Experience in studying and assessing hydrological risks in the transboundary conditions of the Selenga River

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Abstract. The article presents the results of a study of hazardous hydrological phenomena on the example of floods in the transboundary basin of the Selenga River. Based on the analysis of long-term observations of water levels, hazard indicators are identified. This allows to calculate a number of risk indicators. In terms of specific indicators, an integrated risk map has been developed. An assessment of the total economic risk from floods is given, and recommendations for their reduction are proposed.

1. Introduction

The transboundary basin of the Selenga River is the most developed and populated territory of both Buryatia (Russia) and Mongolia, where the river plays a very significant role in the socio-economic development of states. On the one hand, it has common natural boundaries with the conditions for the formation of certain processes and phenomena, on the other hand, different priorities of modern economic development, and “vulnerability windows” that are specifically formed on it.

Certain specifics of natural conditions with climatic extremes and the characteristic periodicity of dry and wet years contribute to the occurrence of quite significant hydrological changes, including the occurrence of extreme events. Typically, catastrophic events spanning the entire basin have rather rare occurrences. But looking at the dynamics of emergency statistics according to the main criteria of scale, its frequency of manifestation, damage caused, we can distinguish two main types and their alternation as a result of abnormal climatic phenomena: high water and related floods, as well as low water.

Moreover, in recent decades, the cause of their activation and development of qualitatively new species is the increasing anthropogenic impact. The construction of the Irkutsk Hydroelectric Station and the commissioning of the Angarsk Hydroelectric Station, resulting in the rise of the level of Baikal Lake, led to a modification of hydrological conditions and increased the development of flooding processes in the lower part of the basin. In addition, in recent years, the construction of the following hydropower plants in the Selenga Basin has been seriously considered: Shuren (245 MW), Egiyn-gol (315 MW), Orkhon (100 MW), and “Chargayt” (25 MW), as well as the “Orkhon Water Complex” project, with specific proposals for creating artificial water pools and sending them to the South Gobi belts. In this case, the water level regime in the Selenga River (periods of low water and high water), which is the main river carrying its waters to Lake Baikal, will directly depend on the technical parameters. These phenomena pose a tremendous danger to sections of the middle and lower reaches of the Selenga River, i.e. the Russian part of the basin.
Thus, the regulation of relationships between subjects requires a comprehensive and thorough study of the research object, analysis of the occurrence and development of natural and anthropogenic processes in the spatio-temporal dynamics leading to the creation of emergency situations. In this regard, the transboundary basin of the Selenga River is of particular interest for the study of risks in order to minimize them, the possible elimination of international conflicts, the sustainable development of natural and man-made systems.

2. Materials and Methods

Based on the specifics of the natural environment, the features of the territorial organization of the two states’ territories, an indispensable condition for researching risks in the transboundary basin is the creation of uniform methodological methods for assessing them to obtain objective quantitative indicators. The results of these studies could serve as an information base for the management system. At the same time, efficiency largely depends on the accuracy and reliability of information about the main sources and recipients of negative impacts, probable future losses, as well as its informatization, which significantly increases the efficiency and literacy of decisions.

Based on the existing experience in studying risks, the accepted theoretical and methodological principles, it is advisable to apply a probabilistic-area approach based on hazard indicators (repeatability, intensity of occurrence of the event and the area of damage), with methodological methods for calculating risk indicators through vulnerability. The calculation of this parameter allows one to get the specific physical risk used in the comparative assessment when mapping and identifying the level of risk. The definition of a physical risk indicator serves as the basis for assessing economic and social risks [1], [2]. An end-to-end process of all work is mapping using GIS technologies and remote methods, which play a key role in the ongoing study.

In the process, the entire volume of primary information and hazard indicators is systematized and compiled into a single database, which allows one to develop scenarios and calculate the total economic risk. In the analysis and calculation of hazard indicators, long-term hydrological data were used for 21 water meter posts in dynamics in Russia since 1931 and for 12 water meter posts in Mongolia. The cartographic base was a vector toposbase of scale 1:100000; the high-altitude basis was a digital terrain model, the initial data for the formation of which were the relief contour vector, elevations, and depths of a scale of 1:50000. When projecting a high-resolution satellite image scene onto the DEM, a digital terrain model of high metric accuracy was created. Within the boundaries of settlements, a basis of a scale of 1:25000 is used.

3. Results

The formation of floods in the rivers of the basin depends on climatic factors and the orography of the basin. For all observation points under consideration, analysis of the source data and calculated hazard indicators shows the complex process of floods in the Selenga River basin. The difference in the range of values is very significant. Their repeatability varies from 0.1 to 0.9, middle ones are found with a probability of 0.1-0.3, and extreme ones are found with a probability of 0.05-0.1. According to the studied hydrological posts, the depth of flooding is from 50 to 437 cm. The maximum values are typical for the period of summer floods. Exceptional rises are observed in certain sections of rivers. In conditions of mountainous terrain and large slopes or narrow valleys, they are maximum for rivers; in areas of flattened terrain and floodplain development, they are significantly reduced. At the same time, the size of flooding sharply increases. Frequent recurrence of significant excesses of the water level is most characteristic of the middle-lower flow, starting from the confluence of the Orkhon River, then at the confluence of the Dzhida and Chikoi Rivers. Thus, in the formation of floods in the basin, the decisive influence is exerted directly by the Selenga River and the Orkhon River, located on the territory of Mongolia. And its main tributaries dumping their waters, such as Dzhida, Chikoi and less often Khilok, Uda, significantly enhance the development of floods [1], [3]. The GIS technology served as a modern tool for the implementation of the task of mapping the floodplain and identifying flood zones.
With its help, in the Arc GIS software environment, necessary areas are defined, as well as the settlements and important economic objects that fall into the flood zone [4], [5].

In accordance with the methodology, a total of three forecast scenarios of flood development have been developed. And necessary hazard indicators are defined for each. The generated database made it possible to calculate physical risk. In terms of specific indicators, the territorial ranking is carried out; private maps and a final map of the integrated risk from floods in the transboundary Selenga River basin are developed [6]. The highest risk level was identified in Russia, in the Republic of Buryatia (Fig. 1).

![An integral risk from flooding in Selenga R.](image)

**Figure 1.** Integral flood risk in the Selenga River basin.

Economic risks are fulfilled for the Russian part of the basin and the territory of the Republic of Buryatia. Also they are identified in the future as possible damage in the absence of protective measures. The calculations were performed using specific indicators of the methodology for assessing probable damage from the harmful effects of water and evaluating the effectiveness of preventive water management measures [7]. To date, indexation of the cost of damage is given using deflator indices and producer price indices by type of economic activity.

The results show that the floods of 480.6 km³/year affect the basin. High rates are noted on the Selenga river, which is 48%, i.e. almost half of all flooded lands. Its tributaries give the rest. The values are significant for the Chikoi, Uda, and Dzhida rivers basins and relatively small for the Khilok River. The agricultural industry is suffering enormous losses. Annually, 35.9 thousand ha of the agricultural land is temporarily withdrawn from circulation. With the most massive flooding on the Selenga river, direct damage to the republic is estimated at more than 11.2 billion rubles; 0.8 billion rubles for the Chikoi river; 0.7 billion rubles for the Uda river; and 0.3 billion rubles for the Dzhida river. Huge damages within the settlements are noted directly on the Selenga river. Damage to business facilities is more than 1.8 billion rubles per year; damage to the population is 153.7 million rubles, 81% of which is damage to the city of Ulan-Ude, which is practically not protected from floods today.

4. **Discussion**

In order to reduce damage, an analysis of the possibilities of minimizing risks from the negative impact of water was carried out. A protection system as the most reliable measure is considered. The
effectiveness of constructing protective structures is economically justified for large settlements with area affected zones, such as Ulan-Ude, or for those settlements which have protective structures, but they are in disrepair. For most small settlements, carrying out protective measures is not economically feasible. In this case, the option of relocating residents from hazardous areas is preferable, but it also requires serious government participation. It should be noted that the technical flood protection system involves the infusion of significant financial resources of the state, not only provided for construction but also for the trouble-free maintenance of hydraulic structures in the future.

One of the alternative tools to reduce natural risks is the development of an economic mechanism. The introduction and development of a system of compulsory insurance of natural (flood) risks and the formation of an insurance fund, as well as the development of tax incentives, will reduce the financial burden on the state and provide certain financial guarantees to certain sectors of the economy and the population in case of emergency. At the same time, an important component is to take into account the degree of danger of the territory (frequency of floods), the object value, and the lost product.

In modern economic conditions, insurance should become the most effective risk management tool. Improvement of the compensation mechanism is possible subject to the interaction of the state and the insurance company.

5. Conclusion
Thus, the conducted risk assessment from floods in the transboundary Selenga river basin using this methodology can serve as an objective basis for effective management and can be applied to a number of other dangerous processes and phenomena of natural and anthropogenic genesis. The created geographic information system is a technical tool and provides the ability to quickly solve a number of problems at different topological levels and develop evidence-based recommendations.

In conclusion, we can add that the result of the entire study should be the identification of optimal ways to develop an integrated risk management system for the transboundary basin territory and the development of relevant recommendations. For this, the solution of the following most important tasks is necessary:

- Developing interstate programs, intergovernmental agreements on the basis of uniform international legal documents, which should include and take into account all existing problems associated with potential risks;
- Defining the positions of norms and rules on the functional organization of the territory and its further development;
- Creating a unified geographic information space of a transboundary basin;
- Organizing system monitoring based on digital elevation models, space, statistical and operational information;
- Defining a rational version of a single organizational and functional structure as the main governing body in emergency situations;
- Building awareness of actions to eliminate conflicts between states.

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