A PRACTICAL EXAMPLE OF INTEGRAL ASSESSMENT OF THE SOCIAL RISK OF EMERGENCIES CAUSED BY FLOODS

Irina Oltyan

All-Russian Scientific Research Institute for Civil Defense and Emergencies
of the EMERCOM of RUSSIA
irenaoltyan@mail.ru

Abstract

Every year, the management bodies of the unified state system for preventing and eliminating emergencies carry out advance preparations for the flood period. However, statistics show no decrease in the number of flood-related deaths and injuries. This is due to the lack of an integrated approach to systematically assessing and considering a set of interrelated factors that determine social risk in the event of a flood. This article provides a practical example of assessing the social risk of emergencies caused by floods, based on a scientific and methodological framework developed by the author. This apparatus is based on hydrological methods, geoinformatics and mathematical modelling, both descriptive and predictive. It can be used by municipalities to solve issues of local importance aimed at protecting the population from emergencies caused by floods.

Keywords: flood risk of death in floods, social risk, integral assessment, integral indicator, metric of social risk, scientific and methodological apparatus, digital model of the population, evacuation during flooding, parametric law of human damage

I. Introduction

Floodwaters claim thousands of human lives every year. Thus, according to the research center of the University of Louvain (Belgium), presented in the annual report "2024 Disaster in Numbers", in 2024 floods ranked first in terms of the number of deaths in the world (in 2023 – third place) and fourth in the period 2004-2023.

Despite the fact that the contribution of Russian emergency situations indicators to the global EM-DAT database is insignificant [1], floods in our country occupy the first place in terms of the disaster coefficient [2], taking into account the number of deaths and the victims. Among all floods, the most dangerous for the population (for humans, for society) are emergencies, the sources of which are floods after heavy rains [3].

The article [4] presents an integrated approach to the systematic assessment and accounting of a set of interrelated factors that determine the level of social risk of emergencies caused by floods: natural and climatic, characterizing the danger of the area, organizational and engineering, characterizing the coping capacity, as well as socio-demographic, characterizing the typology of the population exposed to the damaging factors of flood water. A scientific and methodological apparatus (SMA) has been developed, which is a set of conceptual apparatus, models, methods and algorithms that provide a systematic and informed approach to analyzing and predicting the consequences of the impact of devastating disaster factors on the population, the sources of which are floods, and quantifying the social risk of such emergencies.

The purpose of the article is a brief description of the developed scientific and methodological apparatus, as well as a practical example of assessment of the social risk of emergencies caused by flood in one of the Russian cities.

II. A scientific and methodological apparatus for the integral assessment of the societal risk caused by floods

The developed SMA [4] uses a multifactorial model for assessing the social risk of death in floods, which includes the following factors:

– the danger of the territory, including natural and climatic conditions such as terrain, physical and geographical zoning;

– insufficient potential to counter the danger, including shortcomings in the organization of public notification and information, as well as the lack of evacuation of the population or non-compliance with the established deadlines for emergency evacuation of the population;

– socio-demographic factors characterizing the typology of the population exposed to the damaging factors of flood water.

The main indicator of the risk of emergency, which is used in the developed SMA, is the social risk (death in) an emergency, defined as the probability of death of at least N people, when an emergency occurs with a certain frequency [5].

Two metrics (quantitative indicators) of the social risk (death in) an floods have been established, taking into account the probabilistic nature of the occurrence of floods, the probability of exceeding the predicted water level above the totality of all possible values, as well as the consequences of such emergencies, expressed in the number of people killed:

– F-N diagram (Frequency-Number diagram, frequency–number of victims diagram) – the dependence of the number of losses (deaths) of a population group on the frequency of implementation of various emergency scenarios for a given time [5, 6];

– an integral indicator of the level of social risk of an emergency representing the area under the F-N diagram.

The SMA assumes that the frequency of implementation of various scenarios in F-N diagram F is a discrete value and is set through the probability of exceeding hydrological values (as a rule, 0,5 %, 1 %, 5 %, 10 %, 20 %). The mathematical expectation of the number of deaths N during the event E (flood), which leads to an emergency, is determined by dependence (1), which, unlike the previously adopted approaches [5, 6, 7], includes the variable P_{evac} - evacuation during flood, which characterizes the coping capacity:

$$N = P_{evac} \cdot \iint_S \int_{DF_{min}}^{DF_{max}} P(DF) \cdot f(x, y, DF) \cdot \psi(x, y) dDF dx dy$$

(1)

where S is the area of the municipality; DF is the damaging factor; DF_{min}, DF_{max} are the minimum and maximum possible value of the damaging factor of flood for the territory under consideration; $\psi(x,y)$ is the distribution function of population within the territory under consideration; P(DF) is the parametric law of human damage; f(x,y,DF) are functions of the density distribution of the intensity of the damaging factor within the territory under consideration, P_{evac} is the probability of timely evacuation during flood, $P_{evac} \in [0;1]$.

The geoinformation system (GIS) is an SMA integration platform. It includes digital terrain models, thematic (geographical) databases, spatial data models, algorithms for spatial analysis, data processing, as well as models and algorithms for visualizing results.

The structure of the developed SMA is shown in Fig. 1.
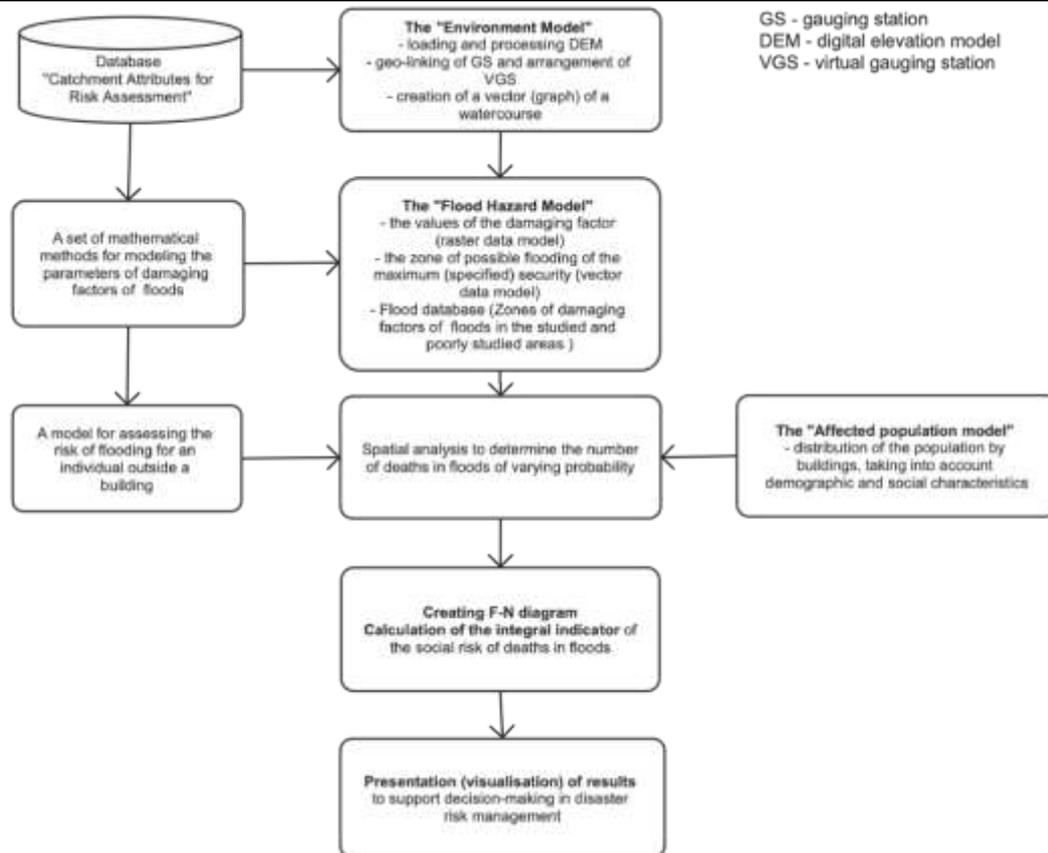
Figure 1: *The structure of the scientific and methodological apparatus for quantifying the social risk of death in floods*

In the functional block "Environment Model" (Fig. 1), a digital twin of a flood-prone area is created. During modeling in this block, the preparation of the DEM, the modeling of the hydrographic network (the construction of a vector (graph) of the watercourse), as well as the arrangement of virtual gauging stations take place. The creation of an "Environment Model" is described in the author's articles [9, 10].

The functional block "Flood hazard model" (Fig. 1) is designed to simulate the values of damaging factors of floods after heavy rains. The simulation is performed for a predefined set of emergency scenarios. For the previously created "Environment Model", the selected digital geographical space is divided into elementary cells that coincide with the DEM matrix using a regular grid. For each elementary cell and a predefined set of scenarios, the values of the damaging factor of flood water are determined, numerically equal to the product of the depth of the flow and the flow velocity of flood water [11]. Flood hazard modeling described in the author's publications [12, 13, 14] and use models for probabilistic modeling of the parameters of damaging factors and mapping of floodwaters in areas that have been studied and poorly studied areas in hydrological terms. The models take into account the physical and geographical zoning of the territory.

As a result of probabilistic modeling of the parameters of damaging factors and flood mapping, created:
- vector data model that describes the geometry of the zone of possible flooding of the maximum (specified) probability.;
- for each scenario, there is a raster data model containing calculated values of the depth of flooding in each cell of the raster;
- for each scenario, a raster data model containing calculated values of the damaging flood factor (product of the depth of the flow and the flow velocity of flood water) in each cell.

The KMeans cluster analysis method [15] was used afor effectively transform a raster model containing calculated values of the damaging flood factor into a formalized system of flood hazard zones.

In the functional block "The affected population model" clustering of the population was performed according to the maximum permissible value of the damaging factors of flood water, exceeding which a person loses stability and may die. Clustering was based on the deterministic criteria obtained in [11] for human damage in flood water outside the building. The population is divided into 5 clusters, taking into account the age of the individual, as well as the classification as a vulnerable population group.

Further, spatial objects (residential buildings) in the zone of possible flooding of the maximum (specified) probability was endowed with "demographic" properties through a set of attributes – quantitative features that characterize the demographic characteristics of the residents living in them (age, gender, vulnerability). In the absence of factual information on the distribution of the population by residential buildings, the assignment of "demographic" properties to the building is carried out in proportion to the area and number of floors of the residential building, as well as the average distribution by age and gender.

So the distribution function of population within the territory under consideration $\psi(x,y)$ in formula (1) is the corresponding digital model of the population of the municipality, which is a table indicating for each residential building a virtual population of residents and assigning them to a specific cluster according to the maximum permissible value of the damaging factors of the flood wave.

As noted earlier (see formula (1)), timely evacuation of the population reduces the social risk of death in an emergency. To determine the probability of evacuation in case of a flood, we apply the well-known empirical formula for determining the probability of evacuation from a building in case of a fire (2) [16]:

$$P_{evac} = \begin{cases} 0{,}999 \times \dfrac{0{,}8 \times t_{MPL} - t_C}{t_S}, \text{если } t_C < 0{,}8 \times t_{MPL} < t_C + t_S \text{ и } t_C > 0, \\ 0{,}999, \text{если } t_C + t_S \leq 0{,}8 \times t_{MPL}, \\ 0, \text{если } t_C > 0{,}8 \times t_{MPL} \end{cases}$$

(2)

where t_C is the time for the evacuation of people from the zone of probable flooding, hour; t_S is the time of the beginning of evacuation (the time from receiving a forecast to the start of evacuation); t_{MPL} is the time from receiving a forecast of the flood to flooding of populated areas before the maximum permissible level of the damaging factors of the flood wave.

We will consider individual stability, as well as the value of the damaging factor in the cluster, as independent normally distributed random variables [16]. Then the parametric law of human damage P(DF) (formula 1) is defined as the probability of loss of stability of a person (population) in a stream of water [16]:

$$P(DF) = \Phi\left(\frac{C^l - MPL^k}{\sqrt{\sigma_l^2 + \sigma_k^2}}\right)$$

(3)

where Φ is the function of the standard normal distribution; $l \in [1; L]$ are clusters of cluster zoning of the municipality by value of the damaging factor; C^l is the centroid of the cluster l; σ_i is the standard deviation of the cluster l; σ_k is the standard deviation of cluster k; $k \in [1; K]$ are clusters of the population, MPL^k is the centroid of the cluster k; σ_k is the standard deviation of cluster k.

The results of the application of the methodology are an F-N diagram characterizing the dependence of the number of losses (deaths) of a group of the population of a municipality on the frequency of implementation of various emergency scenarios (floods with a given probability), as well as an integral indicator of the level of social risk of an emergency for the territory of the municipality.

III. A practical example of using a scientific and methodological apparatus for the integral assessment of the societal risk caused by floods

The approbation of the methodology for obtaining an integral indicator of the level of social risk caused by floods, was carried out using the example of the municipality of the Irkutsk region – Tulun city. The Tulun city is located on a large left–bank tributary of the Angara River - the Iya River. The region under consideration is characterized by increased flood risk, in recent decades there have been severe rain floods, which led to enormous damage [14].

The initial data for obtaining an integral indicator of the level of social risk caused by floods were:

– information on gauging stations, average daily and highest water levels for gauging stations, provided in the Automated Information System of state monitoring of water bodies [17]; raster map of the maximum modules of the rain runoff of the rivers of the USSR probability of exceeding p = 1 % (annex 5 [18]); raster map of the rain runoff layer of the USSR rivers, probability of exceeding p = 1 % (annex 10 [18]);

– NextGIS Data geodata is a basic map of the Irkutsk region (a vector map that includes more than 30 types of data about the territory: administrative divisions, road network, buildings, reservoirs and rivers, urban infrastructure, etc.);

– population data by gender and age in the Irkutsk region for 2024 [19];

– data on the population over the age of 18 with disabilities [20].

The simulation results were obtained using Python program codes written by the author, as well as using spatial analysis and modeling in QGIS.

The following functional models have been created: "Environment model" [13], "Flood hazard model" (Fig. 2), " The affected population model " (Table 1).
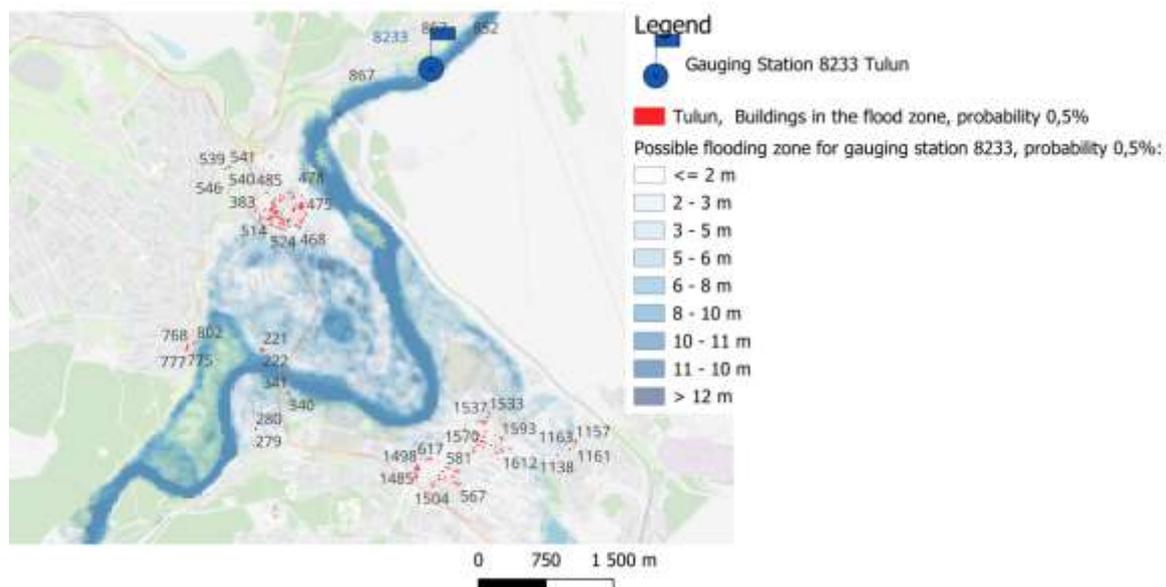
Figure 2: *Flood hazard model (Map of Tulun city showing buildings in the area of possible flooding of maximum (defined) probability)*

The Table 1 shows:
building_id is id number if building in flooding area;
age_group is an assigning residents to a certain age group;
cluster are clusters of the population;
count is number of residents.

The initial data and the results of determining by formula (2) the probability of timely evacuation of the population are shown in the Table 2.

Table 1: *The affected population of Tulun city model (fragment)*

building_id	age_group	gender	cluster	count
121	2-11	female	2	1
220	2-11	female	2	1
220	18-75	female	4	3
220	18-75	male	4	3
221	18-75	female	4	1
222	0-1	female	1	1
222	18-75	female	4	4
222	18-75	male	4	1
222	vulnerable	female	5	1
279	2-11	male	2	1

**Table 2:** *The initial data and the results of determining the probability of timely evacuation of the population*

t_C, hour	t_S, hour	V_{rise}, m per hour	t_{MPL}, hour	P_{evac}
12	3	0,00005	16,17	0,44

The forecast of the consequences of the implementation of emergency scenarios caused by floods (Table 3) was obtained.

Table 3: *Forecast of the consequences of the implementation of emergency scenarios caused by floods in Tulun city*

F (frequency of scenario), 1/year	Probability of scenario, %	Number of houses in the danger zone, units	The number of the exposed population, people	Estimated number of deaths, N, people
0,01	0,5	186	313	138
0,02	1	78	44	19
0,05	5	3	19	8
0,1	10	3	0	0
0,2	20	0	0	0

The F-N diagram for Tulun city reflects the dependence of the number of population losses (deaths) on the frequency of implementation of various emergency scenarios over a given time (Fig. 3). The diagram also shows an integral indicator of the level of social risk of emergencies caused by floods.
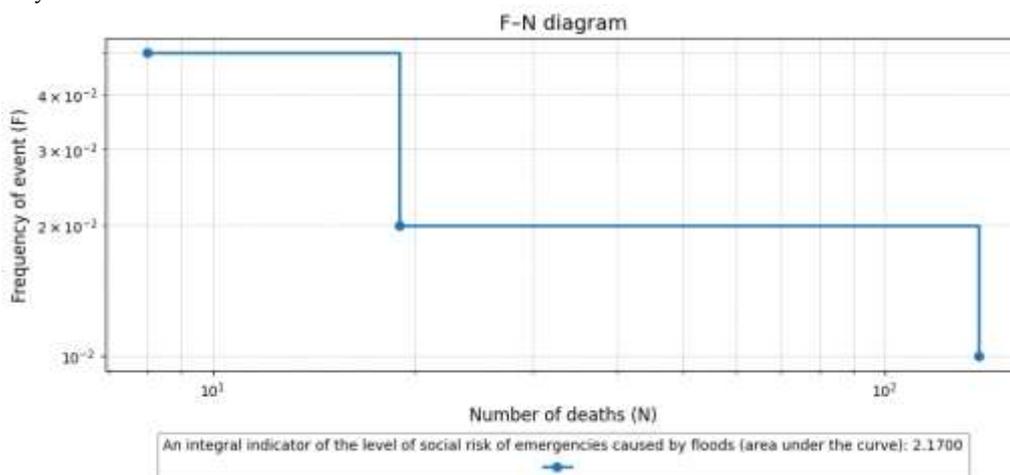
Figure 3: *F-N diagram for the Tulun city flood forecast*

The calculated social risk metrics of an emergency (F-N diagram, integral indicator of the level of social risk of an emergency caused by floods) correspond to the predicted values of the social risk of an emergency at the time of the forecast and can be used in urban planning activities and measures to reduce the risk of an emergency (comparison of social risk metrics in a municipality before and after the implementation of measures).

V. Conclusion

As a result of the research, a comprehensive scientific and methodological apparatus for the integrated assessment of the social risk of emergencies caused by floods has been developed. The practical use of the SMA to predict social risk in case of floods of varying probability for one of the cities made it possible to evaluate the benefits of the developed tool for demonstrating the effects of risk reduction measures. For example, measures to reduce the number of deaths (such as improving warning systems, improving the quality of buildings, spatial planning, and others) shift the line on the F-N diagram horizontally along the X-axis to the left. Reducing the likelihood of flooding, for example, by strengthening dams, will lead to a downward shift of the line on the F-N diagram along the Y axis, which will eventually lead to a decrease in the integral indicator of the level of social risk of an emergency.

A comparison of the integral indicator of the level of social risk of an emergency between municipalities (benchmarking tools) can help identify problem areas and carry out targeted fixation to reduce the social risk of an emergency in a particular municipality.

CONFLICT OF INTEREST.
Authors declare that they do not have any conflict of interest.

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