RT&A, Special Issue № 4 (70)
Volume 17, November 2022

FORECAST OF NATURAL EMERGENCY SITUATIONS WITH MODERN METHODS

Valery Akimov, Maxim Bedilo, Olga Derendiaeva, Ekaterina Ivanova, Irina Oltyan

•

"All-Russian Research Institute for Civil Defense and Emergency Situations of the Emergencies Ministry of Russia" (Federal Center for Science and High Technologies)
akimov@vniigochs.ru
vniigochs@vniigochs.ru
irenaoltyan@mail.ru

Abstract

The article discusses the verbal and mathematical base for the forecast modeling of the most catastrophic natural emergencies, the sources of which are: hazardous hydrological phenomena; hazardous meteorological phenomena; hazardous geophysical phenomena; large natural fires.

Keywords: natural emergency situations, hazardous hydrological phenomena, hazardous meteorological phenomena, dangerous geophysical phenomena, large natural fires, modeling methods.

I. Introduction

According to the degrees of catastrophicity in the Russian Federation, the following natural emergence can be distinguished [1,2]: "Hazardous hydrological phenomena, hazardous meteorological phenomena, dangerous geophysical phenomena, large natural fires."

II. Methods

Hazardous hydrological phenomena [3].

"Sources of natural emergencies are hazardous hydrological phenomena and processes such as floods, tsunami, avalanche. Among them are the most catastrophic (by the number of deaths, affected people and material damage) are floods"[4].

Floods caused by various reasons [5].

"Russia is affected by spring floods caused by the melting of snow cover, accumulated during the cold winter period. The spring floods on the rivers (which current from the south to the north) are often accompanied by the ice. All these aggravate the disaster dimensions. Such floods include a catastrophic flooding of Lensk, which happened on the River Lena in 2001.

Floods can be a result of the fallout of intensive rain or the passage of typhoons and monsions, covering significant waterborne areas and forming rain floors in Russia. Some of the latest examples of this dangerous phenomenon are floods at the Kuban basin in 2002 and at the Amur Basin in 2013.

Another problem is a flood of man-made character. These include floodings caused by unreasonable discharge through the structures of water consumption hydraulosles, superior to the bandwidth of the river bed. The threat of flooding the territories of settlements under the protection of dams requires increased attention to the structures of engineering protection. There are about 180 cities and large settlements in Russia which are in danger due to these disasters. An example of this disaster is the flood in Tulun on the River Jia during 2019. The insufficiency of territorial planning activities was accompanied by poor quality design and construction of the city engineering system.

The threat of flooding as a result of the cooler and burial phenomena is essential for Russia. The ice constrains cross-section of the river and leads to an increase in water level on the over-site and flooding adjacent territories. Ice burrow - a phenomenon similar to the ice traffic, which is a cluster of shugs in the river bed, accompanied by a clogging of some part of its living section and leads to the increase in the water level above this cluster."

There are two approaches to mathematical modeling of complex phenomena [6]. "When deterministic modeling, the variables are entered in such a way to obtain a discrete result, operate with numerically pronounced specific values of the parameters. Stochastic modeling uses the sample and probability to receive answers. It is used a deterministic model for floods. The deterministic approach has the advantages of rapid calculation and fairly accurate results, which plays a special role for the effectiveness of alert and response measures. An additional advantage is the limited amount of input data required for modeling."

The key flood striking factor is the flood zone. To calculate the flood exposure zone, the characteristic of the river flow is required, including the forecast of the depth of the flow, the flow rate and the extent of the flood. Hydraulic models use control equations of the flow in motion (storing the principles of mass and pulse) to predict the flow characteristics. However, the solution of such equations may be expensive depending on their spatial expansion. Moreover, the simulation of a two-or three-dimensional river runoff using high-resolution topographic data for large-scale regions is almost impossible.

The large number of models of flow forming and dynamics of the flow - flooding streams, the most common in domestic practice is the Ecomag model [7].

In [8], Bayesian classifiers are used as a mathematical framework for flood modeling.

The maximum allowable medium-quality level of water lifting in the observed river target (Z np, M) for a period of at least 5 years is determined by the equation:

$$Z^{np} = \varepsilon_{\text{cc}} + k_f + \sum_1^y (\varepsilon_{\text{cc}} - \varepsilon_{\text{т}}), \quad (1)$$

where:

$\varepsilon_{\text{т}}$ — The current level of water lifting in the observed river, m;

ε_{cc} — The average seasonal level of water lifting in the observed river, determined by the historical number of observations, m;

k_f — The estimated coefficient equal to 1/3 of the average seasonal level of water lifting in the observed river to the mark "adverse phenomenon", m;

y — The number of analyzed daily observations, according to which an assessment is made from the beginning of the period of the ice drift (period of increased water level) to the date of recorded observation, units.

After determining the maximum permissible medium-sized level of water lifting, the observed river is monitored by incoming monitoring data for the identification of signs of flooding or catastrophic flooding of the area.

The population that has fallen into the flood zone ($N^{np}_{flooded}$, people) should be determined by the equation:

$$N^{np}_{flooded} = \sum_1^i \frac{S^{flooded}_{\text{building}} h_{\text{зд}}}{\rho^{flooded}_{\text{p/zh}}} \partial^i_t \,, \quad (2)$$

where:

$S^{flooded}_{building}$ — Square of flooded building, m2;

$h_{building}$ — the number of floors and structures, m;
i — Residential, socially significant, administrative and industrial buildings;
$\rho_{\text{p/zh}}^{flooded}$ — a parameter characterizing an exemplary calculation area per victim in the flood zone, m2 / person;
t — time of day, h;
∂_t^i — The proportion of the population residing depending on the time of day in the respective buildings and facilities.

The procedure for determining the calculated hydromorphological parameters characterizing the water system is presented in [8].

Hazardous meteorological phenomena [9]

"Sources of natural emergencies are dangerous meteorological phenomena and processes, such as a strong wind, whirlwind, hurricane, cyclone, typhoon, storm, tornado, flurry, long rain, thunderstorm, shower, hail, heavy snowfall, ice rain, ice, strong blizzard, fog, dust storm, warm waves or cold waves, drought [10]. Among them are the most catastrophic (by the number of deaths, affected people and material damage) are heavy snowfall and strong wind "[4].

The main prognostic tool of dangerous meteorological phenomena (OA) is the numerical atmospheric models - they successfully reproduce many phenomena of the atmosphere and are becoming increasingly popular. The predictive atmosphere model is a complex software package that solves a system of equations describing the evolution of the atmosphere, i.e. calculates temperature, humidity, wind and other parameters at different heights and different points of the globe. The models take into account the processes of thermohydrodynamics, moisture transformations, radiation-cloud interactions, complex processes in the atmosphere border layer and on the border with its underlying surface, etc.

The problem of predictability began to be realized after the first numerical experiments on modeling the evolution of the atmosphere for a long time. Back in the 1950s, it was shown that how small errors of the task of initial data for calculating the forecast over time are transformed into large errors (the Attractor E. Lorenz, the "Butterfly Effect") "[11].

"In general purpose weather forecasts include information on the following weather phenomena: thunderstorm, hail, flurry, fog, ice, hoarfrost, sticking wet snow on wires and trees, blizzard, dusty (sandy) storm, ice drill, frost, severe heat, severe frost, abnormally hot (cold) weather" [12].

A typical list and criteria for meteorological hazardous phenomena, designed to meet the recommendations of WMO [13], is given in the table.

Table 1: *Typical list of meteorological OA and their criteria*

Name of OA	Characteristics and criteria of OA
A.1 Very strong wind	Wind with a maximum speed of 25 m / s or more, on coasts of the seas and in mountainous areas 35 m / s and more
A.2 Hurricane wind	Wind speed of 33 m / s and more
A.3 Squall	Sharp short-term (within a few minutes, but not less than 1 min) wind increasing to 25 m / s and more
A.4 Tornado	Strong small-scale vortex in the form of a pillar (funnels) directed from the cloud to the surface
A.5 Very heavy rain	Rain and mixed sediments with 50 mm and more, in mountainous areas with 30 mm and more for a period of time not more than 12 hours
A.6 Heavy rain	Strong rain with the amount of precipitation 30 mm and more for a period of no more than 1 hour
A.7 Long heavy rain	Rain with precipitation of at least 100 mm and more (in mountainous areas with precipitation 60 mm or more for a period of time 48 hours; and less than or 120 mm and for more than 48 hours)

A.8 Very heavy snow	Snow (snowfall) 20 mm and more for a period of 12 hours and less
A.9 Large hail	Hail with a diameter of 20 mm and more
A.10 Strong blizzard	Transferring snow from the surface, often accompanied by the strong (with an average rate of at least 15 m / s) wind and with a meteorological range of not more than 500 m duration of at least 12 hours
A.11 Strong dusty (sandy) storm	Transfer of dust (sand) strong (with an average rate of at least 15 m / s) wind and with meteorological visibility range of not more than 500 m duration of at least 12 hours
A.12 Strong fog	Strong air clouds due to the accumulation of the smallest water particles (dust, combustion products), with a meteorological range of visibility not more than 50 m duration of at least 12 hours
A.13 Strong iceed - hoarfish deposition	The diameter of the deposit on the wires of the ice alloy: ice is not less than 20 mm; complex sediment or wet (freezing) snow - at least 35 mm; frost - at least 50 mm
A.14 Strong frost	In the period from November to March, the value of the minimum air temperature reaches the dangerous value established for this territory or below it
A.15 Heatwave	In the period from May to August, the value of the air temperature reaches the average maximum or above its
A.16 Very cold weather	In the period from October to March for 5 days and the magnification of the average daily air temperature below the climatic rate is 7 ° C and more
A.17 Very hot weather	In the period from April to September for 5 days and the magnification of the average daily air temperature above the climatic rate is 7 ° C and more
A.18 Freeze	Lowering air temperature and / or soil surfaces (herbage) to values below 0 ° C, when the positive average daily air temperatures during periods of active vegetation of crops or harvesting, leading to their damage and / or partial crop death
A.19 Emergency fire danger	Fifth grade of fire hazard indicator (10 000 ° C and more) calculated by Nesterov's equation)
A.20 Skiming avalanche	Large avalanches can make significant damage to economic objects or create the danger of settlements

Dangerous geophysical phenomena [14].

"Sources of natural emergencies are dangerous geophysical phenomena and processes such as earthquake, volcano, landslide" [10]. Among them are the most catastrophic (by the number of deaths, affected people and material damage) are earthquakes [4].

"In the Russian Federation, seismic zones cover extensive areas of the Far East, Transbaikalia, the North Caucasus, where the intensity of earthquakes can reach nine points" [15, 16].

"Agrowing factors for earthquakes are the mechanical effects of oscillations of the earth's surface and crack. The soil movement is extremely rarely can caused human victims. The main causes of accidents and deaths of people are secondary earthquake factors: damage and destruction of buildings and structures, broken windows, the fall of electrical conductors, explosions and fires associated with gas leakage from damaged pipes, as well as uncontrollable actions of people caused by fright and panic [17, 18].

Successful prediction of catastrophic earthquakes implies a sequential step-by-step definition, which allows to narrow the time interval, a location area and a range of a magnitude of an earthquake. In [19], for predicting such emergency, methods of statistical data processing were proposed based on the Bayes Theorem. A draft relevant national standard has been developed [20], which contains a description of the processes for the formation of a priori information for forecasting earthquakes on a controlled territory.

Earthquake (M) is determined by tool data obtained from surface waves (M_S) based on the conditions:

$$M = \begin{cases} M_s\ , \ with\ h \leq 70 \\ M_s + 0{,}8\ , \ with\ h > 70\ ' \end{cases} \quad (3)$$

where:

h — depth of the epicenter of the earthquake, km;

M_s — Earthquake Magnid on Richter scale.

For calculating the parameters of the seismic effects of the earthquake, it is necessary to devide the territories of settlements in the form of a regular grid of the seismicone. The coordinate values of the platforms are accepted with equal values of the coordinates of their centers. (x, y).

Then the likelihood of incoming the random value of intensity I on the (I_{min}, I_{max}) is determined by the equation:

$$P(I_{min} < I < I_{max}) = \int_{I_{min}}^{I_{max}} f(I)dI. \quad (4)$$

The function of the distribution of a random variable $F(x, y, I)$ should be calculated by the equation:

$$F(x, y, I) = \int_{-\infty}^{I} f(x, y, I)dI. \quad (5)$$

The resulting intensity parameter (I) for each site (cell of the regular mesh matrix) with coordinates (x, y) is subject to evaluation in the medium-term forecasting of earthquakes [14]. The procedure for determining seismic impact parameters is presented in [20].

Large natural fires

Natural fires, uncontrolled combustion processes, spontaneously emerging and spreading in natura (forest, steppe and peat). At the same time, forest fires are applied to the most important damage in the Russian Federation.

"The problem of predicting forest fire parameters and evaluating their consequences did not receive its satisfactory decision, despite its importance for various sectors of the national economy of Russia. The difficulties of solving this problem are due to: the complex nature and variability of the behavior of fires, and even more so multi-day forest fires that develop on a large area in changing natural and weather conditions; insufficiency or inaccuracy of information on the characteristics of the forest, topography of the area, local meteorla; not always reliable reporting information coming from the fire places "[21].

In [22], Bayesian classifiers were offered as a mathematical framework for modeling forest fires.

In this case, the forest fire area (S_{ff}, ha) after the time corresponding to the forecasting step is recommended to determine by the equation:

$$S_{ff} = n_1 \cdot S_{ff}^{1B} + m_1 \cdot S_{ff}^{1medium}, \quad (6)$$

where:

S_{ff}^{1B} — Cell area of the matrix of a regular grid with a high level of threat of hypothesis No. 1, ha;

$S_{ff}^{1medium}$ — Cell area of the regular grid matrix with an average level of threat of hypothesis No. 1, ha;

n_1 — number of cells of the matrix of a regular grid with a high level of threat of hypothesis No. 1, units;

m_1 — Number of cells of the matrix of a regular grid with an average level of threat of hypothesis No. 1, units.

Hypothesis No. 1 means the likelihood of spreading a forest fire on a controlled territory during the day every 3 hours.

Determination of the length of the edge of the forest fire (D_{edge}, м), after the time corresponding to the forecasting step, should be determined by the equation:

$$D_{edge} = 0{,}5 \cdot \sqrt{S \cdot 10000}, m. \quad (7)$$

where:

S — Forest fire square, ha.

The proportion of the controlled territory with a high level of threat is the possibility of the occurrence and distribution of forest fire ($P_{\text{В}}$) is determined by the equation:

$$P_{\text{В}} = n_3 \frac{S_{ff}^{3\text{В}}}{S_{kt}}, \tag{8}$$

where:

$S_{ff}^{3\text{В}}$ — Cell area of the matrix of a regular grid with a high level of threat of hypothesis No. 3, ha;

S_{kt} — The total area of the regular grid for KT, ha;

n_3 — Number of cells of the matrix of a regular grid with a high level of threat of hypothesis No. 3, units.

Hypothesis No. 3 means the possibility of the emergence and spread of a forest fire on a controlled territory over the next 10 days.

III. Results

Thus, this article presents the verbal and mathematical foundations of the forecast modeling of the most catastrophic natural emergencies, the sources of which are: hazardous hydrological phenomena; hazardous meteorological phenomena; dangerous geophysical phenomena; large natural fires.

IV. Discussion

The discussion of the verbal and mathematical foundations of the forecast modeling of the most catastrophic emergencies of a natural nature is quite actively occurring in the scientific literature [1, 5, 6, 7, 11, 17-19, 21], in particular, on the pages of the scientific and technical journal "Civil Security Technologies» [2, 3, 9, 14].

References

[1] Akimov V.A., Bedilo M.V., S. S. S. Study of emergency situations of natural, technogenic and biological and social nature by modern scientific methods: monograph. M.: FSBI VNII GOCC (FC), 2021. 180 p.

[2] Akimov V.A. Applications of the general theory of security to the study of emergency situations of natural, technogenic and biological and social character // Scientific and Technical Journal of Civil Security Technologies, Volume 18, 2021 (Special Education) -PP. 12 - 27.

[3] Akimov V.A., Bedilo M.V., Dangerous hydrological phenomena and processes as sources of emergencies of natural nature: verbal model // Scientific and Technical Journal of Civil Security Technologies, No. 4 (70), 2021. - PP. 4-8.

[4] State reports on the state of protection of the population and territories of the Russian Federation from natural and technogenic emergencies in 2010 - 2019. M.: EMERCOM of Russia. 2011 - 2020 years.

[5] Natural dangers of Russia. Volume 6. Evaluation and management of natural risks. M.: Krook, 2003. - 320 p.

[6] Remark of R & D "Development of uniform standards, functional, technical requirements and projected-analytical solutions of the hardware and software complex" Safe City "with the required regulatory and methodological support." Formation of the scientific and technological basis for the subject area of the agro-industrial complex "Safe City" on the topic: Forecast and analytical models for the main types of threats described in the concept - 2 queue. Book 6. Description of the methodology of the forecast and analytical model "Flooding within the framework of the territory of the municipality" // NCI LLC, 2021. - 338 p.

[7] Motovilov Yu.G., Gelphan A.N. Models of flow formation in river pool hydrology tasks. IVP RAS, Moscow, 2018, 300 p.

[8] GOST R 22.1.Hh-202x. Safety in emergency situations. Safe city. Flood forecasting. General requirements.

[9] Akimov V.A., Bedilo M.V., S. S.P. Hazardous meteorological phenomena and processes as sources of emergencies of natural nature: verbal model // Scientific and Technical Journal of Civil Security Technologies, No. 4 (70), 2021. - p. 14-18.

[10] GOST R 22.0.03 - 2020. Safety in emergency situations. Natural emergencies. Terms and Definitions.

[11] Akimov V.A., Didenko S.L., Olyan I.Yu. Nonlinear science for researching accidents, disasters and natural disasters. M.: FSBI VNII GOCC (FC), 2020, 134 p.

[12] RD 52.27.724-2019. Guidance on short-term general purpose weather forecasts (approved by Roshydromet 11.04.2019).

[13] WMO No. 834. Guidelines for the practice of meteorological services for the population. Second edition. - Geneva-Switzerland: Secretariat of the World Meteorological Organization, 2000.

[14] Akimov V.A., Bedilo M.V., Ivanova E.O. Hazardous geophysical phenomena and processes as sources of emergency situations of a natural nature: a model of medium-term forecasting of earthquakes // Scientific and Technical Journal of Civil Security Technologies, No. 1 (71), 2022. - p. 4-8.

[15] Russia in the fight against disasters. Book 1. IX - XIX century. - M.: Business Express, 2007. – 288 p.

[16] Russia in the fight against catastrophes. Book 2. XX - early XXI century. - M.: Business Express, 2007. – 272p.

[17] Akimov V.A., Didenko S.L., Smirnov A.S. Scientific basis of the overall theory of life safety / ed. A.P. Chupriyan / EMERCOM of Russia. M.: FSBI VNII GOCHS (FC), 2019. - 252 p.

[18] Arsenyev S.A. Earthquake from the point of view of the theory of disasters // Trigger effects in geosystems, 2017. PP. 52-59.

[19] Report on R & D "Development of uniform standards, functional, technical requirements and projected-analytical solutions of the hardware and software complex" Safe City "with the required regulatory and legal and methodological support." Formation of the scientific and technological basis for the subject area of the agro-industrial complex "Safe City" on the topic: Forecast and analytical models for the main types of threats described in the concept - 2 queue. Book 4. General description of a typical forecast and analytical model // NCI LLC, 2021. – 66p.

[20] GOST R 22.1.Hh - 202x. Safety in emergency situations. Safe city. Forecasting earthquakes. General requirements.

[21] Kuleshov, A.A. Mathematical models of forest fires // Mathematical modeling, 2002, vol. 14, No. 11, PP. 33-42.

[22] GOST R 22.1.HX - 202X. Safety in emergency situations. Safe city. Forecasting forest fires. General requirements.