Environmental Risks Caused by Floods in Built-Up Areas

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Abstract. The article considers the possible consequences of flooding for the ecological state of territories, sets the tasks of risk assessment and prevention of damage from dangerous hydrological processes. The authors discuss possible ecological consequences caused by flooding for ecosystems and built-up areas and suggest methods for risk assessment and risk management in flooded areas. Natural and anthropogenic factors of floods and issues of predictability of hazardous hydrological processes are also considered. The article shows that the risk of a disaster, the initiating factor of which is a flood, occurs when hydro-meteorological, geological and other hazards interact with vulnerability factors of a physical, social, economic and environmental nature. It is proposed to take an extreme hydrological event of low probability as a scenario of a catastrophic event, for example, the historical extreme of the maximum water flow. As an example, we consider the decisions taken to prevent flooding in built-up areas on the example of the Kuban river basin of the Krasnodar territory.

1. Introduction

Most of the floods occurring in central Russia are relatively weak and, in most cases, do not cause significant material and environmental damage. However, in some year’s floods can pose a significant danger both for built-up areas and for the ecological situation in the region. For example, in the Republic of Tatarstan, 209 settlements, most of which are located in agricultural areas, can get into the flooding zone during the flood period [1]. In this case, overflowing water can destroy crops, wash away fertile soils and change the natural landscape [2].

The Institute of water problems of the Russian Academy of Sciences believes that "even small floods, which result in flooding of territories where such processes are rare, may well be classified as catastrophic (along with particularly destructive floods), since they can significantly change the existing landscape, the composition and structure of both abiotic and biotic components. Or if flooding, which is common for a given floodplain, for some reason "lingers" on its territory (a phenomenon called "stagnation of hollow waters"), then this can also lead to a significant change in plant communities and depletion of the species composition of vegetation of this landscape" [3].
The occurrence of a disaster risk that is triggered by flooding occurs when hydro-meteorological, geological and other hazards interact with physical, social, economic and environmental vulnerabilities [4-6]. Therefore, when dealing with emergency risk management issues, it is necessary to take into account their interdisciplinary nature and involve the efforts of various departments and organizations to solve the issues.

The threat of flooding cannot be completely eliminated due to the nature of the climate system and the unpredictable nature of dangerous hydrological events. To reduce environmental and economic losses, it is necessary to organize and conduct preventive, protective and evacuation measures [7, 8].

One of the main dangerous hydrological processes in most of the territory of the Russian Federation is the spring flood caused by the melting of snow cover accumulated during the winter period. The danger is also posed by floods as a result of the passage of rainfall floods, which are formed during the precipitation of intense rainfall or the passage of typhoons and monsoons [6].

The negative impact of floods on the ecological state of flooded areas includes:

1) direct flooding of territories and the dynamic impact of waters with corresponding damages;
2) impact in the event of synergistic hazardous processes (deformation of channels, flooding, processing of banks, loss of stability of slopes, deterioration of sanitary and epidemiological conditions, etc.) [9].

Forecasting an emergency (including a possible flood) is a proactive assumption about the likelihood and development of an emergency based on the analysis of the causes of its occurrence and its sources in the past and present, forecasting the consequences of an emergency. The goals and objectives of emergency forecasting are the following:

- obtaining in advance qualitative and quantitative information about a possible emergency situation caused by hazardous hydrological phenomena:
  - planning the necessary forces and means for carrying out protective measures and measures to eliminate an emergency;
  - assessment of possible socio-economic and environmental consequences of the emergency [6].

Based on practical experience, as well as analysis of the existing scientific and methodological base, it is possible to formulate the main reasons for the occurrence of significant negative consequences during floods:

1. When predicting emergency situations arising from floods, the anomalous nature of hydro-meteorological phenomena is not sufficiently taken into account, including due to anthropogenic impacts on the catchment and river bed, as well as climatic changes.
2. There are errors in engineering-geological and hydrological surveys, engineering calculations and design due to insufficient funds, limited data of hydrological and meteorological monitoring, lack of the required qualifications of specialists to interpret the results of monitoring and perform forecast calculations.
3. Often there is a poor quality of construction work in the construction of buildings, engineering structures, as well as in the creation of engineering protection systems in the flooded zone.
4. Unauthorized (or unregulated) modes of operational management during the operation of hydraulic structures, lack of necessary repair work at the facilities.
5. Violation of the conditions of land use in the tail water, including unauthorized development of flooded areas on the coasts of lakes, rivers and reservoirs.
6. Insufficient awareness of the population about the possible consequences of the hazardous effects of water in general and during the passage of a specific hazardous flood, in particular [10-12].

All of these factors aggravate the negative consequences of floods, and require solving problems at the state level. The objectives of public administration in the field of reducing environmental disaster risks include:

1) territorial planning, urban planning zoning, natural and technical supervision, etc.);
2) strengthening control over the prevention of construction in areas prone to floods, flooding, introduce compulsory insurance programs for life and property of the population living in areas prone to flooding, taking into account the results of risk assessment [6].
2. Methods
The task of forecasting and assessing the risk of an emergency as a result of the passage of floods includes an assessment of the negative impact of water in the implementation of scenarios of three types:

1) the scenario of a catastrophic event;
2) the probable scenario, i.e. acceptable risk events;
3) the optimal scenario, accompanied by the implementation of the necessary preventive measures and operational actions.

An extreme, very rare hydrological event of low probability, such as a historical extreme of maximum water flow, is accepted as a scenario of a catastrophic event. In some cases, the practice of designing hydraulic structures refers to the "beyond design" mode of operation of the technical system (built-up area, etc.), which can also be attributed to situations with poorly predictable consequences.

As an event of a probable scenario (or an event of an acceptable risk), a situation is considered that corresponds to the standard safety level, i.e. a scenario of a flood of 1% availability, for which a master plan of the area is designed (a flood, which probability is considered 1 time in a hundred years). For hydraulic engineering systems, this is the reliability of building structures or technological processes, which is set by building codes for each class of hydraulic engineering facilities. The range of safety levels is very wide and varies from 1 event in 10,000 years to 1 time in 10-20 years.

The optimal scenario is considered when taking additional measures of engineering protection, carrying out preventive measures related to resettlement of the population from areas prone to floods, based on the results of forecasting or analyzing the development of a dangerous situation, combating congestion, cleaning and expanding river channels, etc. [13-18].

3. Results
As an example, let's consider the decisions taken to prevent flooding in built-up areas on the example of the Kuban river basin (Krasnodar territory).

1. The most probable scenario for the formation of emergency situations during floods.

Assessment of areas of acceptable risk in relation to the threat of floods is presented based on the materials of the Scheme for the integrated use and protection of water bodies in the basins of the Kuban and Black Sea rivers, developed by the Institute of JSC “Kubanvodproekt” [19].

To develop measures to prevent emergency situations during floods, it is advisable to use a risk-based approach, in which it is important to take into account not only hazards (hazard index), but also vulnerability (vulnerability index) and resilience (index of resilience). The proposed approach is based on the methodology of the risk-based method INFORM (index for risk management). The INFORM integral risk index includes about 50 different indicators for measuring hazards and impact on them, indicators of vulnerability and determining the necessary resources to stop hazards and is determined as a geometric mean by the formula 1:

\[ R = \sqrt[3]{H \times V \times L}, \]  

where \( H \) is an indicator of danger and threats;
\( V \) is vulnerability indicator;
\( L \) is indicator of insufficient resilience to the hazard.

More detailed rates and specific indicators are described in the monograph [3]. All indicators are normalized and take values from 0 to 10.

The population vulnerability index is calculated based on information about the population (age composition, mobility), the deterioration of critical infrastructure, the deterioration of housing stock, and data on the availability of dilapidated housing [20]. The index of resilience shows the availability of forces and means of EMERCOM of informing, alerting the population, as well as by the presence of the necessary equipment for emergency response and evacuation. The system of indicators for the formation of each of the three components of the integral risk index is formed taking into account the indicators identified in the order of the EMERCOM of Russia from 25.10.2004 № 484 [21].
Calculations made on the basis of formula (1) made it possible to rank municipalities of the Krasnodar Territory by the degree of risk of emergencies associated with floods and determine which municipalities need priority measures to prevent and respond to flood risks.

2. A catastrophic scenario for the formation of emergency situations during floods.

Catastrophic hydrological events are rarely observed on rivers and other water bodies, have a low probability of exceeding, but are accompanied by huge economic losses and human casualties. An example of such an event was the rain flood on the Adagum river in 2012, which was accompanied by a large number of human victims. A catastrophic situation of this kind significantly changes our understanding of possible risks. Figure 1A shows the zones of flooding of Krymsk with a flood of 1% supply, estimated before the event of 2012, and taking into account information about the flood of 2012 [14]. The results of the comparison show that the risks of negative impact of water significantly increase during the passage of catastrophic events. Figure 1b shows the result of calculating the flooding zone of Krymsk during the passage of a flood with a period of repeatability once in a thousand years (0.1 %) [3]. In general, for this region, as a catastrophic one, it is possible to propose the consideration of an emergency scenario with a threefold increase in the flooded area, which approximately corresponds to an extreme event in Krymsk.

![Figure 1](image1.png)

**Figure 1.** a) Modelling the boundaries of the flooded zones of the city of Krymsk. Flood zones during a flood with a 1% supply, calculated according to the data before the catastrophic flood of 06-07/07/2012 (materials of the Scheme for the integrated use and protection of water bodies in the Kuban basin [19]); b) Modelling the flooding zones of the city of Krymsk during the passage of a flood of 0.1% supply [3].

3. The optimal scenario of emergency situations during the passage of floods and high water.

The optimal scenario for the development of emergency situations involves considering the situation of the negative impact of water, taking into account the implementation of additional measures for engineering protection of the population and organizational and technical measures to protect economic facilities and the territory from flooding, the implementation of measures to predict the occurrence of emergencies and prevent the population. Engineered flood protection measures include embankments, drainages, spillways, pipelines and pumping stations [7, 20, 21]. Under the protection of the flood control system of the Lower Kuban, there are about 600 thousand hectares of
land in the Krasnodar Territory and the Republic of Adygea, including 322 thousand hectares of arable land, mainly rice systems. The reliability of flood protection of the Lower Kuban in modern conditions is characterized as insufficient: embankment dams are unreliable for a long distance, measures are required to improve the technical condition of reservoirs and hydro engineering complexes. Based on the materials of the scheme for the integrated use and protection of water basins of the Black Sea rivers [19], it can be concluded that the flood protection system of the Kuban River does not meet the operational reliability requirements and does not provide guaranteed flood protection for the entire population of the region living in flooded areas, which negatively affects ecological state of the considered territories.

4. Conclusions
Thus, it can be concluded that the current state of methodological support governing emergency management related to hydrological hazardous phenomena requires further development of the basic provisions in the direction of improving and widespread introduction of a risk-based approach, performing monitoring activities. The proposed methods for analyzing the risk of an emergency situation and recommendations for engineering protection can significantly reduce both environmental and economic damage during the passage of floods.

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