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Economic Efficiency of Debris-flow Control

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Abstract

Debris-flow is one of the most formidable manifestations of nature. A debris-flow moving along the bed of the debris-flow-carrying river on its way destroys bridges, roadways, roads, hydro-technical and other facilities, causes significant damage to agricultural land, residential buildings, social infrastructure, poses a serious danger to the life and health of the population. A possible way to solve this problem is the construction of engineering structures that ensure the protection of the population living in the area at risk of debris-flow passing, the preservation of both natural and man-made material assets. It is determined that the dependence of the Net Present Value (NPV) on the frequency of the debris-flow passage has a hyperbolic character. The value of NPV reaches its maximum with the annual passage of the debris-flow. With a decrease in the frequency of debris-flow passing, the efficiency of capital investments in a protective structure decreases sharply.

Keywords: Debris-flow; Engineering Protection; Prevented Damage; Economic Efficiency; Net Present Value.

1. Introduction

The natural climatic conditions, alpine relief, the presence of watercourses forming in the highlands largely determine the possibility of the debris-flow' occurrence - one of the ominous manifestations of nature. The debris-flow, having formed in the foci of debris-flow forming, at the speed of an express train, rushes along the bed of the debris-flow carrying river, destroying bridges, roadways and roads on its way. Breaking out of the gorge into the open space of the valley, the flow causes significant damage to agricultural land, residential buildings, other social infrastructure, and represents a serious danger to the life and health of the population. One of the possible ways to solve this problem is the construction of engineering structures that ensure the protection of the population living in the territory at risk of debris-flow passing, as well as the preservation of both natural and human-made material values.

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In this regard, such an unexplored issue as the management of cash flows directed to this rather capital-intensive sphere, including the planning of their efficiency and payback, is of some interest.

2. Main part

When calculating the effectiveness of investments in the construction of counter debris-flow structures, we proceed from the fact that prevented damage in its economic essence is a positive effect arising from the operation of the structure. It should also be noted that debris-flow are usually formed quite rarely, and investments in the construction of protective structures are realized in the current period, while the operation of the structure and, accordingly, operating costs are made annually. Here it should be noted that the damage from the passage of debris-flow represents the loss of labor, material and financial resources, while their magnitude is made up of irreplaceable material losses and expenses for liquidation of the consequences of the passage of debris-flow.

The prevented damage from the debris-flow passage can be roughly determined by the calculation formulas:

$$y = \sum_{i=1}^{n} y_i \ , \qquad (1)$$

where y_i is the damage arising in *i* branch, while $y_i = f(x_1, x_2, ...x_n)$, $x_1, x_2, ...x_n$ are the parameters of the debris-flow. The cash flows arising from the construction and operation of the counter debris-flow facilities have the following form (Table 1).

Table 1: The cash flows arising from the construction and operation of the counter debris-flow facility, thousand GEL

N	Cash flow name	Years					
		1	2	3	...	t_{n-1}	t_n
1	Capital construction costs	K					
2	Annual operating costs	C_1	C_2	C_3	…	C_{n-1}	C_n
3	Damage prevented						P

Taking into account the above, the Net Present Value of the constructed counter debris-flow facility can be calculated by the formula:

$$NPV = \frac{P}{(1+\alpha)^n} - K - \sum_{i=1}^{n} \frac{C_i}{(1+\alpha)^i} \ , \qquad (2)$$

where *P* is a prevented damage in year n;

K — capital construction costs in the zero year;

Ci — operating costs in *i* year;

$(1+\alpha)^i$ — discounting factor.

Together with the calculation of the Net Present Value, the indicator of the internal rate of return (profit) (*IRR*) is usually calculated, which largely complements the calculation of the effectiveness of investments, serves as a fairly reliable guideline determining the feasibility of capital construction [1, 3].

In general, for any investment project, the formula for calculating the IRR is:

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} , \qquad (3)$$

where CF_t — cash flows from the project at the moment *t*;

n — the number of time periods;

IRR - internal rate of return.

As is known, mudslides carry dozens and hundreds of thousands, and in some cases, millions of cubic meters of mudstone mass to the lower reaches. At the same time, the intensity of destructive processes in the debris-flow basin depends mainly on the state of the vegetation and soil cover, climate, the geological structure of the basin, and the tectonic activity of its individual sections [2]. The power of the destructive effects of debris-flow can be judged from the following data. So, only in 2017 [4], the gathering of debris-flow in the Philippines caused the death of about 90 people. The victims of debris-flow, descended from the mountains in the Los Lagos area in Chile, were at least 15 people. Debris-flow resulted from heavy rains. In total, about 200 houses were damaged or destroyed. This nature element disrupted the water and electricity supply. In Kabardino-Balkaria, a powerful debris-flow descended from the slopes of the Adyl-Su mountainside. In the mountains, 27 tourist bases and 49 registered tourist groups, which included more than 500 people, were cut off. Three people became victims of the debris-flow. The mudslide led to serious roadside collapses on four sections of the Prokhladny-Baksan-Azau federal highway. Eleven pedestrian, livestock-driving and road bridges, and a number of shore protection structures were damaged. In three villages, the ground coastline, the sewage system, and the elements of drinking water supply were disrupted. In the same region, the debris-flow caused by the melting of glaciers descended along the floodplain of the Gerkhozhan-Su river to the district center Tyrnyauz. The emission of the debris-flow was about 600 thousand cubic meters, and the total mass of the sediment deposits — 300 thousand cubic meters. Immediately, several debris-flow hit the Kadamjay region of Kyrgyzstan. 84 houses were flooded, 25 kilometers of roads were blurred, 12 bridges were destroyed, power lines were tumbled down, 21 cars were damaged, and five people were killed. As a result of the mudslide, a landslide damaged 2 km of the highway in the area of the Georgian Military Highway, and the car traffic was stopped in the Daryal Gorge.

From the above it is clear that the physical destruction of the natural infrastructure leads to significant socio-economic damage, the magnitude of which usually varies from 0.2 to 2.0 or more million US dollars. In order to protect against the destructive impact of the debris-flow, preserve the stable state of the natural infrastructure of the catchment basins, an engineering protection option is proposed, which is an counter-debris-flow semi-conic structure [5]. With a stream width of 10 m, the height of the structure was determined to be 5 m, and the length was 26.5 m. The consumption of materials for the construction of the structure is: retired railroad rails — 500 m, reinforced concrete works — 17.0 m^3, earthworks — 14.13 m^3. For conditions where the coefficient of penetration is 0.56, the number of structures necessary for effective protection of the adjacent territory is 2. Thus, the cost of creating two counter-debris-flow structures in the prices of 2019 reaches 24.7 thousand US dollars. Operational costs necessary for the protection and maintenance of structures in good condition approximately amount to 3.0 thousand USD/year. The values of the Net Present Value (NPV), as well as the internal rate of return on investment in the construction of counter-debris-flow structures (IRR) depending on the frequency of passage of the debris-flow are shown in Table 2.

Table 2: The magnitude of the Net Present Value (NPV) and the internal rate of return on investment in the construction of counter-debris-flow facilities (IRR)

Frequency of debris-flow passing, years	Damage up to 200.0 thousand USD		Damage up to 1000.0 thousand USD		Damage up to 2000.0 thousand USD	
	Net Present Value, thousand USD (*NPV*)	Internal Rate of Return on investment, % (*IRR*)	Net Present Value, thousand USD (*NPV*)	Internal Rate of Return on investment, % (*IRR*)	Net Present Value, thousand USD (*NPV*)	Internal Rate of Return on investment, % (*IRR*)
3	112,8	135	680,85	431	1390	654
5	81,5	41	537,25	115	1107,2	157
10	25,13	7	281,13	30	601,1	41
15	-6,35		137,65	13	317,6	19
20			55,67	5	155,67	9

The results of calculations of NPV and IRR given in Table 2, with the expected damage from the destructive impact of debris-flow to 200.0 thousand USD show that the greatest effect from the construction of a protective structure is observed when a stream passes at a frequency of once every three years. At a satisfactory level, efficiency is at the frequency of the passage of debris-flow once every five years, but already at the frequency of passage once every ten years, despite the fact that the Net Present Value is 25.13 thousand USD, the value of the internal rate of return on investments becomes below the cost of capital advanced in this activity. Figure 1 shows a graph of changes in the economic efficiency of capital investments in the construction of counter-debris-flow protective structures depending on the frequency of debris-flow passing through the territory of a particular locality with an expected economic loss of up to 200.0 thousand USD.

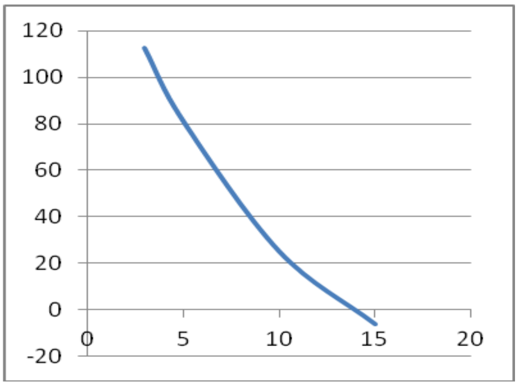

Figure1: Graph of changes in the economic efficiency of investments in the construction of counter-debris-flow protective structures (*y*) depending on the frequency of debris-flow (*x*) with the expected economic damage up to 200.0 thousand USD.

The equation of the relationship between the frequency of debris-flow passage and the effectiveness of capital investments in the construction of counter-debris-flow facilities is:

$$y_1 = \frac{436{,}5}{x^{1{,}24}}, \quad (4)$$

where y_1 is the Net Present Value (NPV) with the expected economic damage of 200.0 thousand USD;

x — debris-flow frequency.

With the expected economic damage from the passage of a debris-flow up to 1000.0 thousand USD, the greatest effect from the construction of a counter-debris-flow protective construction is observed at the frequency of the flow once every three years. At a satisfactory level, efficiency is at the frequency of the passage of debris-flow once every fifteen years, but at the frequency of passing once every twenty years, the value of the internal rate of return on investments becomes lower than the cost of capital advanced into the construction of protective structures.

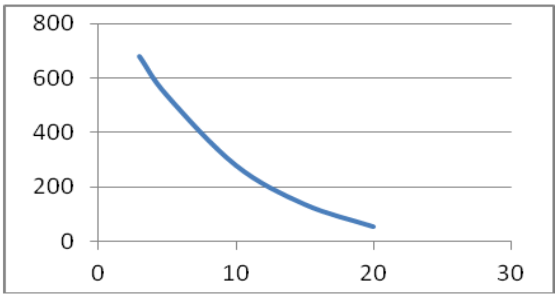

Figure 2: Graph of changes in the economic efficiency of investments in the construction of counter-debris-flow protective structures (*y*) depending on the frequency of the debris-flow (*x*) with the expected economic damageup to 1000.0 thousand USD

Figure 2 shows a graph of changes in the economic efficiency of investments in the construction of counter-debris-flow protective structures, depending on the frequency of debris-flow passing through the territory of a particular locality, with expected economic damage up to 1000.0 thousand USD.

The equation of the relationship between the frequency of debris-flow passage and the effectiveness of capital investments in the counter-debris-flow construction facilities is:

$$y_2 = \frac{1553{,}56}{x^{0{,}72}}, \quad (5)$$

where y_2 is the net present Value (NPV) with the expected economic damage of 1000.0 thousand USD;

x — debris-flow frequency. Approximately the same picture as for the expected economic damage to 1000.0 thousand USD is observed with damage up to 2000.0 thousand USD. At the same time, the greatest effect from the construction of a counter-debris-flow structure occurs when the frequency of the flow passes once every three years. At a satisfactory level, efficiency is at the frequency of passing debris-flow once every fifteen years: but at a frequency of passing once every twenty years, the construction of a protective structure becomes ineffective, since the value of the internal rate of return on investments is lower than the cost of capital advanced into the construction of protective structures. Figure 3 presents a graph of changes in the economic efficiency of investments in the construction of counter-debris-flow protective structures, depending on the frequency of debris-flow passing through the territory of a particular locality with an expected economic loss of up to 2000.0 thousand USD.

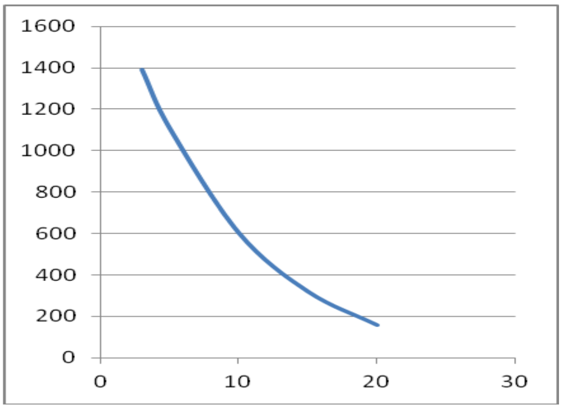

Figure 3: Graph of changes in the economic efficiency of investment in the construction of counter-debris-flow protective structures (y) depending on the frequency of debris-flow (x) with the expected economic damage up to 2000.0 thousand USD

The equation of the relationship between the frequency of debris-flow passage and the effectiveness of capital investments in the construction of counter-debris-flow facilities is:

$$y_3 = \frac{3767{,}0}{x^{0{,}92}}, \quad (6)$$

where y_3 is the Net Present Value (NPV) with the expected economic damage of 200.0 thousand USD;

x — debris-flow frequency. Thus, the dependence of the Net Present Value (NPV) on the frequency of the debris-flow passage has a hyperbolic character. The value of NPV reaches its maximum with the annual passage of the debris-flow. With a decrease in the frequency of debris-flow passing, the efficiency of capital investments in a protective structure decreases sharply. In this regard, it is necessary to carry out capital expenditures only on the basis of a detailed assessment of the potential of the foci of debris-flow, to build defenses as soon as possible from the source of the debris-flow, and systematically carry out cleaning works on the watercourse.

3. Conclusions

(i) Debris-flow is one of the most formidable manifestations of nature. Debris-flow, moving along the bed of the debris-flow-carrying river destroys on its way bridges, dirtroads, roadways, hydro-technical and other structures. Breaking out of the gorge into the open space of the valley, it causes significant damage to agricultural land, residential buildings, social infrastructure, and represents a serious danger to the life and health of the population.

(ii) A possible way to solve this problem is the construction of engineering structures that ensure the protection of the population living in the area at risk of debris-flow passing, the preservation of both natural and man-made material assets.

(iii) The dependence of the Net Present Value (NPV) on the frequency of the debris-flow passage is hyperbolic. The value of NPV reaches its maximum with the annual passage of the debris-flow. With a decrease in the frequency of passing debris-flow, the efficiency of capital investments in a protective structure decreases sharply. In this regard, it is necessary to carry out capital expenditures only on the basis of a detailed assessment of the potential of the debris-flow foci, to build protective structures in the place closest to the predicted time of the debris-flow, to systematically carry out purification works on the watercourse.

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