ГЕОЛОГІЧНА ІНФОРМАТИКА

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EVALUATION OF RISKS EMERGENCIES BY MODELLING THE FUNCTIONAL STATUS OF THE OBJECTS

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Here one can find the approach to develop a model of functional state of researched object for the assessment of the risks emergencies appearance. The analysis of the causes of appearance and development of natural and anthropogenic emergencies is conducted and the most indicative causes are defined.

Emergency risk analysis is part of a system-wide approach to decision-making in the process of managing territories, procedures and practical measures to address the challenges of managing a security process. The basis of risk analysis is the physical and mathematical modeling of natural and socio-economic systems and processes occurring in them, which involves the interaction of the main components of the system with the environment in regular and extra-ordinary situations.

Since dangerous phenomena (emergencies) occur in a certain area with specific coordinates, it is quite clear that geo-information systems (GIS) and geo-information technologies (GIS) are most appropriate for assessing the risk of emergencies.

To describe the functioning of the monitoring object it is necessary to construct its mathematical model. The most complete state of the object of the study is characterized by its mathematical functional and statistical model (a system of equations that describes the dependence of the parameters of the monitoring object, its systems and subsystems on external and internal effects in the process of its functioning). Based on the analysis of this model, it becomes possible to formulate the main tasks that are solved by GIS in monitoring of natural or socio-economic systems, and synthesize the optimal structure of GIS.

Keywords: emergency situations, risk, risk assessment, model, geoinformation systems, geoinformation technologies.

Introduction. Despite the active development of scientific and technological progress, the widespread use of nano-, information and space technologies, society is still not immune to accidents and disasters caused by man-made or natural factors. The media provide information about forest fires, floods, earthquakes, landslides, volcanic eruptions, hurricanes, tornadoes, snowstorms and dust storms and other natural disasters, accidents and catastrophes in enterprises and transport, and the loss of people in the area of military conflicts, destruction of human settlements and objects of economic activity, pollution and infection of the environment.

Elements of the modern natural environment, society and its infrastructure are so closely interconnected and integrated with each other that even a small natural or man-made incident can affect not only its closest environment but also a substantially larger sphere (the "butterfly effect" or the Lorentz attractor), causing mass deaths and huge material damage. It is clear that these circumstances caused the urgent need to assess emergencies, measuring the losses caused by their appearance and the risks of their occurrence (the probability of their occurrence).

Each type of damage has its quantitative expression (the number of people in the danger zone, the number of dead, wounded or sick, the quantity and quality of destroyed material assets, quantitative losses of natural resources, the area of the affected or infected area, etc. In this case, cost approach can be used as well (definition of loss in cash equivalent).

The second, universal, more widespread assessment of danger is "risk". The concept of "risk" in various literary sources is interpreted as a danger, as the probability of an adverse event, as the expected loss from an adverse event, as a vector value, the components of which are the probability of an adverse event and the expected loss from it, etc.

The concept of risk has replaced the concept of normative models and standards and it comes from the fact that the level of danger for people's life and health can never be equal to zero. The use of the concept of risk allows you to get an adequate picture of the real dangers for people's lives, their size, opens new opportunities for the authorities on this basis to develop effective measures to reduce the impact on the health of people, especially highly dangerous and medium-risk factors.

In the mathematical sense, the risk is considered as a function of the probability of occurrence of an adverse situation and the damage made. Mathematical apparatus for analysis and risk assessment includes predictive modeling and scenario analysis, as well as probabilistic estimates *(The Code of Civil Protection of Ukraine…, 2012).*

Risk assessment can serve as the basis for preventing and mitigating the effects of the emergencies. This issue has become more and more relevant in recent years. An example is the UNO program APELL (Awareness and Preparedness for Emergencies at the Local Level *(APELL, 2015)*). The IMPACT project *(FEMA, 2001)* follows a similar goal.

Actuality of theme. Emergencies have a common problem for all countries of the world, they have a significant impact on the living conditions of the population, economic development of the countries and separate regions, the environment and infrastructure which were affected by emergencies. Consequences have a long-lasting effect, which in some cases may increase with time or have irreversible social, economic consequences.

Ukraine is one of the European countries that suffers greatly from the emergencies, which have a negative impact on the territory, cause death of people, destroy the infrastructure of the territories and create serious losses and obstacles for the further socio-economic development of the country.

In the ranking of the security level of the 2018 Institute for Economics and Peace, which was created on the basis of 23 qualitative indicators from authoritative sources, Ukraine ranked 152th *(Awareness and Preparedness for Emergencies at Local Level, n.d.).* The main reasons for such a low level of safety of the population, territories, social, man-made and natural objects in Ukraine are *(Ivanyuta and Kachynskyi, 2012):*

- imperfect state policy aimed at post-factional response to natural and man-made emergencies which negatively affect the life safety of the population and manifests itself in increasing the risk of natural phenomena caused by global warming of the climate, increasing seismic activity, expansion of ozone holes as well as intensification of influence of man's technogenic activity on the environment;

- significant number of dangerous man-made objects on the territory of Ukraine;
- increased probability and scale of the influence of natural emergency phenomena and disasters on the operation of dangerous man-made objects;
- increase of the risk of technogenic accidents and catastrophes caused by the critical degree of deterioration (60-80%) of the main productive assets in the leading industries, in agro-industrial complex, in life support systems of Ukraine;
- high level of traumatism and mortality of the population of Ukraine, caused by the emergencies of man-made and natural character;
- weakening of state control and inefficiency of mechanisms of state regulation of technogenic and natural safety;
- the inadequacy of the state preventive policy in the field of providing technogenic and natural safety in line with the level of real risks of dangerous natural phenomena and the degree of complexity and danger of modern technological complexes on the territory of Ukraine *(Anderson, 1963)*;
- the failure of a universal state system of civil protection of the population and territories in its present form to effectively resist modern threats to the safety of man, society and the state.

In Ukraine, at least 150-200 emergencies of various origin occur annually, resulting in a state losing about 3% of gross domestic product (Fig. 1) *(Bobalo et al., 2015).*

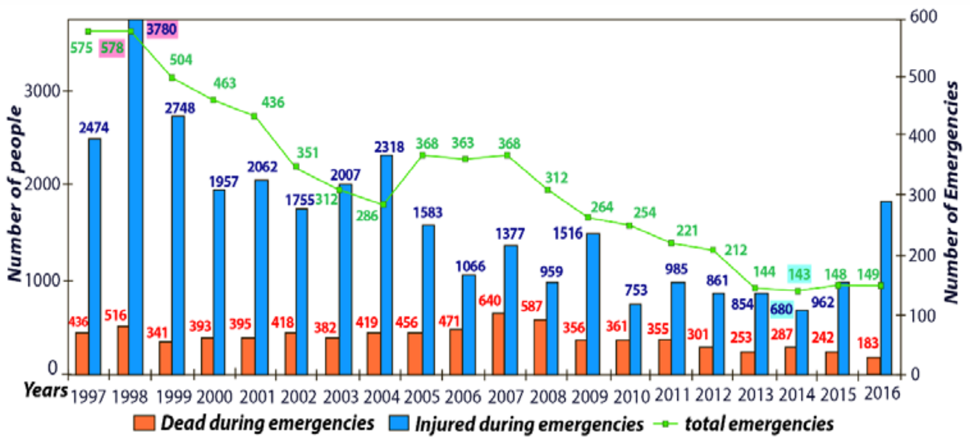

Fig. 1. The dynamics of emergency cases appearance on the territory of Ukraine during the period 1997-2016 ***(FEMA, 2001)***

And these figures will grow due to climate change and intensive socio-economic development of territories in areas of high risk of emergency appearance. As a result, there is a marked slowdown in the rate of economic growth of the country, a loss of a real opportunity for a massive improvement in the living standards of the citizens *(Analytical overview of man-made…, 2016).*

The purpose of the research is to develop mathematical, methodological, algorithmic and programmed software for modeling and assessing risks of emergencies appearance based on GIT and selecting the optimal GIS structure.

The degree/readiness of the topic researched. World practice in its arsenal has considerable experience in mathematical modeling of emergencies, objects and phenomena, represented by a large number of published scientific works, which reflect different aspects of this problem. The research on the control and forecasting of the dynamics of emergencies using mathematical modeling methods was done in the work of O.F. Vasiliev, M.M. Druzhynina, O.V. Ignatova, V.I. Kichigyna, V.I. Kostina, L.S. Kuchmenta, X.J.R. Avula, J. Bear, A. Vervnyt, E.A. Bender, M. Cross, A.A. Moscardini, R. Courant, D. Hilbert and a number of other scientists. Among the authoritative scientists, who made a significant contribution to the development of mathematical support for solving management problems in emergencies, one can mention M.M. Bichenka, B.M. Porfir'eva, I.V. Sergienko, V.S. Deineko, V.I. Pampuro, V.A. Pepelyaeva, K.L. Atoeva, R.I. Trukhayeva, S. Yanga, V.S. Mikhalevych, Y.P. Mikhno, A.A. Sakova, L.F. Nozhenkova, V.A. Rodicheva, A.D. Potapova, V.I. Telichenko, A.I. Shokyna, H.V. Fedulova, V.A. Panteleeva, I.I. Kuzmina, V.I. Osipova, M.Y. Berlyanda and many others.

However, the increased risk of emergencies suggests the need for further research in this area.

The object of the study is emergencies of natural and anthropogenic origin, analysis of approaches to assess the risk of emergencies with the help of geo-information systems.

The subject of the study is the methods of mathematical modeling, algorithms and a set of programs for assessing the risk of emergencies and modeling scenarios for their development using the GIT.

Research methods are based on the fundamental provisions of the theory of mathematical modeling, numerous methods for the solution of differential equations, the theory of complex systems analysis, decision-making, spatial analysis in GIS.

Presenting main material. Emergency situation is an environment on a separate territory or industrial subject or on a water object, which is characterized by violation of normal living conditions of the population caused by a disaster, accident, fire, natural disaster, epidemic, epizootic, epiphytotic, the use of means of destruction or other dangerous event that has led (or may lead to) a threat to the life or health of the population, a large number of dead and injured, significant material damage, as well as the impossibility to live or conduct a business on such territory or object *(Kussul et al., 2014).*

Natural-technological emergencies are distinguished by the nature of the source and magnitude. The following emergencies most often take place on the territory of Ukraine:

- accidents at industrial, civilian and military sites associated with loss of reliability and stability of structures;
- accidents (catastrophes) in transport;
- fires, explosions at industrial sites;
- fires in natural ecosystems;

- accidents with the release (threat of emissions) of unsafe chemicals on the objects of the economy (except transport);
- meteorological;
- geological;
- poisoning of people;
- infectious diseases of people;
- dangers associated with military actions in the area of anti-terrorist operation (ATO).

The analysis of the causes and development of natural and industrial emergencies shows that in most cases the basis of their origin and development are three meteorological factors: temperature, wind, precipitation. These parameters are the primary natural sources of emergencies, which in combination with humidity and atmospheric pressure form conditions for the emergencies and development of other dangerous natural processes and phenomena (floods, avalanches, mudflows, landslides, tornadoes, natural fires, droughts, dust storms, ice, etc.), which can already be considered as "secondary" natural sources of natural and man-made emergencies. *(Zatserkovnyi et al., 2016).* Methodologically, the task of forecasting the emergencies, risk assessment (risk probability) as well as any other multifactorial process or phenomenon can be solved by:

- mathematical modeling with the construction of a predictive model for calculating the forecast parameters;
- construction of semi-empirical forecasting models;
- construction of empirical predictive dependencies;
- construction of forecasting expert systems based on expert formalization of cause-and-effect relationships between types and parameters of process and phenomena sources and the parameters of their consequences.

To solve any problem of prediction by methods of mathematical modeling, semiempirical and empirical calculation of predictive parameters, including the task of short-term prediction of natural-technological disasters and the risk of their occurrence, a sufficient amount of information of high reliability and parametrization is required.

In the simplest form, the risk can be represented as a value derived from the probability and consequences:

$$R = P{\cdot}C,$$

where R is risk; P – probability; C – consequences.

In this case, incidents with high probability and mild consequences and incidents with low probability and severe consequences may have the same risk. For example, cases of collisions on the motorway route have a high probability, but the consequences of such cases are not always serious. It is much less likely that a high voltage pole will fall on a road vehicle, but the consequences will be much more severe. Although the objective values of the risk indicator for these two cases will be the same, people are inclined to assess these risks in different ways.

Consequently, when assessing the risks it is necessary to distinguish between objective and subjective (perceived or felt) risks. Objective risk is a risk calculated by a certain rule, most often - based on the probability of an incident. Subjective risk is a measure of danger that a person feels in one or another situation. Subjective risk can also be a measure of the consequences level, which is sufficient for a person to consider the incident as risky.

The risk is often attributed to a specific event. The vulnerability refers to the system, for example, to transport infrastructure, telecommunications or society as a whole. Vulnerability is a measure of how a system can cope with risk or endure risk. For example, the average risk of a long shutdown of electricity in modern infrastructure is rather low, with the exception of major natural disasters. However, despite the low risk, the vulnerability is very high. Thus, it is obvious that in order for risk to have some meaning, it must be in one way or another connected to the consequences. Implications can be one of the forms of visualization; the visual presentation of the effects often contributes to a better perception of the level of risk.

Risk reporting is the process of creating and delivering a message from an expert to a user that aims at informing about direct danger or providing general information about the risk that ordinary users perceive unlike experts.

Visualization can be divided into research and information visualization. The first approach involves research, that is, the study and analysis of phenomena or events that can be considered as risks. The second approach is aimed at informing and bringing information and attracting public attention.

Risk analysis is understood to mean systematic research and practice aimed at identifying and quantifying risk characteristics, assessing and comparing them with criteria to determine the appropriateness of the risk under consideration and to develop management priorities.

Risk analysis is part of the systematic approach to decision-making in the process of area management, procedures and practical measures while solving the tasks of managing the security process. The basis of risk analysis is the physical and mathematical modeling of natural and socioeconomic systems and processes occurring in them, which includes the interaction of the main components of the system with the environment in the regular and extraordinary situations. In the analysis of risks, scenarios of the emergence and development of accidents and disasters are developed and described using the basic defining equations and criteria of mechanics, physics and other sciences.

Quantitative risk assessment is an integral part of risk analysis. On the basis of risk analysis, a complex of safety-related work is carried out at all stages of the life cycle of natural and socio-economic systems (SES):

- development of means of protection against accidents and disasters;
- monitoring of the hazards of the functioning of the natural environment and SES;
- continuation of the resource of safe exploitation of man-made objects;
- modernization of man-made objects with increasing safety requirements;
- safe decommissioning, storage and disposal of dangerous man-made objects.

The conceptual basis for the analysis of the risk of emergency can be presented in the form of the algorithm depicted on fig. 2.

The overall logical sequence of steps (actions) in the methodology of quantitative analysis of the emergency risk occurrence involves:

1. Justification of goals and objectives of risk analysis. Planning and organization of works. Analysis of technological features of a natural and man-made object.
2. Identification of sources of risk and conditions under which they can negatively impact.
3. Determination of the frequency (or probability) of occurrence of undesirable events.
4. Determination of characteristics of sources of influence of dangerous factors (total quantity, intensity and duration: emissions, discharges, allocation of dangerous factors for the whole spectrum of undesirable events).
5. Justification of models and calculation of spatial-temporal transfer and distribution of source factors of danger to the environment.
6. Building potential risk areas around each of the selected sources of danger.
7. Calculation of direct and indirect consequences (losses) of negative influence of sources of danger on various subjects (recipients) or groups of risk.
8. Risk assessment and calculation of its indicators.

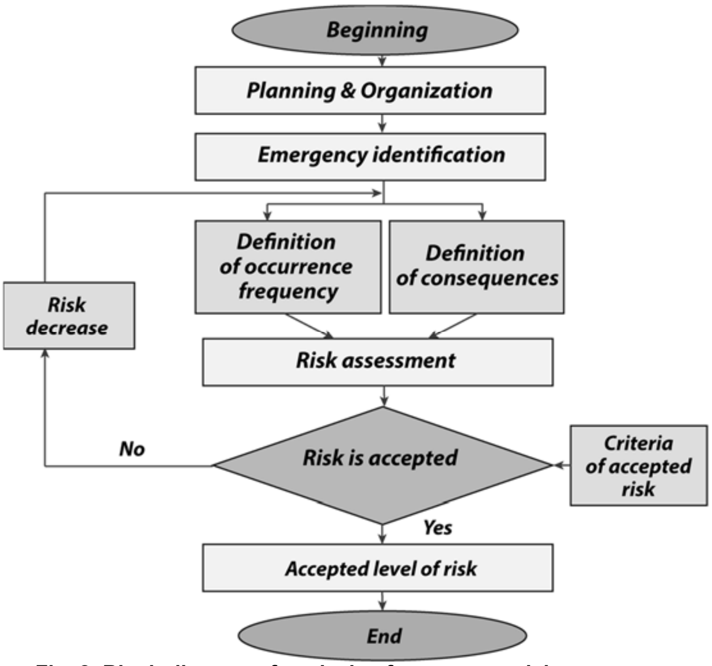

Fig. 2. Block-diagram of analysis of emergency risk occurrence

Since dangerous phenomena (emergencies) occur in a certain area which has specific coordinates, it is quite clear that geographic information systems (GIS) and geographic information technology (GIT) *(Demenkov, 2017)* are most appropriate to assess the risk of emergencies occurrence.

The main purpose of GIS for the tasks of assessing the emergencies risk occurrence is the correct definition of the state of the object of monitoring during a given interval of time. If the GIS task is to predict the normal conditions for the functioning of the monitoring object, then it must predict the behavior of the parameters of the monitoring object in the future.

GIS and GIT can serve as a convenient tool for solving the problems of regionalization of territories, assessing the state of the territory, describing socioeconomic systems, describing its properties, depending on the intended purpose and application, and provide an opportunity to build an effective system of support and management of decision-making. Because of the use of GIS, the time for preparing management, economic efficiency and the visualization of the scenarios for the development of the emergencies decisions is significantly reduced. As an example, on Image 3 the modeling of the flood zones of the city of Chernihiv under various security options is shown.

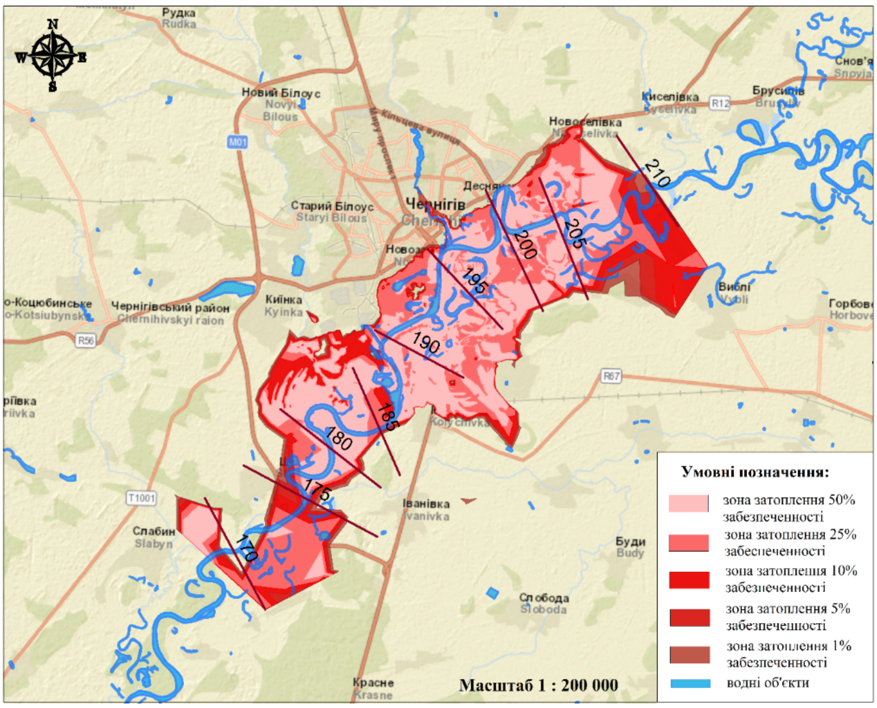

Fig. 3. Flood zones in city of Chernihiv under various security options

The GIS used in the decision-making system should provide control signals for the adoption of efficient (rational) managerial decisions. In this case, GIS acts as a managerial system that performs a substantially wider range of functions, as opposed to simply checking the state of the SES or visualizing the situation.

GIS performance of its functions is carried out at certain material costs, which means that the GIS efficiency assessment must be performed. Finding an optimal GIS option is a non-trivial task, since it requires taking into account a large number of characteristics of the research object (SES) and GIS, which are related to complex dependencies.

The task of GIS optimization is one of the tasks related to the optimization of complex automated systems and based on classical and modern mathematical methods: variational calculus, theory of statistical decisions, game theory, theory of operations research, information theory, probability theory, Pontryagin method, method of Bellman dynamic programming, etc.

On fig. 4 an algorithm for assessing the effectiveness and optimization of GIS is presented.

From fig. 4 one can see that the process of work-outing of general theory of GIS effectiveness and optimization is locked with a plurality of local inverse and direct relationships that are detected and refined in the process of the system design.

Complexity of monitoring process of the monitoring object (natural system, SES) is determined mainly by the complexity of the objects. To describe the functioning of the research object it is necessary to construct its mathematical model.

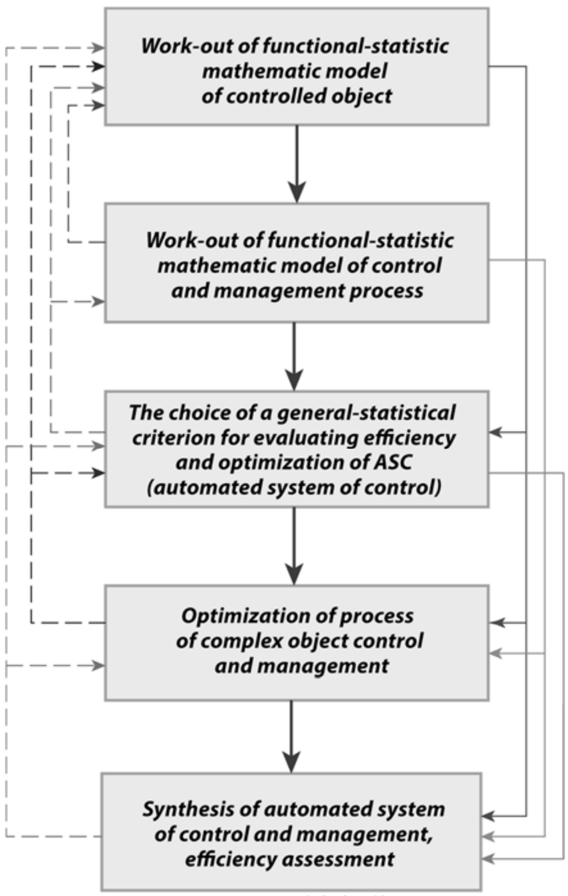

Fig. 4. Algorithm of GIS efficiency and optimization assessment

The most complete state of the object of the study is characterized by its mathematical functional and statistical model (a system of equations describing the dependence of the parameters of the object, system and block on external and internal influences in functioning).On the basis of the analysis of this model, the possibility of formulating the main tasks appears, which are solved by GIS in the process of monitoring of natural systems or SES, as well as synthesizing the optimal structure of GIS *(Zhyltsov, 2015).*

When constructing a mathematical functional and statistical model for monitoring an object, it is necessary to take into account that it contains all sorts of classes, subclasses and types of systems. These systems can be autonomous and non-autonomous, locked and unlocked, stationary and non-stationary, continuous and discrete. Therefore, it is advisable to use a general mathematical apparatus, which, if appropriate, can be extended to any individual cases.

In addition, when constructing a mathematical functional and statistical model of the research object, the main parameters of the criteria for which the optimization of the characteristics of the monitoring process is performed are taken into account. These parameters include:

- time of the process in general and its components;
- the probability of failure-free operation and the probability of the task being performed by various systems that are part of the object and the object as a whole;
- accuracy of different systems, their weight, volume, cost, electricity consumption and other indicators.

The perturbed state of a research object in monitoring and management can be described by the following system of equations, which is generally a mathematical functional model *(APELL, 2015).*

$$\sum_{\rho}^{m} M_{l\rho}(t,\tau,d/dt,Q)\square_{\rho} = F_l(t,\tau,X,Z);\quad l = 1,2,\ldots,m\,,$$

where $X\{\square_1,\ldots,\square_m\}$ – is a vector of random time functions, which characterizes the initial parameters of the object of research; $Z\{\zeta_1,\ldots,\zeta_k\}$ – is a vector of random time functions that characterizes external and internal disturbances and controlling influences; F_l – nonlinear function; $M_{l\rho}(t,\tau,d/dt,Q)$ – a polynomial with respect to differentiation operators d/dt with time-varying vector of coefficients $Q\{q_1,\ldots,q_n\}$; t – current time value; τ – the moment of time till which the object is under observation.

In the process of monitoring, the state of any dynamic system that is under the influence of controlling signals and disturbances, is determined by the initial parameters that are in certain way connected to the influences on the system through the corresponding system of equations (1), vector-operator of the dynamic system, given or a set by totality of mathematical operations $A_{l\rho}(t,\tau,X,Z,Q)$ or a set of linear or nonlinear differential equations:

$$\frac{d\square_i}{dt} F_{0i}(t,\tau,X,Z),\quad i = 1,2,\ldots m'\,, \qquad (1')$$

$$\xi_j = \sum_{i=1}^{k'} \xi_{ij}^0(t,\tau,X)\overline{\xi_i}\,,$$

where ξ_{ij}^0 – nonrandom coordinate functions; $\overline{\xi_i}$ – random coefficients; F_{0i} – nonrandom nonlinear function.

Each group in nominal conditions $\xi_{01},\ldots,\xi_{0k}$ from nominal area G_0 and nominal conditions $\square_{01},\ldots,\square_{0m'}$ has its corresponding solution to the system of equations (1):

$$x_{i0} = \varphi_{i0}\left(\tau_0,\tau,x_{01},\ldots,x_{0m'},\overline{\zeta}_{01},\ldots,\overline{\zeta}_{0k'}\right). \qquad (2)$$

Each group in real conditions at moments of time $t = \tau_1$, $\square'_{01},\ldots,\square'_{0m'}$ $\zeta_1,\ldots,\zeta_{k'}$ of real area G_l has its real solution of equations system (1):

$$x_i = \varphi_i\left(x'_{01},\ldots,x'_{0m'},\overline{\zeta}_1,\ldots,\overline{\zeta_{k'}},\tau_1,\tau\right). \qquad (3)$$

The system of equations (1), both in terms of the number of nonlinear operators and the number of output parameters can break up into *m* separate equations *(Silva et al., 2016).*

To simplify the calculations we will assume that the number of output parameters is equal to the number of operators, although, in general, they may be larger. For the *i*-th parameter the system of equations (1) degenerates into the equation

$$M_{lp}(t,\tau,\frac{d}{dt},q,...,q_n)\square_p = F_l(t,\tau,\square_l,\zeta_1,...,\zeta_k). \quad (4)$$

The impulse function of the system $w(t,\tau,\nu,\square_p,Z,Q)$, the transitive function of the system $h(t,\tau,\nu,\square_p,Z,Q)$, the transfer function of the system $W(t,\tau,p,\square_p,Z,Q)$, as well as the amplitude $A(t,\tau,\omega_1,\square_p,Z,Q)$ and phase $\phi(t,\tau,\omega,\square_p,Z,Q)$ frequency characteristics of the system correspond to this equation under linearization.

Conclusions. Consideration of equation of the perturbation state of the research object for the tasks of assessing the risks of emergencies allows us to perform a functional analysis of the state of the research object. However, a more complete description of the static and dynamic state of an object is the probabilistic description with the help of the laws of probabilities distribution of the parameters of elements of input influences, output parameters and vector-operators.

Since the probability of sudden failure is determined by known formulas of the theory of reliability, the main attention should be paid to determining the probability of the occurrence of gradual failures. Mathematical models based on the method of integration of differential equations based on the Monte Carlo method or on the method of quasilinear perturbations is used to determine the probability of gradual failures.

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РОЗРОБКА МОДЕЛІ ФУНКЦІОНАЛЬНОГО СТАНУ ОБ'ЄКТА МОНІТОРИНГА ДЛЯ ЗАВДАНЬ ОЦІНКИ РИЗИКІВ ВИНИКНЕННЯ НАДЗВИЧАЙНИХ СИТУАЦІЙ

Викладено підхід щодо побудови моделі функціонального стану об'єкта дослідження для завдань оцінки ризиків виникнення надзвичайних ситуацій. Проведено аналіз причин виникнення і розвитку природно-техногенних надзвичайних ситуацій та визначено найбільш характерні з них.

Аналіз ризику виникнення надзвичайних ситуацій є частиною системного підходу до ухвалення рішень у процесі управління територіями, процедур і практичних заходів у вирішенні завдань управління процесом забезпечення безпеки. Основою аналізу ризику є фізичне і математичне моделювання природних і соціально-економічних систем і процесів, що відбуваються в них, яке передбачає взаємодію основних компонентів системи з навколишнім середовищем у штатних і позаштатних ситуаціях.

Оскільки небезпечні явища (надзвичайні ситуації) відбуваються на певній території, яка має конкретні координати, то цілком зрозуміло, що для оцінки ризику виникнення надзвичайних ситуацій найбільш доцільно використовувати геоінформаційні системи (ГІС) та геоінформаційні технології (ГІТ).

Для опису функціонування об'єкта моніторингу необхідно побудувати його математичну модель. Найповніше стан об'єкта дослідження характеризує його математична функціонально-статистична модель (система рівнянь, що описує залежність параметрів об'єкта моніторингу, його систем і підсистем від зовнішніх і внутрішніх впливів у процесі його функціонування). На основі аналізу цієї моделі з'являється можливість формулювання основних задач, що розв'язуються ГІС у процесі моніторингу природних або соціально-економічних систем, а також синтезувати оптимальну структуру ГІС.

Ключові слова: надзвичайні ситуації, ризик, оцінка ризиків, модель, геоінформаційні системи, геоінформаційні технології.

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РАЗРАБОТКА МОДЕЛИ ФУНКЦИОНАЛЬНОГО СОСТОЯНИЯ ОБЪЕКТА МОНИТОРИНГА ДЛЯ ЗАДАЧ ОЦЕНКИ РИСКОВ ВОЗНИКНОВЕНИЯ ЧРЕЗВЫЧАЙНЫХ СИТУАЦИЙ

Изложен подход для построения модели функционального состояния объекта исследования для задач оценки рисков возникновения чрезвычайных ситуаций. Проведен анализ причин возникновения и развития природно-техногенных чрезвычайных ситуаций и определены наиболее характерные из них.

Анализ риска возникновения чрезвычайных ситуаций является частью системного подхода к принятию решений в процессе управления территориями, процедур и практических мер в решении задач управления процессом обеспечения безопасности. Основой анализа риска является физическое и математическое моделирование природных и социально-экономических систем и процессов, которые происходят в них, предусматривающее взаимодействие основных компонентов системы с окружающей средой в штатных и внештатных ситуациях.

Поскольку чрезвычайные ситуации (опасные явления) происходят на определенной территории, которая имеет конкретные координаты, то вполне понятно, что для оценки риска возникновения чрезвычайных ситуаций наиболее целесообразно использовать геоинформационные системы (ГИС) и геоинформационные технологии (ГИТ).

Для описания функционирования объекта мониторинга необходимо построить его математическую модель. Наиболее полно состояние объекта мониторинга характеризует его математическая функционально-статистическая модель (система уравнений, которая описывает зависимость параметров объекта мониторинга, системы и подсистем от внешних и внутренних влияний при его функционировании). На основе анализа этой модели появляется возможность формулирования основных задач, которые решаются ГИС в процессе мониторинга природных или социально-экономических систем, а также синтезирования оптимальной структуры ГИС.

Ключевые слова: чрезвычайные ситуации, риск, оценка рисков, модель, геоинформационные системы, геоинформационные технологии.