Forecast of socio-economic damage caused by flooding

Alexander Volchek, Dmitriy Kostiuk, Dmitriy Petrov and Nikolay Sheshko

Brest State Technical University, Brest, Belarus (dmitriykostiuk@bstu.by)

Flood damage forecasting issues are particularly relevant for highly anthropogenic transformed territories. In relation to the Baltic Sea basin, an increase in world ocean level and, as a result, a possible change in the boundaries of the water area increases the importance of this task. This also applies to flooding in the floodplains of the rivers of this region, which, being hydraulically connected to the Baltic basin, clearly respond to the above changes.

Moreover, flooding is already a frequent guest in a number of river systems of the Baltic basin. In particular, in accordance with the assessment of the flood situation within the Pripyat River, published in the Republican Program by Decree of the Council of Ministers of the Republic of Belarus (2009), during the spring flood, this territory and settlements in its floodplain are subjected to flooding almost every year, resulting in significant economic damage.

If we consider the period of existence of this territory, in which there was a slight technological integration in the domestic and industrial sectors, dangerous meteorological and hydrological phenomena did not cause significant material and social damage. This consisted in the use of devices of labor and home life that do not have energy-dependent mechanisms. A similar situation was observed in the field of agricultural production, the lack of significant mechanization made it possible to transfer such natural phenomena less painfully.

With the constant deepening of the technogenic transformation of natural landscapes, the problem of their protection from natural climatic phenomena becomes more and more significant. Measures to protect against flooding of the territory are generally understood as technical (hydraulic) structures that manage water masses in time and space. At the same time, no less important element is forecasting the development of natural and climatic phenomena, their economic and social consequences.

Methods of geographical analysis and forecasting have found wide application in almost all areas of economic activity, and in particular in predicting the occurrence and development of dangerous hydrological phenomena (flooding of the territory). Many scientists are developing methods and algorithms for calculating the boundaries and zones of flooding. So from the point of view of a compromise between accuracy (taking into account the natural relief and technogenic elements of the territory) and the use of computing resources, we can distinguish the algorithm described in detail by Volchak et al. (2010, 2015). As a result of applying this algorithm and the currently existing digital elevation models (DEM), it is possible to obtain not only the area of flooding of the territory, but also its isobaths (contours of equal depths). This will make it possible to classify the territory according to different depths of flooding and thus create polygons for geographic information systems (GIS) corresponding to them. The application of this kind of approach makes it possible to assess the economic and social consequences of flooding the territory more accurately. The work by Mironchik & Sayechnikov (2009) describes a software package that allows you to evaluate the flood zone, as well as calculate the economic damage. The GIS-based geographic analysis approaches described in it quite fully take into account the main types of technogenic landscapes subject to flooding, however, when assessing economic damage, the depth (level) of flooding of the territory and the period of exposure to dangerous hydrological phenomena are not taken into account.

Economic damage caused by hazardous hydrological phenomena can be estimated using the ArgGIS Spatial Analyst calculation algorithm package, designed to work with raster maps of various types of geographical phenomena. 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 approach used in [4] 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 [4], 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 (or 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, based on weighting factors.

Thus, we can present an equation for assessing the damage from flooding (flooding) of the j-th type of land in general:

$$E_j = \sum_{i=1}^{n} k^h_{i,j} \cdot k^t_{i,j} \cdot F_i \cdot e_j ,$$

where E_j is the amount of damage to the j-th type of land, in monetary units; $k^h_{i,j}$, $k^t_{i,j}$ - respectively, weight coefficients taking into account the depth of water standing and its duration for the i-th plot 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 standing water, in units of area; e_j - specific efficiency (or cost, or social significance) of the j-th type of land, in monetary units per unit area.

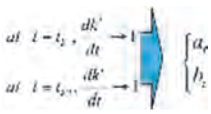
Weights can be determined through the signal functions as follows:

$$k^h = 0.5\left(\frac{e^{2(h \cdot a_h + b_h)} - 1}{e^{2(h \cdot a_h + b_h)} + 1} + 1\right),$$

$$k^t = 0.5t\left(\frac{e^{2(t \cdot a_t + b_t)} - 1}{e^{2(t \cdot a_t + b_t)} + 1} + 1\right),$$

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).

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



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.

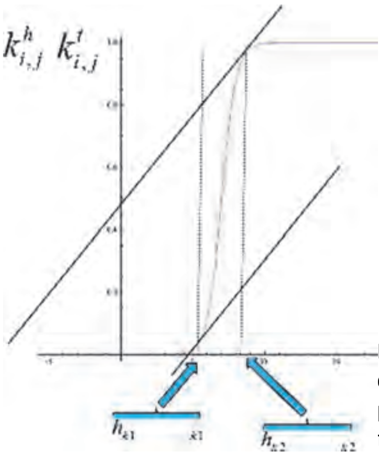


Figure 1. The scheme for determining the parameters of the signal function

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