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Ecology

Controlling Water Erosion Processes on Mountain Slopes Using Innovative Measures

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An innovative design of environmental protection structures for controlling erosion processes on mountain slopes, the priority confirmed by the Georgian Patent #625U, is presented in the work. Three different configurations of the design and schemes of their placement on mountain slopes are discussed. The methodology of designing structures (embankments) to combat water erosion processes on mountain slopes, taking into account the main geological, hydrological and hydraulic parameters of the territory, is considered. In order to forecast erosion processes on mountain slopes, three scientific expeditions were conducted from May to October 2024 on the example of Chiatura Municipality, during which five villages – Melusheti, Kveda Chalovani, Mgvimevi, Zeda Chalovani and Tkemlovana were selected as study objects and a network of ravines and gullies was selected in them. Geographical, biological, hydrological and geological scientific studies of the territory were carried out, on the basis of which the main design parameters of ravines and gullies as well as the percentage of vegetation coverage of the territory were determined. To assess the processes of water erosion, the universal equation of soil loss calculation was used and the assessment of water erosion processes in the bed of gullies and ravines was carried out on the example of five villages, taking into account its main determinants and the maximum intensity of 30-minute precipitation in the territory. Theoretical studies have established that the intensity of erosion processes in gullies and ravines varies in the range of 2-4 classes of erosion according to the scale of English scientist, Professor Roy Morgan, for which the corresponding degree of damage of soils and grounds by water erosion is 3.21-45.0 tons per hectare per year. *© 2025 Bull. Georg. Natl. Acad. Sci.*

mountain slope, erosion processes, erosion control, gully, ravine

Device for Water Erosion Control on Mountain Slopes

To control water erosion processes on mountain slopes, erosion control embankments have been developed (Georgian Patent #925U), which are earth bags placed on the mountain slope in various configurations that provide damping of kinetic energy of surface water flows generated as a result of intense precipitation on the mountain slope [1] (Figure).

The device for water erosion control, shown in Figure 1, consists of long bags made of durable synthetic material (1), which are filled with local inert material (2) and fixed on the mountain slope with high-strength fasteners (3).

In order to dampen the kinetic energy of surface water flows formed as a result of intense precipi-

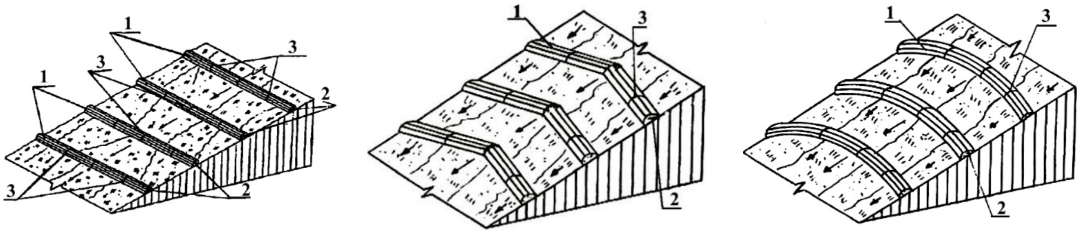

Figure. Erosion control device.

tation on the mountain slope, the placement of long synthetic bags parallel to each other, along a broken line or arc across the entire width of the slope provides a reduction in the speed of the surface water flow and, consequently, reduces the occurrence of longitudinal gaps and gullies between the bags and the ground in the upper part of the structure.

For the erosion control structure to work effectively, the spacing of the synthetic bags must be designed, of course, to consider the rate of erosion so that there is no deep or plain erosion on the mountain slope [2,3].

Design Methodology for Soil Erosion Control Barriers

The placement of erosion control earth embankments on mountain slopes and the re-vegetation between them are carried out according to an appropriate methodology, which is discussed below.

Taking into account topographic, geological, soil, climatic and hydrological parameters of the mountain slope and hydraulic parameters of surface water runoff formed on the slope, the critical distance (spacing) between embankments ensuring soil protection from water erosion processes is determined [4]:

$$X_0 = \frac{V_{\Delta 0}^{5.4}\left(BH_0+1\right)^{2.7} n^{4.4}\sqrt{\alpha^2+\beta^2}}{2.25\ln^2\left(1-R\right)dtg^{0.8}sq} \text{ (m)}, \quad (1)$$

where $V_{\Delta 0}$ is the limit (non-scouring) bed velocity of soil (m/s); B is the slope width, which is determined by the following formula [5]:

$$B = \frac{156250}{w d t} \text{ (m)}, \quad (2)$$

where w is the average value of flow pulsation frequency (1/s); d is the size of detached soil particle ($d = 0.0004$ m); t is the duration of rain of given intensity, seconds; H_0 is the permissible height of stream bed scouring, m; n is the slope roughness coefficient; α, β are the coefficients characterizing unevenness of slope surface (for ploughed soil $\alpha = 13.4$; $\beta = 17.6$); R is the slope reliability in terms of erosion; s is the slope angle of inclination (degree); q is the slope runoff (m/s).

Table 1. Spacing of anti-erosion embankments (m)

Slope gradient (degree)	Sandy soils		Loam		Clays	
	$V_{\Delta 0} = 0.11$ m/s		$V_{\Delta 0} = 0.115$ m/s		$V_{\Delta 0} = 0.12$ m/s	
	$R = 0.95$	$R = 0.99$	$R = 0.95$	$R = 0.99$	$R = 0.95$	$R = 0.99$
5	39.1	16.6	49.7	21.1	62.6	26.6
10	22.5	9.5	28.6	12.1	35.9	15.3
15	16.2	6.9	20.6	8.8	26.0	11.0
20	12.9	5.5	16.4	7.0	20.6	8.8
30	9.3	4.0	11.9	5.0	14.9	6.3
40	7.4	3.1	9.4	4.0	11.9	5.0
50	6.2	2.6	7.9	3.3	9.9	4.2
60	5.4	2.3	6.8	2.9	8.6	3.6
70	4.7	2.0	6.0	2.6	7.6	3.2

If taking into account the values of non-scouring bed velocities recommended by Academician Ts. Mirtskhulava: 0.11 m/s for sandy soils, 0.115 m/s for loamy soils, and 0.12 m/s for clays, then the optimal values of spacing of erosion control embankments calculated by (1) relation are given in Table 1.

The obtained data for the conditions of sandy soils on slopes without vegetation were compared to the data of the world famous scientists R. Morgan and R. Marshall and USLE [6]. The analysis showed that our methodology is more acceptable, since in addition to the main parameters determining erosion, the probabilistic nature of erosion processes is also considered by the calculations.

Forecasting of Water Erosion Processes

From May to October, 2024, field scientific expeditions to studt the erosion processes on the mountain slopes were conducted three times in the territory of Chiatura Municipality.

The aim of the field survey was to identify erosion sensitive areas in the territory of Chiatura Municipality and to determine their sizes by preparing respective sketches.

The orography of the relief was mapped on the sketches by drawing the corresponding rain canals and gullies.

The aim of the field survey was to identify erosion sensitive areas in the territory of Chiatura Municipality and to determine their sizes by preparing respective sketches.

The orography of the relief was mapped on the sketches by drawing the corresponding debris and slope parts. The gradient of the mountain slopes (angle of inclination) and the percentage of vegetation cover were also recorded. To determine the intensity of vegetation cover, soil chemical analysis was necessary, for which 2 soil samples weighing 2.5-3.5 kg were taken from each study area on the ground surface and at a depth of 0.30 m from the ground surface, and soil samples weighing up to 3 kg each were taken for the analysis of geological processes to assess erosive processes on the surface of the corridor. The total number of soil samples was 7.

For visual assessment of erosion-sensitive areas in the territory of Chiatura Municipality, photos were taken, taking into account the relevant GPS coordinates, the corresponding elevations above sea level, sections of eroded area and assessment of geological conditions.

On 5 sections of the territory of Chiatura Municipality, namely: Site #1 (Khreiti-Meleshueti village road; Site #2 (village Zeda Chalovani); Site #3 (village Kveda Chalovani); Site #4 (village Mghvimevi); Site #5 (village Tkemlovana) was assessed on the basis of field scientific and laboratory studies using the universal equation of soil loss by water erosion processes [6].

The calculation equation is as follows:

$$A = R \times K \times L \times C \times P \text{ (t/ha a year)}, \quad (3)$$

where: A is the average annual soil loss (t/ha a year); P is the erosion coefficient of atmospheric precipitation (mm), which is calculated by the following ratio:

$$R = 0.4P \times EI_{30}\,\text{(mm)}, \quad (4)$$

where: P is the sum of storm rainfall (mm), E is the kinetic energy of a unit of erosion rainfall, which is equal to:

$$E = 0.119 + 0.0873 \log I_{30}, \quad (5)$$

where: I_{30} is the maximum intensity of 30-minute rainfall (mm/min); P is the soil erodibility coefficient, which is calculated from the average soil diameter [7]:

$$K = 0.0034 + 0.0397 \exp\left[\frac{-0.5\left(\log D_g + 1.533\right)^2}{0.7671}\right], \quad (6)$$

where: D_g is the average particle diameter, which is calculated by the following formula:

$$D_g = \exp\left(0.01\sum_{i=1}^{n} f_i, \log m_i\right), \quad (7)$$

where: f_i is the mass percentage of coarse fraction; m_i is the particle fraction size; S is the slope gradient coefficient, which is calculated by the following ratio:

Table 2. Main indicators of the intensity of erosion processes in 5 study areas on the territory of Chiatura Municipality

Object	Atmospheric pre-cipitation coefficient (R)	Soil erosion coefficient (K)	Slope gradient coefficient (S)	Slope length factor (L)	Vegetation factor (C)	Area protection factor (P)	Soil loss (A) t/ha	R. Morgan erosion class [9]
Melusheti	157.00	0.012	2.449	2.65	1.0	0.5	6.11	3
Kveda Chalovani	157.00	0.013	0.698	4.51	1.0	0.5	3.21	2
Zeda Chalovani	157.00	0.009	18.565	3.43	1.0	0.5	45.00	4
Mghvimevi	157.00	0.010	5.629	1.84	1.0	0.5	8.13	3
Tkemlovan	157.00	0.011	2.449	1.84	1.0	0.5	3.89	2

$$S = 0.065 + 0.045, S + 0.0065S^2, \qquad (8)$$

where: S is the slope gradient percentage (%); L is the slope length coefficient, which is calculated by the following ratio:

$$L = (l / 22.13)^{0.5} \text{ (m)}, \qquad (9)$$

where: l is teh slope length (m); C is the influence of vegetation, which is calculated according to the following formula:

$$C = e^{-0.06v}, \qquad (10)$$

where: v is the percentage function of vegetation cover; The value of C can be taken as C = 1.0 for the area of bare ground, and C = 1.2 for the area heavily compacted and hardened by the vehicles; P is the protective factor. P = 0.5 in the case of water protection embankments and P = 1.0 when no protection measures are applied.

Using the above methodology, the forecast of erosion of mountain slopes in the 5 study areas of the territory of Chiatura Municiplaity is presented in Table 2.

Conclusion

The work presents an innovative design of environmental protection structures for controlling erosion processes on mountain slopes and a calculation methodology for their design to control erosion processes on mountain slopes.

Thus, as a result of field scientific and laboratory studies conducted on the territory of Chiatura Municipality, it was found that the activity of erosion processes in debris and ditches on five study sites, according to the scale of the English scientist, Professor Roy Morgan, varies within the 2-4 class of erosion with corresponding water erosion damage of soil on the mountain slopes of 3.21-45.0 t/ha a year, indicating a fairly high degree of soil loss on the mountain slopes.

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ეკოლოგია

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ნაშრომში წარმოდგენილია გარემოს დამცავი ნაგებობების ინოვაციური კონსტრუქცია, მთის ფერდობების წყლისმიერი ეროზიული პროცესების კონტროლისათვის, რომლის მეცნიერული სიახლის პრიორიტეტი დამოწმებულია საქართველოს პატენტის მოწმობით #625U. განხილულია წარმოდგენილი ნაგებობის სამი სხვადასხვა კონფიგურაცია და მთის ფერდობებზე მათი განლაგების სქემები. მთის ფერდობზე წყლისმიერი ეროზიული პროცესების საწინააღმდეგოდ განხილულია კონსტრუქციის (ზვინულების) დაპროექტების მეთოდოლოგია ტერიტორიის გეოლოგიური, ჰიდროლოგიური და ჰიდრავლიკური ძირითადი პარამეტრების მხედველობაში მიღებით. მთის ფერდობებზე მიმდინარე ეროზიული პროცესების პროგნოზირების მიზნით ჭიათურის მუნიციპალიტეტის მაგალითზე 2024 წლის მაისი-ოქტომბრის პერიოდში განხორციელდა სამი სამეცნიერო ექსპედიცია, რომლის დროს შეირჩა საკვლევი ობიექტები, კერძოდ, ხუთი სოფელი - მელუშეთი, ქვედა ჭალოვანი, მღვიმევი, ზედა ჭალოვანი, ტყემლოვანა - სადაც გამოიყო ნაღვარევებისა და ხრამების ქსელი. განხორციელდა ტერიტორიის, გეოგრაფიული, ბიოლოგიური, ჰიდროლოგიური და გეოლოგიური სამეცნიერო კვლევები, რის საფუძველზეც დადგინდა ნაღვარევებისა და ხრამების ძირითადი საანგარიშო პარამეტრები, ასევე ტერიტორიის მცენარეული საფარით დაფარვის პროცენტული მაჩვენებლები. წყლისმიერი ეროზიული პროცესების შესაფასებლად გამოყენებულ იქნა ნიადაგის დანაკარგების საანგარიშო უნივერსალური განტოლება და ხუთი სოფლის მაგალითზე შეფასდა ნაღვარევებისა და ხრამების კალაპოტში მიმდინარე წყლისმიერი ეროზიული პროცესები მისი ძირითადი განმსაზღვრელი ფაქტორებისა და ტერიტორიაზე მოსული წვიმის 30-წუთიანი წვიმიანობის მაქსიმალური ინტენსივობის გათვალისწინებით. თეორიული კვლევებით დადგინდა, რომ ნაღვარევებისა და ხრამების ეროზიული პროცესების ინტენსივობა, ინგლისელი მეცნიერის, პროფესორის როი მორგანის შკალის მიხედვით იცვლება 2-4 ეროზიის კლასის ფარგლებში, რომლის შესაბამისი ნიადაგ-გრუნტის წყლისმიერი ეროზიული დაზიანების ხარისხი უტოლდება 3,21-45,0 ტონას ჰექტარზე წელიწადში.

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