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Application of selected engineering geological methods for landslide hazard assessment in the Klisan/Sartka area, western Sulaymaniyah

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Abstract
The study of slope stability in the Sartka region, a significant tourist destination in the Dukan district of the Kurdistan Region of Iraq, is crucial due to its ongoing urban expansion. The landslide rock falls, and ground failures have considerably affected family camps, tourist roads, and recently built residential areas on slopes affected by cutting and filling operations, exposing them to landslide risks. This study focuses on assessing the risk of landslides in mountainous regions using the Landslide Possibility Index method. The method assesses factors that affect slope stability and identifies areas of risk. It improves predictions about cut slopes in mountainous roads. The study identifies the predominant type of landslides and classifies sites based on factors like slope angle, fracture degree, weathering degree, discontinuity gradient, spacing, orientation of discontinuities, vegetation cover, water infiltration, and previous landslides. In addition to the magnitude and range of the dangers that slopes are subject to, five stations were selected, information was gathered, and ten LPI system parameters were measured in the field. The results indicate varying degrees of risk for different sections, ranging from moderate to very high. The slopes in the study area are characterized by a high degree of fracturing and weathering, with very minimal spacing between the joints, and a favorable orientation of these joints in relation to the bedding plane dip. as well as the marl layers of the Kometan and Tanjero formations increase the vulnerability of rock slopes to weathering and erosion, leading to more slope failures. The research highlights the need for preventative measures and engineering solutions to protect structures and ensure public safety in the area.

Keywords: Discontinuities, land slide possibility index, rock slope, Kurdistan regoin

Introduction

Slope stability is a concept that represents the ability of a slope to maintain its shape and structural integrity without collapsing or sliding. This stability depends on the balance of forces acting on the slope, including the weight of soil and rocks, gravity, and environmental factors such as moisture and seismic vibrations. (Ramesh, 2021) [10], (Sharma & Ahirwar, 2024) [11]. The study area represents one of the most important tourist destinations overlooking the banks of the Dukan River, specifically the Lesser Zab. The selected stretch extends approximately 3 kilometers along the liser zab river course and attracts a large number of tourists throughout the year, resulting in heavy traffic and pedestrian congestion. Additionally, numerous buildings have been constructed on the slope through cut-and-fill techniques, as was observed during the fieldwork. This factor increases the likelihood of landslides. To assess the risks of these landslides, the Landslide Possibility Index (LPI), developed by Bejerman (1994) [2], was used to evaluate slope stability. This system was chosen for its ease of field application, as it provides a detailed and accurate study of the entire area, allowing for the assessment of the engineering and structural characteristics of the slopes. The stability of cut slopes on highways is crucial, as even minor failures can lead to severe financial and human losses. A detailed analysis of failure mechanisms is required both before and after cutting and filling (Kainthola *et al.*, 2013) [6]. While physical and chemical weathering of bedrock produces fragmented particles that accumulate on the surface, sufficient erosion processes remove them. Gravity causes these particles to move down the slope and accumulate as deposits (Turner, 1996) [14]. Factor is an important element to consider in landslide modeling. Among the various impacts of plants, root reinforcement is widely recognized as one of the most significant factors for slope stability.

However, in layers with numerous fractures, its effect can sometimes be opposite, as it increases the spacing between rock layers (Masi *et al*., 2021) [9]. The Landslide Possibility Index (LPI) method, developed by Bejerman (1994) [2], includes ten key factors: slope steepness, angle, fracture degree, weathering extent, discontinuities, spacing between layers, layer orientation, vegetation cover, and previous landslides. The Dokan area holds a significant geographic position as a junction of major roads connecting Sulaymaniyah to nearby regions. It is also home to the Dokan Dam and Basin, which are notable for their important geological and structural characteristics. Dokan lies on the southwestern limb of the Kosret Anticline. (Zarraq, 2021) [16]. In 2024, a road risk assessment was conducted along the main road crossing the Qiwan Anticline, situated approximately 20 km north of Sulaymaniyah Governorate. The study utilized the Landslide Possibility Index (LPI) and the Rockfall Hazard Rating System (RHRS) to evaluate potential geohazards. (Zarraq, 2021) [16]. The roads in the northern part of Iraq are primarily mountainous, characterized by steep ascents and descents. Haphazard road cuts have led to instability issues and/or potential areas prone to sliding. Satellite images of the road and all those potential areas were checked in the field, and a study was conducted. (Sissakian *et al*., n.d.)

1.1 Geologic settings

The study area is situated in a highly folded zone characterized by numerous high-amplitude, closely spaced, tight, and overturned folds of varying geometries and dimensions. The landforms, characterized by erosion-resistant Cretaceous rock formations, have significant structural features, manifesting in the topography as elevated, rocky anticlinal mountains interspersed with narrow, deep synclinal valleys. The study area is located in the west of Dukan, along the southwestern part of the Dukan stream, near the Dukan-Qashquli road, northwest of Sulaimaniyah city, approximately 57 km northeast of the Kurdistan Region, Iraq. Geologically, it is located within the Tanjero Formation along the main road (Figure 1). In the Surdash anticline, the formation is divided into two members: Lower Member (300 m), which consists of alternation of sandstone, mudstone, shale, conglomerate, claystone, and sandy limestone. Upper Member (659 m) consists of alternation of sandstone, mudstone, and silty claystone, dominated by mudstone and silty claystone (Al-Shwialy *et al*., 2011) [1].

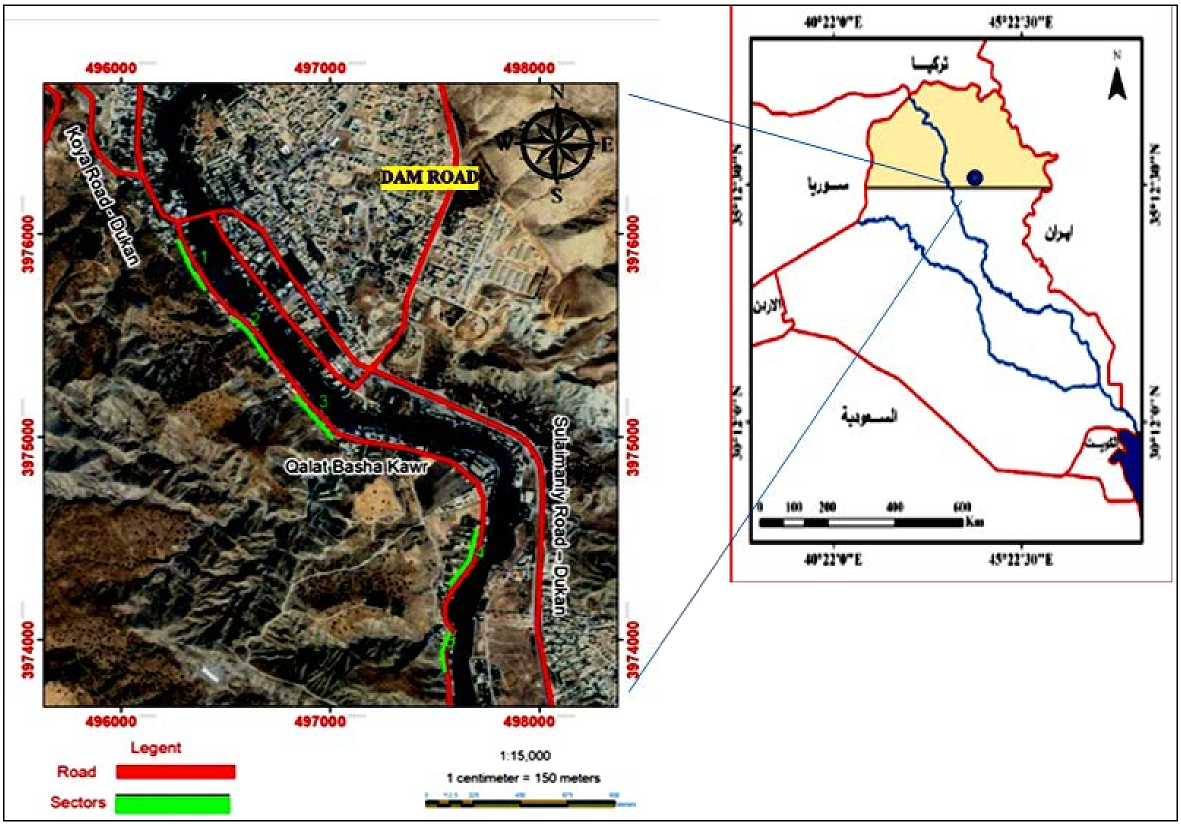

Fig 1: Aerial Image Showing the Study Area - dukan, Northern Iraq.

1.2 Tectonics and Structural Geology

The road lies in the high folded zone, marked by tightly spaced, broad folds and prominent landforms shaped by erosion-resistant Cretaceous rocks (Fouad, 2019) [4]. Within the research region, four locations were chosen, all of which were at different elevations and lined up along the Dokan River's path. At the first and second stations, the dip direction is oriented in opposition to the slope direction, and the dip angle at each station varies roughly between 42° and 65°.

2. Materials and methods

This study used an integrated approach to identify unstable slopes along the Sartka-Qashqoli route by analyzing satellite pictures (such as those from Google Earth and ArcMap GIS). Following this, fieldwork was conducted to record visual evidence and signs of instability. Additionally, a modified checklist was used to classify slope characteristics (Beijerman, 1994). Fig. 1. Using the Offline Maps application to plot the coordinates for each station and create a topographic map for the study area, as shown in Fig. 2. The Landslide Probability Index (LPI) is a quantitative assessment of risk in landslides, based on ten factors such as elevation, slope, rock mass fracturing, weathering, discontinuity spacing, orientation, vegetation cover, water seepage rate, and previous landslide data. It aids in informed decision-making for risk management and urban planning in landslide-prone areas.

NUMBER SLOPE ☐☐☐		PAGE ☐☐☐
KILOMETER ☐☐☐☐☐		DATE ☐☐☐☐☐☐
1. SLOPE ESTIMATE HEIGHT (m) 1 ----------- 8 1 9 ----------- 15 2 16 ---------- 25 3 26 ---------- 35 4 > ---------- 35 5	**2. SLOPE ESTIMATE ANGLE** < 15° 0 15° ------ 30° 1 30° ------ 45° 2 45° ------ 60° 3 > 60° 4	**3. GRADE OF ESTIMATE FRACTURE** Sound 0 moderately fractured 1 highly fractured 2 completely fractured 3
4. GRADE OF ESTIMATE WEATHERING Fresh 0 slightly weathered 1 moderately weathered 2 highly weathered 3 completely weathered 4 residual soil 5	**5. GRADIENT OF ESTIMATE THE DISCONTINUITIES** < 15° 0 15° ------ 30° 1 30° ------ 45° 2 45° ------ 60° 3 > 60° 4	**6. SPACING OF ESTIMATE THE DISCONTINUITIES** > 3 m 0 1 --------- 3 m 1 0.3 ------- 1 m 2 0.05 --- 0.3 m 3 < 0.05 m 4
7. ORIENTATION OF THE ESTIMATE DISCONTINUITIES favorable 0 unfavorable 4		**8. VEGETATION ESTIMATE COVER** void (< 20%) 0 scarce (20 - 60%) 1 abundant (> 60%) 2
9. WATER INFILTRATION ESTIMATE inexistent 0 scarce 1 abundant: permanent 2 seasonal 3		**10. PREVIOUS LANDSLIDES ESTIMATE** Not registered 0 registered (small volume) 1 registered (high volume) 2
1 + 2 + 3 + 4 ± 5 + 6 + 7 + 8 + 9 + 10 = ☐☐		
I (small) (0 – 5) II (very low) (6 – 10)	III (low) (11 – 15) IV (moderate) (16 – 20)	V (high) (21 – 25) ☐☐☐ VI (very high) (> 25)
The LPI value is obtained by adding the estimations of attributes 1 to 10. If the orientation of the discontinuities is favorable, subtract the estimation of gradient.		
OBSERVATIONS:		

Fig 2: Illustrates the estimated parameter values of the Landslide Possibility Index (LPI) used in this study (After Bejerman).

This area was chosen because it is one of the most prominent tourist spots that gets crowded with vehicles and visitors during the tourist season. Additionally, many houses, buildings, and farms have been constructed on those slopes. The fieldwork tools were as shown in Fig. 3, which include a distance measuring wheel, measuring tape, and GPS, and the locations of the study sites with their coordinates are indicated on the topographic map as shown in Fig2.

App).

Both the slope elevation and height measurement ruler were determined. Data were recorded for the slope elevation, the length of the slope face, weathering degree, spacing between discontinuities and their arrangement, vegetation cover, and previous landslides in the area, as shown in Fig. 2. According to Beijerman (1994), we apply LPI on each station. Where the slope length and spacing as shown in Fig., height, degree of inclination, and its directions were measured, the degree of fractures and weathering were determined, and then the percentage of vegetation cover on those slopes, the width of the pavement, the degree of rainwater infiltration, and the impact of weather factors during the wet seasons were assessed. Surveys were conducted in both the wet and dry seasons and compared, and the percentage of the impact of erosion factors and cutting processes on those slopes was determined.

1. **Slope height (m):** This is the vertical distance from the bottom of a slope to the top of the slope hill, measured in meters oe. The steepness of a slope has a direct effect on how strong the rock is against sliding, so it's an important factor in studies about earth movements, like predicting landslides (Zhang *et al.*, 2018 [17]; Wang *et al.*, 2019) [18].

2. **Slope angle:** This is how the steep a slope is, measured in degrees from a flat horizontal line.

3. **Grade of fracture:** When rocks crack, it's because the stress inside them becomes too much for the rock to handle. This changes the rock from bending and flowing to sliding against itself. These cracks usually happen in narrow zones where the rock grains move differently, and the way they move depends on how fast or slow the stress is applied. (Liu *et al.*, 2020) [8].

4. **Grade of weathering:** This refers to how much a rock or soil has changed over time due to physical, chemical, or biological processes.
5. **Gradient of discontinuities:** angle of inclination of repeated, uniform discontinuities (e.g., joints, bedding planes, fractures) within the slope, if present.
6. **Spacing of discontinuities:** It refers to the uniform attitude, or perpendicular distances between the discontinuities, which, together with the stratification levels, define the sizes of the failed or potentially failing rock masses. (Tokmachy & Mohammad, 2024) [19].
7. The distance between adjacent discontinuities is measured along a given plane or direction, usually in meters or centimeters. The spacing distribution of natural joints or fractures in rock masses affects the rock mass's deformability, strength, and transport properties, depending on the size, spatial distribution, and deformability of these features (Stavropoulou *et al*., 2021) [13].
8. **Orientation of discontinuities:** If the slope and the direction a rock surface is tilted don't help start a landslide, it's a good condition. But if the tilted and crossed joint with the other joint set makes it easier for a landslide to happen, it's a bad condition.
9. **Vegetation Cover:** Vegetation cover is the plants growing on the land. prevent erosion, help to hold the soil together, and reduce the chance of landslides. Sometimes making a space between the joints is more than enough to increase the hazard.
10. **Water Infiltration:** Water infiltration is when water moves into the soil.
11. If too much water enters the ground, it can weaken the soil and increase the risk of erosion or a landslide.
12. **Previous Landslides:** Previous landslides refer to past ground shifts or collapses, highlighting areas with a higher risk of future landslides.

Fig 3: Scope of field work while using distance measuring wheel, measuring tape, and compass.

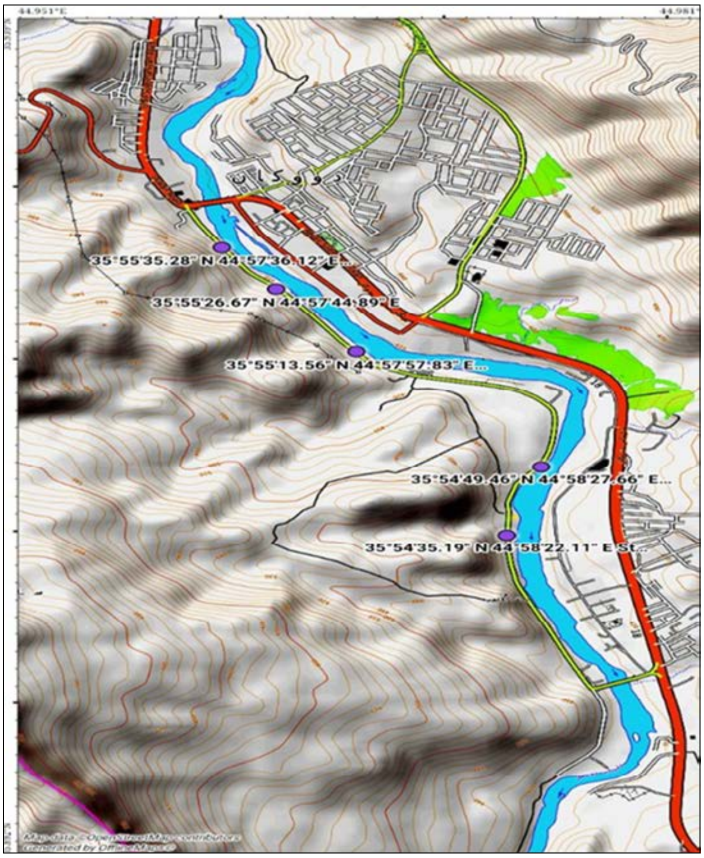

Fig 2: Topographic map for the study area by (Offline map

Table 1: Landslides hazard category (After Bejerman, 1994).

LPI category	Failure possibility	LPI
I	Small	0-5
II	V. Low	6-10
III	Low	11-15
IV	Moderate	16-20
V	High	21-25
VI	V. High	> 25

3. Results

Summary of the System Transaction Rating (LPI) for District (1) and the Second Sections

Table 2: LPI Parameter of station (1).

points	Parameter factor
2	slope high 9-15(m)
4	slope angle 60 ° >
1	grade of fracture (moderate)
2	grade of weathering ⁄moderate weathered
3	gradient of discontinuities
3	Spacing of discontinuities
4	orientation of discontinuities
1	Vegetation Cover
3	water infiltration (seasonal)
2	Previous Land Sliding
25	Total point

Table 3: Parameter of station (2).

points	Parameter factor
1	slope high 9-15(m)
3	slope angle 60 ° >
1	grade of fracture (moderate)
2	grade of weathering ⁄moderate weathered
2	gradient of discontinuities
3	Spacing of discontinuities
0	orientation of discontinuities
1	Vegetation Cover
3	water infiltration (seasonal)
2	Previous Land Sliding
18	Total point

Based on the total points of station one as showed in Table (2), the result demonstrate that the first district falls within the (fifth category) of risk according to Table (1), which is relatively high and requires a warning tape to reduce the risk of landslides or to warn people against building houses on those slopes. Through Table (2) of station tow the total points obtained in the landslide probability index classification system, the finding indicate that the second district falls within the moderate risk zone, specifically at the fourth level of the risk categories classification. This is due to the narrow width of the pavement and the steepness of the slope. The slope does not currently pose a significant risk, but it could become unstable if exposed to factors such as heavy rainfall or earthquakes. It is recommended to monitor it continuously and take preventive measures such as improving drainage and stabilizing the soil.

Summary of the System Transaction Rating (LPI) for District (3) and (4)

Table 3: LPI Parameter of station (3).

points	Parameter factor
4	slope high 16-25(m)
3	slope angle 60 ° >
1	grade of fracture (moderate)
2	grade of weathering ⁄moderate weathered
0	gradient of discontinuities
2	Spacing of discontinuities
4	orientation of discontinuities
1	Vegetation Cover
3	water infiltration (seasonal)
2	Previous Land Sliding
22	Total point

Table 4: LPI Parameter of station (4).

points	Parameter factor
5	slope high 26-35(m)
4	slope angle 58 °
2	grade of fracture (highly fracture)
2	grade of weathering ⁄moderate weathered
3	gradient of discontinuities
3	Spacing of discontinuities
4	orientation of discontinuities
0	Vegetation Cover
3	water infiltration (seasonal)
1	Previous Land Sliding
27	Total point

The Table (3) summarizes that the total points for the second segment amount to (22) points, which is also classified as category V, high risk, according to the LPI classification. The steep slope angle and the type of deposited layers, which are marly limestone found in the Tangier formation, contribute to the sliding of rock masses, leading to the collapse of the retaining wall beneath the road. Also, the infiltration of water beneath the rock layers on which the wall was built is considered one of the most dangerous factors contributing to the sliding of the rock layer, causing an increase in the weight of the rock layers and consequently increasing the pressure on the wall, leading to its collapse.

The results of the slope engineering assessment, as shown in the Table (4), indicate that it falls within the sixth category in terms of severity, "Very High," based on a total score of 27 points. Several geological and geomorphological factors have contributed to increasing the level of risk, the most notable of which are the steep slope exceeding 35 meters and the sharp inclination angle ranging between 45° and 60°, which increases the likelihood of landslides. The rocks also showed a high degree of fracturing and weathering, in addition to very minimal spacing of the joints (less than 0.05 m) and an unfavorable orientation of these joints relative to the layer dip, which are critical factors in assessing slope stability. Additionally, the limited vegetation cover and the presence of seasonal surface water, along with previous landslides, enhance the high-risk classification. Accordingly, this site is considered one of the most dangerous locations, especially with the presence of tourist facilities and parking lots at the bottom of the slope, which necessitates urgent engineering interventions to mitigate potential risks

4. Discussion

The field data collected from the four stations (ST.1 to ST.4) shows clear differences in how likely each area is to experience landslides. These differences are mainly due to variations in slope height, angle, rock conditions, and environmental factors. as shown (fig.3a. b) Station.1 also shows a high risk (L.P.I = 25). While it shares many of the same risk factors as ST.4, such as steep slopes and weak rock structure (marly limestone of Tanjero formation), it has slightly better conditions when it comes to vegetation and water absorption, making it a bit more stable. ST.4 stands out as the most susceptible. Location and more hazard, with the highest landslide susceptibility index (LPI = 27).This station features a lot of cracks with little space between them, the sharpest slope, and the worst weathering. When combined with the lack of vegetation and insufficient water penetration, these factors make the slope extremely unstable station. station three is classified as moderately risky (L.P.I = 22). The greater distance between fractures may offer some extra stability despite its comparatively high slope. Although they are present, weathering and fracturing are not as severe as they are at the higher-risk sites (Fig. 4) (Fig. 5).

Fig 4: Station 4 on the slope showing the collapse of large rock masses down the slope due to weathering, erosion, and gravity**.**

Fig 3a: Station 4: Side view of a rock fall on Middle Street**, (Fig 3b)** Station 1: Side view of a wall and debris material Using (Leveling Rod)**, Fig (3a)** demonstrates the rock fall incident at Station 4, with rock fragments descending the slope, surpassing the curb, and reaching

the central area of the main road.

Fig 5a: Station No.2 The photo is taken in the direction of 072º, showing the slope face. However, the entire height of the slope could not be captured by the camera**. (Fig.5b)** It shows that the sidewalk is narrow, with a width of approximately 2 meters**.**

Station No. 2 is by far the most stable station, though, with the lowest L.P.I. rating of 18. The slope's overall stability is increased by its softer slope and less worn and weathered bedrock, which allow for adequate plant and water infiltration seasonally as shown in FIG (5a, 5b). In conclusion, the likelihood of landslides increases when several unfavorable elements are present, including slope height, slope angle degree, degree of fracture, a lack of vegetation, and previous landslides. Human actions can also increase this danger, such as clearing vegetation and changing natural drainage patterns. Protective actions, including replanting vegetation, enhancing drainage, and fortifying slopes, should be taken into consideration in order to lessen the likelihood of future landslides in regions like ST.1 and ST.4.

5. Conclusions

After careful analysis of the dataset and field information measured, several distinct hazard categories emerged. Station ST.4 has a very high Landslide Probability Index (LPI) of 27, placing it in the "very high" hazard category.This scale indicates a high risk of landslides, necessitating immediate intervention, which may include slope reinforcement or a comprehensive soil assessment. Furthermore, due to the high Landslide Probability Indices (LPIs) at stations ST1 and ST2, which are 25 and 22, respectively, the two stations are classified as "high" hazards.Likewise, these sites pose a high risk and require close monitoring with proactive measures to maintain overall stability. In contrast, ST.2 has the lowest Landslide Probability Index (LPI) at 18, placing it in the "medium" risk category. At this stage, periodic monitoring should be sufficient for this site; however, cutting and filling operations on these slopes must be prohibited to avoid any events that could threaten its stability.

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