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MATHEMATICAL MODEL OF DAMAGE DETECTION IN CASE OF ACCIDENT AT HYDRAULIC FACILITY

Annotation. The article presents the algorithm for constructing the dependence of flood consequences on the scope of work and costs to increase the protection of the hydraulic structure. Based on the regression analysis, an analytical model for assessing possible flood damage was constructed. The calculation example is given. The resulting model allows us to formulate a new scientific task to minimize possible damage from flood emergencies by rationally choosing the amount of engineering work and the necessary costs according to the efficiency-cost criterion.

Keywords: regression analysis, scope of work, consequences of emergency, efficiency, cost.

Floods rank first place among natural disasters in terms of frequency, coverage and average annual damage. The damage from them grows from decade to decade. Over the past 100 years alone, according to UNESCO, more than 10 million people have died from floods in the world. In the late XX - early XXI centuries, an important role in increasing the frequency and destructive force of floods is played by the improper implementation of flood control measures, which leads to the breakthrough of dumping dams, the destruction of artificial dams, as well as the erosion of protective embankments [1].

During catastrophic floods in the zone of flooding and destruction there are hundreds of thousands of hectares of farmland, hundreds of settlements, tens of cities, thousands of kilometers of roads and railways, bridges, power and communication lines, industrial facilities, residential buildings, and human economic activity paralyzed for a long time. Flood damage can amount to hundreds of millions of rubles. Flood mitigation has been carried out over a number of years with the involvement of the main resources of local executive authorities, as well as the federal budget [2].

Flood prevention measures can be divided into three groups.

The first is the work of a forecasting and analytical nature - hydrological forecasting, analysis and assessment of a possible situation. The hydrological forecast is a scientifically based prediction of the course, nature and scale of the flood.

The second group of preventive measures is an organizational and operational nature. This is the decision of the local executive bodies, the territorial divisions of the State Security Council and officials to carry out preventive measures and prepare for flood control;

development of draft administrative documents of resources of local executive authorities (on the procedure for evacuation, protection of citizens' property, traffic, on involving the population in work, sanitary and epidemic measures, etc.);

authorization of specific engineering and technical works, protective measures and others, organization of their execution;

clarification of action plans of control bodies and forces, setting of tasks by them [1].

The third group of preventive measures is engineering, etc. They are based mainly on standard methods for mitigating the effects of floods. These may include: reducing the maximum water consumption in the river by redistributing runoff over time, building enclosing dams (shafts), straightening the river bed, filling up territories, coastal and bottom strengthening work, regulating flood flow (flood) using reservoirs, using a combined method of flood prevention. Part of these measures can be carried out only on a long-term basis, part - quickly in anticipation of the elements, and part - both long-term and quickly [1].

However, existing approaches to the planning and implementation of engineering activities to mitigate the effects of floods do not sufficiently justify the development of the scope of their implementation, taking into account the allocated financial resources.

The purpose of this article is, therefore, to develop an approach that would allow for the analytical dependence of possible impacts on the volume and resources spent on flood prevention engineering. This will further make it possible to justify management decisions to prevent and reduce the consequences of floods according to the efficiency-cost criterion.

Setting the task

For constructing the analytical dependence of flood consequences on the scope of work and the costs of increasing the protection of the hydraulic structure, we choose a multiple regression with two explanatory variables. The linear multiple regression function in this case is written as

$$\hat{y} = a + b_1 x_1 + b_2 x_2 \quad (1)$$

where x_1 is the scope of work carried out to improve the safety of the hydraulic structure, increase the gap threshold, in meters; x_2 - costs of works to increase the gap threshold, in nominal units; y ̂ - possible consequences in case of destruction of hydraulic structure, width of flooding, in meters.

To generate a data table for $\boldsymbol{x_1}, \boldsymbol{x_2}, \hat{\boldsymbol{y}}$ we will calculate the forecast of flooding zones and assess the engineering situation. To do this, we will use the technique "Engineering situation during catastrophic flooding from the destruction of hydraulic structures" [3]. The initial data used in the methodology are:

1. Hydrological data (type of section of the river bed, catchment area);
2. Meteorological data (snow thickness and snowmelt intensity, precipitation intensity)
3. Characteristics of the object of impact;
4. Information about the terrain in the flood zone.

The task is to estimate the regression parameters based on the results of sample observations over the variables included in the analysis. For this purpose, we apply the least squares method. Let us set the condition that regression should be as well consistent as possible with empirical data. The sum of the squares of the deviations of all observed values of the dependent variable y_i values calculated from the regression equation y_i (i. e. sum of the remaining squares) must be minimal. So, the requirement must be met

$$S(a, b_1, b_2) = \sum_{i=1}^{n} (y_i - \hat{y_i})^2 \to \min \quad (2)$$

Problem solving algorithm

We will consider the procedure for solving this problem using the example of the Kirov reservoir of the West Kazakhstan region of the Republic of Kazakhstan. The hydroelectric complex includes a channel earthen dam, a floodplain dam, a construction and production spillway and pressure and station structures.

In the event of a breakthrough of the hydraulic structure in question, settlements and socially significant objects may be in the zone of possible flooding.

As stated in the setting of the task, the execution of work to increase the gap threshold is considered as the engineering and technical measures. Using the technique "Engineering situation in case of catastrophic flooding from the destruction of hydraulic structures," we get the values of the volumes of work carried out to increase the safety of the hydraulic structure, to increase the gap threshold, in meters; costs of works to increase the gap threshold, in nominal units; possible consequences in case of destruction of hydraulic structure, width of flooding, in meters. The obtained data are entered in the table, the fragment is presented in Table 1.

Table 1 - Fragment of initial data presentation for regression construction

№	Height of gap threshold, m	Expenses	Width of flooding on the left bank, m
1	0	1000	48,28
2	0,2	1020	48,27
3	0,4	1040	48,26
4	0,6	1060	48,24
5	0,8	1080	48,22
6	1	1100	48,21
7	1,2	1120	48,2
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296	59	6900	3,89
297	59,2	6920	3,01
298	59,4	6940	3,01
299	59,6	6960	3,01
300	59,8	6980	3,01
301	60	7000	3,01

We select the values of the coefficient of regression (1) so as to ensure the best correspondence to the observations in the hope of obtaining optimal estimates for unknown true values of parameters. The assessment of the optimal correspondence is determined by the minimum S (2), that is, the sum of the squares of the deviations:

$$S = e_1^2 + ... + e_n^2 \quad (3)$$

where e_i, is the residue in observation i, the difference between the actual value in this observation and the value y^predicted by regression equation (1).

$$e_i = y_i - \hat{y}_i = y_i - a - b_1 x_{1i} - b_2 x_{2i} \quad (4)$$

Using equation (4), we can write:

$$S = \sum e^2 = \sum (y_i - a - b_1 x_{1i} - b_2 x_{2i})^2 \quad (5)$$

First order necessary conditions for the minimum, i.e.

∂S/∂a = 0,∂S/∂b_1=0 and ∂S/∂b_2 = 0 give the following equations:

$$\frac{\partial S}{\partial a} = -2\sum(y_i - a - b_1x_{1i} - b_2x_{2i}) = 0 \quad (6)$$

$$\frac{\partial S}{\partial b_1} = -2\sum x_{1i}(y_i - a - b_1x_{1i} - b_2x_{2i}) = 0 \quad (7)$$

$$\frac{\partial S}{\partial b_2} = -2\sum x_{2i}\,(y_i - a - b_1x_{1i} - b_2x_{2i}) = 0 \quad (8)$$

Therefore, we have three equations with three unknowns: a, b_1 и b_2.The first equation can be easily rearranged to express the value of a through b_1 and b_2 the observation data of y:

$$a = \bar{y} - b_1\overline{x_1} - b_2\overline{x_2} \quad (9)$$

Using this expression and two other equations, by some transformations it is possible to obtain the following expression for b_1, defined through variance and covariance cov:

$$b_1 = \frac{Cov(x_1, y)Var(x_2) - Cov(x_2, y)Cov(x_1, x_2)}{Var(x_1)Var(x_2) - (Cov(x_1, x_2))^2} \quad (10)$$

A similar expression for b_2 can be obtained by permuting x_1 and x_2, in equation (10). The principles underlying the calculation of regression coefficients do not differ in cases of multiple and paired regression.

Using the data of Table 1, calculating the average values, variances, covariances, independent variables x_1 and x_2 we substitute the found values in (1) - (10). Thus, we determine the analytical type of the regression model of the dependence of the consequences of floods on the scope of work and the costs of improving the protection of the hydraulic structure:

$$\hat{y} = 59{,}564 - 0{,}357x_1 - 0{,}004x_2 \quad (11)$$

Multiple regression analysis allows you to distinguish between influential independent variables, while allowing for their correlation. The regression coefficient at each variable x gives an estimate of its influence on the value of the constant influence on it of all other variables.

The correlation coefficient, which shows how related the fluctuations in the values of the indicators of consequences, scope of work and costs, is 91%. The coefficient of determination was 84%, i.e. the obtained value is a fraction of the variance characteristic of the dependent variable (consequences from floods), which is explained by the influence of independent variables (scope of work and costs). Validation of the Fisher test of F (2.298) = 796.54 when compared with table data at significance level 0.05 also showed high significance of the regression model.

Thus, the obtained designed model (11), the dependence of the consequences of floods on the volume of work and the costs of improving the protection of the hydraulic structure, will allow in the future to scientifically substantiate engineering and technical measures aimed at reducing the consequences of floods in case of destruction of the hydraulic structure.

The resulting model also allows us to formulate a new scientific task to minimize possible damage from flood emergencies by rationally choosing the amount of engineering work and the necessary costs according to the efficiency-cost criterion.

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ГИДРОТЕХНИКАЛЫҚ ҚҰРЫЛЫСТАҒЫ АПАТ КЕЗІНДЕ ЗАҚЫМДАНУДЫ АНЫҚТАУДЫҢ МАТЕМАТИКАЛЫҚ МОДЕЛІ

Андатпа. Мақалада су тасқыны салдарының жұмыс көлеміне және гидротехникалық құрылыстың қауіпсіздігін арттыру шығындарына тәуелділігін құру алгоритмі келтірілген. Регрессиялық талдау негізінде су тасқынынан болуы мүмкін залалды бағалаудың аналитикалық моделі жасалды. Есептік мысал келтірілген. Алынған модель инженерлік жұмыстардың және "тиімділік-құн"критерийі бойынша қажетті шығындардыңнегізінде су тасқынына байланысты төтенше жағдайлардан болатын шығындарды азайтудың жаңа ғылыми міндетін құруға мүмкіндік береді.

Түйінді сөздер: регрессиялық талдау, жұмыс көлемі, төтенше жағдайдың салдары, тиімділігі, құны.

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МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ВЫЯВЛЕНИЯ УЩЕРБА В СЛУЧАЕ АВАРИИ НА ГИДРОТЕХНИЧЕСКОМ СООРУЖЕНИИ

Аннотация. В статье представлен алгоритм построения зависимости последствий наводнений от объема работ и затрат на повышение защищенности гидротехнического сооружения. На основе проведенного регрессионного анализа построена аналитическая модель оценки возможного ущерба от наводнений. Приведен расчетный пример. Полученная модель позволяет сформулировать новую научную задачу по минимизации возможного ущерба от чрезвычайных ситуаций, связанных с наводнениями, за счет рационального выбора объема инженерных работ и необходимых затрат по критерию «эффективность-стоимость».

Ключевые слова: регрессионный анализ, объемы работ, последствия чрезвычайной ситуации, эффективность, стоимость.

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