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APPROACHES TO ESTIMATE THE SOCIO-ECONOMIC RISKS CAUSED BY THE RIVER FLOOD

A. A. Volchak[1], D. A. Kostiuk[2], D. O. Petrov[3], N. N. Sheshko[4]

[1] Doctor of Geographical Sciences, Professor, Dean of the Faculty of Engineering Systems and Ecology, Brest State Technical University, Brest, Belarus; e-mail: volchak@tut.by
[2] Ph.D in Engineering, Associate Professor of the Department of Electronic Computing Machines and Systems, Docent of Brest State Technical University, Brest, Belarus, e-mail: dmitriykostiuk@gmail.com
[3] Ph.D in Engineering, Associate Professor of the Department of Electronic Computing Machines and Systems, Brest State Technical University, Brest, Belarus, e-mail: polegdo@gmail.com
[4] Ph.D in Engineering, Associate Professor of the Department of Environmental Engineering, Brest State Technical University, Brest, Belarus, e-mail: optimum@tut.by

Abstract

The issues of forecasting damage caused by flooding of anthropogenically transformed territories in a river floodplain of a plain type are considered based on the case of the floodplain of the Pripyat River. A method of spatial analysis of the level of the territory usage and the depth/duration of flooding is proposed, the results of which are applicable in preparation of maps of the socio-economic risks associated with flooding, and in planning anti-flood measures.

Keywords: river flood, anthropogenic transformed territories, socio-economic damage.

ПОДХОДЫ К ОЦЕНКЕ СОЦИАЛЬНО-ЭКОНОМИЧЕСКИХ РИСКОВ, ВЫЗВАННЫХ РЕЧНЫМ ПАВОДКОМ

А. А. Волчек, Д. А. Костюк, Д. О. Петров, Н. Н. Шешко

Реферат

Рассматриваются вопросы прогнозирования ущерба в результате затопления антропогенно-преобразованных территорий в пойме рек равнинного типа на примере поймы реки Припять. Предлагается метод пространственного анализа уровня использования территории и глубины/длительности затопления территории, результаты применения которого применимы при картировании связанных с наводнением социально-экономических рисков и планировании противопаводковых мероприятий.

Ключевые слова: речной паводок, антропогенно-преобразованные территории, социально-экономический ущерб.

Introduction

Methods of geographical analysis and forecasting have found wide application in almost all areas of the economic activity, and in particular in predicting the occurrence and development of dangerous hydrological phenomena (flooding of the territory) [3, 6]. Many scientists are developing methods and algorithms for calculating the boundaries and zones of flooding [8], and flood damage forecasting issues are particularly relevant for highly anthropogenic transformed territories [4, 7]. This also applies to flooding in the floodplains of the rivers.

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In particular, flooding is already a frequent guest in a number of river systems of the Baltic basin. In Belarus, the flood situation within the Pripyat River during the spring flood should be specifically mentioned: almost every year this territory and settlements in its floodplain are subjected to flooding typical for lowland rivers with predominantly snow feeding, resulting in significant economic damage [1, 2].

Flood prevention can be an effective defense mechanism by recognizing the need for information about the causes and consequences of floods and taking flood protection measures. An important element of this is the forecasting of the development of natural and climatic phenomena, their economic and social effect.

The degree of risk associated with such phenomena can generally be expressed as a combination of the probability of occurrence of damage and its consequences. Risk is most often expressed by multiplying the probability of occurrence of a negative event by the severity of its consequences. In one form or another, a similar equation is used to express flood risk in many sources [3, 4], but the specific variables vary significantly depending on the region and source data being assessed.

Estimating the socio-economic damage

Economic damage caused by hazardous hydrological phenomena can be estimated using the ArcGIS Spatial Analyst calculation algorithm package, designed to work with raster maps of various types of geographical phenomena [5]. First, it is necessary to prepare thematic layers of GIS (digital layers) of territories with different levels of economic efficiency, book value and social significance. Thus, it is possible to generalize the study area from a socio-economic point of view. In turn, the mentioned above approach requires a complete and detailed GIS with technical and technological parameters of technogenic objects, which is currently not possible for large areas due to the lack of such an integrated system, and the accuracy of the estimates will not increase significantly. This is due to the fact that enlargement and generalization when performing such estimates makes it possible to smooth out the forecast errors of the flood zone. To represent such an effect, one can conduct a mental experiment: the forecast of the flood zone was made with an accuracy of 100-500 m, while within the limits of the forecast accuracy there is an object with great economic efficiency, in which case the economic damage will be significantly overstated. The overestimation of economic damage will be proportional to the ratio of economic efficiency (or cost, or social significance) of the considered individual object to its average value over the territory of flooding.

The next issue that needs attention is the depth of the water within the flood zone. Depending on the depth of water, the magnitude of socio-economic damage per unit area is estimated. To take into account these features, weights can be used, obtained from preliminary physical, technical and economic analysis of the effect of the water depth of the territory in question on the amount of damage. At the same time, the application of expert estimates method for determining the weight coefficients is quite effective.

The duration of flooding of the territory can be taken into account in the same way as in the case of the depth of water in the territory in question [6], based on weighting factors. Thus, a quantitative risk assessment R can be represented as a product of combinations of the probabilities of flooding events and its duration by an assessment of the socio-economic significance of the j-th area of the territory:

$$R = E_j \cdot \left(p_{i,j}^h \cdot p_{i,j}^t\right) = \sum_{i=1}^{n}\left(p_{i,j}^h \cdot k_{i,j}^h\right) \cdot \left(p_{i,j}^t \cdot k_{i,j}^t\right) \cdot F_i \cdot e_j, \quad (1)$$

where E_j is the amount of damage to the j^{th} type of land, in monetary units;

$p^h_{i,j}$, $p^t_{i,j}$ – probabilistic estimates of the depth and duration of flooding of the j[th] fragment of the territory of the i^{th} area;

$k^h_{i,j}$, $k^t_{i,j}$ – respectively, weight coefficients taking into account the depth of the water standing and its duration for the i^{th} fragment of the j^{th} type of land, dimensionless;

F_i is the area of the i^{th} section formed by the intersection of the geometric polygon of the j^{th} type of land and the flooding polygon classified by depth and duration of the water standing, in the units of area;

e_j – specific efficiency (or cost, or social significance) of the j^{th} type of land, in monetary units per unit of area.

Weights can be determined through the signal functions as follows:

$$k^h = 0{,}5 \cdot \left(\frac{e^{2(h \cdot a_h + b_h)} - 1}{e^{2(h \cdot a_h + b_h)} + 1} + 1 \right) , \quad (2)$$

$$k^t = 0{,}5 \cdot t \cdot \left(\frac{e^{2(t \cdot a_t + b_t)} - 1}{e^{2(t \cdot a_t + b_t)} + 1} + 1 \right) , \quad (3)$$

where a_h, b_h, a_t, b_t are the parameters of the function determined based on the inflection points of the hyperbolic tangent (Fig. 1). In this case, the inflection points correspond to the first and second critical zones.

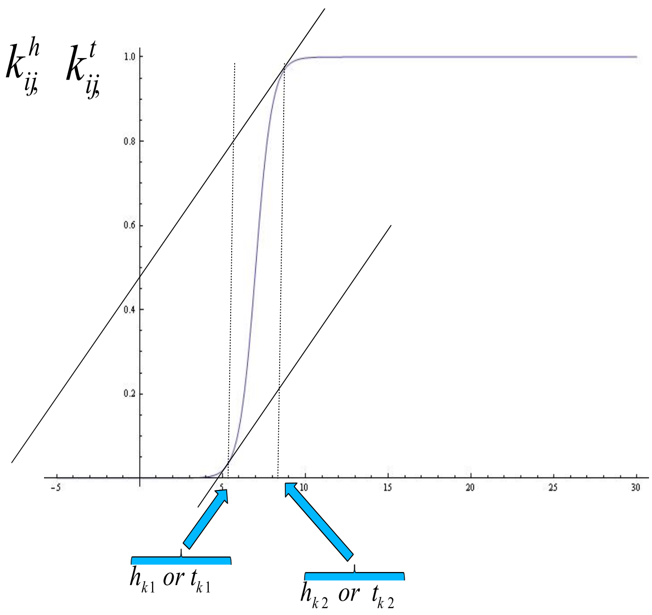

Figure 1 – The scheme for determining the parameters of the signal function

In the figure, one can see the signal function and two critical zones of the conditions for the formation of damages (and, accordingly, the risks of their occurrence) from flooding. The abscissa shows the parameters of the depth and duration of flooding, given by weight coefficients, the values of which depend on the critical zones k_1 and k_2, which, in turn, are determined by the physical and social conditions of damage formation. Thus, 3 zones of damage formation can be distinguished:

1. The first zone is taken for the depth/duration of flooding, when the amount of damage becomes calculable.
2. The second zone means that the damage increases linearly with the increase of the factor (depth or time of flooding);
3. The third zone corresponds to the depth/duration of flooding, the increase of which does not lead to an increase in damage, but is characterized by the areas taken out of circulation and the actual damage calculated for the second zone.

Using the example of determining the flooding time weight coefficient, we define the parameters of the function as follows

$$\begin{matrix} at\ h = h_{k1}, \frac{dk^h}{dh} \to 1 \\ at\ h = h_{k2}, \frac{dk^h}{dh} \to 1 \end{matrix} \to \begin{bmatrix} a_h \\ b_h \end{bmatrix}. \quad (4)$$

It should also be noted that there are differences in the equations for determining the weight coefficient of the depth of flooding and its duration. In the case of a relationship between the depth of flooding, when a certain level is exceeded, the damage stops growing almost completely. However, considering the time of flooding, from a certain moment only fixed costs can be considered as damage, the amount of which is directly proportional to the time of flooded territories exclusion from economic operation.

Risk visualization

It can be assumed that when representing a function in the form of a three-dimensional model, the line of intersection of the resulting surfaces corresponds to the most critical zone and maximum risks in terms of representing socio-economic consequences, thus forming the curve of the greatest damage in three-dimensional coordinates (Fig. 2).

Taking into account the equation of these functions intersection for local conditions of the flood formation, it is possible to obtain the personal weight coefficients of the damage risks.

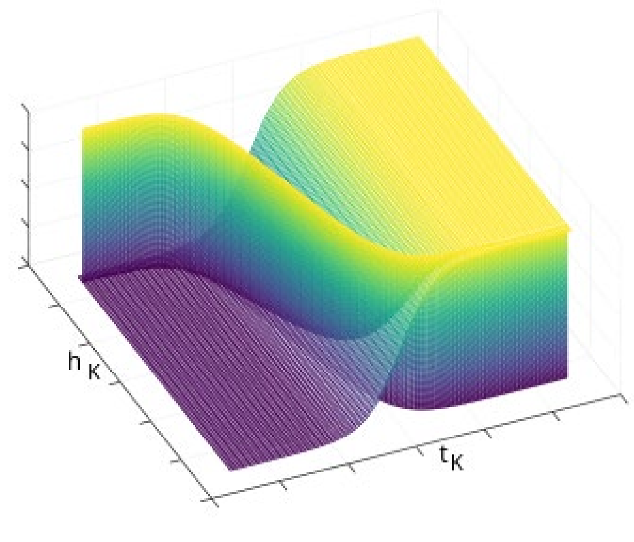

Figure 2 – A three-dimensional to find the line of intersection of the signal functions

The mouth of the Shchara River near a rural settlement was taken as a model site (Fig. 3). A spatial model of the distribution of the probabilities of occurrence of material damage was built using the predicted flooding of the territory and previously obtained weight coefficients (Fig. 3). Zones with a high level of amenities and a low degree of resistance to prolonged flooding are noticeably distinguished in this figure. The predicted value of damage as a result of flooding of the territory can be calculated based on this approach and using the cadastral database of land value and real estate. This, in turn, will make it possible to take into account such probable expenses in the preparation of both local budgets of the territories and the budget of the country as a whole.

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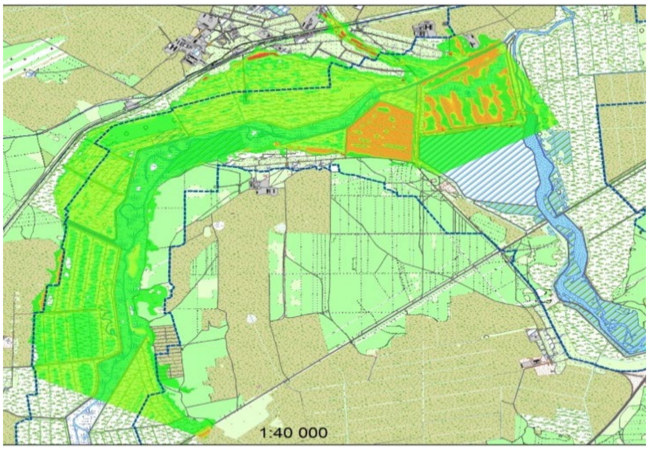

Figure 3 – Visual representation of the socio-economic risk

The approach based on the results of flood prediction, land segmentation based on its anthropogenic transformation, and GIS-based visualization provides the basis for further risk assessment and in planning the needed anti-flood measures and changes to the socio-economic activity on the territory.

Conclusion

Prevention or at least minimization of damage from natural disasters in modern conditions of high anthropogenic transformation is becoming increasingly important. In recent decades, there has been a steady trend towards an increase in the number of dangerous meteorological phenomena, which leads to an increase in socio-economic damage. The use of complex engineering measures, as a rule, reduces the damage caused by minor deviations of hydrological indicators from the average value [10]. A decrease in the calculated hydrological probabilities (less than 1%) leads to a significant increase in the cost of protective engineering and technical measures. Considering the problem from the point of view of the socio-economic damage probability makes the forecast of the allowable amount of damage with a given probability an urgent task. The approach presented in the paper, based on the identification of two critical levels of the impact of flooding, made it possible to establish the most unfavorable case of flood development. For these conditions, the boundary values of the depth and duration of flooding are determined. Using the established boundary conditions, a forecast of the socio-economic risks of flooding was developed for the model river section and the residential area adjacent to it.

The presented methodology for predicting socio-economic risks as a result of flooding of territories makes it possible to obtain quantitative estimates of probable material damage, which makes it possible to carry out budget planning on its basis, which ensures compensatory measures.

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