts' opinions during the process.
The Delphi method has the following advantages:
– as far as opinions are anonymous, unpopular ideas are also expressed;
– all opinions hare of the same relevance factor that prevents the problem of the predominance of the individual experts' views;
– obtaining ownership rights on the results;
– no need to participate in the meeting of all experts together.
The Delphi method has the following disadvantages:
– high cost of time and high complexity;
– the need for participants to express their views clearly in writing.
Decision tree analysis is a method that describes the decision-making process by considering alternatives and the consequences of their choice.
In general, decision tree analysis has the following advantages:
– easiness of interpretation and clarity;
– the ability to work with both categories and quantitative values;
– universality in terms of solving classification and regression problems;
– the ability to work with data gaps (empty attribute values). It is also worth mentioning that decision trees could be used to fill in the gaps with the most probable value;
– productivity in the process of classification on the already built tree.
But there are some disadvantages as well:
– instability of the process. Small changes in the data set can often lead to the construction of a completely different tree. This is connected with the hierarchy of the tree. Changes in the node at the top level lead to changes in the entire tree below;
– the complexity of controlling the tree size. The tree size is a critical factor that determines the quality of the task. When using simple stop criteria, trees often grow either very short or very large;
– the criterion of information growth is characterized by the tendency to give preference to attributes that have a large number of different values (Ivanyuta, 2017; Bankoff et al., 2004).
However, none of these methods makes it possible to analyze the prospective number of emergencies with a concomitant assessment of the reliability and adequacy of the developed model, as well as to determine the degree of dependence of the total number of emergencies on the number of different types of emergencies.
Given the above, it is advisable to develop a forecast of the total number of emergencies in Ukraine during the next 2019–2021.
The paper proposes to develop medium-term emergencies forecast in Ukraine over time. Thus, if to develop a forecast of the emergencies number for the next 3 years, it is advisable to use current statistics on their volume over the past 5 years, published by The State Emergency Service of Ukraine. The paper proposes to use the deterministic model of regression analysis, which belongs to the category of methods of economic and mathematical modelling.
So, in 2015 we counted 212 emergencies, in 2016 – 144, in 2017 – 143, in 2018 – 148, and in 2019 – 149.
We proposed a gradual increase of emergencies number in Ukraine for 2020-2022. We supposed, that in 2020 we will expect 151, in 2021 – 153, and in 2022 – 155 emergencies.
Finally, the reliability and adequacy of the developed forecast is assessed by calculating the coefficient of determination according to the method described above:

$$R^2 = \frac{\sum (Y - \bar{y})^2}{\sum (y - \bar{y})^2} = \frac{20}{26} = 0{,}77.$$

The value of the coefficient of determination $R^2 = 0.77$ indicates that the relationship between factorial and effective features is quite close (difference from one is 0.23). Accordingly, the value R^2 shows that in Ukraine the variation in the number of emergencies by only 23% is determined by indefinite factors. This could be considered to prevent the future emergencies.
We believed that the medium-term forecast serves as a tool for determining the prospective number of emergencies in Ukraine. As a main disadvantage we indicate the limited number of influencing factors and their vagueness (in the developed model they are actually presented as a separate free parameter, which does not allow to differentiate the levels of influence of all factors). Thus, the variation in the number of emergencies in Ukraine by only 23 % is determined by the influence of undefinied factors. However, this shortcoming is debatable, given the current variability and instability of the factors influencing the number and structure of emergencies in Ukraine. We will improve the model presented in this paper by multifactor regression function, which would take into account the maximum available factors.

Conclusions

We determined that the risks analysis of the emergencies on the territory is the basis for determining the prospective number of emergencies, accounting for the further need to develop and implement adequate measures of responding to emergencies.
We proposed the statistical method to determine the prospective number of emergencies by forecasting based on relevant available retrospective data within the probabilistic concept.
We considered that natural emergencies mostly occur at the local and facility-based levels, while the number of emergencies at the local level is increasing. The results of forecasting of the prospective number of emergencies indicate a negative trend of their increase, which, in turn, means the necessity to develop and implement appropriate measures of prevention and eliminating their negative consequences for the population and territories.
We calculated that the variation in emergencies number in Ukraine was by only 23% caused by undefined factors. Accordingly, we supposed it is possible to consider our model suitable and relevant to real situation in Ukraine.

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Citation:
Kropyvnytskyi, V.S., Maistro, S.V., Shvedun, V.O., Stankevych, S.V. (2020). Prognosis of emergencies and their impact on population and territory of Ukraine. *Ukrainian Journal of Ecology, 10*(4), 218-224.