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ANALYSIS OF THE APPROACHES TO THE DEVELOPMENT OF THE MATHEMATICAL MODEL FOR THE MONITORING OF NATURAL AND ANTHROPOGENIC SYSTEMS ON THE BASIS OF DETERMINATION OF GRADUAL FAILURES PROBABILITY

(Представлено членом редакційної колегії д-ом геол. наук, проф. О. М. Іванік)

The approaches for creating a mathematical model for monitoring natural and technogenic systems (PTS) and emergency situations (ES) based on the probability of gradual failures are outlined.

The monitoring of the NAS and ES provides for comprehensive monitoring of changes in the natural and anthropogenic environment and its components. The complexity of this process is determined mainly by the complexity of the diagnostics of the monitoring objects and the precise measurement of a large number of indicators that determine the conditions and factors of the state of the NAS, environmental pollution, etc.

The practical solution of this problem is possible on the basis of the use of modern mathematical and geo-information methods of modeling that provide a comprehensive reflection of heterogeneous and multi-linked processes of formation and development of emergency situations of different origins, which can not be achieved with the use of traditional technologies.

To describe the functioning of monitoring systems, it is worth building a mathematical model of the research object. The most complete state of the object of the study is characterized by its mathematical functional and statistical model. However, a more complete description of the static and dynamic state of the monitoring object is a probabilistic description of the state of objects with the help of distribution laws of the probabilities of the parameters of the input influences elements, output parameters and vector-operators. Since the probabilities of sudden bounces are determined by known formulas of the reliability theory, the main attention is drawn to the determination of the probability of the gradual failures occurrence.It is established that three mathematical models may be applied to determine the probability of gradual failures (a mathematical model based on the integration of differential equations; a mathematical model based on the Monte Carlo method; a mathematical model based on the quasilinear disturbances method). The results show, that the proposed method of research may use to simulate various scenarios of flooding in the territories of the Chernihiv region.

Keywords: natural anthropogenic systems, emergency situations, models, geo-information systems, geo-information technologies.

Introduction. The complexification of modern technical systems, the growth of anthropogenic risks arising from environmental pollution, requires not only the increased safety of such systems, which is achieved, in particular, by the use of advanced control and diagnostics tools, but also in case of the effective monitoring system availability.

Monitoring of natural and anthropogenic systems (NAS) and emergency situations (ES) provides for comprehensive monitoring of changes in the natural and anthropogenic environment and its components. The complexity of this process is determined mainly by the complexity of the diagnostics of the monitoring objects and the precise measurement of a large number of indicators that determine the conditions and factors of the NAS state, manifestations of the movements of the geological environment, environmental pollution, etc.

Analysis of recent research and publications. Fundamentals of a comprehensive methodological approach to assessing the level of ecological safety of NAS and their monitoring are presented in the study of national scientists G. V. Lysychenko (*Lysychenko et al., 2008*), M. S. Malyovany (*Kharlamova et al., 2012*) and others, and of foreign authors A. M. Dies (*Dies, 2015*), M. N. Ordoueia (*Ordoueia et al., 2015*), V. Costantini (*Costantini et al., 2012*) and others.

Methodical provision of risk analysis were widely covered in the works of such scientists as A. B. Kaczynski (*Kachinsky et al., 2013*), Y. O. Yakovleva (*Bychenok et al., 2009*), H. O. Statyuhy (*Statyukhy and Boyko, 2013*) and in the studies of foreign authors – D. W. Connell (*Cao et al., 2013*), M. H. Whittaker (*Whittaker, 2015*) and others. However, the issue of the introduction of GIS and GIT in the task of monitoring of NA and ES, the development of reference models of their state, modeling scenarios for their development are considered only fragmentary. Therefore, the development of mathematical models for effective monitoring (diagnosis) of the NAS state and the development of ESs on the basis of determining the gradual failures probability is necessary and very relevant. This will detect, at an early stage, the processes of destabilization and stabilization of the state of the NAS, and let to model scenarios for the development of the state of the NAS objects.

Definition still unsolved aspects of the problem. Despite the existence of substantial studies on assess of the level of ecological safety of NAS and monitoring, but undoubtedlymuch remains to be done in the issue of the study of mathematical models for effective monitoring of the state of the NAS and the development of ES based on determining the probability of gradual failure.

The purpose and tasks of the study. The purpose of the study is to solve a scientific and practical task in analyzing approaches to creation of a mathematical model for monitoring the NAS and ES using GIS, GIT and methods of stochastic modeling, because it allows investigating the influence of factors that cannot be investigated by the determinate factor model.

The purpose and tasks of the study. The purpose of the study is to solve a scientific and practical task in analyzing approaches to creation of a mathematical model for monitoring the NAS and ES using GIS and GIT.

The object of the study is the mathematical models for the tasks of monitoring and diagnosing the state of the NAS with the help of GIS and GIT based on determining the gradual failures probability.

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

Presentation of the main material. The monitoring process consists of monitoring the properties of the objects and the implementation of targeted actions to identify and evaluate important researcher-relevant relationships between the characteristics of these properties.

The practical solution of this problem is possible on the basis of the use of modern methods of mathematical modeling and the means of geoinformation systems (GIS) and geo-information technologies (GITs), which provide a comprehensive mapping of heterogeneous and multi-linked processes of formation and development of the different origin ES which cannot be achieved under the condition of traditional technologies use.

The use of GIS enables operational monitoring, the construction of various ecological maps, as well as modeling of possible scenarios for the development of an environmental situation or emergency (*Kharlamova et al., 2012*). Execution of estimated calculations and cartographic visualization of the results give an opportunity to evaluate the consequences of management actions according to the most probable scenarios of the NAS and ES development and on this basis to work out adequate protective measures (*Zatserkovnyi, 2014; Zatserkovnyi and Tustanovska, 2018*). This provides an opportunity to increase the efficiency and validity of management decisions for warning reaction to the danger of the emergence occurrence, reduce the risk of their occurrence, in contrast to the traditional response to the consequences of their occurrence.

Relevance of the problem. Existing in Ukraine environmentally dangerous conditions connected with the presence of anthropogenic dangerous objects (nuclear power plants, chemical enterprises, objects of the petrochemical industry, dams, pipelines, etc.). In the context of improving the ecological sustainability of the NAS, reducing the risks of emergency occurrence, the task of constructing mathematical models of objects and monitoring processes is very relevant.

Mathematical models must meet certain requirements for the adequacy of the simulated process, the possibilities of their realization in automated monitoring systems in real time, the ability of automated decision making as for the state of the object and the forecast of its development (*Burachek et al., 2011*).

To describe the functioning of such systems, it is worth building a mathematical model of the research object. The most complete state of the object of the study is characterized by its mathematical functional and statistical model.

Under a mathematical functional statistical model one can understand the system of equations, which describes the dependence of the parameters of the object of study (NAS), GIS on external and internal impacts during functioning. Based on the analysis of this model, it is possible to formulate the main tasks that are solved by GIS when monitoring the object, and also synthesize the optimal structure of GIS.

When constructing a mathematical functional and statistical model of a monitoring object, it is necessary to take into account the fact that it includes various classes and types of systems. These systems can be stand-alone and non-autonomous, closed and open, stationary and non-stationary, non-stop and discrete. Therefore, it is relevant to use a general mathematical apparatus, which, if appropriate, can be extended to a variety of partial cases.

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

- time of the process as a whole and of its components;
- the probability of failure-free operation and the probability of the task being performed by the various systems included in the research object and SES in general;
- accuracy of different systems, their weight, volume, cost, energy consumption and other important 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 (*Demenkov, 2017*):

$$\sum_{\rho}^{m} M_{l\rho}\left(t,\tau,\frac{d}{dt},Q\right)x_{\rho} = F_l(t,\tau,X,Z);\ l=1,2,\dots,m\ , \qquad (1)$$

where $X\{x_1,\dots,x_m\}$ – a vector of random time functions that characterizes the output parameters of a research object; $Z\{\zeta_1,\dots,\zeta_k\}$ – a vector of random time functions that characterizes external and internal disturbances and operating impacts; F_l – non-linear function; $M_{l\rho}(t,\tau,d/dt,Q)$ – a polynomial relative to differentiation operators d/dt with variable-time vector of coefficients $Q\{q_1,\dots,q_n\}$; *t* – current time; τ – moment of time up to which the research of the object is done.

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

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

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

where ξ_{ij}^0 – non-random coordination functions; $\bar{\xi}_i$ – random coefficients; F_{0i} – non-randomnonlinearfunction.

Each group of nominal conditions with $t=\tau_0$, $\bar{\xi}_{01},\dots,\bar{\xi}_{0k}$ from nominal area $G_0$and initial conditions $x_{01},\dots,x_{0m'}$ corresponds to solution of equation system (1):

$$x_{i0} = \phi_{i0}(\tau_0,\tau,x_{01},\dots,x_{0m'},\bar{\xi}_{01},\dots,\bar{\xi}_{0k'})\ . \qquad (2)$$

Eachgroupofrealconditionsatcertainmomentoftime $t=\tau_1, x'_{01},\dots,x'_{0m'},\zeta_1,\dots,\zeta_{k'}$ ofrealarea G_1corresponds to the real solution of the equation system (1):

$$x_i = \phi_i(x'_{01},\dots,x'_{0m'},\bar{\zeta}_1,\dots,\overline{\zeta_{k'}},\tau_1,\tau)\ . \qquad (3)$$

The system of equations (1) both according to the number of nonlinear operators and the number of output parameters can split into *m*of separate equations.

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

$$M_{l\rho}(t,\tau,d/dt,q,\dots,q_n)x_{\rho} = F_l(t,\tau,x_i,\zeta_1,\dots,\zeta_k). \qquad (4)$$

Impulse function of the system $w(t,\tau,\nu,x_{\rho},Z,Q)$, transition function of the system $h(t,\tau,\nu,x_{\rho},Z,Q)$, transfer function of the system $W(t,\tau,\nu,p,x_\rho,Z,Q)$, as well as amplitude $A(t,\tau,w_1,x_\rho,Z,Q)$ and phase $\phi(t,\tau,w,x_\rho,Z,Q)$ frequency characteristics of the system correspond to this equation during linearization.

Consideration of the equation of perturbation state of an object allows us to perform a functional analysis of the state of the object, synthesis of the control system and evaluation of its effectiveness. 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 distribution of the probabilities of parameters of input impacts elements, output parameters and vector-operators. Since the probabilities of sudden bounces are determined by known formulas of the theory of reliability, the main attention is drawn to the determination of the probability of the gradual failures occurrence.

Three mathematical models can be used to determine the probability of gradual failures:

- mathematical model based on the method of differential equations integration;
- a mathematical model based on the Monte Carlo method;
- a mathematical model based on the method of quasilinear perturbations.

Under the method of integrating differential equations one can see is a method of direct calculation of multidimensional probability densities of output parameters of a study object with the help of integration of variables that are mathematical expressions of probability densities.

Monte Carlo method consists in repeated selection of random variable of system parameters with the following definition of the law of distribution of the output parameters of the research object.

The method of quasi-linear perturbations consists in representing the output parameters in the form of a Taylor line with the following definition of the law of distribution of probabilities of the initial parameters.

To determine the differential law of the system of random output parameters $x_1(t),...,x_{m'}(t)$ one can use the method described in (*Demenkov, 2017*).

Assuming that the solutions are obtained (2), differential law of probability distribution $f_0(x_1(t),...,x_{m'}(t),\bar{\xi}_{01},...,\bar{\xi}_{0k'},\tau_0,\tau)$ of the system of random variables $x_{01},...,x_{0m'}\zeta_{01},...,\zeta_{0k'}$, is known, the function F_{0i} has lump-continuous partial derivatives of the coordinates *xi*, the solution of the system of equations (1) *φi*has second partial derivatives of *xi* and *t*, and, moreover, the solutions have the first derivatives ζ_i, then the differential law of the distribution of the system of random variables $x_1,...,x_{m'}$ is determined by the equality (*Gnedenko,1988; Anderson,1963*).

$$f(x_1,...,x_{m'},t,\tau)=$$

$$=\int_{-\infty}^{\infty}...(k')...\int_{-\infty}^{\infty} f_0\exp\left\{-\int_{\tau_0}^{t}\sum_{j=1}^{m'}\frac{\partial F_{0j}}{\partial\eta_j}d\tau\right\}d\bar{\zeta}_1,...,d\bar{\zeta}_{k'}. \quad (5)$$

If we take into account the boundaries of value changes $\bar{\zeta}_1,...,\bar{\zeta}_{k'}$, thenthe equation (5) may be re-written in the following way:

$$f(x_1,...,x_m,t,\tau)=$$

$$=\int_{-\bar{\xi}_{1\min}}^{\bar{\xi}_{1\max}}...(k')...\int_{-\bar{\xi}_{k'\min}}^{\bar{\xi}_{k'\max'}} f_0\exp\left\{-\int_{\tau_0}^{t}\sum_{j=1}^{m'}\frac{\partial F_{0j}}{d\eta_j}d\tau'\right\}d\bar{\xi}_1,...,d\bar{\xi}_{k'},$$

Where $\eta_j=\phi_j\left[\tau_0,\tau,\phi_\gamma(\tau,\tau_0,x_\sigma,\bar{\xi}_\nu),\bar{\xi}_\nu\right]$ with indices *j, γ, σ,* which take on value $1,2,...,m$, and *ν* take on value $1,2,...,k'$.

To determine the law of distribution of the transitive function of the study object it is necessary on its entry to submit leap-like effects and to determine the law

$$f(h_1,...,h_{m'},t,\tau)=$$

$$=\int_{-\bar{\xi}_{1\min}}^{\bar{\xi}_{1\max}}...(k')...\int_{-\bar{\bar{\zeta}}_{k'\min}}^{\bar{\xi}_{k'\max}} f_0\exp\left\{-\int_{\tau_0}^{t}\sum_{j=1}^{m'}\frac{\partial F_{0j}}{\partial\eta_j}d\tau'\right\}d\bar{\zeta}_1,...,d\bar{\zeta}_{k'}.$$

To determine the differential *m'*-dimensional law of the distribution of impulse functions, one can use the Jacobian of the transformation *I(fh⟶ fw)*, taking into account that

$$w(t,\tau,X,Z,Q)=h'(t,\tau,X,Z,Q).$$

The differential law of the distribution of the transfer function of amplitude and phase-frequency characteristics is determined in case of harmonic impacts on the object.

Then we get:

- law of distribution of the transfer function of an object

$$f(W_1,...,W_{m'},t,\tau)=$$

$$=\int_{-\bar{\xi}_{1\min}}^{\bar{\xi}_{1\max}}...(k')...\int_{-\bar{\xi}_{k'\min}}^{\bar{\xi}_{k'\max}} f_0\exp\left\{-\int_{\tau_0}^{t}\sum_{j=1}^{m}\frac{\partial F_{0j}}{\partial\eta_j}d\tau'\right\}d\bar{\zeta}_1,...,d\bar{\zeta}_{k'};$$

- the law of the distribution of the amplitude-frequency characteristic of the object:

$$f(A_1,...,A_{m'},t,\tau)=$$

$$=\int_{-\bar{\xi}_{1\min}}^{\bar{\xi}_{1\max}}...(k')...\int_{-\bar{\xi}_{k'\min}}^{\bar{\xi}_{k'\max}} f_0\exp\left\{-\int_{\tau_0}^{t}\sum_{j=1}^{m'}\frac{\partial F_{0j}}{\partial\eta_j}d\tau'\right\}d\bar{\zeta}_1,...,d\bar{\zeta}_{k'};$$

- the law of the distribution of the phase-frequency characteristics of the object:

$$f(\phi_1,...,\phi_{m'},t,\tau)=$$

$$=\int_{-\bar{\xi}_{1\min}}^{\bar{\xi}_{1\max}}...(k')...\int_{-\bar{\xi}_{k'\min}}^{\bar{\xi}_{k'\max}} f_0\exp\left\{-\int_{\tau_0}^{t}\sum_{j=1}^{m'}\frac{\partial F_{0j}}{\partial\eta_j}d\tau'\right\}d\bar{\zeta}_1,...,d\bar{\zeta}_{k'}.$$

Thus, it is theoretically possible to quite precisely define *m'*-dimensional differential laws of the distribution of the output parameter and vector-operators. However, integration in explicit way is possible only when the probability density is a simple analytic function of random parameters. With the increasing number of parameters and complexity of the analytical functions, the use of the method brings up significant mathematical difficulties.

For complex objects with nonlinearities at probabilistic analysis, for practical tasks it is sometimes enough to evaluate only the first two moments of the output parameters: the mathematical expectation and the correlation function or dispersion. These moments allow us to fully determine the probability distribution law, which can be roughly considered normal.

The system of differential equations of perturbed state of an object in a generalized form is represented as (*Demenkov, 2017*):

$$\begin{cases}\sum_{\rho=1}^{m}M_{l\rho}(t,\tau,\frac{d}{dt},Q)x_\rho=F_l(X,Z,t,\tau)+\phi_l(Z_l);\\ Z_l=\sum_{i=1}^{S_l}a_i^l x_i+\sum_{j=1}^{N_l}c_j^l\zeta_j;\quad l=1,...,m,\end{cases} \quad (6)$$

where a_i^l, c_j^l – constant coefficients; $X\{x_1,...x_m\}$ – vector of random functions of parameter *t*, which determines the object motion; $Z\{\zeta_1,...,\zeta_k\}$ – perturbation vector which is a random function of parameter *t*; F_l – nonlinear functions which that assume linearization vs certain regime of object motion within working ranges of value or functions; ϕ_l – nonlinear functions which that do not assume regular linearization; $M_{l\rho}$ – polynomials vs differentiation operator with variable coefficients in time; S_l – number of parameters that determine the object behavior; N_l – number of acting perturbations.

Aftercorrespondingtransformationsalinearsystemofequationsis created for further definition of mathematical expectation of random functions:

$$\begin{cases} \sum_{\rho=1}^{m} M_{l\rho}(t,\tau,\frac{d}{dt},Q)m_{x\rho} = F_l(t,\tau,m_x,m_l) + K_0^l m_l; \\ m_l = \sum_{i=1}^{S_l} a_i^l m_{xi} + \sum_{j=1}^{N_l} c_j^l m_{\zeta j}. \end{cases} \quad (7)$$

And system of equations for definition of random components of functions:

$$\begin{cases} \sum_{\rho=1}^{m} M_{l\rho}(t,\tau,\frac{d}{dt},Q)x_\rho^0 = \sum_{\mu=1}^{m}\left[\frac{\partial F_l}{\partial m_{x\mu}}\right]_0 x_\mu^0 + \sum_{j=1}\left[\frac{\partial F_l}{\partial m_{\zeta j}}\right]_0 \zeta_\mu^0 + K_1^l z_l^0; \\ z_l^0 = \sum_{i=1}^{S_l} a_i^l x_i^0 + \sum_{j=1}^{N_l} c_j^l \zeta_j^0, \end{cases} \quad (8)$$

where K_0^l and K_1^l – statistical gain factors (*Demenkov, 2017*).

After integrating the systems of equations (7) and (8), for example, by the method of successive approximations, let us define the mathematical expectation, the correlation functions and the dispersion of the initial parameters.

This method of an approximate solution may be used when the method of harmonic linearization does not give the desired results.

Applying the proposed approaches for modeling scenarios of flooding the territories of the region, the authors found that a majority of match between the simulation results and the actual data provided by the Desnyanskym BUVR gives a methodology for determining the probability of gradual failures (quasilinear disturbances). The simulation results for this approach are presented in fig. 1.

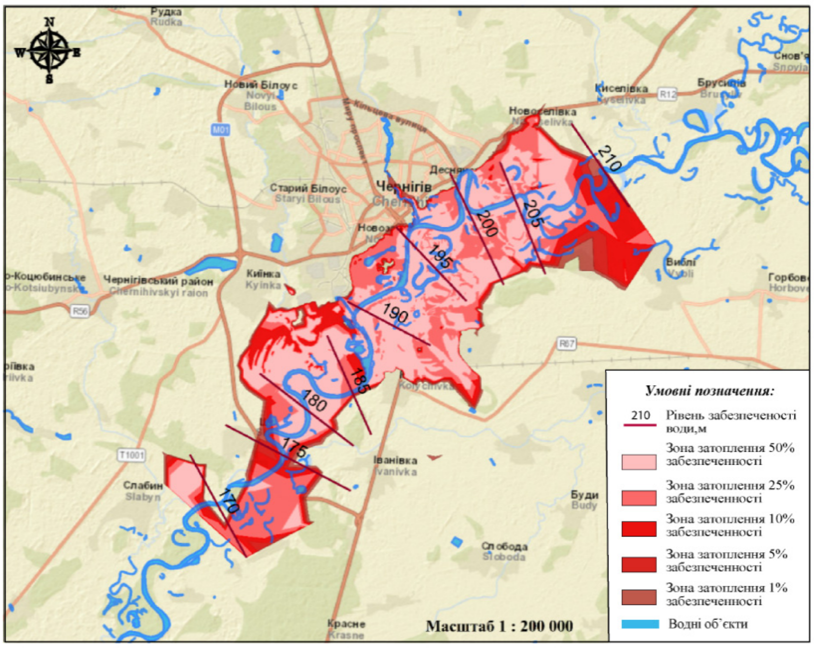

Fig. 1. Visualization of flood areas of Chernihiv surroundings with different safety levels(translation of the map signs: light pink – flood area of 50 % safety; pinks – flood area of 25 % safety; red – flood area of 10 % safety; dark red – flood area of 5 % safety; brown – flood area of 1 % safety; blue line – water objects)

Water objects of the region and points of hydrological observations are represented in the digital model by three main types of spatial objects: point (hydrometric points, sampling points), linear (rivers) and polygonal (lakes, large rivers and reservoirs).As the result, a complete set of objects of the same class within a given territory forms a layer. The map provides an opportunity to designate lines of estimated water levels of 1%, 5%, 10%, 25%, 50% of the Desna River's safety in the Chernihiv region.

The terrain relief in the digital model is reflected in the form of three-dimensional data as a set of elevations and horizontal records. The digital model is used to obtain a number of morphometric derivatives or other data, including the exposure of slopes, cross-sectional profiles, generation of watershed lines, etc. Hence, a common form of creating a surface model is triangulation. One of the most frequently used triangulation models for creating a digital elevation model is TIN, when constructed, discrete points are connected by lines forming triangles. Since the surface of each triangle is determined by the height of its three vertices, the use of triangles ensures that each surface of the network fits snugly to adjacent areas. This ensures the continuity of surfaces with an irregular location of points and determines the complete topological connections for points, and for the construction of triangles only a local search is required. The TIN contains an array of coordinates and a pointer file in which for each point all output data from it is recorded. Thus, each side is recorded twice. Based on the three-dimensional model of the relief, it is possible to assess, predict and monitor water resources, to study the change of the coastline due to the rise of the water level.

Conclusions. This study has shown that the described approaches to creating a mathematical model for the monitoring of natural-anthropogenic systems (NAS) and emergency situations (ES) based on determining the probability of gradual failures, it is advisable to use in the tasks of managing territories, forecasting the development of emergencies in monitoring NAS, making decisions in

situational centers on emergency response. It is established that three mathematical models may be applied to determine the probability of gradual failures (a mathematical model based on the integration of differential equations; a mathematical model based on the Monte Carlo method; a mathematical model based on the quasilinear disturbances method). The research results were used to simulate various scenarios of flooding in the territories of the Chernihiv region. Therefore, the construction and application of the proposed mathematical models is an important in the creation of effective monitoring systems and increase the control of territory management.

Список використаних джерел

Андерсон, Т. (1963). Введение и многомерный статистический анализ. Киев.

Биченок, М. М.,Іванюта, С. П., Яковлєв,Є. О. (2009). Ризики життєдіяльності у природно-техногенному середовищі: монографія. Київ: РНБО.

Бурачек, В. Г.,Железняк,О. О., Зацерковний, В. І. (2011). Геоінформаційний аналіз просторових даних: монографія. Ніжин: Аспект-Поліграф.

Гнеденко, Б. В. (1988). Курс теории вероятностей. Москва: Наука.

Деменков, Н. П. (2017). Статистическая динамика систем управления: учебное пособие. Москва: Издательство МГТУ им. Н. Э. Баумана.

Зацерковний, В. І.,Тустановська, Л. В. (2018). Геоінформатика.Ніжин: НДУ ім. М. Гоголя.

Зацерковний, В. І. (2014). Аналіз моделей інтеграції технологій ГІС, ДЗЗ і GPS в задачах моніторингу стану навколишнього середовища. *Математичні машини і системи*, 4, 44-52.

Качинский, А. Б., Агаркова, Н. В., (2013). Структурный анализ системы обеспечения экологической и природно-техногенной безопасности Украины. *Системні дослідження та інформаційні технології*, 1, 7–15.

Лисиченко, Г. В., Забулонов, Ю. .Л., Хміль, Г. А. (2008). Природний, техногенний та екологічний ризики: аналіз, оцінка, управління. Київ: Наукова думка.

Статюха, Г. О., Бойко, Т. В. (2013). Системний підхід до оцінювання ризиків при проектуванні промислових об'єктів. *Східно–Європейський журнал передових технологій*, 14, 8–12.

Харламова, Е. В., Малеваный, М. С., Пляцук, Л. Д. (2012). Теоретические основы управления экологической безопасностью техногенно нагруженного региона. *Екологічнабезпека*, 1, 9–12.

Cao, Q., Yu, Q., Connell, D. W. (2013). Health risk characterisation for environmental pollutants with a new concept of overall risk probability. *Journal of Hazardous Materials*, 187, 480–487.

Costantini, V. H., Mazzanti, M., Montini, A. (2012). Economic-Environmental Accounts Routledge: New York.

Dies, A. M. (2015). Economic aspects of thermal treatment of solid waste in sustainable system. *Waste Management*, 37, 45–57.

Ordoueia, M. H., Dusseaultb, M. B., Alhajric, I. (2015). New sustainability indices for product design employing environmental impact and risk reduction: case study on gasoline blends. *Journal of Cleaner Production*, 108, Part A, 312–320.

Whittaker, M. H. (2015). Risk Assessment and Alternatives Assessment: Comparing Two Methodologies. *Risk Analysis*, 35, 12,2129–2136.

References

Anderson, T. (1963). Introduction and multidimensional statistical analysis. Kiev. [in Russian].

Burachek, V. G., Zheleznyak, O. O., Zatserkovny, V. I. (2011). Geoinformation analysis of spatial data: monograph. Nizhyn: Aspect-Polygraph. [in Ukrainian]

Bychenok, M. M., Ivaniuta, S. P., Yakovleva, E. A. (2009). Risks of life in the natural and man-made environment: monograph. Kyiv: NSDC. [in Ukrainian]

Cao, Q., Yu, Q., Connell, D. W. (2013). Health risk characterisation for environmental pollutants with a new concept of overall risk probability. *Journal of Hazardous Materials*, 187, 480–487.

Costantini, V. H., Mazzanti, M., Montini, A. (2012). Economic-Environmental Accounts Routledge: New York.

Demenkov, N. P. (2017). Statistical dynamics of control systems: a manual. Moscow: Publishing MGTU N.E. Baumana. [in Russian]

Dies, A. M. (2015). Economic aspects of thermal treatment of solid waste in sustainable system. *Waste Management*, 37, 45–57.

Gnedenko, B. V. (1988). The course of probability theory. Moscow: Science. [in Russian].

Kachinsky, A. B., Agarkova, N. V. (2013). Structural analysis of the system for ensuring ecological and natural and technogenic safety of Ukraine. *System Research and Information Technology*, 1, 7-15. [in Ukrainian]

Kharlamova, E. V., Malevany, M. S., Plyatsuk, L. D. (2012). Theoretical bases of environmental safety management of a technologically loaded region. *Ecological safety*, 1, 9–12. [in Russian]

Lysychenko, H. V, Zabulonov, Yu. L., Khmil, G. A. (2008). Natural, technological and environmental risk analysis, assessment and management. Kyiv: Scientific Thought. [in Ukrainian]

Ordoueia, M. H., Dusseaultb, M. B., Alhajric, I. (2015). New sustainability indices for product design employing environmental impact and risk reduction: case study on gasoline blends. *Journal of Cleaner Production*,108, Part A, 312-320.

Statyukha, G. O., Boyko, T. V. (2013). System approach to risk assessment when designing industrial objects. *Eastern European Journal of Advanced Technologies*, 14, 8-12. [in Ukrainian]

Whittaker, M. H. (2015). Risk Assessment and Alternatives Assessment: Comparing Two Methodologies. *Risk Analysis*, 35, 12, 2129–2136.

Zatserkovnyi, V. I. (2014). Analysis of models of integration of GIS, remote sensing and GPS technologies in environmental monitoring tasks. *Mathematical Machines and Systems*, 4, 44-52. [in Ukrainian]

Zatserkovnyi, V. I., Tustanovska, L. V. (2018). Geoinformatics. Nizhyn: NDU M. Gogol. [in Ukrainian]

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АНАЛІЗ ПІДХОДІВ ЩОДО СТВОРЕННЯ МАТЕМАТИЧНОЇ МОДЕЛІ ДЛЯ ЗАДАЧ МОНІТОРИНГУ ПРИРОДНО-ТЕХНОГЕННИХ СИСТЕМ НА ОСНОВІ ВИЗНАЧЕННЯ ІМОВІРНОСТІ ПОСТУПОВИХ ВІДМОВ

Викладено підходи створення математичної моделі для задач моніторингу природно-техногенних систем (ПТС) і надзвичайних ситуацій (НС) на основі визначення імовірності поступових відмов.

Моніторинг ПТС і НС передбачає комплексні спостереження за змінами природно-техногенного середовища та його компонентів. Складність цього процесу зумовлюється головним чином складністю діагностування об'єктів моніторингу і точного виміру великої кількості показників, що визначають умови і фактори стану ПТС, екологічного забруднення тощо.

Практичне розв'язання цієї задачі можливе на основі використання сучасних методів математичного та геоінформаційного моделювання, які забезпечують комплексне відображення різнорідних і багатозв'язаних процесів формування і розвитку надзвичайних ситуацій різного походження, що неможливо досягти за умови використання традиційних технологій.

Для опису функціонування систем моніторингу доцільно побудувати математичну модель об'єкта дослідження. Найбільш повно стан об'єкта дослідження характеризує його математична функціонально-статистична модель. Проте більш повною характеристикою статичного і динамічного стану об'єкта моніторингу є імовірнісний опис стану об'єктів за допомогою законів розподілу імовірностей параметрів елементів вхідних впливів, вихідних параметрів і векторів-операторів. Оскільки імовірності раптових відмов визначаються за відомими формулами теорії надійності, то основна увага звертається на визначення імовірності появи поступових відмов. Установлено, що для визначення імовірності поступових відмов можуть бути використані три математичні моделі (математична модель, заснована на інтеграції диференціальних рівнянь; математична модель на основі методу Монте-Карло; математична модель на основі методу квазілінійних збурень). Результати показують, що запропонований метод дослідження можливо використовувати для моделювання різних сценаріїв затоплення території Чернігівської області.

Ключові слова: природно-техногенні системи, надзвичайні ситуації, моделі, геоінформаційні системи, геоінформаційні технології.

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АНАЛИЗ ПОДХОДОВ К СОЗДАНИЮ МАТЕМАТИЧЕСКОЙ МОДЕЛИ ДЛЯ ЗАДАЧ МОНИТОРИНГА ПРИРОДНО-ТЕХНОГЕННЫХ СИСТЕМ НА ОСНОВЕ ОПРЕДЕЛЕНИЯ ВЕРОЯТНОСТИ ПОСТЕПЕННЫХ ОТКАЗОВ

Изложены подходы создания математической модели для задач мониторинга природно-техногенных систем (ПТС) и чрезвычайных ситуаций (ЧС) на основе определения вероятности постепенных отказов.

Мониторинг ПТС и ЧС предусматривает комплексные наблюдения за изменениями природно-техногенной среды и ее компонентов. Сложность этого процесса обусловливается главным образом сложностью диагностирования объектов мониторинга и точного измерения большого количества показателей, которые определяют условия и факторы состояния ПТС, экологического загрязнения и т.д.

Практическое решение этой задачи возможно на основе использования современных методов математического и геоинформационного моделирования, которые обеспечивают комплексное отображение разнородных и многосвязных процессов формирования и развития чрезвычайных ситуаций различного происхождения, что невозможно достичь при условии использования традиционных технологий.

Для описания функционирования систем мониторинга целесообразно построить математическую модель объекта исследования. Наиболее полно состояние объекта исследования характеризует его математическая функционально-статистическая модель. Однако более полной характеристикой статического и динамического состояния объекта мониторинга является вероятностное описание состояния объектов с помощью законов распределения вероятностей параметров элементов входных влияний, выходных параметров и векторов-операторов. Поскольку вероятность внезапных отказов определяется по известным формулам теории надежности, то основное внимание уделяется определению вероятности появления постепенных отказов. Установлено, что для определения вероятности постепенных отказов могут применяться три математические модели (математическая модель, основанная на интегрировании дифференциальных уравнений; математическая модель, основанная на методе Монте-Карло; математическая модель, основанная на методе квазилинейных возмущений). Полученные результаты показывают, что предлагаемый метод исследования можно использовать для моделирования различных сценариев затопления территории Черниговской области.

Ключевые слова: природно-техногенные системы, чрезвычайные ситуации, модели, геоинформационные системы, геоинформационные технологии.