

Article

Geotechnical Study for Assessing Slope Stability at the Proposed Weito Dam Site in Ethiopia: Implications for Environmental Sustainability and Resilience

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Abstract: There is a proposed dam at Weito in Ethiopia's Southern Nations Nationalities and People Regional State. This embankment-type dam primarily serves irrigation purposes. Weito's proposed dam's slope stability is the primary focus of this investigation. The objective is to assess the geological and geotechnical conditions influencing slope stability using the slope mass rating (SMR) classification system. This study examined various slope stability parameters. Uniaxial compressive strength, rock quality designation, joint condition, discontinuity spacing, joint orientation, and groundwater conditions were measured. An analysis of field data, including geological structures and lithology, was used to generate a structural discontinuity map. The slope mass rating was calculated to assess rock mass stability. The study area was examined for faults, joints, fractures, and shear zones during fieldwork. Schmidt hammer tests indicated a range of 10.5–50 MPa uniaxial compressive strength. Rock quality designation values were also within 72.5% to 95%. Additionally, the joint spacing of rocks varied from 3.95 cm to 47.5 cm. Rock mass ratings ranged from 39% to 62%. The study contributes to the understanding of the geological conditions at the Weito dam site and ensures the dam's safe design and construction.

Keywords: Ethiopia; geotechnical analysis; rock quality designation; slope stability; Weito proposed dam



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1. Introduction

Dams retain water across streams, rivers, and estuaries. Water is used for power generation, irrigation, recreation, industrial processes, and others [1–3]. A dam's reservoir area is affected by the lithology, geological structures, geomorphic features, and weathering grade. A dam's reservoir area is affected by weathering grade, voids, fracture, fault, bedding, joint spacing, joint orientation, aperture, rock strength, porosity, permeability, groundwater conditions, and weak planes [4–8]. In addition to overflowing, earthquakes, active faults, the karstification of rocks, landslides into reservoirs, and reservoir silting, dam structures have short lifespans [9–12].

One of the different geomechanical classification systems developed for analyzing the stability of rock masses is the rock mass rating (RMR) classification system by [13]—this system involves using six parameters based on which a rock mass is classified, including the uniaxial compressive strength of rock material, RQD (rock quality designation), spacing of discontinuities, condition of discontinuities, groundwater conditions and orientation of discontinuities. The Rock Tunneling Quality Index (Q-system) proposed by [14] is a classification system based on six parameters based on which the quality of the rock mass is determined: RQD, J_n (joint set number), J_r (joint roughness number), J_a (joint alteration

number), J_w (joint water reduction factor), and SRF (stress reduction factor). The slope mass rating system (SMR) proposed by Romana is a modification of the RMR system, exclusively for classifying the stability of rock slopes. The RMR parameters are considered along with the slope face, the parallelism of the discontinuities, the dip of the discontinuities, and the method of excavation. The Rock Slope Instability Score (RSIS) system [15] considers the combined effect of geomechanical, geology structure, seismic, environmental, and anthropogenic factors to quantitatively assess rock slope instability. The Q-Slope system developed by [16] is an empirical design approach for rock slope engineering, and it is based on the Q-system. The system developed by [17] for the SMR and slope stability analysis has some advantages over the other systems. The SMR system is an extension of the RMR system, and necessary adjustments are made to consider the orientation of the discontinuities with respect to the slope face for a more realistic prediction of slope behavior under a variety of conditions [15]. The SMR system has successfully been applied to a number of field projects and has also been verified through a number of case studies [18,19]. For instance, Ref. [18] showed that using SMR can assist in the prediction of landslides and in guiding the measures of stabilization in mountainous areas.

The slope mass rating (SMR) is calculated from the rock mass rating basic [20,21] designed for tunneling. Still, it considered discontinuity orientation's effect on slope stability conditions [22–24]. The SMR index is calculated using the SMR Tool. It calculates SMR from geo-mechanical rock mass and slope and discontinuity orientation. Based on a 3D point cloud, the SMR index was calculated [25,26]. Rock hardness is measured by indentation or scratch resistance. This knowledge helps engineers determine how readily rock can be dug or pierced during construction.

Joint spacing measurements determine rock mass natural fracture frequency and dispersion. These data are essential for understanding the structural integrity and stability of the dam site's rock formations. Joint condition examination evaluates rock joint orientation, persistence, and features. Joints alter rock mass stability and permeability, affecting the dam foundation structure and seepage management [27,28]. RQD quantifies rock core sample quality from drilling operations. It indicates rock mass integrity and helps engineers estimate excavation and support needs during dam building [29,30]. Groundwater conditions must be understood to estimate seepage, uplift pressure, and slope stability issues. Hydrogeological studies assess groundwater flow, aquifer properties, dam foundation and abutment water intrusion [31–33]. Assessing structural instability and seepage requires identifying and visualizing rock mass faults and weak zones [34,35]. Geophysical surveys like seismic reflection, electrical resistivity, and ground-penetrating radar can identify underlying structures and discontinuities. Including these assessments in dam site investigations helps engineers choose dam foundation design, building methods, and risk mitigation techniques [36,37]. Engineers may improve the dam structure's safety, robustness, and long-term performance by elucidating the site's geological and hydrogeological circumstances, protecting nearby residents and infrastructure [38,39].

With this background, the present study aims to assess slope stability within the reservoir area of the proposed Weito dam in Southern Ethiopia. This assessment is imperative to ensure the long-term safety and integrity of the dam and its surrounding environment. This study has the following specific objectives:

- To measure rock hardness using uniaxial compressive strength. The precise measurement of rock joint spacing is crucial for structural stability assessment.
- To assess rock joint conditions, including signs of fractures or instability, for rock mass stability.
- To determine rock quality designation (RQD) values for slope stability analysis, assessing rock quality and continuity.
- To assess groundwater conditions to understand their impact on slope stability.
- To visualize faults and weak zones is critical to assessing potential instability sources.
- To measure the orientations of geological features, such as joints and fractures, in order to understand their influence on slope stability.

This study examined the slope stability of Weito's proposed dam in Southern Ethiopia. During fieldwork, rock hardness and joint spacing measurements, joint condition assessment, rock quality designation evaluation, groundwater condition, fault and weak zone visualization, and orientation measurement were conducted to accomplish the study's objective.

Its novelty lies in its comprehensive and detailed assessment of slope stability in the reservoir area of the Weito proposed dam. Several factors contribute to the uniqueness of this study:

- The study's focus on Southern Ethiopia's unique geological and hydrological conditions adds novelty;
- Examining the Weito embankment dam for irrigation stands out due to its unique engineering features;
- The study provides a holistic view of geological structures, rock properties, joint data, and groundwater conditions;
- Precision is enhanced by integrating lithological and structural data;
- The quantitative rock mass rating (RMR) evaluation adds systematic rigor to the study;
- The study addresses weak zones and faults, often overlooked in similar research;
- Results apply directly to the design and long-term stability of the Weito dam.

2. Materials and Methods

2.1. Study Area

The Southern Nations, Nationalities, and People Regional State study area lies between Benetsemay and Ale Special Woreda administrative boundaries. Geographically, it spans coordinates 605,700–613,890 m N and 280,589–288,230 m E in UTM coordinate zone 37, covering 76 sq. km (Figure 1). Located 580 km southwest of Addis Ababa, it is accessible via the Addis Ababa-Arba Minch-Jinka asphalt road and a newly constructed dry weather road branching from Arba Minch-Jinka asphalt road. The region features a high, rugged topography with altitudes ranging from 624 to 1290 m and spiny vegetation. Geologically, it is part of the Southern Main Ethiopian Rift System with diverse rock formations, including metamorphic and igneous rocks. The sedimentary deposits, including lacustrine silt clay deposits, are colluvial and alluvial sediment exposed along the Weito River.

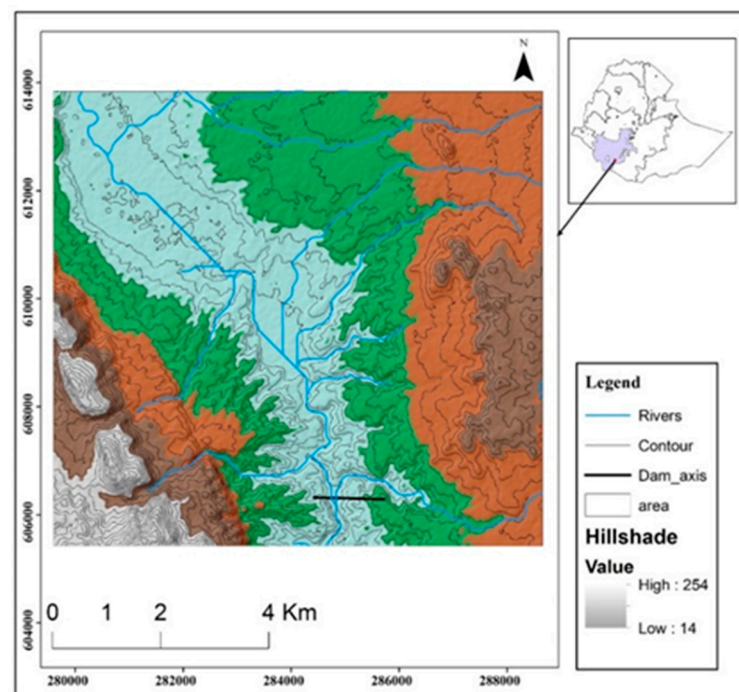


Figure 1. Location of the study area.

2.2. Methods

Six geomechanical stations serve as the representatives based on the following criteria:

The selected areas have varying slope angles such that the different slope inclination leads to an assessment of the effect of slope geometry on stability. Diversity available regarding rock types in the study area, including but not limited to basalt, limestone, and sandstone, inform the selection. Stations had to be accessible regarding making it possible for detailed field investigation and sampling. Locations near key components of the dam structure, such as the abutments and the reservoir perimeter, ensure comprehensive stability assessment.

2.2.1. Field Data Collection

This approach was applied with respect to a detailed methodology involving field data gathering, laboratory tests, and the assessment of SMR. Careful selection of six geomechanical stations was made in view of the dynamic slope conditions, representativeness on rock templates, and good vehicle access. A Schmidt hammer test was carried out for more detailed hardness assessment of rocks, joint geometry and conditions, and RQD from core logging or visual inspection. The groundwater conditions have also been appraised to identify the role that they play in the stability of the slopes. A detailed geological mapping exercise was carried out to identify the major lithological units, structural features, and controlling discontinuities of slope stability.

2.2.2. Laboratory Analysis

Key datasets were generated in this study, including the uniaxial compressive strength of intact rock, rock quality designation, joint spacing, joint orientation, and groundwater conditions. Six steep slope sites were selected to assess slope stability, and slope mass rating parameters were analyzed.

Uniaxial Compressive Strength (UCS) Tests

The uniaxial compressive strength of rock was determined using Schmidt's hammer test [40], with values normalized as per [41]. Furthermore, the Schmidt hammer rebound values were changed to UCS using the following Equation (1), as outlined by [42].

$$UCS = 4.52927^{0.05609RL} \quad (1)$$

where $R = 0.774$ for any rock type without a specific expression and correction method.

Further, the uniaxial compressive strength of rock can be categorized into subclasses based on [43] classification methods.

RQD Measurements

Rock quality designation (RQD) is based on the unbroken percentage of drill core samples longer than 10 cm [44]. In order to calculate RQD, either drill core samples or surface discontinuities are used [45]. RQD is a crucial indicator of rock strength [46] and was determined in this study based on the number of discontinuities per unit volume [46]. It is calculated from the number of discontinuities available over the reservoir area, as shown in the following Equation (2).

$$RQD = 115 - 3.3J_v \quad (2)$$

where RQD stands for rock quality designation and J_v represents a volumetric joint count > 10 cm.

Slope Mass Rating (SMR) Calculation

An important parameter in both slope mass rating (SMR) and rock mass rating (RMR) systems is joint spacing [47]. SMR and RMR were determined by a field-based assessment, in accordance with [47].

Rock and soil pore spaces and fractures are filled with groundwater. Rainfall, reservoir fluctuations, and water loss change the water table's level. The stability of rock slopes is affected by infiltration and water loss. Based on rock surface observations, groundwater conditions were classified as dry, damp, wet, dripping, or flowing. Wet and dry conditions affect slope stability, increasing instability in wet conditions and decreasing it in dry conditions [48]. Thus, rock and slope mass ratings were based on groundwater conditions in the reservoir area.

Slope mass rating (SMR) classifies rock slope stability, derived from Romana's rock mass rating [49], with added parameters for discontinuity orientations and excavation methods. The study employed open-source SMR software (v207) for calculating the reservoir area's SMR index. The orientation of discontinuity was determined based on [49], which derived the slope mass rating system for rock slope stability assessment from the studies of natural and cut slopes along the roads. It was obtained using the following equation.

$$SMR = RMRb + (F1 \times F2 \times F3) + F4 \quad (3)$$

where RMRb is the rock mass rating basic, F1 depends upon the parallelism between discontinuity (joint strike—slope strike), F2 depends on the discontinuity dip, F3 depends on the relationship between slope dip and discontinuity dip, and F4 is a correction factor that depends on the excavation method.

3. Results

3.1. Slope Mass Rating

To determine the slope stability of the study area, six slopes were selected. After slope selection, slope mass rating parameters such as uniaxial compressive strength, rock quality designation, joint spacing, condition of joints, groundwater condition, and orientation of discontinuities were performed.

3.1.1. Uniaxial Compressive Strength of Rock

Rock strength determines slope stability and appropriateness for engineering reasons, including dam building. In this work, the Schmidt hammer rebound value estimates rock uniaxial compressive strengths, which are crucial to understanding their mechanical characteristics. Uniaxial compressive strength, which ranges from 10.5 to 50 MPa, indicates the rock load-bearing capacity. Qualitative categorization of rocks in the research region from weak to strong helps determine their potential for various purposes. Note that slopes one and four have strong rock, indicating structural integrity and deformation resistance. Slopes two, five, and three have medium-strong rock, whereas slope six has weak rock, indicating poorer resistance to external pressures and instability (Table 1).

Table 1. Uniaxial compressive strength of rock.

Slope	Location		Rock Type	Average SHV	Position	Corrected SHV	USC(MPa)	Qualitative Strength
	Easting	Northing						
1	284209	606834	Hypabyssal phonolite	47	V/d	50	50	Strong
2	281306	608207	Leucocratic biotite schist	31	In/d	33	33	Medium strong
3	283915	607442	Hypabyssal phonolite	32	In/d	35	33.42	Medium strong
4	282208	607056	Leucocratic biotite schist	45	In/d	47	60.96	Strong
5	284660	606599	Leucocratic biotite schist	30	V/d	33	30.25	Medium strong
6	284228	607756	Leucocratic biotite schist	15	V/d	16	10.50	Weak

V/d stands for vertical direction, and In/d stands for inclined direction.

3.1.2. Rock Quality Designation (RQD)

Rock quality designation (RQD) is a key indicator of rock mass integrity and appropriateness for building and engineering applications. RQD scores between 65% and 95% suggest good-to-medium quality in this investigation. Qualitative categorization is essential for recognizing the difficulties and strengths in the studied region. Slopes one, three, and five have excellent rock masses, suggesting stability and excavation. Some portions of slope four include rocks with good integrity and little fracture. Slope six has fair-quality rocks with fragmentation and structural discontinuity that may make building and excavation difficult. RQD calculations in a 1 m-by-1 m area using field joint measurements over 10 cm enable quantitative rock mass integrity evaluation in dam site investigations and other geotechnical projects. Table 2 shows the rock quality designation in the present study.

Table 2. Rock quality designation (RQD).

Slope	Location		Jv Value	RQD
	Easing	Northing		
1	284209	606834	13	72.1
2	281306	608207	9	85.3
3	283915	607442	11	78.7
4	282208	607056	6	95
5	284660	606599	10	15
6	284228	607756	82	65

3.1.3. Joint Spacing

Joint spacing measurement is essential for determining rock mass structural features and weaknesses on examined slopes. Joint spacing varies from 3.95 cm to 47.5 cm on the six slopes. This variation shows the study area's varied geology. Joint spacing measures in slopes four and six were moderate, indicating a reasonably dispersed fracture pattern in the rock bulk. In the remaining slopes, joint spacing measurements show tightly spaced joints, indicating more fracture and structural discontinuities. Dam site research and construction design must take into account such narrow joint spacing, which might affect stability and excavation. Table 3 shows the joint spacing details of the present study.

Table 3. Joint spacing.

Slope	Location		Average Spacing Value (cm)
	Easing	Northing	
1	284209	606834	3.95
2	281306	608207	14.5
3	283915	607442	18.9
4	282208	607056	47.75
5	284660	606599	17.9
6	284228	607756	27.85

3.1.4. Condition of Discontinuity

Weathered and fresh joints in the examined region have different characteristics and effects on geological stability. Area joints are weathered, reducing structural integrity. Clay and ash fill worn joints, affecting rock mass stability. Open joints enable geological processes and water infiltration on slopes one, three, and four. Soft joints indicate mechanical weakness and distortion on slopes two and six. Different degrees of connectivity and fluid flow are indicated by 45 cm to continuous joints and 1 mm-to-8 mm aperture sizes. Three

slopes are unweathered, slopes one and four have little weathering, while the remainder are heavily weathered. These variances in joint characteristics and weathering conditions show the complexity of the earth's crust and the necessity for extensive evaluations to influence dam site studies, construction mitigation strategies, and engineering interventions. Persistence ranged from 45 cm to continuous, with apertures between 1 mm and 8 mm. Slopes one and four were slightly weathered, slope three was unweathered, and the remaining slopes were highly weathered (Table 4).

Table 4. Condition of discontinuity.

Discontinuity Condition	Slope					
	1	2	3	4	5	6
Conditions						
Persistence	Value	80 cm	Continuous	45 cm	87 cm	3 m
	Rating	6	0	6	6	2
Separation (aperture)	Value	8 mm	6.5 mm	5 mm	10 mm	4 mm
	Rating	0	0	1	0	1
Roughness	Value	Slightly Rough	Slicken sided	Rough	Slightly rough	Slightly rough
	Rating	3	0	5	3	3
Infilling	Value	No filling	Soft filling	No filling	No filling	No filling
	Rating	6	0	6	6	6
Weathering	Value	Slight weathered	Highly weathered	Unweathered	Slight weathered	Highly weathered
	Rating	5	0	6	5	2

3.1.5. Groundwater Condition

Groundwater conditions reveal the research area's hydrogeology, affecting dam building and stability evaluations. Outcrop rock surfaces were used to measure groundwater conditions in this investigation. Note that slopes two, three, and six had wet groundwater conditions, indicating rock moisture. Dampness indicates moderate water intrusion, which may affect excavation and stability. Other slopes had moist groundwater, indicating higher rock stratum saturation. Wet circumstances during construction may enhance seepage, instability, and erosion concerns (Table 5).

Table 5. Groundwater condition.

Slope No.	Location		Parameters				
			Completely Dry	Damp	Wet	Dripping	Flowing
			Rating				
			15	10	7	4	0
	Easting	Northing					
1	284209	606834			✓		
2	281306	608207		✓			
3	283915	607442		✓			
4	282208	607056		✓			
5	284660	606599			✓		
6	284228	607756		✓			

3.1.6. Orientation of Discontinuity

The SMR system is the extension of the basic rock mass rating along with four adjustment factors that take into account the geometrical relationship between the rock slope face and discontinuity affecting rock mass (factors F1, F2, F3) and the excavation method used (F4). The results of the orientation of discontinuity are shown in Table 6.

Table 6. Orientation of discontinuity.

		Joint			Slope		Auxiliary Angles											
RMR Slope		Joint	Dip Drn	Dip	Dip Drn	Dip	A	B	C	F1	F2	F3	F4	F1F2F3	SMR	Ave.SMR		
49	1	1	110	65	90	60	20	65	5	0.4	1	−6	15	−2.4	61	62		
		2	57	65			30	65	5	0.15	1	−6	15	−0.9	63			
		3	80	70			10	70	10	0.7	1	−6	15	−4.2	59			
		4	124	65			34	65	5	0.15	1	−6	15	−0.9	63			
		5	60	72			30	72	12	0.15	1	0	15	0	64			
39	2	1	50	40	300	32	50	40	8	0.15	0.85	−6	15	0.765	53	53.25		
		2	245	35			55	35	3	0.15	0.7	−6	15	−0.63	53			
		3	235	40			65	40	8	0.15	0.85	−6	15	−0.765	53			
		4	220	47			80	47	13	0.15	1	0	15	0	54			
62	3	1	31	55	350	50	41	55	5	0.15	1	−6	15	−0.9	76	73.2		
		2	30	40			40	40	−10	0.15	0.85	−60	15	−7.65	69			
		3	22	60			32	60	10	0.15	1	−6	15	−0.9	76			
		4	33	54			47	54	4	0.15	1	−6	15	−0.9	76			
		5	24	40			34	40	−10	0.15	0.85	−60	15	−7.65	69			
62	4	1	318	45	280	50	38	45	−5	0.15	0.85	−50	15	−6.375	70	73.8		
		2	320	53			40	53	3	0.15	1	−6	15	−0.9	76			
		3	320	55			30	55	5	0.15	1	−6	15	−0.9	76			
		4	320	50			40	50	0	0.15	1	−25	15	−3.75	73			
		5	300	54			20	54	4	0.15	0.4	1	15	−6	74			
54	5	1	80	75	10	65	70	75	10	0.15	1	−6	0	−0.9	53	52.2		
		2	60	70			50	70	5	0.15	1	−6	0	−0.9	53			
		3	350	75			20	75	10	0.4	1	−6	0	−2.4	51			
		4	35	70			25	70	5	0.4	1	−6	0	−0.9	51			
		5	330	72			40	72	7	0.15	1	−6	0	−0.9	53			
47	6	1	210	60	270	50	60	60	10	0.15	1	−6	15	−0.9	61	61.6		
		2	230	65			40	65	15	0.15	1	0	15	0	62			
		3	245	67			25	67	17	0.4	1	0	15	0	62			
		4	215	57			55	57	7	0.15	1	−6	15	−0.9	61			
		5	247	70			23	70	20	0.4	1	0	15	0	62			

Dip Drn stands for dip direction.

F1 depends on the auxiliary angles (A) between the discontinuity dip direction and slope dip direction

- (a) The strikes of the discontinuity and the slope for planar and toppling failures;
- (b) The azimuth of the line of intersection and the dip direction of the slope for wedge failure.

F2 depends on the discontinuity dip angle (B)

F3 depends on (C)

- (a) The difference between the discontinuity and the slope dip angles for plane failure;
- (b) The sum of the discontinuity and the slope dip angles for toppling;
- (c) The difference between the plunge in the line of intersection and the slope dip angle for wedge failure.

F4 depends on the excavation method.

Most of the slope failures on selected slopes were in a dominantly planar failure mode. In this area, there is no wedge and toppling mode of failure. Except for selected slope five,

all slopes show the natural slope cut excavation method. There was road excavation at selected slope five. So, its method of excavation is mechanical excavation or blasting.

3.1.7. Slope Mass Rating (SMR) and Stability Assessment

Based on SMR calculations, selected slopes two and five were categorized as Normal III with SMR values of 53 and 51. Slopes one and five were partially stable, requiring systematic support due to potential joint and wedge failures. Selected slopes one, three, four, and six were rated Good II with SMR values of 62, 73, 74, and 61, indicating overall stability but with the potential for some block failures. These slopes had relatively higher UCS, and this showed or depicted stronger rock materials, thus leading to more UCS in general stability. High RQD values (e.g., between slope four with 95%) show better rock quality and less fracture along with increased stability. Despite this, the joint conditions for these slopes revealed that the severity of joint conditions was generally lower and the joint ratings were better and more expressed: slightly rough with minimal separation. These slopes mainly comprised sloping grounds that received more or less rain or were dank in some way; measures were, however, taken to prevent any complications regarding stability. A summary of the slope mass rating is shown in Table 7. The SMR values of slope 5 and 6, calculated using SMR Tool software, are shown in Figures 2 and 3, respectively.

Table 7. Summary of slope mass rating.

Parameters		Slope					
		1	2	3	4	5	6
UCS	Value	27.7	50	19.9	11	11.9	30.25
	Rating	4	4	2	2	2	4
RQD	Value (%)	72.1	85.3	78.7	95	82	65
	Rating	13	17	17	20	17	13
Joint spacing	Value	3.95	14.5	18.9	47.5	17.9	27.85
	Rating	5	8	8	10	8	10
D.condition	Value	Slightly rough Separation <1 mm	separation >8 mm Continuous	Very rough separation <1 m not continuous	Slightly rough Separation <1 mm and weathered	Slightly rough Separation <1 mm	3 m and rough
	Rating	20	0	25	20	20	10
G.water condition	Value	Wet	Damp	Damp	Damp	Wet	Damp
	Rating	7	10	10	10	7	10
RMR Value		49	39	62	62	54	47
Description		Fair	Poor	Good	Good	Fair	Fair
SMR Value		62	53	73	74	51	61
Description		Good	Normal	Good	Good	Normal	Good
Class		II	III	II	II	III	II
Stability		Stable	Partially stable	Stable	Stable	Partially stable	Stable
Failure		Some blocks	Some joints or many wedges	Some blocks	Some blocks	Some joints or many wedges	Some blocks
Support		Occasional	Systematic	Occasional	Occasional	Systematic	Occasional

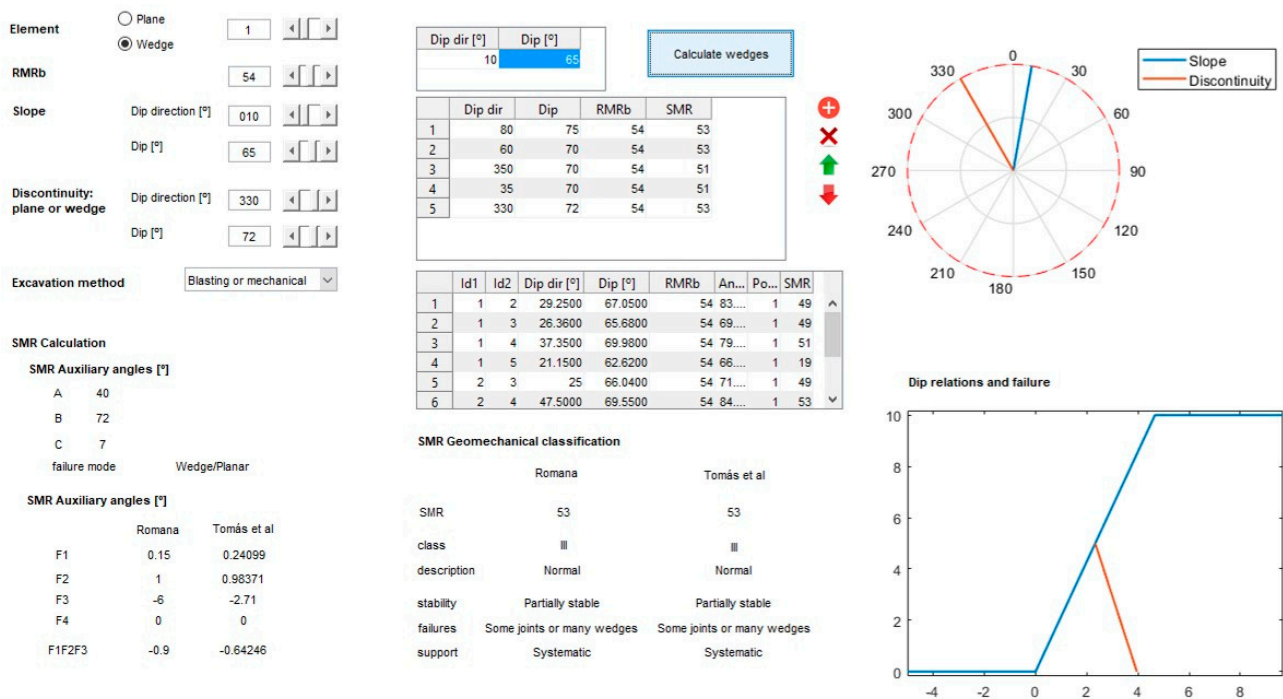


Figure 2. SMR value of selected slope 5, calculated using SMR Tool software.

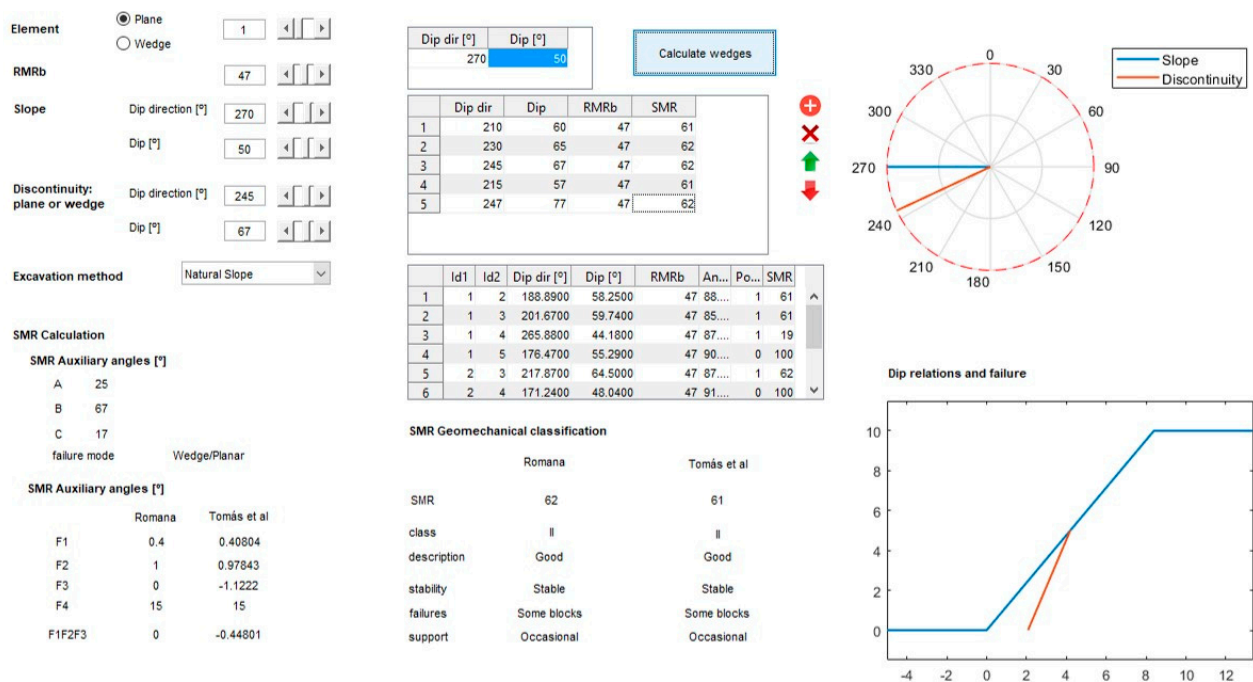


Figure 3. SMR value of selected slope 6, calculated using SMR Tool software.

3.1.8. Geological Structures

Grabens, horsts, and tension cracks characterize the study area. Two regional faults with strike directions of N 500 W were identified southwest of the proposed dam site (Figure 4). A regional fault traverses the proposed reservoir and dam axis. Reservoir area faults require careful consideration. A hot spring approximately 8 km downstream indicates active seismic activity, highlighting the need for meticulous construction.

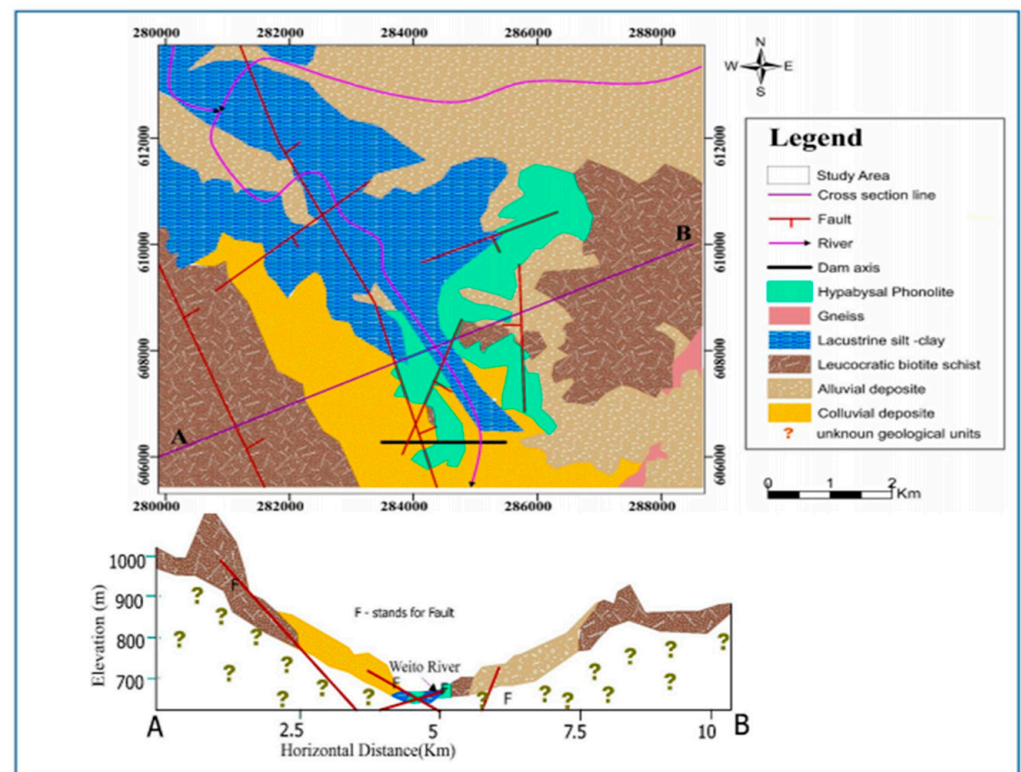


Figure 4. Geological map of study area.

4. Discussion

SMR considered in this study includes parameters such as uniaxial compressive strength, RQD, joint spacing, joint condition, groundwater, and discontinuity orientation. From Schmidt hammer tests, the uniaxial compressive strength was found to range between 10.5 MPa and 50 MPa. This comes out true because, from the results, the weaker rocks in the area are more susceptible to mass failure [50]. Based on RQD values, the estimated RQD of the rocks varies from 65% to 95% and is poor to excellent, indicative that poor RQD values are susceptible to instability; these results thus testify to the importance of RQD in the estimation of slope stability [51]. Joint spacing in the Weito reservoir area takes values with spacing in the area ranging between 3.95 and 47.5 cm. The closer the joint spacing, the greater the instability. This points out the importance of joint spacing when it comes to site selection [52]. The nature of the joints in the area ranges from close to moderately spaced, which calls for due consideration in the design process. Discontinuities are also important in determining the stability of the reservoir. Some of the important discontinuity conditions that need to be studied are roughness, separation, and weathering [53,54]. The presence of accumulations of groundwater has also been observed to create damp conditions at the site of study. This will grossly affect the SMR estimation; thus, proper hydrogeological studies are essential in rock stability estimation. The existence and orientations of geological structures are essential information to be considered in engineering works, including dam construction [53,54]. The present study's results indicate a preferability in selecting a dam axis that is perpendicular to the geological structure's strike since the dam axis in this case displays topmost stability. Similarly, dam foundations are recommended to be constructed on steepness for better slope stability. Conversely, permeable beds that transmit water and slope downstream exhibit greater leakage risks and may become unstable over time, largely due to tectonic actions that might cause sedimentation and worsen their stability [55,56]. Comparisons with other studies reveal similar patterns, where the values of uniaxial compressive strength and RQD are essential parameters in the stability of rocks. However, the peculiarity of the present study is the detailed spatial distribution of rock strength and the all-round assessment of groundwater impact, which has not been carried

out much in the past. Factors contributing to dam site selection considering the geological setting is one of the most critical aspects in any engineering work [55,56]. The orientation of the joint sets had a significant influence, largely on the criterion of site selection. This fact indicated that the central core of the dam should be set in a way to cut across the strike of the sets. Certainly, this further provides better slope stability, especially when the dam foundations are constructed on steep upstream beds. Our observations can also be closely linked with that of [41], who also recommended such geological orientations to provide better conditions for dam stability.

Groundwater conditions are very important to the stability of slopes. The presence of groundwater has been noted to create damp conditions that might significantly affect the stability of slopes through increasing the seepage and erosion hazard [57–59]. Proper hydrogeological studies are required for the correct apprehension and mitigation of these impacts. It is of the utmost importance, therefore, that the orientation of all geological structures, including joints and faults, be carefully considered when estimating the stability of slope in the dam [57–59]. The findings of the present study are that it would be advantageous, from the stability view, to choose the dam axis at right angles to the strike of the geological structure. Moreover, dam foundations on beds with steep upstreams are advisable for enhancing slope stability [57–59]. The study discusses that parameters such as UCS and RQD are necessary for the assessment of rock stability, and the findings of this study do not differ in this context. Unique contributions of this study include the detailed spatial distribution of rock strength and comprehensive assessment of the impact on groundwater.

5. Conclusions

Geotechnical field investigation has provided valuable insights into the site's conditions. A variety of geotechnical challenges have been identified that require careful consideration. A number of challenges are involved, including variations in the strength and quality of the rock, the presence of discontinuities within the rock formations, and the assessment of ground stability. In order to address these challenges effectively, specific adjustments must be made to the geometry of certain slopes, especially in areas where the natural terrain poses a risk. In addition, faults require meticulous planning and remediation to ensure the structural integrity of the proposed dam. In addition, erosion concerns have been identified, necessitating the implementation of protective measures to prevent soil erosion and maintain the stability of the site. The key findings of this study are as follows: variability in UCS values between 10.5 and 50 MPa and RQD measurements of 72.5% to 95% indicate that the rock mass conditions are quite heterogeneous. Closely spaced jointing and variable joint conditions are the main characteristic features with impacts on the stability of this structure. From these results, one can observe that the groundwater condition poses significant influence on the stability of slopes; hence, stabilization measures should be directed accordingly. The geological characteristics of the area dictate cautious construction practices in order to minimize potential risks. A critical aspect of the investigation is the presence of fractured rock coverage. In order to avoid future seepage problems that could compromise the dam's functionality and safety, this issue must be addressed. Overall, the comprehensive geotechnical study emphasizes the importance of meticulous planning, remediation, and adherence to best practices in engineering and construction. In addition to ensuring the stability of the proposed dam, these measures are crucial to its long-term durability and success.

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