STATISTICAL MODELS FOR FORECASTING NATURAL EMERGENCIES

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Abstract

The article considers predictive-analytical solutions for natural hazards for urbanized areas, the mathematical basis of which is Bayesian classifiers. The result of the work is a formalized description of models for predicting forest fires, the consequences of earthquakes and floods resulting from floods.

Keywords: predictive and analytical solutions; Bayes method; emergency situations of a natural nature; Forest fires; earthquakes; floods.

I. Introduction

The subject of the study is natural hazards for urban areas with the aim of their formalized description using Bayesian classifiers. The main part of the work contains three sections: a model for predicting forest fires; model for predicting the consequences of earthquakes; model for forecasting floods due to floods.

II. Methods

Statistical Model for Forest Fire Prediction. As part of the creation of the hardware-software complex "Safe City", an approach to modeling forest fires (hereinafter referred to as LP) is proposed, which is based on Bayesian methods [1]. In the statistical model for predicting the LP, the following parameters are subject to probabilistic assessment using a Bayesian classifier: speed of the riding LP; area and speed of the downstream LP [2]. The calculation of the average speed of the front of the upper LP for various gradations of wind speed is calculated by the equation:

$$v_{frsr}^{j} = \frac{\sum_{i=1}^{N_j} v_{fri}}{N_j}, \quad (1)$$

Where:
j is the range of wind speed values corresponding to the j-th gradation (according to Table 1);

Nj is the number of upper LPs recorded at wind speeds that are in the detected values, detection of the j-th gradation, units;

vfri is the front speed of the i-th riding LP, m/min.

Table 1: *Directory of gradations of wind speed values*

№	Range of values, m/s
1.	Less than 0,3
2.	[0,3; 1,6)
3.	[1,6; 3,4)
4.	[3,4; 5,5)
5.	[5,5; 8)
6.	[8; 10,8)
7.	[10,8; 13,9)
8.	[13,9; 17,2)
9.	[17,2; 20,8)
10.	[20,8; 24,5)
11.	[24,5; 28,5)
12.	[28,5; 32,7)
13.	from 32,7 and more

The main indicators of the propagation of low-level LPs are calculated according to the Rothermel model, which is based on the position that the flame propagation speed is proportional to the ratio of the heat of combustion of the material to the heat of heating new portions of combustible material to the ignition temperature [3].

Determining the speed of the propagation front of the grassroots LP in this model is carried out as follows.

According to the data obtained from the results of collecting the characteristics of the forest area, the composition of the forest combustible material (FCM) for this area is determined, after which the surface area per 1 m2 of the territory is determined for each layer of the FCM according to the formula:

$$A_i = \frac{\sigma_i \omega_{0i}}{\rho_i}, \tag{1}$$

Where:

ω_0 is the average reserve of the layer of forest materials, kg/m^2;

σ is the specific surface area of the FCM layer, m–1;

ϱ is the density of the LCM layer, kg/m$^{3.}$

The values of the parameters of formula (2) are determined according to table 2.

Table 2: *Average characteristics of the ground cover*

Compound	Designation	Lichen	Moss schreber	Nee dles	Leaves	Dry cereal s	Bush	Logging waste
Average stock of a layer of LCM, kg/m^2	ω_0	1,7	1,0	0,3	0,15		0,225	0,9
Specific surface area of the LCM layer, m^{-1}	σ	2000	2500	6000	11560	18170	6560	4920

Heat of combustion, kcal/kg	h	4300	4700	4500	4880	4200		4400	
Density LGM layer, kg/m[3]	ρ	300		512	460	420		512	
Layer height, m	δ	0,12	0,1		0,075	0,5	0,6		0,7
Critical moisture content, kg/kg	M_x	0,3	0,5	0,3	0,4			0,2	

The total surface area (AT) of all LCM layers is calculated by the formula:

$$A_T = \sum_{i=1}^{n} A_{i.} \tag{3}$$

Next, the wind speed is calculated at a level of 6 meters above the crowns of the forest stand (WZ6) according to the formula:

$$W_{Z6} = W_{Z10}\left[\frac{Z_d + 6}{10}\right]^{0,28}, \tag{4}$$

Where:

W_{Z10} - wind speed according to the nearest weather station;

$Z_d$is the average stand height.

Then the speed of propagation of the fire front in the absence of wind and slope (v_{fr}^0) can be calculated by the formula:

$$v_{fr}^0 = \frac{0{,}048\mathrm{h}_{sr}\eta_S\omega_{0sr}\eta_m r\xi}{(\rho_{sr} + \rho_{sr}S_T)Q\gamma\varepsilon\sigma_{sr}{}^{-0,8189}}, \tag{5}$$

Where:

η_S is a coefficient that takes into account the mineral composition of forest fuels (assumed
to be 0.42);

SR - mineral content.

Based on the assumption that the lower LP in a homogeneous medium propagates in an ellipse,
the area of the LP can be determined as follows.

First, the ratio of the length of the LP to its width (LB) is determined by the formula:

$$LB = 0{,}936\exp(0{,}2566W) + 0{,}461\exp(-0{,}1548W) - 0{,}397. \tag{6}$$

Next, the ratio of the leading edge of the LA to its trailing edge (HB) is determined by the formula:

$$HB = \frac{LB + \sqrt{LB^2 - 1}}{LB - \sqrt{LB^2 - 1}}. \tag{7}$$

The values a, b and c are calculated by the formulas:

$$b = \frac{v_{fr}(1 + HB)}{2HB}, \tag{8}$$

$$a = \frac{b}{LB}, \tag{9}$$

$$c = b - \frac{v_{fr}}{HB}. \tag{10}$$

The final value of a, b and c is determined by multiplying each of the given values by the forecast period in minutes.

Then the LP area (S_{lp}) is calculated by the formula:

$$S_{lp} = \pi ab. \tag{11}$$

Statistical model for predicting the consequences of earthquakes

The model for predicting the consequences of earthquakes is based on calculation methods for assessing the parameters of seismic impact, determining the degree of destruction of buildings and structures, elements of urban infrastructure, including theoretical approaches in the field of statistical data analysis based on the Bayesian method of interpreting probability.

The main initial data for the formation of the basic training set of the model for predicting the consequences of earthquakes are the following groups of parameters: characteristics of earthquakes; characteristics of damage to buildings and structures during earthquakes; characteristics of buildings and structures; characteristics of territories; parameters of the meteorological situation [4].

At the stage of training the model, the parameters of the hypotheses are determined based on the values of the parameter "Degree of damage to the building (structure)".

After training, the process of predicting events corresponding to hypotheses begins on new values of the observed parameters.

The order of collecting new values of the observed input data and processing them corresponds to similar processes when training the model, except that the parameters of the hypotheses (estimating the posterior probabilities of the hypotheses) are determined by the Bayesian classifier.

When forecasting using this model, each building or structure is considered separately. For these purposes, the characteristics of all buildings and structures in the controlled area are prepared in advance [5].

Statistical model for flood forecasting

The main input data for the formation of the base training set of the model for flood forecasting due to floods are flood data due to heavy rainfall floods; data characterizing sections of rivers with sections of their watersheds; data characterizing the watersheds of the observed sections of the rivers; data characterizing water management systems in the observed sections of rivers; data characterizing controlled settlements (hereinafter referred to as CPs) located in areas of probable flooding of the area; data characterizing the hydrological situation in river sections; data characterizing the meteorological situation in the observed areas of the terrain; data characterizing the prevailing landscape of the area, the types and composition of soils within the boundaries of the NP and the catchment areas of the observed rivers [6].

In this model, the most significant indicators are the calculated hydromorphological parameters during the flood period.

When determining the calculated hydromorphological characteristics of river points, the following calculation methods are used [7]:

in the presence of data from hydrometric observations - directly from these data;

in case of insufficiency of hydrometric observation data, by reducing them to a multi-year period according to the data of analogue rivers with longer observation series;

in the absence of hydrometric observation data and the impossibility of comparison with the given analogous rivers, according to calculation formulas using maps based on the totality of observational data from the entire network of monitoring points for the hydrological situation in the corresponding area or a larger territory.

III. Results

Thus, this article considers predictive and analytical solutions for natural hazards for urban areas, the mathematical basis of which is Bayesian classifiers. The result of the work is a formalized description of models for predicting forest fires, the consequences of earthquakes and floods resulting from floods.

IV. Discussion

The discussion of the verbal and mathematical foundations of predictive modeling of natural emergencies is quite active in the scientific literature [8 - 10].

The scientific novelty of the developed models lies in a single scientific approach to their creation, namely, the use of a statistical processing method based on Bayes' theorem.

Bayesian probability is currently developing as the main method of forecasting in terms of building and training neural networks, in contrast to frequency probability - when the probability is determined by the relative frequency of occurrence of a random event with sufficiently long observations.

For scientific forecasting of crisis situations and incidents using the Bayesian method and Bayesian networks, a large amount of up-to-date data is required for modeling natural disasters, which is typical for often recurring negative events.

Due to the lack of statistical data, Bayesian methods are not applicable for predicting catastrophic natural disasters that occur rarely, but with significant damage.

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