Розроблено комбінований метод прогнозування процесу виникнення надзвичайних ситуацій природного характеру, який відрізняється тим, що дозволяє здійснювати комплексний прогноз надзвичайних ситуацій як в цілому, так і за видами з врахуванням тенденцій періодичних змін даного процесу. В якості узагальненого параметру даного процесу розглядається кількість надзвичайних ситуацій за деякий період часу. З врахуванням дії всіх дестабілізуючих факторів цей процес доцільно зобразити у вигляді адитивної суміші систематичної періодичної та випадкової складових. Систематична складова уявляє собою поліном деякого ступеня. Виявлення та оцінка параметрів періодичної складової здійснюється на основі статистичного критерію, підпорядкованого хі-квадрат розподілу. Для прогнозування випадкової складової використовується метод групового врахування аргументів. Прогнозування надзвичайних ситуацій за видами здійснюється ймовірнісно-статистичним методом прогнозу.

Необхідність розробки комбінованого методу прогнозу пов'язана з тим, що існуючі методи прогнозу надзвичайних ситуацій орієнтовані в основному на прогнозування окремих видів надзвичайних ситуацій. Існуючі методи не вирішують задачі комплексного прогнозування надзвичайних ситуацій. Крім того слід зазначити, що для процесу виникнення природних надзвичайних ситуацій характерні наявності періодичних складових довільної форми. Врахування таких складових при прогнозування надзвичайних ситуацій дозволить глибше проаналізувати процеси виникнення та розвитку надзвичайних ситуацій.

В результаті експериментальних досліджень встановлено, що застосування комбінованого методу дозволяє здійснювати прогнозування надзвичайних ситуацій як мінімум на рік вперед з відносною похибкою прогнозу не більше трьох відсотків.

Корисність і доцільність застосування даного методу обумовлена тим, що комбінований метод об'єднує метод регресійного аналізу, метод перевірки статистичних гіпотез, метод групового врахування аргументів. Це дозволяє компенсувати недоліки одних за допомогою інших, що призведе до підвищення точності прогнозування

Ключеві слова: надзвичайна ситуація, узагальнений параметр, метод групового врахування аргументів, метод перевірки статистичних гіпотез, метод регресійний аналі

UDC 614.8
DOI: 10.15587/1729-4061.2018.143045

DEVELOPMENT OF COMBINED METHOD FOR PREDICTING THE PROCESS OF THE OCCURRENCE OF EMERGENCIES OF NATURAL CHARACTER

H. Ivanets
PhD, Associate Professor*
E-mail: iwa.gri@nuczu.edu.ua

S. Horielyshev
PhD, Associate Professor**
E-mail: port_6633@ukr.net

M. Ivanets
PhD Scientific Center of Air Force***
E-mail: miwqan@meta.ua

D. Baulin
PhD, Senior Researcher**
E-mail: baulinds1966@ukr.net

I. Tolkunov
PhD, Associate Professor*
E-mail: tolkunov_ia@nuczu.edu.ua

N. Gleizer
PhD, Associate Professor
Department of Physics
Ukrainian State University of Railway Transport
Feierbakha sq., 7, Kharkiv, Ukraine, 61050
E-mail: glejzer@kart.edu.ua

A. Nakonechnyi
PhD, Associate Professor
Department of armament of the Air Defense Forces of the Land Forces***
E-mail: nakon61@gmail.com

*Department of pyrotechnic and special training
National University of Civil Defence of Ukraine
Chernyshevska str., 94, Kharkiv, Ukraine, 61023
**Research laboratory for the provision of Service and Military Activities of the National Guard of Ukraine
Scientific and Research Center of Service and Military Activities of the National Guard of Ukraine
National Academy of National Guard of Ukraine
Zakhysnykiv Ukrainy sq., 3, Kharkiv, Ukraine, 61001
***Ivan Kozhedub Kharkiv University of Air Force
Symska str., 77/79, Kharkiv, Ukraine, 61023

1. Introduction

There is a persistent tendency throughout the world to the increase in contradictions between man and his natural environment (disasters at nuclear power plants, tsunamis, tornadoes, earthquakes) nowadays. All this leads to the occurrence of emergencies (ES) and their components, respectively, by types, levels, and regional distribution. Their consequences have a strong negative impact on economies of countries [1, 2]. For example, 795 emergencies occurred in Ukraine only in the last five years. Their results are 1,266 deaths, 5,213 people suffered, and the state suffered losses of UAH 1,599 million [1, 3].

The essence of emergencies of a natural character is violation of normal conditions of life and activities of people in a particular area or object located in this area, as well as a water body. Such emergencies relate to dangerous geophysical and geological phenomena, soil degradation, fires in natural ecological systems, changes in the state of air basins, infectious diseases and poisoning of people, infectious diseases of domestic animals, etc.

There are different types of natural emergencies; they are geological, meteorological, hydrological, hydrogeological, natural fires and biomedical emergencies. Emergencies have the following characteristics: contingency, unexpectedness and rapid development of events, a different spectrum of negative consequences. We can group all these factors into the following blocks: social-ecological, psychological, social-political, economic, organizational-managerial, multiplicative, etc. Emergencies cannot be long-term. It is not possible to eliminate them by ordinary activities in everyday situations [4]. Successful results of elimination of emergency consequences are directly connected with timely intervention and resolution of an emerged situation.

Protection of population and territories from natural disasters is one of the important tasks of the civil protection of the state. Ensuring of safety in emergency situations requires reliable functioning of the emergency response sys-tem; it should be adequate to levels and character of threats [5].

Prevention of occurrence of natural emergencies consists in implementation of a complex of legal, social-economic, organizational, technical, and other activities. The aim of activities is regulation of natural security, assessment of a risk level and early response to threats of natural disasters [6]. The basis of the activities is factual information of emergency monitoring, expertise, research and forecasts regarding possible development of events in order to prevent their development into emergency situations or to mitigate possible consequences for humans and the environment [7].

An important aspect to prevent occurrence of emergencies is timely forecasting of opportunities for occurrence and assessment of economic consequences and losses from emergencies of natural character [8].

Thus, the necessity to respond to the threat of occurrence of emergencies in advance and to minimize possible consequences proves the relevance of the study aimed at improvement of methods for forecasting of a process of occurrence of natural emergencies.

2. Literature review and problem statement

A base of factual forecasting methods [9] is data from monitoring of emergencies for a certain period. The methods include extrapolation and interpolation methods, extrapolation methods based on envelope curves, regressions and correlations, factor models, expert models of logic modeling, construction of development scenarios [10, 11].

Papers [12–14] present results of studies on application of a probabilistic approach to forecasting of natural emergencies. They show that the cumulative effect of numerous sources of uncertainty for validity of estimates is taken into consideration in this case. But issues of development of models of processes of occurrence of emergencies remained not fully resolved, which makes difficult to analyze dynamics of development of the mentioned processes. An option to overcome the corresponding difficulties is a use of statistical and structural forecasting models.

Statistical models described in papers [15, 16] set the functional dependence between future and actual values of a time series, as well as external factors, analytically. The statistical models include the following groups: regression models, autoregressive models, exponential smoothing models. Structural models set the functional relationship between future and actual values of a time series, as well as external factors, structurally [17, 18]. Structural models include the following groups: neural network models, models based on Markov chains, models based on classification – regression trees.

Works [18, 19] show that it is possible to use models based on Markov chains in case of insufficient information on a process of emergency occurrence. However, this model takes into consideration only the current state of a process at forecasting of a future state of a process. And it does not take into consideration information on previous development of a process. This does not make it possible to trace dynamics of a process and to identify trends in its development. The way out of this situation is a use of regression models. An important advantage of autoregressive models and methods is their simplicity and transparency of modeling, as well as unambiguity of analysis. The disadvantages of such class of models are a large number of model parameters, ambiguity of their identification, low adaptability of models and inability to model nonlinear processes of emergency occurrence. Paper [19] shows this.

It is convenient to use neural network models for modeling of nonlinear processes [20, 21]. The main advantage of neural network models is non-linearity, that is, ability to establish non-linear dependencies between future and actual process values. The disadvantages of such models are: lack of modeling transparency, complexity of a choice of architecture, complexity of a choice of a neural network learning algorithm. In this regard, models based on classification-regression trees are preferable [22]. Such models make it possible to process super-large amounts of data quickly, as well as to use categorical external data. The disadvantages of these models are ambiguity of construction of a tree structure and lack of unambiguity of their analysis.

A common disadvantage of the considered methods and models of forecasting is orientation towards forecasting of certain types of natural disasters not taking into consideration periodic components of an arbitrary form in the study of processes of emergency occurrence. In addition, the methods do not make it possible to perform a complex forecast of emergencies both in general and by types.

All the above allows us to state that the study on creation of a combined method for forecasting of natural emergencies is expedient. Development of this method will compensate disadvantages of some methods with a help of others. The aim of the development is improvement of accuracy of forecasting of processes of emergency occurrence and emergency development.

3. The aim and objectives of the study

The objective of the study is to develop a combined method for forecasting of natural emergencies taking into consideration trends of periodic changes in emergencies. The proposed method should make it possible to make a forecast of a total number of emergencies and the number of emergencies of natural character of different types for a certain period of pre-action.

It is necessary to solve the following tasks to achieve the objective:

– to justify a choice of the generalized parameter for forecasting of natural emergencies;

– to determine the dependence of this parameter on destabilization factors that affect it based on factual information;

– to propose a method for forecasting of natural emergencies, which makes it possible to eliminate disadvantages of existing methods;

– to conduct experimental study on effectiveness of the method of forecasting of natural emergencies.

4. Materials to study the process to change the generalized parameter of emergencies of natural character

4. 1. Choice of the generalized parameter for forecasting the process of the occurrence of natural emergencies

We impose the following requirements on a generalized parameter as an indicator of occurrence of a natural emergency:

– a selected parameter should reflect the main trends of a process;

– it should characterize a process as a whole;

– it should provide possibility to obtain a quantitative assessment with required accuracy.

Therefore, we consider the number of emergencies over a certain period of time as the generalized parameter of a process of occurrence of natural emergencies.

For forecasting the number of natural emergencies, it is necessary to know their dependence on destabilizing factors, which affect them.

Forecasting consists of determining the number of emergencies over a certain period after the last observation based on possible effects of destabilizing factors, which affect a process of changing of the generalized parameter.

Taking into consideration an impact of all destabilizing factors, we represent the process of changing of the generalized parameter as an additive mixture of a systematic component, which characterizes irreversible processes of a parameters drift, a periodic component, and a random component [23]:

$$Z(t)=C(t)+X(t)+m(t), \qquad (1)$$

where $Z(t)$ is the number of natural emergencies over a certain period (generalized parameter); $C(t)$ is the systematic component of the generalized parameter; $X(t)$ is the periodic component of a generalized parameter; $m(t)$ is the random component of the generalized parameter.

Such a model makes it possible to take into consideration an effect of all destabilizing factors on the process of changing of the generalized parameter of a natural emergency most fully. Assessment of all three components of the process of changing of the generalized parameter will make it possible not only to make a forecast for each of them, but also to analyze causes of emergencies more deeply.

4. 2. Method for assessment of a systematic component of the generalized parameter

We find $C(t)$ systematic component in the form of a polynomial of k degree [23]

$$C(t)=r_0+r_1t+r_2t^2+\ldots+r_kt^k. \qquad (2)$$

We choose a degree of the polynomial in such a way that the number of specified points is approximately five times higher than the degree of the polynomial [24]. We can find coefficients of the polynomial using the least-squares method (LSM):

$$\overline{R}=\left(T^T\cdot T\right)^{-1}\cdot T^T\cdot\overline{Z}, \qquad (3)$$

where $\overline{R}=\left(r_0,r_1,r_2,\ldots,r_k\right)^{\mathrm{T}}$ is the vector of coefficients of $(k\times1)$ dimension; $\overline{Z}=\left(z_1,z_2,\ldots,z_n\right)^{\mathrm{T}}$ is the vector of measured values of the generalized parameter of $(n\times1)$ dimensionality;

$$T=\begin{bmatrix}1 & 1 & \ldots & 1\\ 1 & 2 & \ldots & 2^k\\ .. & \ldots & \ldots & \ldots\\ 1 & n & \ldots & n^k\end{bmatrix},$$

T is the matrix of $(n\times k)$ dimensionality.

In the matrix form, we can represent the systematic component as:

$$\overline{C}=T\cdot\overline{R}. \qquad (4)$$

Such representation is compact and convenient for further use in calculations.

4. 3. Method for identification and assessment of a periodic component of an arbitrary form of the generalized parameter

We denote a random process by $\overline{Y}=\overline{Z}-\overline{!}=\overline{X}+\overline{m}$. It contains the sum of the periodic component and the random component after removal of the systematic component.

Let us assume that length of $Y(t)$ realization is not a multiple of the period of the periodic component in general case:

$$n=qp+n', \qquad (5)$$

where n is the length of implementation; p is the period of the periodic component; q is the number of periods of the periodic component in implementation; n' is the number of $Y(t)$ discrete values that are not included to implementation of qp length.

Obviously, in this case $n'<p$. Thus, we can record the model of $Y(t)$ process in the matrix form:

$$\begin{pmatrix}Y\\ Y'\end{pmatrix}=\begin{pmatrix}1\otimes X\\ X'\end{pmatrix}+\begin{pmatrix}m\\ m'\end{pmatrix}, \qquad (6)$$

where

$$Y=\left(y_0,y_1,\ldots,y_{qp-1}\right)^{\mathrm{T}}$$

is the block matrix of $Y(t)$ implementation values of $(qp\times1)$ dimensionality;

$$Y'=\left(y_{qp},y_{qp+1},\ldots,y_{n-1}\right)^{\mathrm{T}}$$

is the block matrix of $Y(t)$ implementation values of $(n'\mathbf{x1})$; dimensionality;

$$1=(1,1,1,...,1)^T$$

is the matrix of $(q\times1)$ dimensionality;

$$X=\left(x_0,x_1,...,x_{p-1}\right)^{\mathrm{T}}$$

is the block matrix of values of a periodic component of $(p\times1)$ dimensionality;

$$X^{'}=\left(x_{qp},x_{qp+1},...,x_{n-1}\right)^{\mathrm{T}}$$

is the block matrix of values of a periodic component not included in implementation of qp length of $(n'\times1)$ dimensionality;

$$m=\left(m_0,m_1,m_2,...,m_{qp-1}\right)^{\mathrm{T}}$$

is the block matrix of values of a random component of $(qp\times1)$ dimensionality;

$$m'=\left(m_{qp},m_{qp+1},...,m_{n-1}\right)^{\mathrm{T}}$$

is the block matrix of values of a random component of $(n'\times1)$ dimensionality; $\otimes$ is the symbol for a Kronecker product; $n=qp+n'$ is the length of implementation; p is the period of a periodic component; q is the number of periods of a periodic component in implementation.

We reduce the task of identification and assessment of the periodic component to the task of verification of statistical hypotheses. We use d random variable as a criterion for verification of validity of the hypothesis that a periodic component is present in the implementation. d random variable subordinates to the chi-square distribution [25]:

$$d=\sum_{i=0}^{p-1}\left(\sqrt{\frac{2}{\hat{\sigma}^2}}W_i\right)^2, \qquad (7)$$

where

$$W_i=\begin{cases}\sqrt{\frac{q+1}{2}}\hat{x}_i', & i=0,1,2,...,n'-1;\\ \sqrt{\frac{q}{2}}\hat{x}_i'', & i=n',n'+1,...,p.\end{cases}$$

We determine estimates of the discrete values of the periodic component $\hat{x}_i$ and $\hat{\sigma}^2$ variance as follows:

$$\hat{x}_i=\begin{cases}\hat{x}_i^{'}=\frac{1}{(q+1)}\sum_{s=0}^{q}y_{i+sp}, & i=0,1,2,...,n'-1;\\ \hat{x}_i''=\frac{1}{q}\sum_{s=0}^{q-1}y_{i+sp}, & i=n',n'+1,...,p;\end{cases} \qquad (8)$$

$$\hat{\sigma}^2=\frac{1}{n}\left(\begin{pmatrix}Y\\Y'\end{pmatrix}-\begin{pmatrix}1\otimes X\\X^{'}\end{pmatrix}\right)^{\mathrm{T}}\left(\begin{pmatrix}Y\\Y^{'}\end{pmatrix}-\begin{pmatrix}1\otimes X\\X^{'}\end{pmatrix}\right). \qquad (9)$$

The algorithm for identification and assessment of the period and discrete values of the periodic component consists in finding such a value of the period of the periodic component at which d statistical criterion has the maximum value.

If the value of the statistical criterion exceeds the detection threshold, then we can talk about the presence of the periodic component in this implementation. The detection threshold is set for a given level of significance. We estimate the value of the period and the discrete values of the periodic component for the period in accordance with the expression (7).

4. 4. Method for forecasting of a random component of the generalized parameter

After assessment and removal of the systematic component and the periodic component from $Z(t)$ implementation, the task of forecasting of the random component arises. We denote the random component of the process of changing of natural emergency after the removal of the periodic component by $m(t)=Y(t)-X(t)$. We can use the method of group consideration of arguments (MGCA), as a competitor to the method of stochastic approximation [23] to forecast the random component of the generalized parameter. MGCA consists in a recurrent solution of several systems of equations obtained for each pair of arguments, which makes it possible to increase the accuracy of the forecast sharply with a simultaneous decrease in the amount of calculations. The method makes it possible to make calculations at time when data is received and to take into consideration a large set of parameters, which are assigned with an appropriate weight, and to select parameters for the forecast automatically [26, 27].

After determination of components of the process of changing of the generalized parameter, we calculate the value for the number of natural emergencies for a certain period of pre-action in accordance with the expression:

$$Z(t_{\text{fc}})=C(t_{\text{fc}})+X(t_{\text{fc}})+m(t_{\text{fc}}). \qquad (10)$$

This makes it possible to make a forecast of values of a total number of emergencies and of components of this process.

4. 5. Method of forecasting of emergencies by types

We perform forecasting of natural emergencies by types with a use of the probabilistic-statistical method in accordance with the expression:

$$Z_i(t_{\text{fc}})=Z(t_{\text{fc}})\cdot P_i, \qquad (11)$$

where $Z(t_{\text{fc}})$ is the forecasted value for the number of emergencies of i-th type for a forecasting period; P_i is the probability of emergency of i-th type at occurrence of an emergency of natural character.

We determine P_i probability based on factual information on natural emergencies according to monitoring results for a certain observation period:

$$P_i=\frac{n_i}{n}, \qquad (12)$$

where n is the total number of natural emergencies for a monitoring period; n_i is the total number of emergencies of i-th type at occurrence of natural emergencies for a monitoring period.

5. Results of experimental application of the combined method for forecasting natural emergencies

The described method is applicable for any state based on correct statistical data on natural emergencies monitoring for a certain period and generalized data on the process of their occurrence.

In addition, characteristic of natural emergencies in any state is presence of periodic changes. A geographical position of the state and climatic conditions determine the periodic changes.

As an example of the method application, we implement an emergency forecast for Ukraine, as a state, for the following reasons:

– in contrast to other countries, generalized correct statistical data on natural emergencies in general and by types of origin are fully known for Ukraine;

– in contrast to other countries, signs of classification by types of emergencies are known for natural emergencies.

We use factual information on natural emergencies in Ukraine for the period from 1997 to 2013 to study effectiveness of the combined method.

We should note that local officials began to publish such aggregated data since 1997 in Ukraine. The data relate to 1997–2013, because of the situation in Ukraine caused by the military actions in the Donbas and the Luhansk region, as well as the occupation of the Autonomous Republic of Crimea (ARC). As a result, the data, starting from 2014, do not fully reflect natural processes occurring in Ukraine in general, and are not entirely correct for forecasting (limited data for Donbas and Luhansk region, as well as the lack of reliable data for the ARC). Thus, we conduct a forecast for 2013 with a use of the sample for 1997–2012 to test performance of the method described.

Fig. 1 shows the dynamics of n number of emergencies of a natural character for the period of 1997–2013 [28].

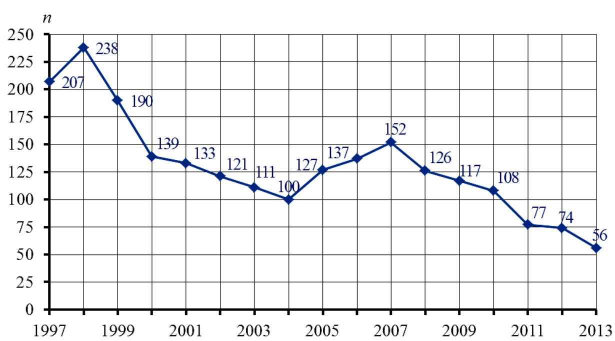

Fig. 1. Dynamics of n number of natural emergencies of natural character for the period of 1997–2013

We perform the forecast of the number of natural emergencies for one year ahead (for 2013) based on the previous data (1997–2012). Each time we use all available data to express coefficients of polynomials, and leave the data for the last year to check the accuracy (that is, the data of the previous 15 years is for 16th year).

Since the length of $Z(t)$ input implementation n=15 (t= =1, 2, 3,..., 15), we find $C(t)$ systematic component in the form of a regression model of the form:

$$C(t)=r_0+r_1t+r_2t^2+r_3t^3. \quad (13)$$

Fig. 2 presents the graph of the systematic component (point 1 corresponds to 1997, and so on, and point 16 corresponds to 2013, respectively).

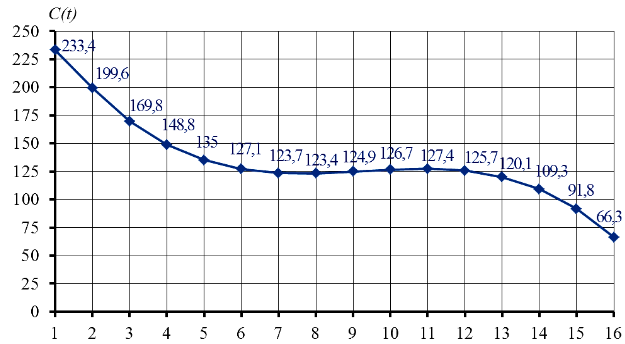

Fig. 2. Graph of C(t) systematic component of the process of the occurrence of natural emergencies

We detect and assess parameters of the periodic component after assessment and removal of the systematic component from $Z(t)$ implementation. Fig. 3 shows the graph of the periodic component.

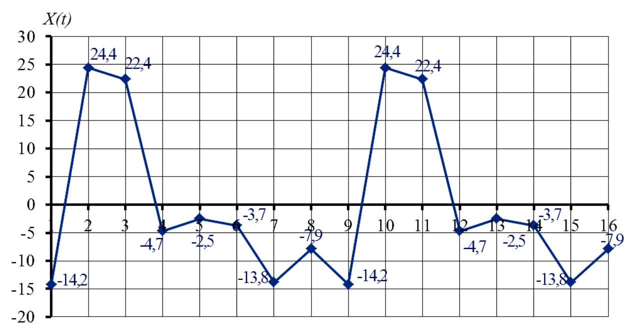

Fig. 3. Graph of $X(t)$ periodic component of the process of occurrence of natural emergencies

We forecast the random component in accordance with the method of group consideration of arguments after assessment and removal of the systematic component and the periodic component from Z(t) implementation.

Fig. 4 presents actual and forecasted values of the random component for 2002–2013.

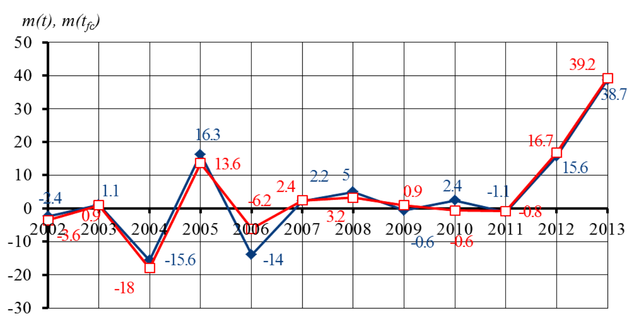

Fig. 4. Values of $m(t)$ random component and its $m(t_{fc})$ predicted values for the period of 2002–2013: ——— – represents actual values of the random component; ——— – represents forecasted values of the random component

There are forecasted values of $m(t_{fc})$ random component correlated with values of $m(t)$ random component with a correlation coefficient of 0.979635.

We produce the forecast of a possible number of emergencies of a natural character taking into consideration systematic, periodic, and random components in accordance with the expression (9). Fig. 5 presents actual data and the forecasted data on the number of natural emergencies for 2002–2013.

Thus, there were 56 emergency situations of a natural character recorded in 2013, and the expected value was 57 emergency situations of a natural character. We define the module of the average relative forecast error based on the factual information:

$$|\Delta| = \frac{\sum_{i=1}^{n} |\Delta_i|}{n} \approx 0{,}03. \quad (14)$$

Taking it into consideration, the expected value for the number of emergencies is in the range from 56 to 58.

In general, we can also use the method to make a forecast for a longer period, for example, two, three, and so on years ahead. Fig. 6 shows the graph of changes in the relative forecast error at making a forecast for a year, two years, three years, and four years ahead.

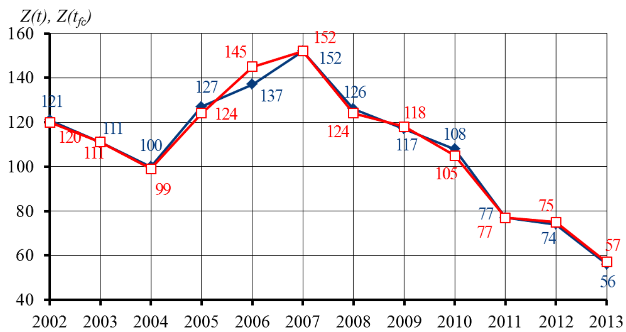

Fig. 5. Actual $Z(t)$ and forecasted $Z(t_{fc})$ values for the number of natural emergencies for the period of 2002–2013: ——— – represents actual values of a number of emergencies; ——— – represents forecasted values of a number of emergencies

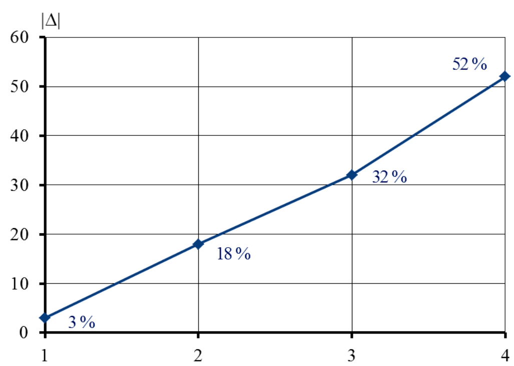

Fig. 6. Graph of the change in $|\Delta|$ relative forecast error in dependence on forecasted period

Analysis of the graph (Fig. 6) shows that the method provides the best accuracy at forecasting for a year ahead. However, we can also use it for forecasting for two years ahead with a relative forecasting error of up to 18 %, and then the forecast accuracy deteriorates sharply.

We determine the expected value of the number of emergencies by types based on the forecasted value of emergencies in 2013.

We use factual information on emergencies for 1997–2013 to calculate probabilities of occurrence of various types of emergencies in the case of occurrence of natural emergencies in Ukraine. “National Reports on the State of Technogenic and Natural Safety in Ukraine” present these data annually.

Fig. 7 shows the calculation results. We used the following designations in Fig. 7: 1 – geological emergencies, 2 – meteorological emergencies, 3 – hydrological emergencies, 4 – emergencies due to fires in natural ecosystems, 5 – medical and biological emergencies.

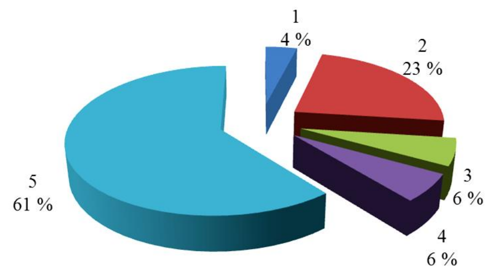

Fig. 7. Results of calculations of probabilities of natural emergencies by type (1 – geological emergencies, 2 – meteorological emergencies, 3 – hydrological emergencies, 4 – emergencies due to fires in natural ecosystems, 5 – medical and biological emergencies)

An analysis of the calculations (Fig. 7) shows that in the case of occurrence of an emergency in Ukraine, the most likely ones are the biomedical (with a probability of 61 %) and meteorological (with a probability of 23 %) emergencies.

The estimated number of geological emergencies is from 1 to 2 (actually, 2), meteorological emergencies from 12 to 13 (actually, 12), hydrological emergencies from 2 to 3 (actually, 2), emergencies due to fires in natural ecosystems from 2 to 3 (actually, 2), biomedical emergencies – from 34 to 36 (actually, 38).

6. Discussion of results of experimental study into combined method for forecasting of emergencies of natural character

The combined forecasting method makes it possible to make a forecast of possible number of emergencies for a certain pre-action time, taking into consideration the systematic (trend), periodic and random components of the process of occurrence of emergencies. The method combines methods of regression analysis, testing of statistical hypotheses, MGCA and probabilistic-statistical method of forecasting. This makes it possible to compensate disadvantages of some methods with a help of others and improves the accuracy of forecasting.

Assessment of all three components of the process of changing of the generalized parameter makes it possible not only to make a forecast for each of them, but also to analyze causes of emergencies more deeply.

The results of the experimental study (Fig. 2–7) showed that the combined method makes it possible to forecast emergency situations at least a year ahead with a relative forecast error of no more than three percent.

In general, we can use the method to forecast for several years ahead. At the same time, we use forecasted values as the latest statistical data, which inevitably leads to the loss of forecast accuracy. For example, for a forecast for two years ahead – the relative error of the forecast is about eighteen percent, for three years – about thirty-two percent, and for four years – about fifty-two percent. Thus, we can make a forecast for one or two years ahead with acceptable accuracy.

Consideration of periodic changes makes it possible to trace tendencies of periodic changes in the process of occurrence of natural emergencies due to an influence of destabilizing factors on its change. This circumstance plays an important role in a long-term planning of measures aimed at prevention or pre-action of such phenomena, maintenance of civil defense forces at a level, which guarantees an adequate response to emergencies and minimization of damage caused by them.

The proposed method makes it possible to forecast both the total number of emergencies and the number of natural emergencies by types for some time of prevention taking into consideration trends of their periodic changes.

We should note that MGCA solves the problem of construction of a mathematical model, which approximates an unknown pattern of the process. A sample of available data contains implicitly information on the process. Thus, there are some difficulties in the selection of destabilizing parameters of the process due to limited possibilities of their measurement.

It is necessary to direct further improvement of the method to the study of seasonal changes, which are characteristic to natural processes and phenomena.

7. Conclusions

1. We showed that the number of emergencies for a certain period of time describe the process of the occurrence of natural emergencies in general and reflects main trends of the process in general.

2. Taking into consideration an impact of all destabilizing factors, it is necessary to present the model of the process of changing of the generalized parameter in the form of an additive mixture of a systematic component, which characterizes irreversible processes of drift of parameters, periodic and random components. Such model makes it possible to take into consideration an influence of all destabilizing factors on the process of changing of the generalized parameter more fully and to analyze causes of occurrence of an emergency more deeply.

3. We proposed a combined method for forecasting of emergencies of natural character. The approach combines the method of regression analysis to forecast a systematic component of the generalized parameter, the method of verification of statistical hypotheses to identify a periodic component and the method of MGCA to forecast a random component. We used the probabilistic-statistical method to forecast the number of emergencies by type.

The combined method makes it possible to compensate disadvantages of some methods using other methods in order to improve accuracy of a forecast. The advantage of the proposed method is the ability to perform integrated forecasting of both the total number of emergencies and the number of emergencies by type taking into consideration trends of periodic changes.

4. We carried out experimental studies on effectiveness of application of the developed method for forecasting of natural emergencies based on statistical data on natural emergencies in Ukraine. We established that the method makes it possible to forecast natural emergencies for a year ahead with a relative forecast error of no more than three percent, two years ahead – about eighteen percent, three years ahead – about thirty two percent, four years ahead – about fifty two percent. Thus, we can make a forecast up to two years ahead with acceptable accuracy.

References

1. Zvit pro osnovni rezultaty diyalnosti Derzhavnoi sluzhby Ukrainy z nadzvychainykh sytuatsiy u 2017 rotsi. URL: http://www.dsns.gov.ua/files/2018/1/26/Zvit%202017(КМУ).pdf
2. Guskova N. D., Neretina E. A. Threats of natural character, factors affecting sustainable development of territories and their prevention // Journal of the Geographical Institute Jovan Cvijic, SASA. 2013. Vol. 63, Issue 3. P. 227–237. doi: https://doi.org/10.2298/ijgi1303227g
3. Numerical simulation of the creation of a fire fighting barrier using an explosion of a combustible charge / Dubinin D., Korytchenko K., Lisnyak A., Hrytsyna I., Trigub V. // Eastern-European Journal of Enterprise Technologies. 2017. Vol. 6, Issue 10 (90). P. 11–16. doi: https://doi.org/10.15587/1729-4061.2017.114504
4. Ivanets H. V. Analiz stanu tekhnohennoi, pryrodnoi ta sotsialnoi nebezpeky administratyvno-terytorialnykh odynyts Ukrainy na osnovi danykh monitorynhu // Zbirnyk naukovykh prats Kharkivskoho universytetu Povitrianykh Syl. 2016. Issue 3. P. 142–145.
5. System approach for readiness assessment units of civil defense to actions at emergency situations / Tiutiunyk V. V., Ivanets H. V., Tolkunov I. A., Stetsyuk E. I. // Scientific Bulletin of National Mining University. 2018. Vol. 1. P. 99–105. doi: https://doi.org/10.29202/nvngu/2018-1/7
6. Nivolianitou Z., Synodinou B. Towards emergency management of natural disasters and critical accidents: The Greek experience // Journal of Environmental Management. 2011. Vol. 92, Issue 10. P. 2657–2665. doi: https://doi.org/10.1016/j.jenvman.2011.06.003
7. Golovan Yu. V., Kozyr' T. V. Zashchita naseleniya v chrezvychaynyh situaciyah. Organizacionno-metodicheskiy kompleks. Moscow: Prospekt, 2015. 219 p.
8. Neisser F., Runkel S. The future is now! Extrapolated riskscapes, anticipatory action and the management of potential emergencies // Geoforum. 2017. Vol. 82. P. 170–179. doi: https://doi.org/10.1016/j.geoforum.2017.04.008
9. Novoselov S. V., Panikhidnikov S. A. Problems in prediction of number of emergencies by statistical methods // Mining Informational and Analytical Bulletin. 2017. Issue 10. P. 60–71. doi: https://doi.org/10.25018/0236-1493-2017-10-0-60-71

10. Extrapolation of Functions of Many Variables by Means of Metric Analysis / Kryanev A., Ivanov V., Romanova A., Sevastianov L., Udumyan D. // EPJ Web of Conferences. 2018. Vol. 173. P. 03014. doi: https://doi.org/10.1051/epjconf/201817303014
11. McCarthy J., Graniero P., Rozic S. An Integrated GIS-Expert System Framework for Live Hazard Monitoring and Detection // Sensors. 2008. Vol. 8, Issue 2. P. 830–846. doi: https://doi.org/10.3390/s8020830
12. Vasiliev M., Movchan I., Koval O. Diminishing of ecological risk via optimization of fire-extinguishing system projects in timber-yards // Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. 2014. Issue 5. P. 106–113.
13. Development of the technique for restricting the propagation of fire in natural peat ecosystems / Migalenko K., Nuianzin V., Zemlianskyi A., Dominik A., Pozdieiev S. // Eastern-European Journal of Enterprise Technologies. 2018. Vol. 1, Issue 10 (90). P. 31–37. doi: https://doi.org/10.15587/1729-4061.2018.121727
14. Predictor-weighting strategies for probabilistic wind power forecasting with an analog ensemble / Junk C., Delle Monache L., Alessandrini S., Cervone G., von Bremen L. // Meteorologische Zeitschrift. 2015. Vol. 24, Issue 4. P. 361–379. doi: https://doi.org/10.1127/metz/2015/0659
15. Cheyas I. A., Smith L. S. Neural Network Approach to Time Series Forecasting // Proceedings of the World Congress on Engineering. London, 2009. Vol. 2. URL: http://www.iaeng.org/publication/WCE2009/WCE2009_pp1292-1296.pdf
16. Morariu N., Iancu E., Vlad S. A neural network model for time series forecasting // Romanian Journal of Economic Forecasting. 2009. Issue 4. P. 213–223.
17. Hinman J., Hickey E. Modeling and forecasting sort-term electricity load using regression analysis // Journal of Institute for Regulatory Policy Studies. 2009. URL: https://irps.illinoisstate.edu/downloads/research/documents/LoadForecastingHinman-HickeyFall2009.pdf
18. Mazengia D. H. Forecasting Spot Electricity Market Prices Using Time Series Models. Gothenburg, 2008. 89 p.
19. Pradhan R. P., Kumar R. Forecasting Exchange Rate in India: An Application of Artificial Neural Network Model // Journal of Mathematics Research. 2010. Vol. 2, Issue 4. P. 111–117. doi: https://doi.org/10.5539/jmr.v2n4p111
20. Al-Jumeily D., Ghazali R., Hussain A. Predicting Physical Time Series Using Dynamic Ridge Polynomial Neural Networks // PLoS ONE. 2014. Vol. 9, Issue 8. P. e105766. doi: https://doi.org/10.1371/journal.pone.0105766
21. Szoplik J. Forecasting of natural gas consumption with artificial neural networks // Energy. 2015. Vol. 85. P. 208–220. doi: https://doi.org/10.1016/j.energy.2015.03.084
22. Yohannes Y., Webb P. Classification and regression tress: A User Manual for Identifying Indicators of Vulnerability to Famine and Chronis Food Insecurity. International Food Policy Research Institute, 1999. 59 p. URL: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1.1523&rep=rep1&type=pdf
23. Ivanets H. V., Tolkunov I. O., Stetsiuk Ye. I. Model protsesu zminy uzahalnenykh parametriv nadzvychainykh sytuatsiy pryrodnoho kharakteru // Problemy nadzvychainykh sytuatsiy. 2016. Issue 23. P. 46–52.
24. Ivahnenko A. G., Lapa V. G. Predskazanie sluchaynyh processov. Kyiv: Naukova dumka, 1971. 416 p.
25. Ivanec G. V. Odin iz metodov ocenivaniya periodicheskoy sostavlyayushchey lyuboy formy sluchaynogo processa pri proizvol'noy dline realizacii izmeryaemogo parametra // Zbirnyk naukovykh prats Kharkivskoho universytetu Povitrianykh Syl. 2017. Issue 1 (50). P. 38–41.
26. Stepashko V. S. Dostizheniya i perspektivy induktivnogo modelirovaniya // Upravlyayushchie sistemy i mashiny. 2017. Issue 2. P. 58–73.
27. Balasyanyan S. Sh., Gevorgyan E. M. Sravnitel'niy analiz metodov regressii i metoda gruppovogo ucheta argumentov pri modelirovanii processov pererabotki poleznyh iskopaemyh // Izvestiya Tomskogo politekhnicheskogo universiteta. Inzhiring georesursov. 2016. Vol. 327, Issue 4. P. 23–34.
28. Natsionalna dopovid pro stan tekhnohennoi ta pryrodnoi bezpeky v Ukraini u 2013 rotsi. Kyiv, 2014. 542 p.