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Investigation and Slope Improvement of Landslides on Bodor River Slopes

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ABSTRACT

The Bodor River is an important source of rice irrigation because most of the population works in the agricultural sector. The slopes of the Bodor River have experienced landslides, causing a major negative impact on the community. Many studies state that soil type, consistency, and friction angle influence slope failure. However, the relationship between soil characteristics and landslides on slopes, especially on the Bodor River, has not been studied. This research aims to identify soil characteristics and their influence on landslides on the slopes of the Bodor River, along with recommendations for improvement. The soil was taken after a landslide occurred at a depth of 80 cm for a sieve gradation test, Atterberg limit test, direct shear test, and slope stability analysis using the Cullman method. The research results show that the SW-SM soil type on the slopes of the Bodor River is highly vulnerable to landslides. A steep slope of 50° and a low soil friction angle between 1.38 and 14.11 have less than one safety factor. Changes in soil conditions, such as increased water content, contribute to a higher risk of landslides. Therefore, strengthening the slope is necessary, with the recommendation to increase the slope to 34.5° so that the slope safety factor increases by 73%. The results of this research provide an overview of the relationship between geotechnical soil parameters that influence slope failure in river areas and recommendations for slope improvement to prevent future collapse.

1. Introduction

The Bodor River is located in Plosoharjo Village, Pace District, Nganjuk Regency, East Java. According to data from the Nganjuk Central Statistics Agency, in 2022, the population of Plosoharjo Village will reach 4349 people, classified as densely populated, with the majority of people working as farmers [1]. Economic activities in this area include planting and managing crops, selling agricultural raw materials, and distributing and trading agricultural

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products. The Bodor River is an important source of irrigation for rice fields in this region. However, if there is a landslide on the river slope, it will impact the rice fields' irrigation system so that economic activities in the area will be disrupted. This happened on February 16, 2023, when the slopes of the Bodor River experienced a landslide due to high rainfall. Visual observation shows an asphalt road on the above slopes of the Bodor River. Landslides on the slopes of the Bodor River also caused roads to become narrow, disrupting the economy, especially in the agricultural sector.

Landslides are slope instability that causes masses of soil rock to move down the slope [2], which can cause property damage and economic disruption [3]–[5]. Landslides are triggered by earthquakes, slopes, high rainfall, and human exploitation of natural resources [6][7]. Understanding the causes of landslides to know slope changes and their threats is very important. [8]. Landslides on river slopes can cause flooding, changes in water flow patterns, water pollution, and changes in the topography and morphology of river slopes, resulting in erosion and sedimentation around the river in the long term. Therefore, it is important to identify landslides on the slopes of the Bodor River to prevent subsequent landslides.

Several studies reveal that slope failure is influenced by soil type, soil consistency, and friction angle [9][10]. Saturated sandy clay soil has weak soil strength, making it susceptible to landslides [11][12]. Increasing water content to saturated conditions can eliminate cohesion by up to 30% - 45%, thereby triggering slope collapse [9]. Soil grain size distribution, shear strength, and rainfall influence slope stability [13][14]. Due to rainwater infiltration, coarse-grained soil types are prone to landslides [15]. On the other hand, slopes with dusty clay soil with a friction angle between 11°-15° are prone to landslides. [16]. The steep slope is also important in influencing slope failure [17]. Slopes with 45°- 55° with an increase in water content of 5% - 12% are susceptible to landslides [18]. Various studies have evaluated various factors that influence slope failure. They have conducted studies regarding size distribution, soil type, soil consistency, cohesion and water content. However, the relationship between soil characteristics and landslides on slopes, especially on the Bodor River, has not been studied.

This research aims to identify soil characteristics and their influence on landslides on the slopes of the Bodor River, along with recommendations for improvement. From this, grain size distribution values, Atterberg limits, and soil shear strength will be obtained to determine soil type, soil consistency, and slope stabilization. It is hoped that these results will be able to provide recommendations for slope improvement to increase slope safety factors and reduce the risk of landslides on river slopes in the future.

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2. Research Method

The research was carried out using direct experimental methods in the laboratory. The experimental method was chosen to determine the soil characteristics on the river slope after the landslide. Undisturbed soil samples were taken at a depth of 80 cm. Next, tests included gradation, atteberg limit, and direct shear strength. Test data will be analyzed to determine soil type, soil consistency, friction angle, cohesion, and calculate slope safety factors. The results will be compared with previous research, which will then be used to justify the slope's safety. Improvements will be recommended based on the slope safety results obtained to increase the safety factor.

2.1 Soil Test

Several soil tests carried out include analysis of soil gradation, liquid limit, plastic limit, and direct shear strength. Soil gradation analysis aims to determine the value of the soil uniformity coefficient (Cu) and sieve gradation coefficient (Cc) using a sieve shaker according to the ASTM C 136-06 procedure.[19][20]. The liquid limit test was carried out using a Casagrande apparatus, and the plastic limit test was carried out using a rolling test with a glass plate based on ASTM D 4318 [21][22]. The plastic limit value is obtained from the average water content of all samples [23]. The soil plasticity index value is obtained from the difference between the liquid and plastic limit values.

Furthermore, soil types are classified based on the Unified Soil Classification System (USCS) based on the results of soil gradation tests, liquid limit tests, plastic limit tests, and soil plasticity values. Direct shear tests were performed according to ASTM D3080 procedures to determine friction angles and cohesion [24][25]. Tests on soil samples used loads of 800 grams, 1595 grams, and 3163 grams. The test was carried out four times with varying water content to describe the relationship between water content, soil cohesion, and friction angle.

2.2 Slope FS Analysis

The slope safety factor (FS) is used to determine the level of slope stability. Slope stability is determined using the Cullman method with parameters: water content, friction angle (φ'), slope height (H), soil specific gravity (γ), and shear soil stress. The value of FS is obtained from the division between the average shear stress and the average shear strength. If $FS > 1$, the condition is declared safe, and if $FS < 1$, the slope is unsafe and has a high potential for landslides, and slope improvements are needed. [26].

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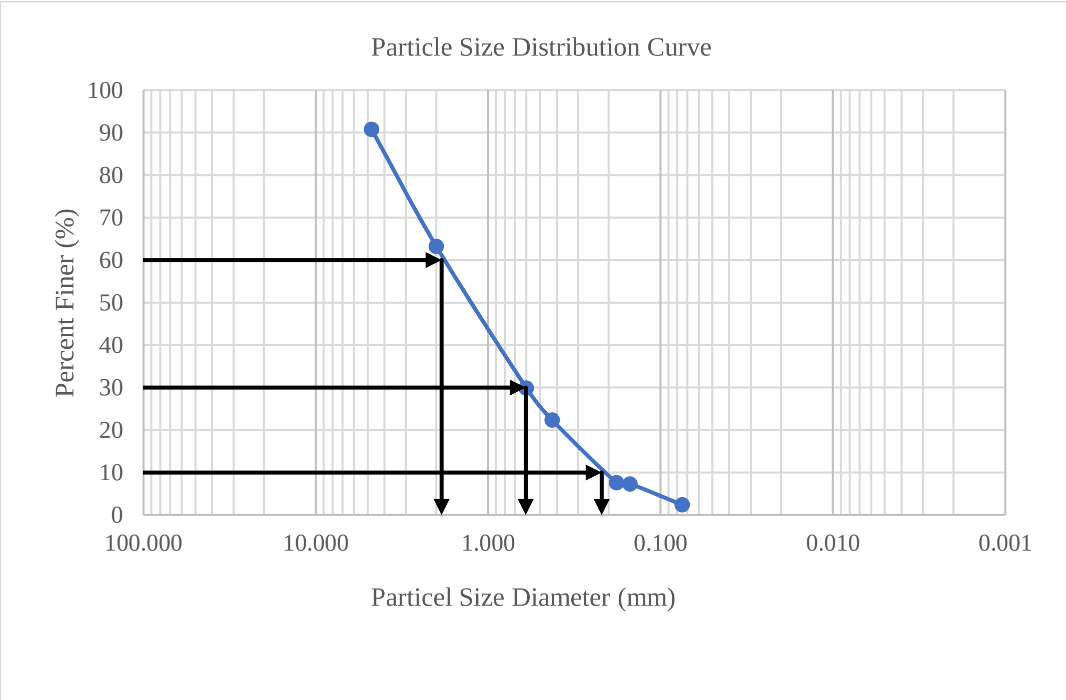
3. Results and Discussion

3.1 Soil Type and Landslides

From the gradation test, soil grain size distribution values were obtained with a uniformity coefficient (cu) value of 10.980 and a gradation coefficient (cc) value of 1.173, which was used to determine the type of soil based on the USCS classification.



Source: Research Data (2023).

Figure 1. Particle Size Distribution Curve.

Table 1. USCS Classification System.

Criteria for assigning group symbols				Group Symbol
Coarse-grained soils More than 50% retained on No. 200 sieve	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines	Cu ≥ 6 and 1 ≤ Cc ≤ 3	SW
		Sands with Fines More than 12% fines	*PI > 7 and plots on or above "A"line*	SM

Source : B. M. Das and K. Sobhan (2018) [27].

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Table 2. Relationship between 45° and 63.4° Slopes in Silty Sandy Soil with Landslides.

High op scarp	Stage 2				Stage 3			
	FS	R (m)	$V_d(m^3)$	K(1/m)	FS	R (m)	$V_d(m^3)$	K(1/m)
(a) 45 °								
0.1 Hz	0.893	2.7	7.73	0.067	0.955	5.11	26.04	0.080
0.2 Hz	0.923	0.82	11.33	0.064	1.007	-	-	-
0.3 Hz	0.944	1.35	14.16	0.060	1.056	-	-	-
0.4 Hz	0.960	1.41	18.63	0.076	1.089	-	-	-
0.5 Hz	0.961	2.02	20.79	0.066	1.139	-	-	-

High op scarp	Stage 2				Stage 2				FS
	FS	R (m)	$V_d(m^3)$	K(1/m)	FS	R (m)	$V_d(m^3)$	K(1/m)	
(b) 63,4°									
0.1 Hz	0.714	0.1	2.94	0.200	0.842	0.63	1.62	0.252	0.893
0.2 Hz	0.740	0.28	3.81	0.214	0.883	1.65	6.03	0.166	0.950
0.3 Hz	0.753	0.28	3.81	0.214	0.896	1.65	6.03	0.166	1.002
0.4 Hz	0.762	0.42	4.39	0.234	0.924	2.53	8.24	0.134	1.057
0.5 Hz	0.764	0.42	4.39	0.234	0.916	2.17	7.11	0.152	1.103

Source: A. Rajabian (2023) [28].

Based on **Table 1**, the soil type on the Bodor River slopes is SW-SM, namely well-graded silty sand. Well-graded silty sand is often used in construction because it can withstand large loads. However, it is unstable in moist soil conditions or high water content, making it susceptible to erosion [29]. The silty sandy soil in the river is highly susceptible to landslides [30]. In addition, a slope angle of 50° increases the vulnerability to landslides, referring to **Table 2** as previous research states that silty sandy soil with slope angles of 45° and 63.5° has an FS < 1.

SW-SM, under buildings' weight, is susceptible to subsidence [31][32]. In addition, silty sand soil with 85% and 90% saturation experience a decrease in shear strength of 2.5 kPa, which increases the risk of soil shifting when there is a load from above [33]. Therefore, the soil on the Bodor River slopes is susceptible to landslides because of direct contact with river water. It has an additional load, namely the weight of vehicles because there is a road above it. River slopes with SW-SM soil types have a high potential for landslides, so it is not recommended to build buildings on silty sandy soil slopes.

3.2 Consistency and Landslides

Soil consistency is known from the soil plasticity index (PI) value. Obtaining the liquid limit (LL) and plastic limit (PL) values will be used to find the plasticity index, which describes the plasticity properties of the soil when the water content and the soil shape change.

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Table 3. Soil Plasticity Index.

PI	Description
0	Nonplastic
1-5	Slightly Plastic
5-10	Low Plasticity
10-20	Medium Plasticity
20-40	High Plasticity

Source: B. M. Das and K. Sobhan (2018) [27].

Table 4. Soil Consistency Test Results.

Soil Type	Water Content	LL (%)	PL (%)	PI
SW SM	29,26%	29,503	29.21	0,482

Source: Author Research Results (2023).

Table 5. Relationship between Soil Plasticity Index and Landslides.

	Sample 4	Sample 13	Sample 21
Location	Betar, Shimultoli	Barnashari, Kaptai	Manikchari, Rangamati Sadar
Soil type	Sand	Silt	Clay
LL(%)	20	22.5	29.7
PL(%)	11.10	14.20	13.30
PI	8.9	15.5	9.2
Comments	Vulnerable for landslide	Highly vulnerable for landslide	Highly vulnerable for landslide

Source: M. S. Islam et al. (2021) [34].

In **Table 4**, the soil on the Bodor River slope has a liquid limit value of 29.503%, a plastic limit of 29.21%, and a plasticity index of 0.482%. Referring to **Table 3**, this soil is classified as nonplastic soil with the potential for landslides because it can only bind a few particles, so it is susceptible to movement when exposed to significant pressure [35]. Based on previous research in **Table 5**, sandy soil has a low plastic index value of 8.9, which has the potential for landslides. Soil with a low plasticity index value between 2.05 – 14.96 is known to be susceptible to landslides [36]. Soil with a low plasticity index is easily brittle and loses its consistency [37].

Soil consistency with a PL between 28.01 and 40.48, namely 29.21, is prone to landslides [16]. Soil water content near the PL can reduce the strength of the soil surface [38]. In addition, high rainfall can increase soil water content, which causes soil consistency and strength to decrease, resulting in erosion and soil degradation, which triggers soil collapse [12][18]. River slopes with SW-SM soil types with a low plastic index value (0.482) are very susceptible to landslides. For this reason, slope improvement is necessary to prevent potential landslides.

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3.3 Friction Angle, Cohesion, and Landslide

Obtaining shear strength parameters in the form of friction angle and cohesion are used to determine soil strength and slope stability analysis.

Table 6. Direct Shear Test Results.

Water Content	Friction Angle	Cohesion
38,75	2,72	0,274
35,33	14,11	0,029
25,00	3,38	0,600
21,23	1,38	0,487

Source: Author Research Results (2023).

Table 6 shows that an increase in water content in the soil results in a decrease in the friction angle and cohesion. This shows that the soil will become weak and unstable when saturated.

Table 7. Relationship between Friction Angle and Landslide.

Station	Friction Angle	Cohesion	Safety Factor	Compactness	Landslide Intensity
ST 1	20	0.301	0.192	Very loose	landslide are frequent (unstable)
ST 4	25	0.301	0.480	Very loose	landslide are frequent (unstable)
ST 6	18	0.296	0.278	Very loose	landslide are frequent (unstable)
ST 9	11	0.311	0.210	Very loose	landslide are frequent (unstable)
ST 10	17	0.321	0.361	Very loose	landslide are frequent (unstable)

Source: C. Cahyaningsih et al (2019)[39].

Table 6 shows that the soil on Bodor River slope has a low friction angle between 1.38 to 14.11, indicating that the soil is prone to landslides. This follows previous research in **Table 7**, which states that soil with a friction angle between 11° and 25° has a very loose density, so it is at risk of landslides [39]. Increasing soil water content can cause the friction angle and cohesion values to decrease significantly, indicating that the slope is unstable [14][40]. The shear strength value of the soil decreases by 30-45% when the soil is saturated, thus affecting soil stability [9]. Soil saturation also causes soil pore water pressure to increase so that the shear strength and soil cohesion decrease [41]. A low soil friction angle causes the movement of soil masses to increase, resulting in the risk of landslides, which can result in damage and loss to surrounding humans [42].

3.4 Slope Safety Factor

The slope safety factor (FS) is used to determine the safety level of the slope. Calculation of slope FS on the Bodor River slopes using the Cullman method based on the parameters of the relationship between water content and slope FS [43].

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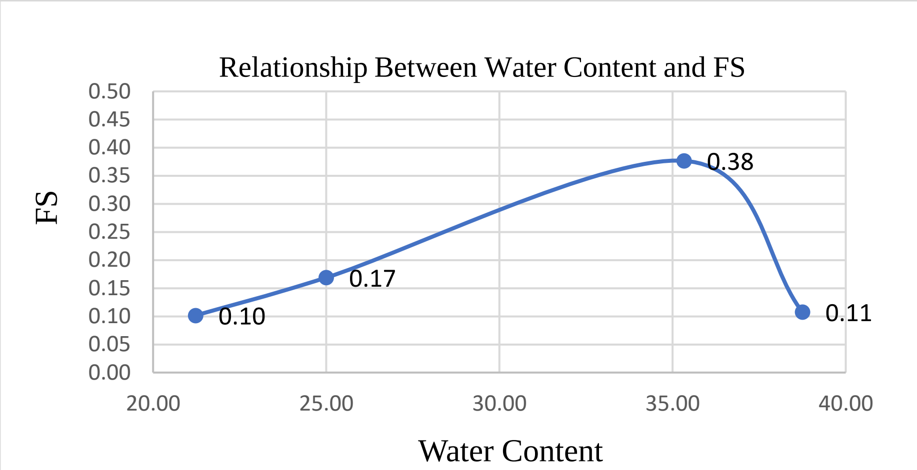


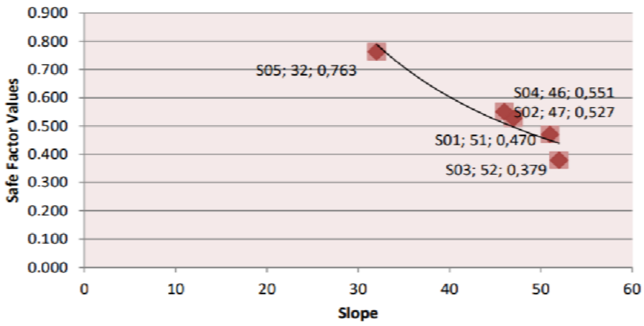
Source: Author Research Results (2023).

Figure 2. Relationship between Water Content and FS (Existing Slope).

Table 8. Relationship between water content and landslides**.**

Slope category	Soil condition	SF using Bishop simplified method	SF using Bishop simplified method after support
Slope 1	15 % water	2.03	
	>25 % water	0.55	1.41
Slope 2	15 % water	2.12	
	>25 % water	0.57	1.25
Slope 3	15 % water	1.92	
	>25 % water	0.69	1.53

Source: M. S. Islam et al. (2021) [34].



Source : A. Patola DM (2023) [44] .

Figure 3. Relationship between Slope Angle and FS

Based on **Figure 2**, the soil on Bodor River slopes has an FS < 1, which indicates slope instability and is susceptible to landslides. This finding follows previous research in **Table 8,** which states that slopes with more than 25% water content tend to have FS < 1. River slopes with a slope angle of 50° are susceptible to landslides, as seen in **Figure 3**. Landslide-prone zones are often found in river valleys that have steep slopes [45]. The steeper the slope, the higher the risk of instability and landslides [40]. River slopes with a slope angle of 50° and soil type SW-SM have an FS of less than 1, potentially landslides. Therefore, stabilization measures are very important to prevent further potential landslides on the slopes of the Bodor River.

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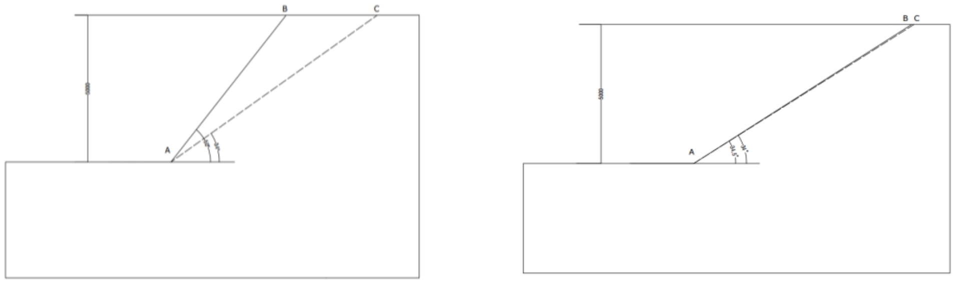
3.5 Slope Improvement

To prevent further damage and landslides on the Bodor River slopes, it is necessary to stabilize by adjusting the slope angle to increase FS slope becomes stable.



(a) (b)

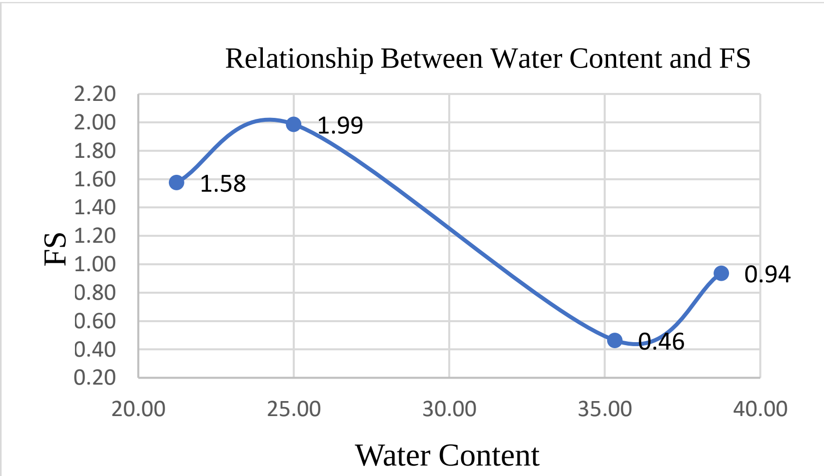
Source: Author Research Results (2023).

Figure 4. River Slope Conditions; (a) Existing Slope; (b) Recommendation Slope

Table 9. Relationship between Slope Angle and Slope FS.

α	Tan (α)	FoS		
		Sandy-Clay	Clayey	Sandy
36.87	0.75	0.9231	1.3978	0.9096
33.69	0.667	1.0363	1.5426	1.045
30.96	0.600	1.1466	1.6392	1.164
28.61	0.545	1.2547	1.7364	1.942
26.56	0.500	1.3566	1.8437	1.425
24.78	0.462	1.4393	1.9469	1.5616
23.2	0.429	1.5211	2.0364	1.7254
21.8	0.400	1.5995	2.1268	1.8564
20.56	0.375	1.693	2.294	1.9837
19.44	0.353	1.793	2.3296	2.1049
18.43	0.333	1.8677	2.4187	2.2181
17.53	0.316	1.9471	2.5094	2.3365
		-0.984	-0.9787	-0.9730

Source: H. M. Shiferaw (2021) [46].



Source: Author Research Results (2023).

Figure 5. Relationship Between Water Content and FS (Recommendation Slope).

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In **Figure 4 (a)**, the Bodor River Slope has a steep slope of 50° and has a low FS (FS < 1). This indicates an unstable slope that has the potential for landslides, so repairs are needed by adjusting the slope angle [46]. Based on **Table 9**, improvements to the sandy soil slopes on the Bodor River were carried out by reducing the slope to 34.5° to achieve an FS > 1, as seen in **Figure 4 (b)**. From **Figure 5**, the optimal water content to maintain slope safety is balanced, neither too high or too low. The best water content for the FS value is 25%, so if the slope water content increases/decreases, the FS value will decrease. River slopes with SW-SM soil types prone to landslides can be improved by increasing the slope safety number FS > 1 to obtain a slope safety angle of 34.5° to stabilize the slope. This will help reduce the risk of landslides and increase infrastructure resilience above the slopes.

4. Conclusion

The research results show that the soil type on the Bodor River Slopes is well-graded silty sand (SW-SM), which is highly susceptible to landslides. This is because sand has loose bonds, so the bonds between the grains are weak and more susceptible to landslides. Apart from that, the steep slope (50°) and friction angle between 1.38 and 14.11 has a safety factor (SF) of less than 1. This value further strengthens the indication of potential landslide risk. Furthermore, changes in soil conditions, such as increased water content, also contribute to an increased risk of landslides. An increase in soil water content of up to 35% can cause soil strength to decrease to a safety value of 0.46. This is because soil particles are eroded by water, reducing soil stability and triggering landslides. Slope strengthening measures are required, with the main recommendation focusing on improving the slope to 34.5° so it is stable. With these slope improvements, the slope FS has increased by 73%, reducing the risk of river slope failures in the future.

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