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Slope Stability of Darbendikhan Dam Site and Near Surroundings. A Reconnaissance Study, Kurdistan Region, NE Iraq

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Abstract

Darbendikhan Dam is constructed on the Sirwan (Diyala) River during 1955- 1961. The dam is of earth fill type with concrete spill ways and gates for electric power generation. The dam axis is almost E – W with both left and right abutments being constructed within the Gercus Formation, which consists of red clastics with more claystones. The Gercus Formation is overlain by the Pila Spi Formation that consists of hard to very hard, well bedded carbonates. The Pila Spi Formation is overlain by the Fatha Formation that consists of thick reddish brown claystones alternated with thin gypsum and limestone beds.

Both Gercus and Fatha formations form steep to very steep slopes on upstream and downstream, respectively. All the slopes on the dam site and near surroundings suffer from different types of mass movements with different sizes. Some of them are old and dormant; others are recent and active exhibiting geological hazards, which may cause large loss of human life and the existing properties and infrastructure.

We studied the slopes using different types of satellite images with different resolutions and conducted field trips to the dam site to collect data. We recommended some precautions to make the slopes more stable.

Introduction

The Darbendikhan Dam (Kurdish: Bandawie Darbandixan) is a multi-purpose embankment dam on the Diyala River in Sulaimaniyah Governorate, Iraqi Kurdistan Region. The dam is located about 1.5 Km northeast of Darbendikhan town, the studied area is about 30 Km^2 (Fig. 1); however, the study emphasised on nearby areas of the dam site. The dam was constructed between 1956 and 1961. The purpose of the dam is irrigation, flood control, hydroelectric power production and recreation (World Bank, 2006) [1].

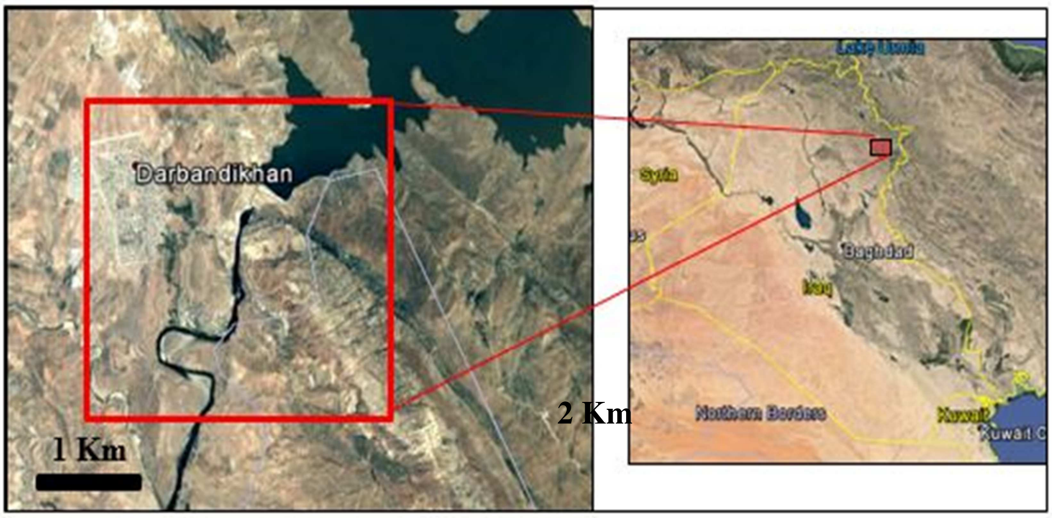

Figure 1: Google Earth image showing the location of the studied area. The red triangle shows the more emphasised area.

The Darbendikhan Dam is a rock-fill embankment type with a central clay core. The dam is 128 m tall and 445 m long. Its crest is 17 m wide. The dam collects water from a catchment area that covers 17,850 km^2 (World Bank, 2006) [1].

The aim of this study is to demonstrate the stability of the slopes and cliffs in the site of Darbendikhan Dam with up-stream and down-stream areas (Fig.1). Moreover, to recommend precautions to keep the stability of the area as best as possible, besides showing some areas those suffering from very unstable areas with hazardous status.

Previous Studies

The majority of the performed studies in the dam site is in form of conducting civil engineering and geotechnical works to keep the stability of the slopes. Few studies; however, are documented, among them are:

Al-Khateeb and Capigian (2000) [2] conducted a slope stability study for the slopes of the Darbendikhan Dam and marked unstable slopes on the eastern side of the dam site.

Sissakian and Ibrahim (2002) [3] conducted a geological hazards study of the whole Iraqi territory and considered the area under study as Active Mass Movement Zone.

Sissakian and Ibrahim (2005) [4] compiled the Geological Hazards Map of Iraq and considered the area around the Darbendikhan Dam and Reservoir as Unstable Mass Movements Zone.

Sissakian et al. (2007) [5] compiled the Geological Hazards Map of Sulaimaniyah Quadrangle at a scale of 1:250,000 and presented the landslide area on the map as unstable area.

Materials and Methods

In order to achieve the main aim of this study, we have used the following materials:

- Topographic and geological maps of different scales. Geological published articles.
- Google Earth and FLASH Earth images.

We have conducted field work during 15th of December 2015 and 1st of July 2017 to study the existing mass movements, unstable slopes and to conduct significant measurements, besides documentary field photos. We also have applied Bejerman (1994) [6] method for estimation of the Landslide Probability Index (Form 1).

Form 1: Field data form for estimating LPI after Bejermen, 1994 [6])

Station No.	Coordinates X: Y:	Date

1. Slope Height (m)	Estimate	**2. Slope Angle**	Estimate	**3. Grade of Fracture**	Estimate
1 -- 8	1	< 15°	0	Sound	0
9 --- 15	2	15° -- 30°	1	Moderately fractured	1
16 – 25	3	30° -- 45°	2	Highly fractured	2
26 – 35	4	45° -- 60°	3	Completely fractured	3
> 35	5	> 60°	4		

4. Grade of Weathering	Estimate	**5. Gradient of Discontinuities**	Estimate	**6. Spacing of Discontinuities**	Estimate
Fresh	0	< 15°	0	> 3 m	0
Slightly weathered	1	15°--- 30°	1	1 --- 3 m	1
Moderat. weathered	2	30°--- 45°	2	0.3 --1 m	2
Highly weathered	3	45°--- 60°	3	0.05 -- 0.3 m	3
Complet. weathered	4	> 60°	4	< 0.05 m	4
Residual Soil	5				

7. Orientation of the Discontinuities	Estimate	**8. Vegetation Cover**	Estimate
		Void (< 20%)	0
Favorable	0	Scarce (20 - 60%)	1
Unfavorable	4	Abundant (> 60%)	2

9. Water Infiltration	Estimate	**10. Previous Landslides**	Estimate
Inexistent	0	Not registered	0
Scarce	1	Registered (Small volume)	1
Abundant:	2	Registered (High volume)	2
Permanent	3		
Seasonal			

1 + 2 + 3 + 4 ± 5 + 6 + 7 + 8 + 9 + 10 =

I (Small) (0 – 5)	III (Low) (11 – 15)	V (High) (21 – 25)
II (Very low) (6 – 10)	IV (Moderate) (16 – 20)	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 the gradient.

Observations:

Using the available topographical and geological maps of different scales with the help of FLASH Earth and Google Earth images, we determined the location of mass movements and unstable slopes. Accordingly, we have evaluated the stability of Darbendikhan Dam site area and near surroundings and presented on satellite images.

Geological Setting

The geological setting of the studied area; including Geomorphology, Tectonics and Structure, and Stratigraphy are quoted from Fouad, (2012) [7], Sissakian and Fouad (2012 and 20140) [8 and 9] and Barwary and Slewa (2014) [10]. The three main aspects are described briefly; hereinafter.

Geomorphology

The studied area is located within the High Mountainous Province. The main significant geomorphological units and forms, which influence the stability are:

- **Structures – Denudational Units:** Among them are **Anticlinal Ridges:** These are well developed along the Pila Spi and Fatha Formation and extend for a few kilometres without interruption (Fig. 2). Hogbags, also well developed in the Fatha Formation (Fig. 2).

Figure 2: Google Earth image facing NW shows anticlinal ridges in Pila Spi (**PS**) and Fatha (**Fa**) formations. Note the unstable terraces (**UT**) on top of an anticlinal ridge and also note Hogbags (**Hb**).

- **Fluvial Unit:** Among them are **Terraces**, which are developed in many stages. Higher old stage forms unstable slope downstream side (Fig. 2).
- **Denudational Unit:** Among this unit is the original slopes (Fig. 3). These are the main form that has formed the most unstable parts in the studied area.
- **Mass Movements:** Among them are **Mud Flow**, **Landslide**, **Rock Fall** and **Creep** (Fig. 3). These phenomena are developed in soils and rocks in different sizes. Some of them are very active; others are dormant.

Figure 3: Google Earth image showing erosional slopes. Note the majority of the slopes are unstable (**US**), also note rock fall (**RF**), Mud Flow (**MF**), Landslide (**LS**) and Creep (**Cr**) phenomena.

Tectonics and Structural Geology

The studied area is located in the High Folded Zone of the Outer Platform of the Arabian Plate. It is also part of the Zagros Fold- Thrust Belt. The anticlinal trend is NW – SE; however, in the southern part of the studied area changes to almost N – S (Fig. 4). The main anticline in the studied area is Darbendikhan anticline; it is very tight, narrow and long with steep limbs. Many faults of different origin exist in the studied area, but they have no significant role in the stability of the slopes. The acute change in the trend of the beds from NW – SE to almost N – S has more influence on the stability than the existing faults. This is attributed to the intense fracturing due to the change of the folding trend, especially incompetent rocks.

Stratigraphy

Only those formations which are involved in the studied area and exhibit different mass movement phenomena are described briefly. The geological map is show in Figure (4).

- **Tanjero Formation** (Upper Cretaceous): The formation consists of yellowish black to olive green fine clastics with rare very thin limestone beds and fine conglomerate. The main constituent is the claystone, which forms the majority of mass movement phenomena.
- **Kolosh Formation** (Paleocene): The formation consists of black fine clastics with rare very thin limestone beds. The main constituent is the claystone, which forms the majority of mass movement phenomena.
- **Gercus Formation** (Eocene): The formation consists of reddish brown fine clastics with rare conglomerate. The main constituent is the claystone, which forms the majority of mass movement phenomena.
- **Pila Spi Formation** (Upper Eocene): The formation consists of well bedded, hard to very hard carbonates. The rocks of the formation exhibit rock fall and landslide phenomena.
- **Fatha Formation** (Middle Miocene): The formation consists of cyclic deposits. Each cycle consists of reddish brown and/ or green claystone, limestone, and gypsum; however, the abundant rock type in the cycles is the claystone. The formation exhibits creep, mud flow and landslide phenomena.
- **Injana Formation** (Upper Miocene): The formation consists of rhythmic sediments of reddish brown sandstone, siltstone, and claystone. The rocks of the formation exhibit toppling and very rare mud flow and landslide.

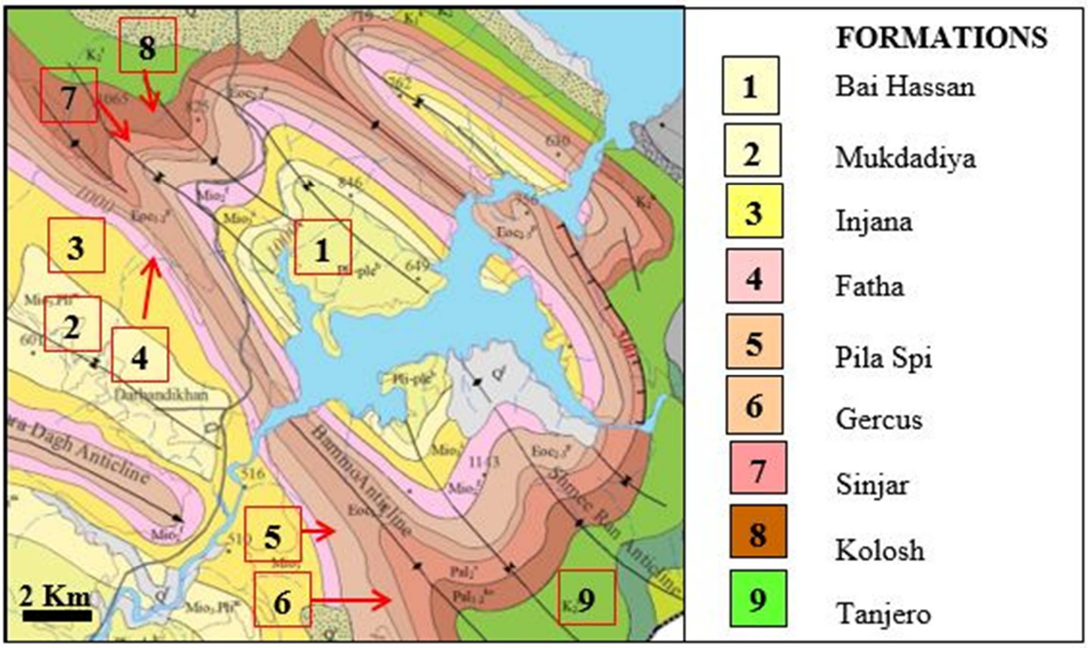

Figure 4: Geological Map of the studied area and near surroundings (After Sissakian and Fouad, 2014) [9]

Stability of Darbendikhan Dam Site and Near Surroundings

After the Harza Engineering Company of USA designed the dam, construction began in 1956. The reservoir began to fill in November 1961 and the dam was completed that same year. After the reservoir filled, several problems occurred. In 1967, there was a major slope failure about 100 m upstream of the dam. The bedrock beneath the dam has to be re-grouted and the crest of the dam settled too much, required it to be repaired. The rip-rap on the upstream face of the dam was also repaired in 1999 and 2000) (Word Bank, 2006) [1].

Figure 5: The crest of the Darbendikhan Dam, in the back ground is the Gercus Formation (**GF**) overlain by the Pila Spi Formation (**PF**). Note the fallen rock blocks from the Pila Spi Formation and the unstable slopes within the Gercus Formation.

The dam is located within a gorge on a foundation of the rocks of the Gercus Formation; it is overlain by the Pila Spi Formation (Figs. 1 and 5) (Sissakian and Fouad, 2014) [9].

The stability of the slopes of the upstream and downstream is described hereinafter; with special emphasis on the active and large phenomena. Moreover, Bejerman (1994) [6] method is used to indicate Landslide Stability Index (LSI) in certain locations within the studied area. Accordingly, the studied area is divided into two main parts, upstream and downstream.

Upstream Slopes

The upstream slopes within the studied area include the Tanjero, Kolosh, Gercus, Pila Spi, Fatha, Injana, Mukdadiya and Bai Hassan formations (Figs. 3 and 4). The most unstable slopes; however, are those within the Kolosh and Gercus formations. We paid attention to those unstable areas, which are close to the dam and have selected the following sites (Stations Nos. 1 – 6) (Figs. 5, 6, 7 and 8) within this part and have described them in details.

At each studied station, we have applied the LPI using the special Form 1 (Bejerman, 1994) [6], the results are presented in Table (1).

- ***Station 1:*** The station is within Kolosh and Gercus formations. The main mass movements' phenomena are landslide, creep and toppling. The main landslides and creep phenomena are presented in Figure (6). The applied LPI estimation for this station is presented Table (1).

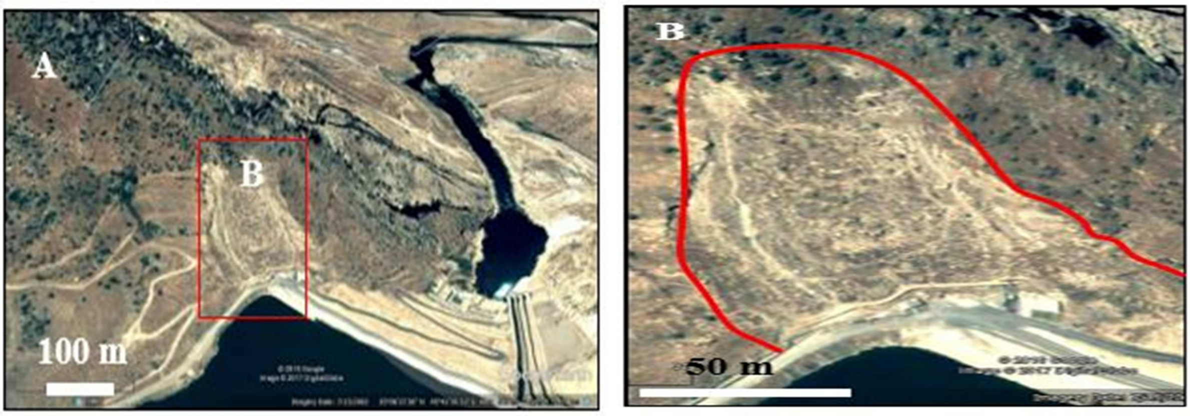

Figure 6: **A)** Google Earth image shows unstable slopes along the left bank of upstream slopes (**Station 1**). **B)** Details of the main landslide. The red line represents the main unstable slope

Table 1: Raw field data of the nine studied Stations (After Bejerman, 1994 [6])

Station No.	Numbers of the aspects used in LPI Form										Tot
	1	2	3	4	5	6	7	8	9	10	
	Slope		Grade		Discontinuities			Vegitation Cover (%)	Water Infiltration (%)	Previous Land slide	
	Height (m)	Angle (°)	of Fracture	of Weathering	Gradient (°)	Spacing (m)	Orientation				
1	119	63	High	High	31	< 0.05	Favorable	Scarce	Perm.	High Vol.	
2	220	58	High	High	28	0.3 – 1	Unfav.	Scarce	Perm.	High Vo.	
3	135	53	High	High	22	< 0.05	Unfav.	Scarce	Perm.	High Vol.	
4	193	43	High	High	16	< 0.05	Unfav.	Void	Scarce	Small Vol.	
5	162	42	High	High	25	< 0.05	Unfav.	Void	Scarce	Small Vol.	
6	164	63	Compl.	High	26	< 0.05	Unfav.	Void	Scarce	High Vol.	
7	110	67	High	High	29	0.3 – 1	Unfav.	Void	Scarce	High Vol.	
8	273	72	High	High	46	1 – 3	Unfav.	Void	Inexist	Small Vol.	
9	142	63	Moder.	High	22	< 0.05	Unfav.	Void	Scarce	Small Vol.	

Unfav. = Unfavorable, Inexist. = Inexistence

- ***Station 2:*** The station is within Kolosh and Gercus formations. The main mass movements' phenomena are landslide, creep and toppling. The main landslides and creep phenomena are presented in Figure (7). The applied LPI estimation for this station is presented Table (1).

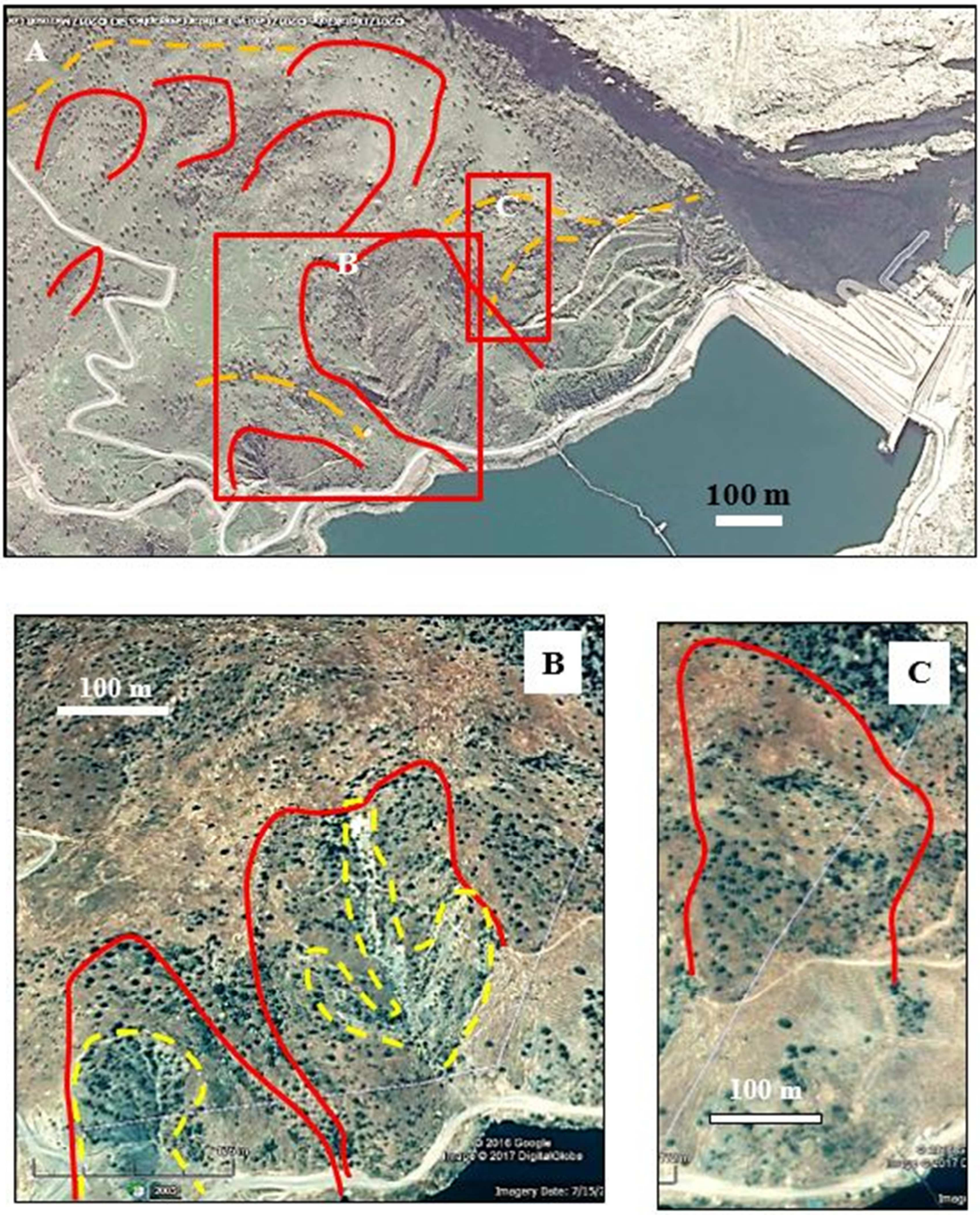

Figure 7: **A)** Google Earth image showing unstable slopes along the left bank of the upstream slopes (**Station 2**). **B)** Two old landslides with active areas and **C)** Old landslide. The red lines represent the main landslides. The dashed orange lines represent the main creep area and the yellow dashed lines represent active erosion areas.

- ***Station 3:*** The station is within Kolosh and Gercus formations. The main mass movements' phenomena are landslide and creep. The main landslides and creep phenomena are presented in Figure (8). The applied LPI estimation for this station is presented in Table (1). Moreover, many areas suffer from active
- erosion, which will trigger different types of mass movements in the near future; if no relevant precautions are considered.

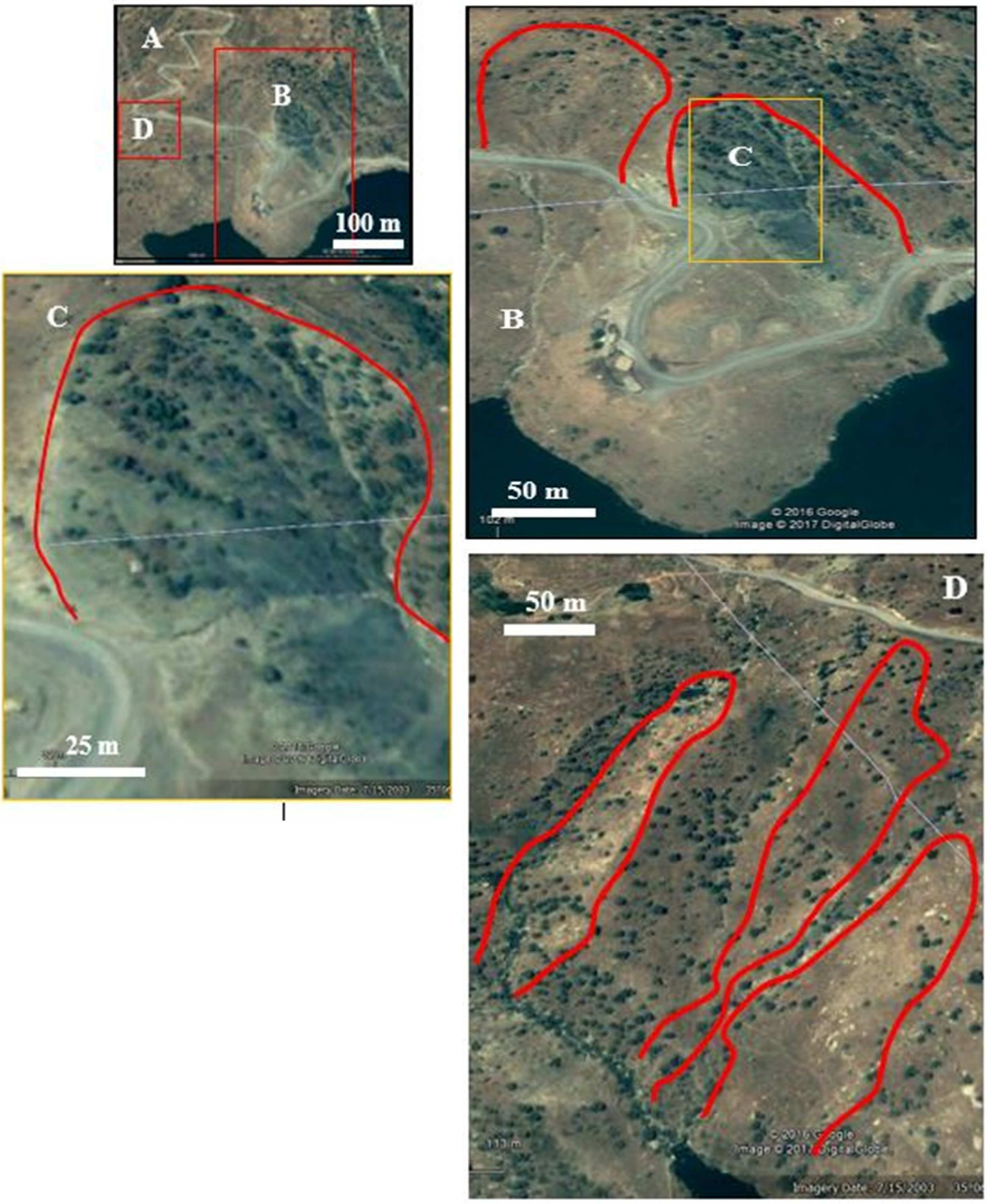

Figure 8: Google Earth image of the left bank of upstream slopes (**Station 3**). **A)** Old landslide, **B)** Details of part of the old landslide **C)** Active slide area, **D)** Three old landslides. Red lines are the limits of the landslides.

- ***Stations 4, 5 and 6*****:** These stations are within Kolosh and Gercus formations on the right side of upstream slopes. The main mass movements' phenomena are landslide, creep and rock fall. The main landslides and creep phenomena are presented in Figure (9). The applied LPI estimation for these stations is presented in Table (1). Moreover, many areas suffer from active erosion, which will trigger different types of mass movements in the near future; if no relevant precautions are considered.

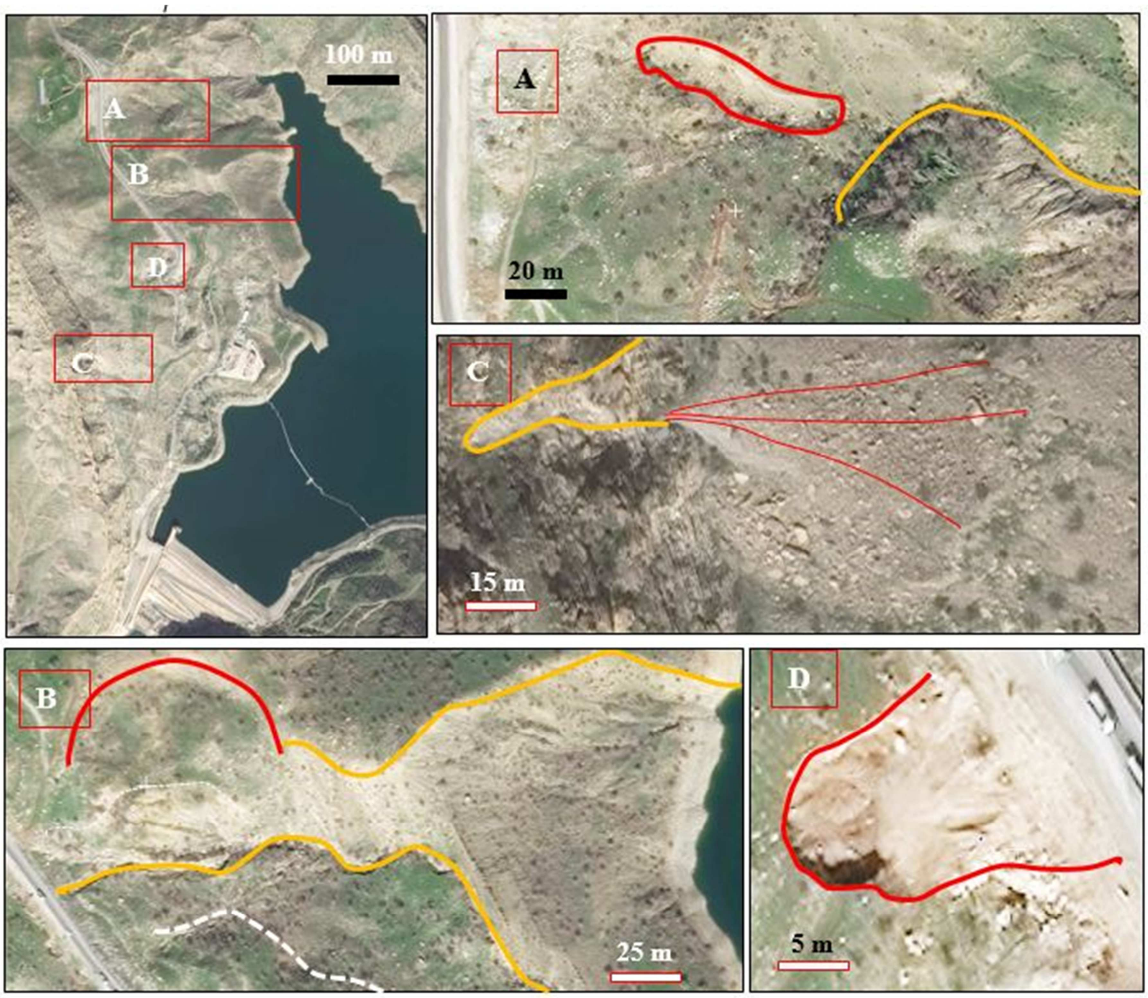

Figure 9: Flash Earth image of the right bank of upstream slopes (**Stations 4, 5 and 6**). **A)** Old landslide with active erosion area (**Station 4**), **B)** Active erosion along valley bank with creep phenomenon (**Station 5**), **C)** Rock fall (**Station 6**); forming active rock fan, **D)** Small active landslide. The red lines represent the main landslides. The dotted white lines represent the main creep areas. The orange lines represent the limits of active erosion areas.

Downstream Slopes

On the downstream side, we studied three stations (Fig. 10); they all are in the Pila Spi and/ or the Fatha formations. Their LPI is studied as well and presented in Table (1). The details are described hereinafter.

- ***Station 7:*** This station is within the Fatha Formation. The main mass movement phenomenon is a very old landslide (Fig. 10, **A**). The applied LPI estimation for this station is presented in Table (1). The steep slope is a prone area for rock fall of large blocks endangering the unpaved road.

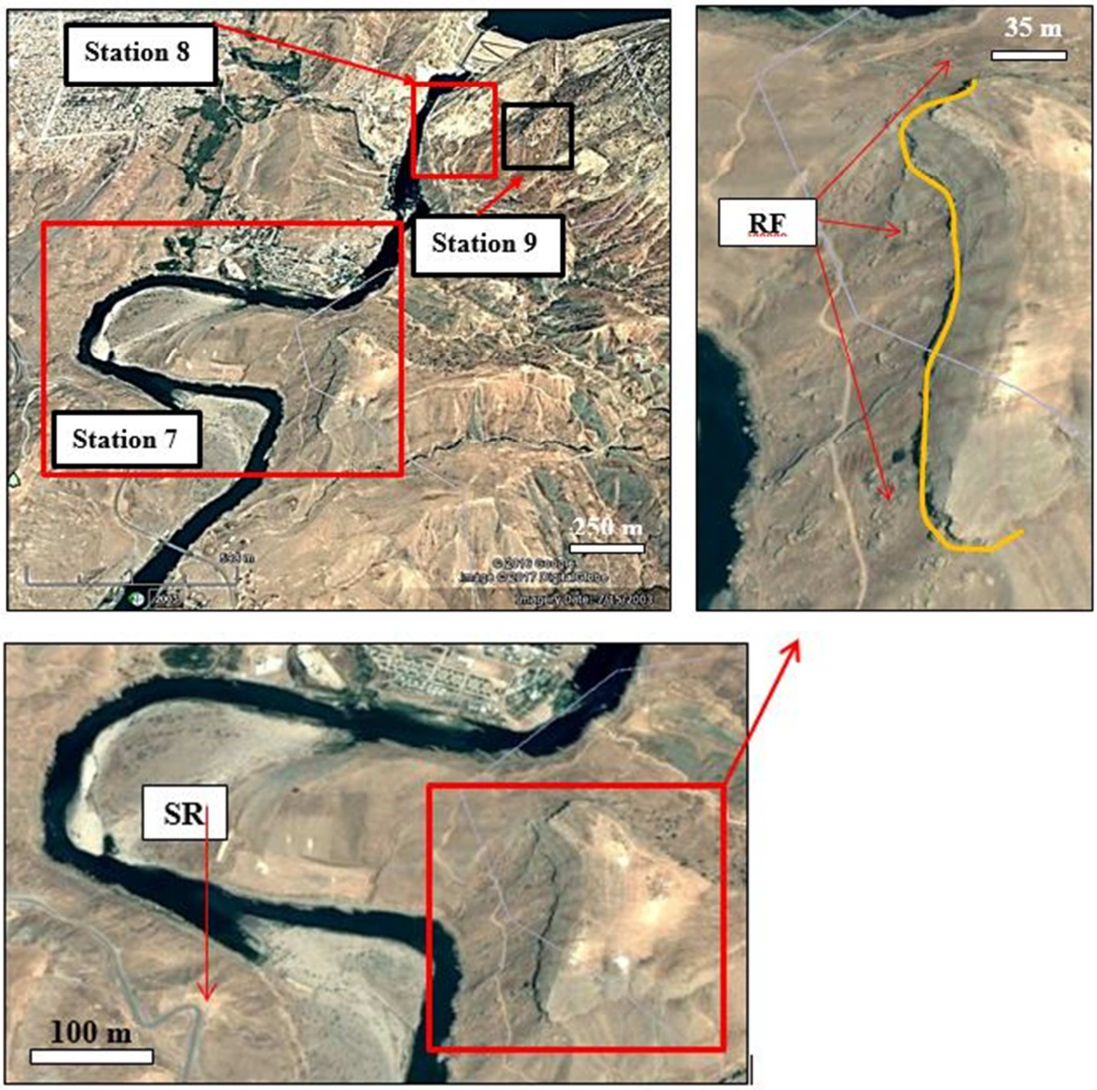

Figure 10: Google Earth image of the left bank of downstream slopes (**Station 7**). **Top)** Very old landslide that has shifted the river course, **Bottom)** Details of the old slide, note the steep slope, fallen rock blocks (**RF**), slid part of the road (**SR**) and active erosion areas. In orange is the scarp of the active rock fall area. Compare the size of the fallen blocks with the width of the road.

- ***Station 8:*** This station is within the Pila Spi (Fig. 11). It is an active rock fall with a very steep slope. The applied LPI estimation for this station is presented in Table (1). The steep slope is a prone area for rock fall of large blocks endangering the unpaved road.

- ***Station 9:*** This station is within the terraces of the Serwan River (Fig. 11). It is an active rock fall area for parts of the old preserved terrace body and the pebbles; with a very steep slope. The applied LPI estimation for this station is presented in Table (1).

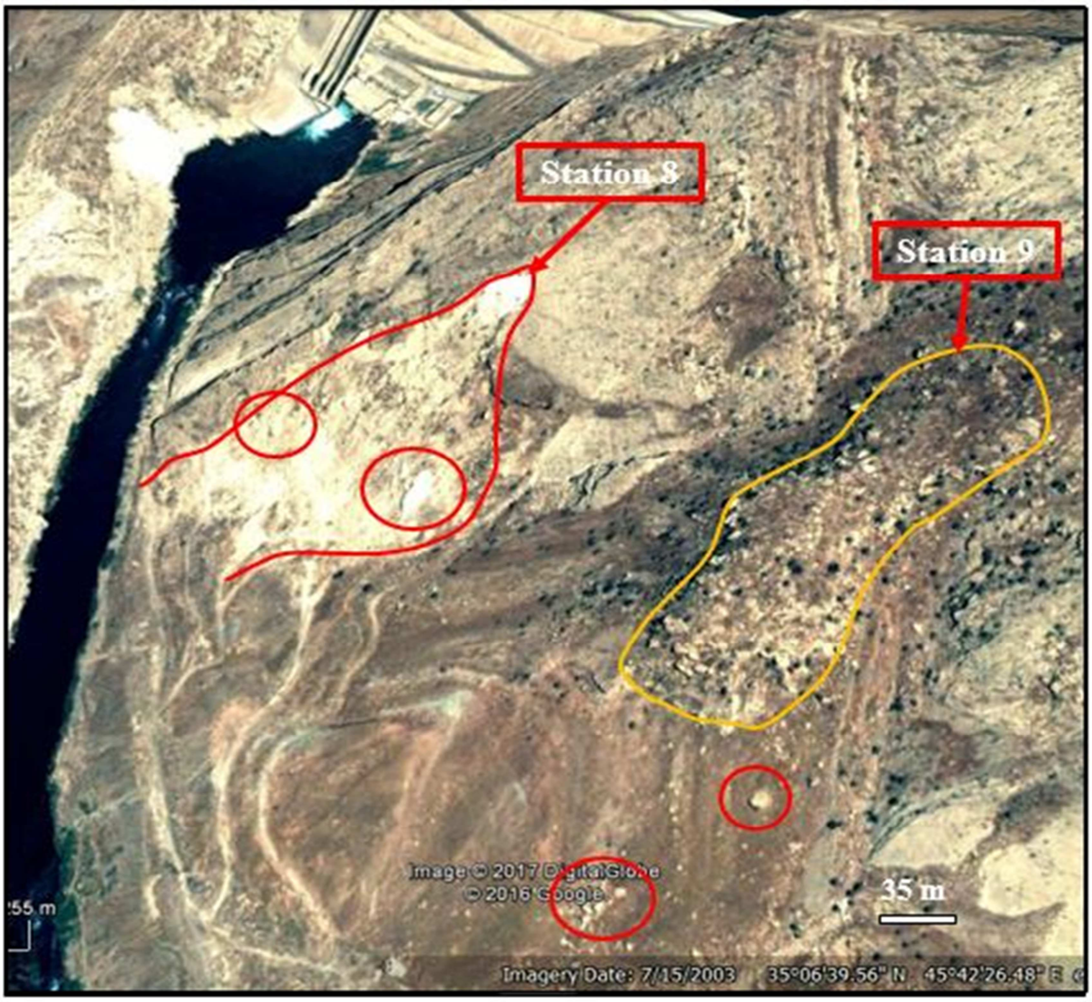

Figure 11: Google Earth image of **Stations 8 and 9**. Note the very active rock fall area (Station 8) with large blocks being in very critical equilibrium. Also, note the old river terrace body (Station 9) and the fallen large blocks. (Some of the blocks are encircled by red).

Results

The data of the studied nine stations (Table 1) are processed according to the grades given by Bejerman (1994) (Form 1). The total scored marks are shown in Table (2).

Table 2: The scored grades of the studied nine stations following Bejerman (1994) [6] method

Station No.	Slope		Grade		Discontinuities			Vegi-tation Cover	Water Infil-tration	Previous Land slide	Total Scored Mark
	Height	Angle	of Frac-ture	of Weath-ering	Grad-ient	Spa-cing	Orien-tation				
	Numbers of the aspects used in LPI Form										
	1	2	3	4	5	6	7	8	9	10	
1	5	4	2	3	2	4	0	1	2	2	25
2	5	3	2	3	1	2	4	1	2	2	25
3	5	3	2	3	1	4	4	1	2	2	27
4	5	2	2	3	1	4	4	0	1	1	23
5	5	2	2	3	1	4	4	0	1	1	23
6	5	4	3	3	1	4	4	0	1	2	27
7	5	4	2	3	1	2	4	0	1	2	23
8	5	4	2	3	3	1	4	0	0	1	23
9	5	4	1	3	1	4	4	0	1	1	24

By applying the total scored marks (Table 2) at each of the nine studied stations, the category of LPI is obtained; following the given classification (Table 3) by Bejerman (1994 and 1998) [6 and 11]. The results are shown in Table (4). Moreover, the Landslide Possibility Index (LPI) allows assessing the landslide possibility for rock slopes cut in mountainous roads (Bejerman, 1994) [6], as well in natural slopes, as we have applied in this study. This estimation system takes into consideration characteristic features of the slope estimated in the field, and later processed following the given marks in the LPI estimation form (Form 1), and the results are shown in Table (4).

Table 3: Landslides hazard categories (After Bejerman, 1994 and 1998) [6 and 11]

Landslide Possibility Index			Hazard Zone	
Grade	Category	Estimation		
VI	Very High	25>	> 25	High Hazard
V	High	21 – 25		
IV	Moderate	16 – 20	(11 – 25)	Moderate Hazard
III	Low	11 – 15		
II	Very Low	6 – 10	< 10	Low Hazard
I	Small	1 – 5		

Table 4: Landslides hazard categories (After Bejerman, 1994 and 1998) [6 and 11] of the studied nine stations

Station No.	Total mark	Landslide Possibility Index		Hazard Zone
		Grade	Category	
1	25	VI	Very High	High
2	25	V	High	High
3	27	VI	Very High	High
4	23	25	High	High
5	23	25	High	High
6	27	VI	Very High	High
7	23	25	High	High
8	23	25	High	High
9	24	25	High	High

The estimated values for each of the nine studied stations (Table 2) are compared with the failure possibility classification (Bejerman, 1994) [6], which consists of six classes; as shown in Table (5). Accordingly, the failure possibility is indicated on each of the nine studied stations. The results are shown in Table (6).

Table 5: Failure Possibility category for each LPI category (After Bejerman, 1994) [6]

LPI Category	Failure Possibility	LPI
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

Table 6: Failure possibility estimation at each of the nine studied stations

Station No.	Total mark	LPI Category	Failure Possibility
1	25	VI	High
2	25	V	High
3	27	VI	Very High
4	23	V	High
5	23	V	High
6	27	VI	Very High
7	23	V	High
8	23	V	High
9	24	V	High

Discussion

The upstream side of Darbendikhan Dam forms a tectonically controlled depression; formed in the core of Darbendikhan anticline. This is attributed to the presence of hard carbonate rocks of the Pila Spi Formation; along both limbs of the anticline; whereas, the soft clastics of the Gercus and Kolosh formations form the core (Figs. 1 and 4). Therefore, majority of the slopes on both sides of the upstream are unstable exhibiting different mass movements' phenomena. Among the movements are landslides, creep, flow and very rare rock fall. However, many of them are very old and dormant; others are still active (Figs. 3, 5, 6, 7, 8 and 9). The unstable slopes nature is attributed to the following: **1)** Steep slopes including soft clastic rocks, which are easily eroded by rain water; besides being highly pervious; consequently, oversaturated. This in term will cause decrease in the internal friction angle (Terzaghi, 1943 and Terzaghi et al., 1996) [12 and 13], 2) Construction of roads along the slopes with haphazard cuts (Fig. 12, Left) has affected on the stability of the slopes due to road cuts, which are left without any treatment; consequently has developed very active erosional areas and/ or facilitating rain water infiltration, 3) The well bedded carbonate rocks of the Pila Spi Formation are underlain by soft clastic rocks of the Gercus Formation, the difference in the hardness has developed day light slopes, which exhibit continuously rock falls; although in a small scale (Fig. 12, Right).

Figure 12: Upstream slopes of the Darbendikhan Dam. **Left)** Constructed unpaved roads with haphazard road cuts, **Right)** A rock fall in the day light slopes of the Pila Spi Formation.

In the downstream side of Darbendikhan Dam, the slopes are developed within the Pila Spi, Fatha and Injana formations (Figs. 2, 4, 10 and 11). The main reasons in this side for the development of unstable slopes are: **1)** The steep slopes, which always form dip slopes, especially in the Pila Spi Formation (Figs. 2 and 4), **2)** The presence of thick claystone beds within the successions of the Fatha and Injana formations. The thick claystone beds form perfect lubricant plains for sliding and **3)** The Sirwan (Diyala) River acts as very effective erosional media by eroding both banks; consequently, developing unstable slopes (Figs. 10 and 11).

The landslide hazards catagtagories (Table 3) show that the estimated hazard catagories of the nine stations (Table 4) are: Stations Nos. 3 and 6 have Grade **VI**, Category **Very High** and Hazard Zone of **High**; whereas the other stations Nos. 1, 2, 4, 5, 7, 8 and 9 have Grade **V**, Category of **High** and Hazard Zone of **High** too.

The Failure Possibility in the studied nine stations (Table 6) shows that the station Nos. 3 and 6 have Grade **VI** and are within Category of **Very High** landslide possibility; whereas, the stations Nos. 1, 2, 4, 5, 7, 8 and 9 have Grade **V** and are within the Category of **High** landslide possibility.

These estimated grades, categories and failure possibility are attributed to: **1)** The heights of the slopes are more than 35 m (Aspect No.1), **2)** The slopes consist of fine clastics of Gercus and Kolosh Formations; therefore, the spacing is less than 0.05 m (Aspect No.6), **3)** The gradient of the slopes and those of the discontinuities is also moderate to high and ranges from (22 – 30)° (Aspects Nos. 2 and 5), **4)** Because the rocks are mainly of soft clastics; therefore, the weathring grade is **Highly Weathered**, and **5)** The orientation of the the estimated discontinuties is always Unfavorable (Aspect No.7), and **6)** In all the studied statins, there are more than one landslide (Aspect No.10).

Conclusions

The upstream slopes of Darbendikhan Dam show very unstable conditions; mainly landslide, flow, creep and rare rock fall, majority of them are active with different sizes. The main reasons for unstable slopes are the existence of soft rocks with huge thicknesses and high dip amount, the haphazard road cuts that are left unpaved and the oscillation of the water level in Darbendikhan reservoir.

The downstream slopes show also unstable slopes; however, the rocks in this side are hard well bedded carbonates of the Pila Spi Formation with fine clastics of Fatha and Injana formations; the former includes some gypsum and limestone beds too. The types of mass movements in this side are rock fall and landslide, with very steep slopes.

The estimated LPI at the studied nine stations shows that Stations Nos. 3 and 6 have Grade **VI**, Category **Very High** and Hazard Zone of **High**; whereas the other stations; Nos. 1, 2, 4, 5, 7, 8 and 9 have Grade **V**, Category of **High** and Hazard Zone of **High**. Moreover, the Failure Possibility in the studied nine stations (Table 6) shows that the Stations Nos. 3 and 6 have Grade **VI** and are within Category of **Very High** landslide possibility; whereas, the Stations Nos. 1, 2, 4, 5, 7, 8 and 9 have Grade **V** and are within the Category of **High** landslide possibility.

Recommendations

Generally, the whole slopes; both upstream and downstream are in very critical stability; however, those in the upstream are more unstable and endangering the safety of Darbendikhan Dam. To keep the slopes as stable as possible, the following actions should be considered: **1)** All those unpaved roads nearby to the dam should be paved to prevent erosion and water infiltration, **2)** Along the existing roads, systematic ditches should be constructed and lined either by concrete or impermeable stuff to prevent water infiltration, **3)** Construction of systematic retention walls in relevant heights; depending on the slope gradient and should be provided with good draining pipes to decrease water infiltration, **4)** Terracing of the steep slopes and planting them with dense trees to prevent creeping and erosion of the top soil layer, and **5)** Installing remedial devises to observe the stability of the slopes at different parts and at different elevations with establishing very accurate surveying stations for continuous monitoring of the slope movements.

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