Journal of Zankoy Sulaimani
Part-A- (Pure and Applied Sciences)
http://jzs.univsul.edu.iq

Landslide susceptibility assessment along Biyara-Tawella road, Kurdistan region, NE-Iraq

Fahmy Osman Mohammed[1*]. Ashna Jalal Ahmed[1] and Sarkhel Hawre Mohammed[1]

1 Department of Geology, College of Science, University of Sulaimani, Sulaimani, Kurdistan Region- Iraq
**Corresponding author's e-mail: fahmy.mohammed@univsul.edu.iq*

Article info

Original: 3 November 2019
Revised: 31 December 2019
Accepted: 30 January 2020
Published online: 20 June 2020

Key Words:
Hazard rating,
Kinematic analysis,
Landslide possibility index,
slope failure

Abstract

Landslide hazard assessment is carried out for the slope failures along the 12km road-cut between Biyara-Tawella which is considered a crucial road connecting the Iraq-Kurdistan region with the Iranian border; in the meantime, it is an important tourist route during the summer and spring season. Slope stability assessments consist of twenty-four stations were done include a regional survey of slopes and a detailed discontinuity assessment was performed along the outcropped rock units represented by the highly deformed Qulqula Formation, quaternary clastic deposit, and some local body of pillow basalt. Different types of failures in the area were identified and classified along the cut slopes, from most to least abundant are rockfall, wedge siding, and lateral detachments theses unstable slope contain many joint sets which is acted as lateral, back or composite back release surfaces during slope failure. The earthquake effect as a trigging mechanism of rockfalls leads to decreasing stability along the roadsides.

Different rock physical factors have been used and evaluated; the highly fractured properties of rocks, intense rainfall, and freeze-thaw cycles consider the main factors influencing the slope failure. The slopes were assessed by using landslide possibility index (LPI), it shows various geo-hazard categories that range between "moderate hazard" to "very high" LPI categories and "low" to "high" hazard categories. Kinematic analysis carried out for two sites only by using DIPS V6.008 and the results show wedge sliding at site No.22 and lateral detachment in site No.23.

Rockfall hazard assessment system (RHRS) developed by the Oregon State Highway Division has drawn based on vehicle vulnerability and elements regarding the rockfall hazard. The analysis of twenty-four cross-section of the cut slopes shows various unacceptable risk categories and it needs remedial works.

1-Introduction

Biyara-Tawella (Hawraman area) are natural beauty due to their unique landscape and freshwater springs, it is a popular tourist destination in the Sulaymaniyah province, but there mountainous region condition danger to properties and life. Generally, landslides are triggered by heavy rain and seismicity such us The earthquake in 2017 near the Hawraman area represents a good example, which trigged more landslide in the area and at least 5 people died, 200 injured, many villages collapsed and main roads closed because earth quack high value magnitude of 7.3 (Richter scale). The epicenter of this earthquake was located 32 km far from the city of Halabja and less than 20 km from the studied area. The hill slopes and road cutting profiles along the main classified into six categories depending on the Landslide possibility index (LPI) (Bejerman, 1994). For road hazard assessment the most abundant method used which is Rockfall Hazard Rating System (RHRS) improved by the Oregon State Highway Division (Pierson et al. 1990), different categories were determined based on scoring ten parameters.

The stability analyses along the Biyara-Tawella road identified in Twenty-Four stations which is affected by two root cause include natural and anthropogenic.

The highly tectonically deformation of hard rock and cutting slope toe of road, slope orientation, heavy rainfall, and recently high magnitude earth quack play a crucial role in the stability of highly fractured rocks along the main road.

Construction of Highway and roads in the mountainous region represent a special challenge to geologists and geotechnical engineers (Hoek, 1998). A various method developed for the assessment of rockfall hazard (Guzzetti et al., 2002, Budetta, 2004,) these methods use the rockfall velocity, geological characteristics, Slope mass rating (SMR) and risk rockfall on vehicles.

The kinematic analysis was used to recognize the probability of unstable block and its direction of movements (Wyllie et al., 2004). The kinematic method was only applied on two sites (Site No.22 and site No.23) to determining the possibility of slope failure and mode of slope instability using DIPS software (V6.008).

The main purposes of the paper are to identified and describe the unstable slope along Biyara-Tawella road which is particularly hazardous and requires urgent remedial work or further detailed study.

2-General characteristics of the study area

The studied area (12 km road) is located in East of Halabja city and 79 km far from southeastern Sulaymaniyah passed through a mountainous area, hilly road, single carriageway connecting Sulaymaniyah city (Iraq) with Iranian border (Figure 1)

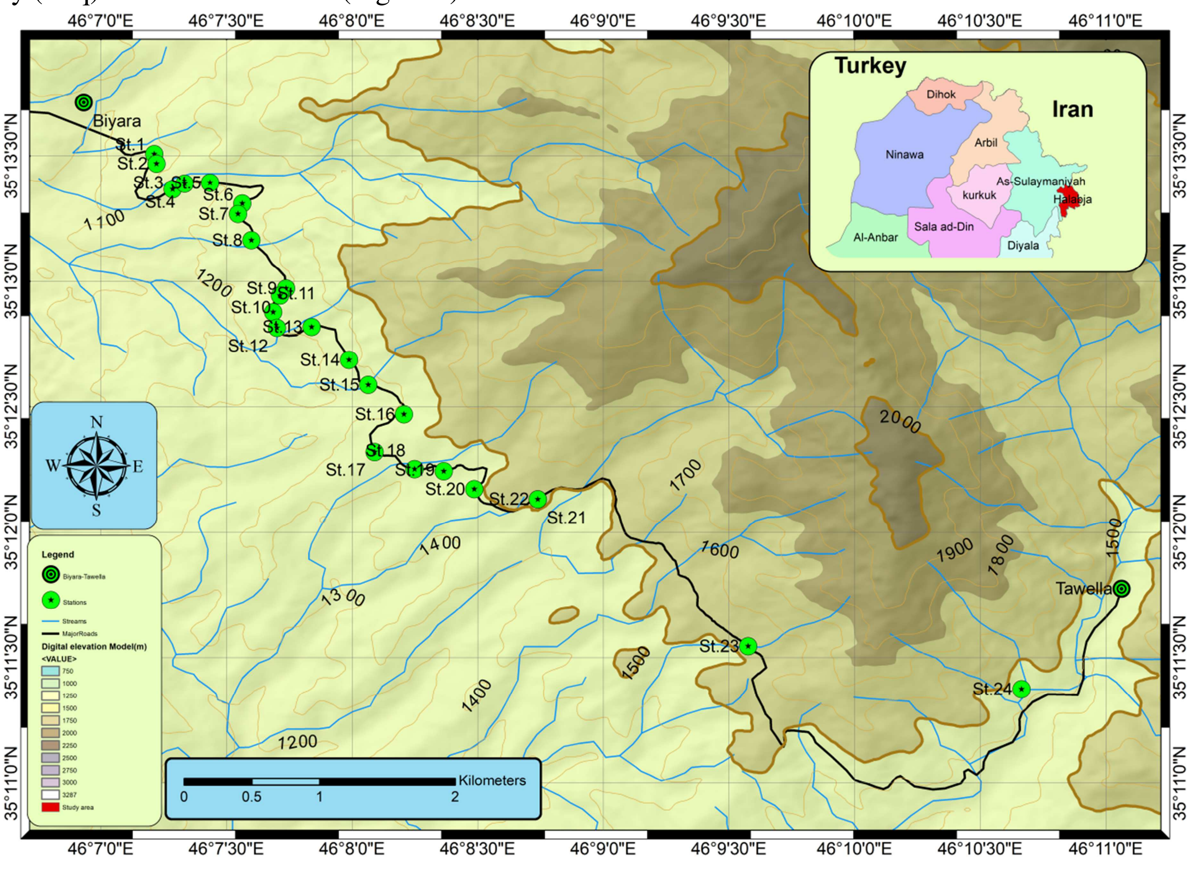

Figure 1: Topographic map shows the location of the studied area

Tectonically the studied area located in Zagros Suture Zone NE-Iraq (Jassim and Goff, 2006) near the subduction zone between Arabian and Eurasian tectonic plates this zone classified as the High Zagros Zone (Zagros Crushed Zone) by (STÖCKLIN 1968). Lithologically consist of bedded chert, shale and siliceous limestone (Qulqula Radiolarian Fn.) (Bolton 1958) (Figure 2, 3), with local body of pillow basalt (Fig. 2a), highly deformed Avroman Limestone of Mesozoic age and Quaternary clastic deposits (Karim, 2007, Baziany, 2013) (Figure 2b).

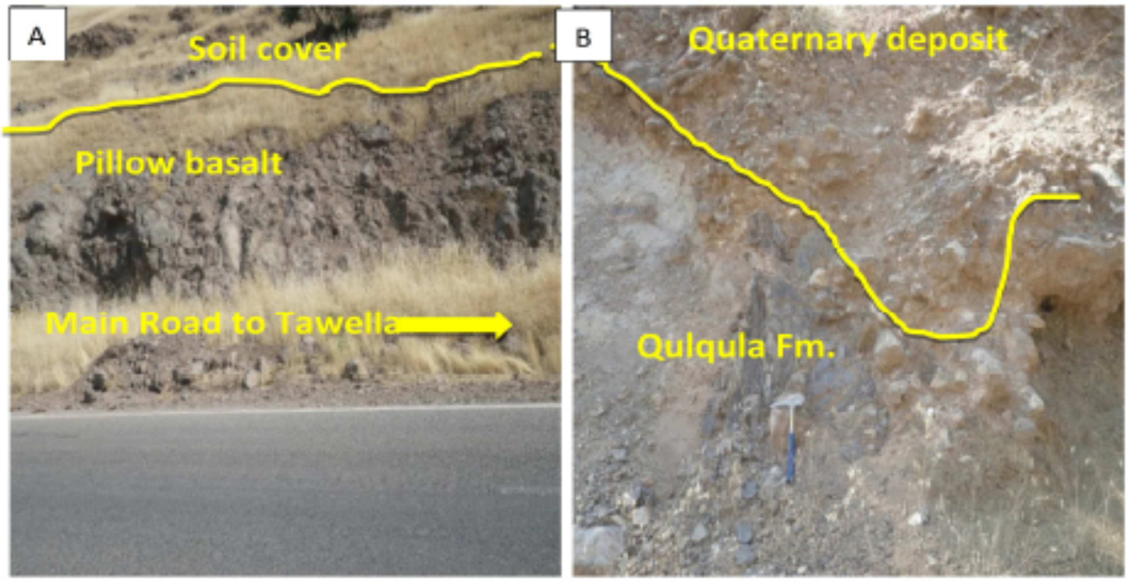

Figure 2: A. Pillow basalt, B. Reddish siliceous mudstone unit (Qulaqula Fm), and Quaternary clastic deposit

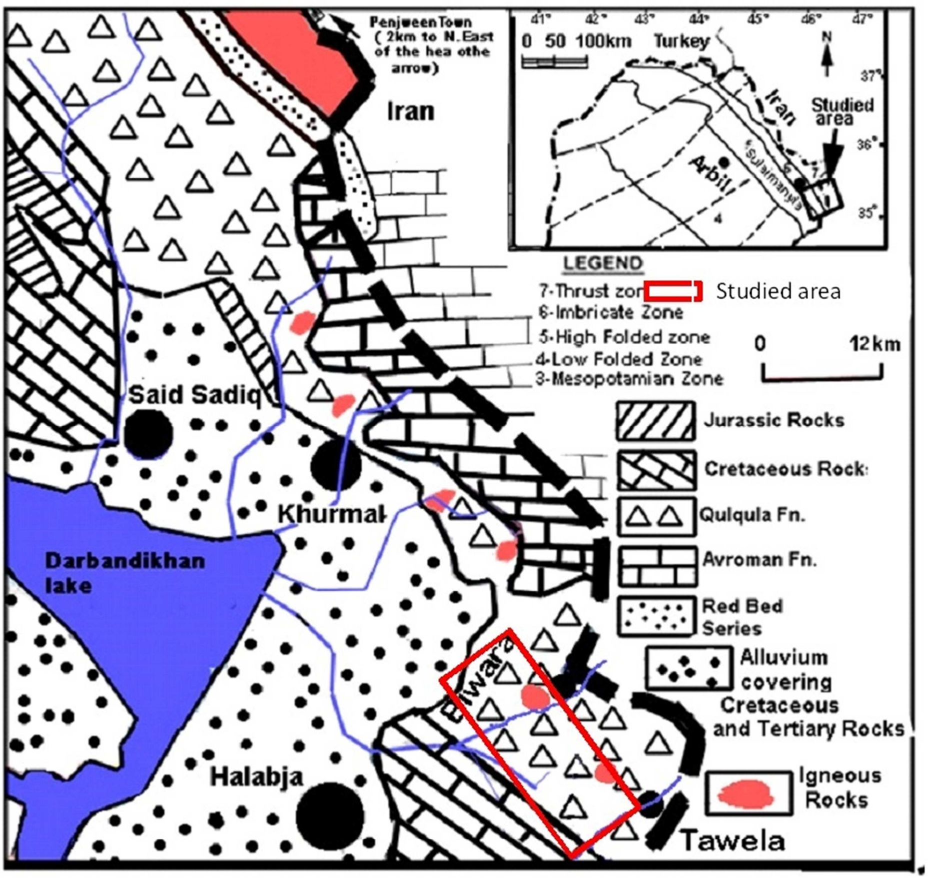

Figure 3: Geological map of the studied area (after Karim, 2007 and Sissakian, 2000)

The rock mass is heavily fractured and affected by huge tectonic activity; it makes the study of a structural feature as well as the bedding plane and joint attitude very difficult or limited due to intense deformation, imbrication and even thrusting, depending on (Stille et al., 2008) classification for rock mass the studied rock mass belongs to class (D) (Figure 4).

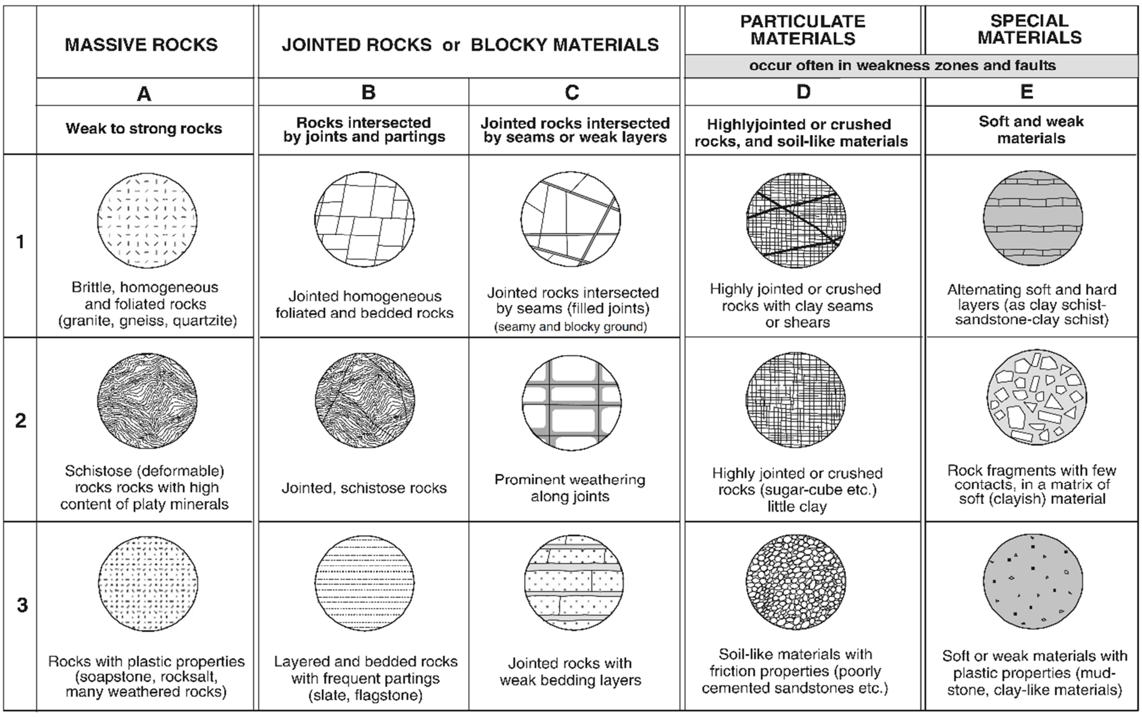

Figure 4: Main types of rock mass compositions after (Palmstrom, 1995)

***Classes A:** Massive. Few joints or very wide joint spacing where the properties of the rock material dominate the behavior.

***Classes B and C:** Jointed or blocky, i.e. slightly to strongly jointed rock masses. Here, the joints have the main influence on behavior.

***Class D**: Particulate rock mass. Includes heavily jointed or crushed rock, loose sedimentary (friable) rocks, and materials of particles, grains or fragments with no or little bonding. The behavior in this group is a result of the interactions between the blocks or fragments, as is the case in a bulk material.

*** Class E**: Rocks or rock masses with special properties different from the other four classes. An important feature is weathered and altered rocks are partly included (in class C, D or E). Such rocks may also occur in weakness zones (in group II).

The Hawraman area contains many fault zones which are formed by faulting during the brittle condition of hard siliceous rock Qulqula Formation, also contain shear zones which are formed under the ductile condition of shale layer in Qulqula it represent both conditions of brittle and ductile signs (Davis et al, 2012). Based on Palmstrom, (1995) classification for weak zone in rock mass, the studied slopes characterized by heavily fractured, crushed, and contain many random joints which are classified as (crashed zone) fault shear zone (Figure 5).

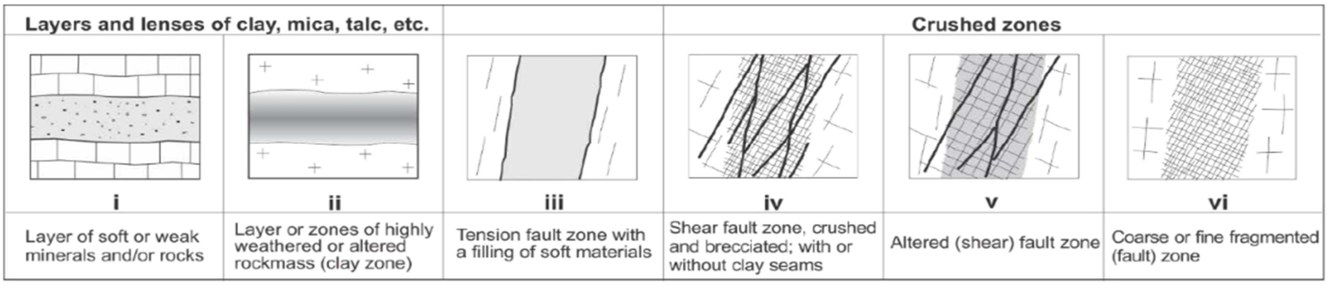

Figure 5: Main types of weakness zones after (Palmstrom, 1995)

The main types of landslide in the studied area is rockfall because the area located at the boundary between Arabian plate and Eurasian Plate which characterized by high tectonic activity and seismic activity lead to imbrication and intense deformation in the country rock, the other causal factors for the cut slope are intense rainfall during rainy season, high erosive shale layer between highly fractured rocks of radiolarian chert and recent high magnitude earth quack activity is a good example (Figure 6).

The possibility of the other type of landslide such us plane sliding, wedge sliding, and toppling are very low due to the high tectonic activity which leads to creation fault shear zone in this area and there is no clear structural data at this site.

Figure 6: Large rock block was collapsed due to the effect of an Earthquake inside Tawela Town

3-Methodology:

The detail slope survey along both sides of the Biara-Tawella road was determined in order to assess the slope instability, types of slopes, failure possibility, rating potential hazard and risk associated with these slopes. In term of the slope failure possibility of site the most widely method Landslide possibility index (LPI) and hazard categories (Bejerman 1994, 1998) were selected, which is depend on rating of many parameters such as (slope attitude , joint attitude , joint condition, weather condition) (Table 1).

The kinematic analysis used to determine the type of failure and possibility of slope failure by using (DIPS software V6.008), which is used of determining the likelihood for the mode of slope failure and quantifying the risk of failure. A kinematic analysis method was first described by (Hoek and Bray, 1981) and developed by (Goodman, 198), which is designated to evaluate the possibility of potential planar, wedge and toppling failure and modes of rock slopes.

For rating the risk, scoring potential hazard rockfall, and to develop remedial designs for road, the Rockfall Hazard Rating System (RHRS) were used (Pierson et al., 1990); this method allows agencies to manage the rock slope along the high way. It depends on two different groups of parameter, the first group are relating vehicle vulnerability (ditch effectiveness, average vehicle risk, percent of decision sight distance, roadway width) and the second group are related to elements regarding the rockfall hazard (slope height, geologic character, volume of rockfall/block size, climate and presence of water on slope and rockfall history). The result of total score assesses the degree of the exposition to the risk along roads and slopes with a rating of less than 300 are assigned a very low priority while slopes with a rating in excess of 500 are identified for urgent remedial action (Pierson et al., 1990) (Table 2).

4-Result and discussion

Landslide possibility index (LPI) along Biyara-Tawella Road

A slope survey including slope height ((the vertical distance between the top and the toe of slopes at the stations), a slope angle, a grade of fracture, a grade of weathering, a gradient of discontinuities, a spacing of discontinuities, the orientation of discontinuities, vegetation cover, water infiltration, and previous landslide) were done. Those ten parameters were integrated for determining the hazard degree of slopes according to the Landslide Possibility Index chart (LPI) (Table 1).

In the studied area along the road 24 site were surveyed, 95% of the studied slopes were shown High hazard categories (Figure 7a,7b)and only site (No.4) (Figure 8) show moderate hazard categories (Table 1). The rockfall is the main type of slope failure and it can be seen in all surveyed slopes, lateral detachment, except in one site wedge sliding was recorded.

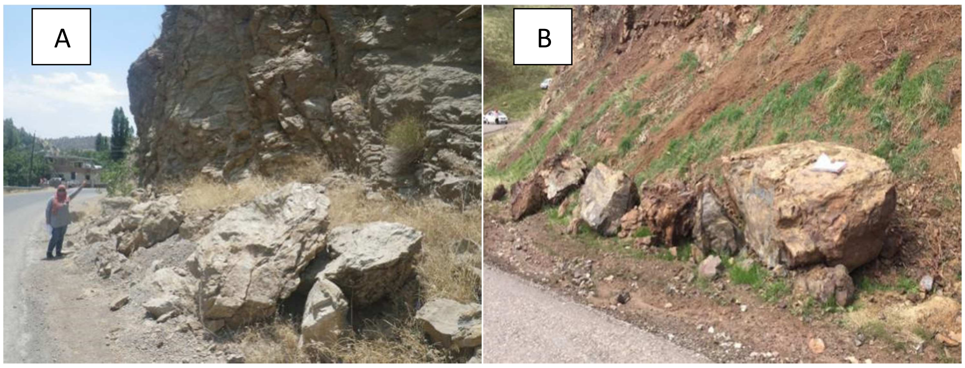

Figure 7: a, shows a large block fall at site No. 24 b, shows a large block fall at site No. 19

Figure 8: front view of site No.4 shows moderate (LPI) hazard category

Table 1: Landslide possibility index for the studied sites

St.	Slope height		Slope angle		Grade of fracture	Grade of weathering		Gradient the of Discontinuities		Spacing of the Discontinuities		Orientation of the Discontinuities		Vegetation Cover		Water Infiltration		Previous Landslides		LPI	Class	Hazard Category
1	8	1	50	3	Highly	highly	3	65	4	0.05	4	Unfavor.	4	25	1	Inexistent	0	R (small v)	1	23	high	High
2	8	1	55	3	Highly fr.	highly	3	45	3	0.005	4	Unfavor.	4	21	1	Scarce	1	R (high v)	2	24	high	High
3	7	1	65	4	Completely	completely	4	62	4	0.05	4	Unfavor.	4	30	1	seasonal	3	R (high v)	2	30	very high	High
4	6	1	48	3	Moderate	highly	1	65	4	0.2	3	Unfavor.	4	19	0	Scarce	1	R (high v)	2	20	moderate	Mod.
5	10	2	51	3	Completely	completely	4	62	4	0.2	3	Unfavor.	4	16	0	Inexistent	0	R (high v)	2	25	high	High
6	13	2	60	3	Highly fr.	highly	3	61	4	0.04	4	Unfavor.	4	15	0	Inexistent	0	R (high v)	2	24	high	High
7	7	1	48	3	Completely	completely	4	63	4	0.03	4	Unfavor.	4	30	1	seasonal	3	R (high v)	2	29	very high	High
8	10	2	50	3	Completely	completely	4	70	4	0.05	4	Unfavor.	4	25	1	seasonal	3	R (high v)	2	30	very high	High
9	6	1	52	3	Highly fr.	highly	3	80	4	0.04	4	Unfavor.	4	27	1	Scarce	1	R (high v)	2	25	high	High
10	14	2	58	3	Highly fr.	highly	3	75	4	0.02	4	Unfavor.	4	17	0	seasonal	3	R (high v)	2	27	very high	High
11	12	2	60	3	Highly fr.	highly	3	70	4	0.03	4	Unfavor.	4	15	0	seasonal	3	R (small v)	1	26	very high	High
12	20	3	50	3	Highly fr.	completely	4	83	4	0.02	4	Unfavor.	4	25	1	seasonal	3	R (high v)	2	30	very high	High
13	8	1	70	4	Completely	completely	4	65	4	0.001	4	Unfavor.	4	16	0	seasonal	3	R (high v)	2	29	very high	High
14	15	2	69	4	Highly fr.	highly	3	70	4	0.05	4	Unfavor.	4	55	1	seasonal	3	R (high v)	2	29	very high	High
15	7	1	85	4	Highly fr.	highly	3	66	4	0.02	4	Unfavor.	4	65	2	seasonal	3	R (high v)	2	29	very high	High
16	7	1	60	3	Completely	residual soil	5	80	4	0.03	4	Unfavor.	4	40	1	seasonal	3	R (high v)	2	30	very high	High
17	13	2	58	3	Highly fr.	highly	3	67	4	0.01	4	Unfavor.	4	45	1	Scarce	1	R (small v)	1	25	high	High
18	15	2	70	4	Moderate	highly	3	61	4	0.04	4	Unfavor.	4	22	1	Scarce	1	R (high v)	2	26	very high	High
19	13	2	65	4	Moderate	highly	3	53	3	0.02	4	Unfavor.	4	23	1	Scarce	1	R (high v)	2	25	high	High
20	14	2	60	3	Highly fr.	highly	3	65	4	0.03	4	Unfavor.	4	27	1	seasonal	3	R (small v)	1	27	very high	High
21	18	3	62	4	Highly fr.	highly	3	75	4	0.05	4	Unfavor.	4	50	1	Scarce	1	R (high v)	2	28	very high	High
22	15	2	85	4	Highly fr.	highly	3	60	3	0.05	4	Unfavor.	4	27	1	seasonal	3	R (high v)	2	28	very high	High
23	8	1	60	3	Completely	completely	4	70	4	0.03	4	Unfavor.	4	65	2	Scarce	1	R (high v)	2	28	very high	High
24	13	2	48	3	Highly fr.	highly	3	65	4	0.04	4	Unfavor.	4	17	0	seasonal	3	R (high v)	2	27	very high	High

The kinematic analysis:

The possibility of unstable slopes and the direction of block movements were assessed by Kinematic analysis. This method was implemented for only two sites (site No.22, 23), because of lack of structural data and high deformation at other sites leading to creation fault shear zone, unclear bedding plane and joints.

The kinematic analysis for Site (No.22) shows wedge sliding type of slope failure with the possibility of 66.67% (Figure 9a,9b,10), due to the intersection of two sets of joints (J1:286/64, J2:53/207), the line of the intersection was located within the direction of slope (SW).

The Site (No.23) reveal lateral detachment type with the possibility of 33.32% (Figure 11,12) which formed due to the intersection bedding with a joint set (J1: 90/120), and the line of intersection (So, J1) located in the direction of slope (N30E)

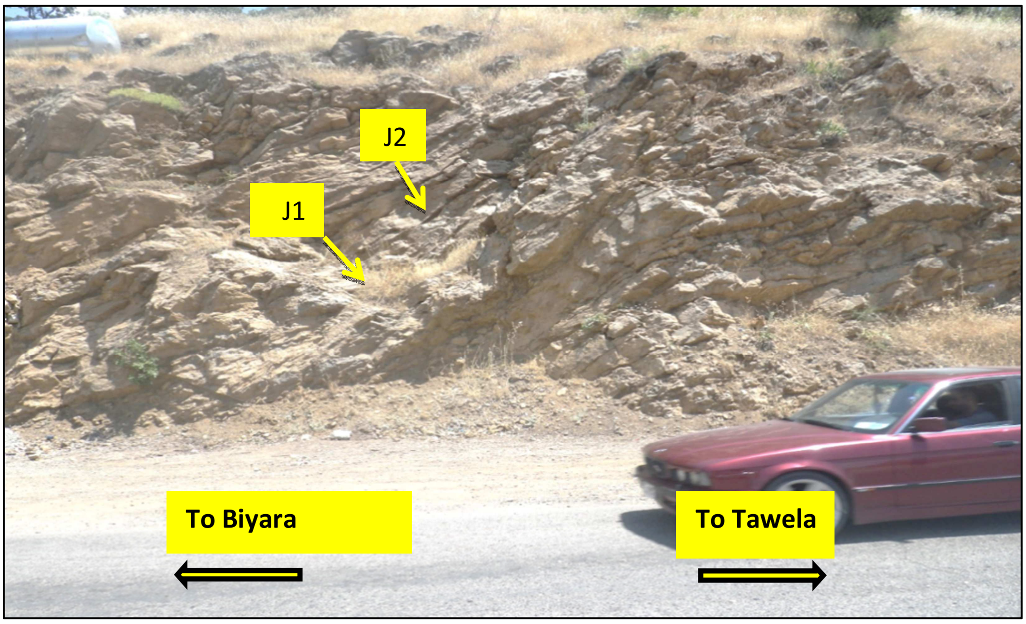

Figure 9a: front view of the site No.22 showing wedge sliding

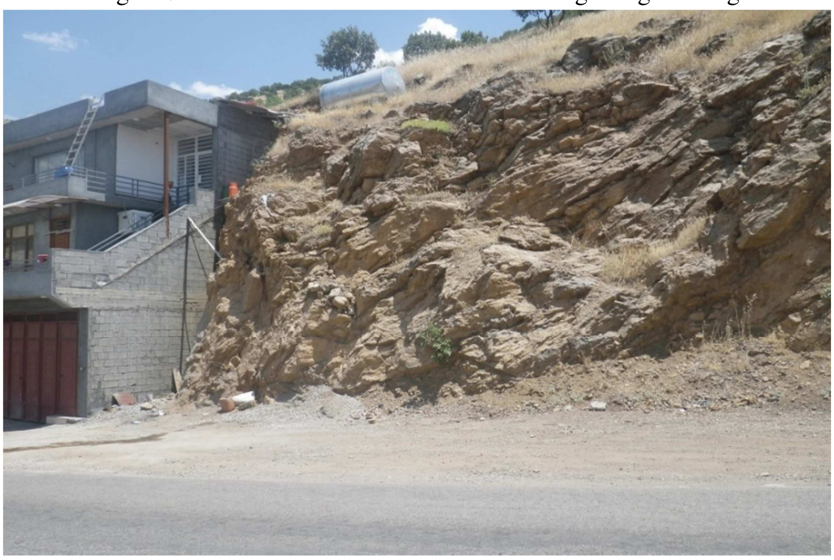

Figure 9b: lateral view of the site No.22 showing wedge sliding

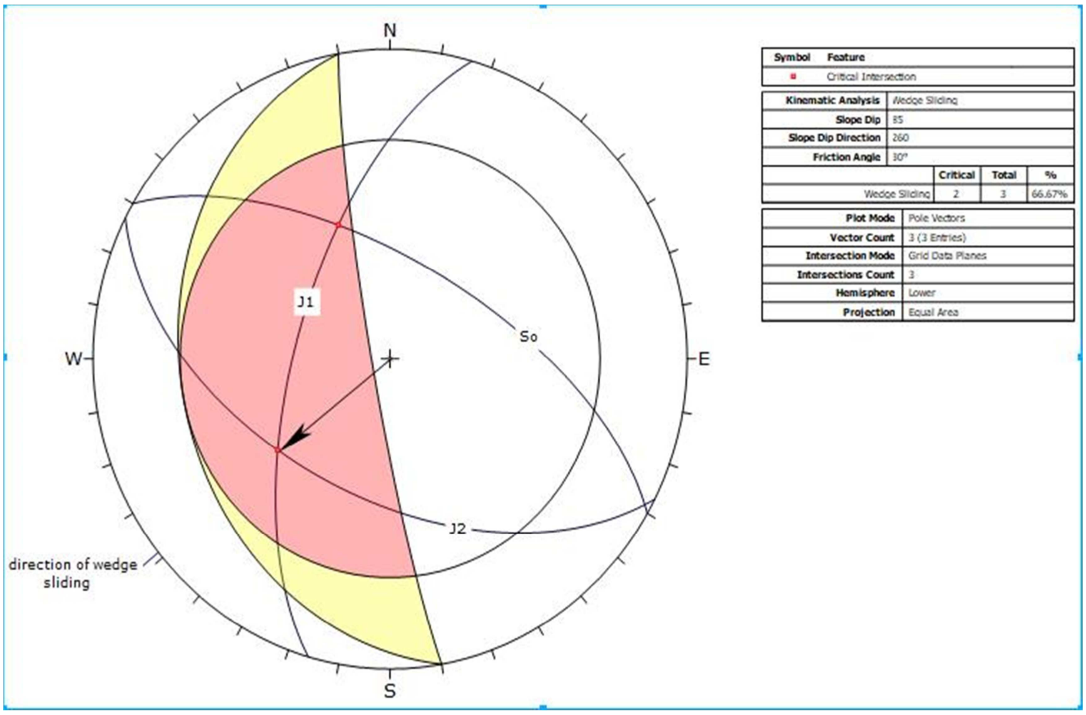

Figure 10: Kinematic analysis result for site No.22 showing wedge sliding and critical intersections (red circles).

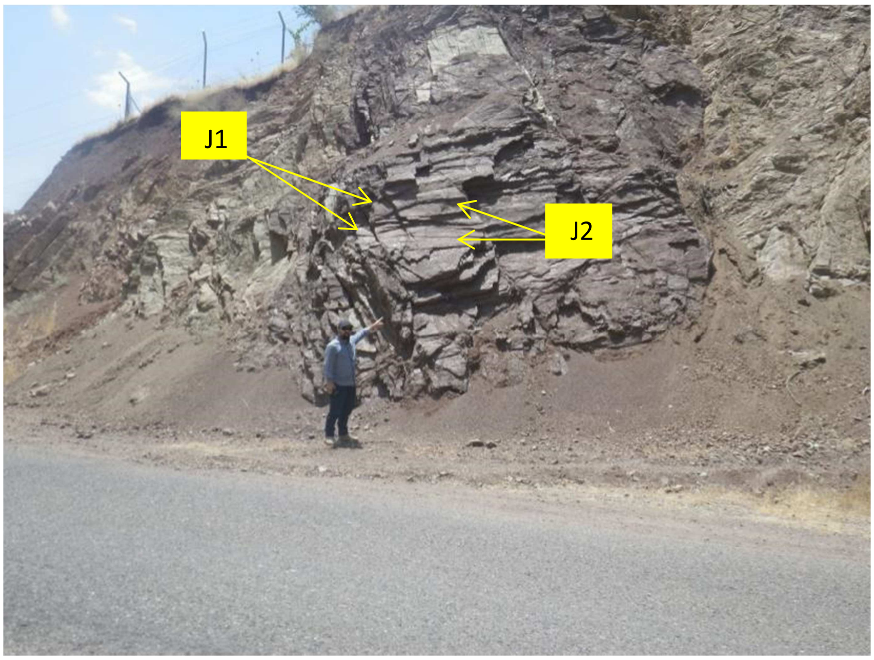

Figure11: site No.23 showing the detached blocks due to differential erosion

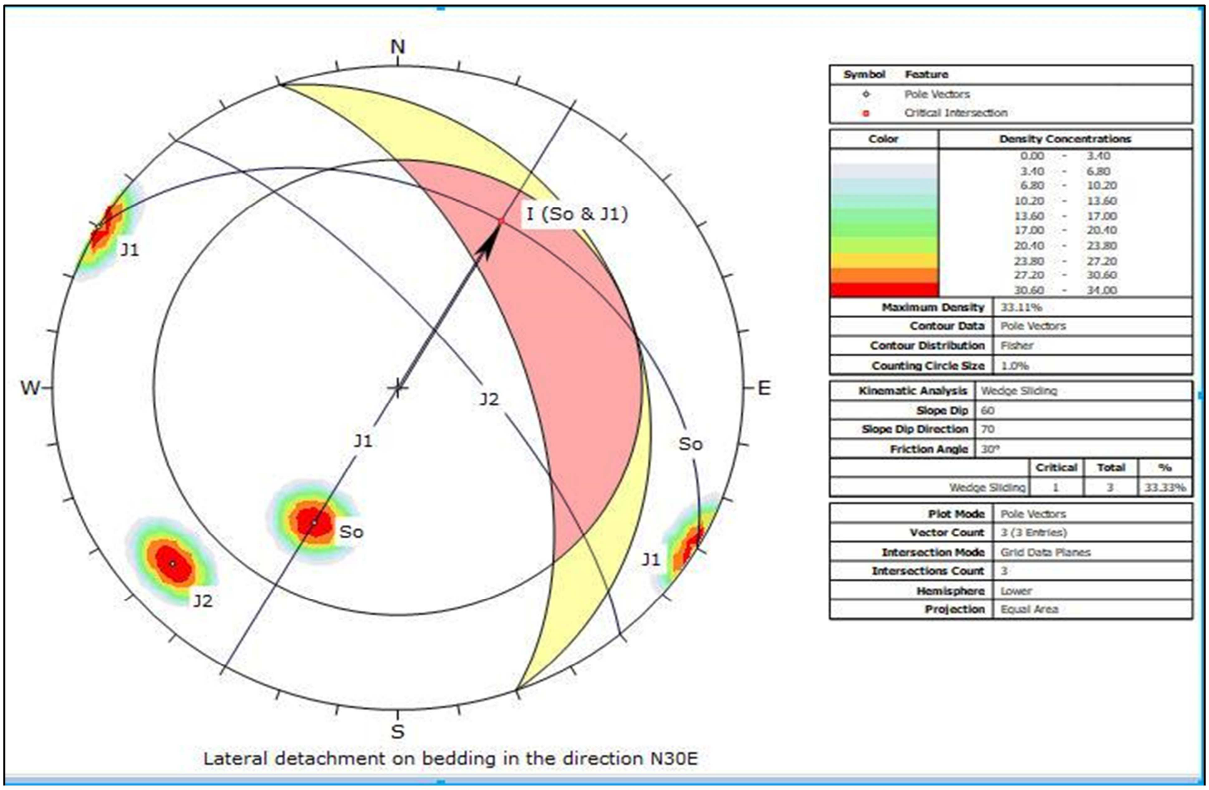

Figure 12: Kinematic analysis site 23 Stereonet plot of joint orientation and Failure envelope for Lateral detachments on bedding (So, J1).

Rockfall hazard rating system (RHRS) analysis

The RHRS analysis was applied on the rock mass of 12km long road which composed of bedded chert, shale and siliceous limestone of Qulaqula Formation includes many fault shear zones and it is classified as a crushed zone due to intense deformation (Figure 13a). The unstable slopes were created by either removing the underlying supports (slope toe) (Figure 13b), and differential erosion of the shale or road cutting.

The RHRS analysis for twenty-four sites listed in (Table 2) it shows that all studied sites located between (309-394) rating, the highest rating value recorded at site No.24 (394) and the lowest value recorded at site No.7, 23 (309), which is classified as a moderate hazard and needs remedial measures with moderate urgency

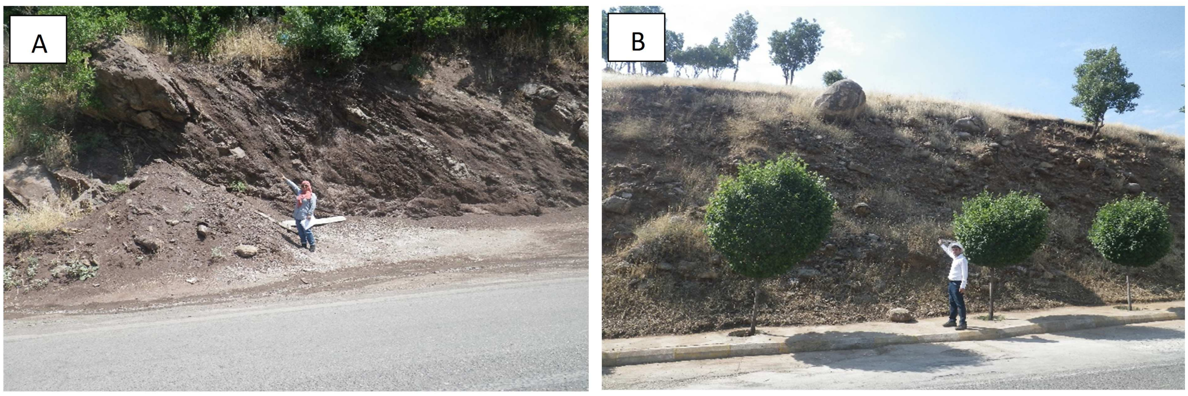

Figure 13: a, shows the crushed rock mass at site No.15 b, quaternary deposit at site No.2

Table 2: Rockfall hazard rating system of the studied rock-cut slopes

Parameters	**Site no.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Slope height (m)	value	8	8	7	6	10	13	7	10	6	14	12
	Score	3	3	3	3	9	9	3	9	3	9	9
Ditch effectiveness	value	No	No	No	No	No	No	No	No	No	No	No
	Score	81	81	81	81	81	81	81	81	81	81	81
Average vehicle risk %	value	25	25	25	25	25	25	25	25	25	25	25
	Score	3	3	3	3	3	3	3	3	3	3	3
Decision sight distance %	value	V.limited	V.limited	V. limited	V. limited	V. limited	V .limited	V. limited	V. limited	V .limited	V. limited	V. limited
	Score	81	81	81	81	81	81	81	81	81	81	81
Roadway width (m)	value	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45
	Score	27	27	27	27	27	27	27	27	27	27	27
Geological character (case two) – **Structural condition**	value	Many. Er	Many. Er	Many. Er	Many. Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er
	Score	27	27	27	27	27	27	27	27	27	27	27
Geological character (case two) – **Difference in erosion rates**	value	Large	Large	Large	Large	Large	Large	Large	Large	Large	Large	Large
	Score	27	27	27	27	27	27	27	27	27	27	27
Block size(m)	value	0.6	0.9	<0.6	0.9	0.6	0.3	0.3	0.6	0.6	0.3	0.6
	Score	9	27	9	27	9	3	3	9	9	3	9
Volume of rockfall per event (m^3)	value	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3
	Score	3	3	3	3	3	3	3	3	3	3	3
Climate and presence of water on slope	value	High. P	High.P	High.P	High .P	High. P	High.P	High.P	High.P	High.P	High.P	High.P
	Score	27	27	27	27	27	27	27	27	27	27	27
Rockfall history	value	Many. Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall
	Score	27	27	27	27	27	27	27	27	27	27	27
Total Rating		315	333	315	333	321	315	309	321	315	315	321

Table 2: Continue…

12	13	14	15	16	17	18	19	20	21	22	23	24
20	8	15	7	7	13	15	13	14	18	15	8	13
27	3	9	3	3	9	9	9	9	27	9	3	9
No	No	No	No	No.	No	No	No	No	No	No	No	No
81	81	81	81	81	81	81	81	81	81	81	81	81
25	25	25	25	25	25	25	25	25	25	25	25	25
3	3	3	3	3	3	3	3	3	3	3	3	3
V.limited	V.limited	V.limited	V.limited	V.limited	V.limited	V.limited	V.limited	V.limited	V.limited	V.limited	V.limited	V.limited
81	81	81	81	81	81	81	81	81	81	81	81	81
8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45	8.45
27	27	27	27	27	27	27	27	27	27	27	27	27
Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er	Many.Er
27	27	27	27	27	27	27	27	27	27	27	27	27
Large	Large	Large	Large	Large	Large	Large	Large	Large	Large	small	large	small
27	27	27	27	27	27	27	27	27	27	27	27	27
0.6	0.6	0.6	0.9	0.6	0.9	0.9	0.9	0.9	0.6	0.6	0.3	1.2
9	9	9	27	9	27	27	27	27	9	9	3	81
<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3	<2.3
3	3	3	3	3	3	3	3	3	3	3	3	3
High.P	High.P	High. P	High.P	High.P	High.P	High.P	High.P	High.P	High.P	High.P	High.P	High.P
27	27	27	27	27	27	27	27	27	27	27	27	27
Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall	Many.Fall
27	27	27	27	27	27	27	27	27	27	27	27	28
339	315	321	333	315	339	339	339	339	339	321	309	394

5- Conclusions:

1. The rock mass in the studied sections is highly jointed or crushed and it's classified as type (D) also, it contains weakness zones that are classified as crushed zone.
2. Landslide possibility index value from twenty-four sites show two different categories of hazards. Twenty-three sites show high hazard categories except for site No.4 which show moderate hazard categories. The possibility of high hazard categories is related to the intense rainfall, highly fractured rocks, and high erosive shale in between highly fractured of radiolarian chert.
3. The kinematic analysis was done for Site (No.22 and No.23) because all other sites the rock was effected intense deformation and imbrication lead to creating fault shear zone at these sites. The result of kinematic analysis reveals two types of failure possibility, Wedge slide at site No.22 due to intersection two set joint (J1:286/64, J2:53/207), Lateral detachment at site No.23 due to intersection bedding with joint (J.1; 90/120).
4. The Road hazard rating system (RHRS) applied along the road between Biyara-Tawella by scoring ten parameters to identify slopes which are particularly hazardous and require urgent remedial work. The RHRS analysis results show that the score range between 309-398 means the risk is unacceptable, it needs urgent remedial works.

Acknowledgment

The authors are grateful to Ghafor Ameen Hamasur for valuable comments helped to improve the quality of this paper and Anwar Osman Mohammad for their manuscript revision

References

[1] Bejerman, N.J. *"Evaluation of landslide susceptibility along a sector of state road E-55, Cordoba Argentina"*. Proceedings, 8th International Congress of IAEG, Vancouver, Canada, Balkema, (1998).

[2] Bejerman, N. J. *"Landslide possibility index system"*. Proceedings 7th International Congress of IAEG. Vol. 3. Rotterdam: Balkema. pp. 1303-1306. (1994).

[3] Bolton, C.M.G., *"The Geology of Ranyia area*". Site Inv Co. Upubl. Report, SOM Library, Baghdad. (1958).

[4] Davis, G., Reynolds, S.J., Klutch, C. F. *"Structural geology of rocks and regions*", 3rd edition. New York, John Wiley & sons, Inc. (2012).

[5] Goodman, R.E. *"Introduction to rock mechanics*". Wiley, New York. pp. 478. (1989).

[6] Guzzetti, F., Crosta, G., Detti, R., and Agliardi, F. *"STONE: a computer program for the three-dimensional simulation of rockfalls*", Computers and Geosciences Vol. 28, pp. 1079–1093, (2002).

[7] Hoek, E. and Bray, J.W. *"Rock Slope Engineering*". Revised 3rd Edition, The Institution of Mining and Metallurgy, London, pp. 341-351. (1981).

[8] Hoek, E. *"Practical Rock Engineering*", Rocscience, Toronto. (2000).

[9] Jassim, S. Z. and Goff, J. C. *"Geology of Iraq*". Dolin, Prague and Moravian Museun, Berno. pp. 341. (2006).

[10] Karim, K.H. *"Stratigraphy and lithology of the Avroman Formation (Triassic)*". Iraqi Journal of Earth Sciences, Vol. 7, pp. 1–12. (2007).

[11] Baziany, M.M. *"Stratigraphy and Sedimentology of Qulqula Conglomerate Formation, NE – Iraq*". Ph.D. thesis, University of Sulaimani, Sulaimaniyah, Kurdistan, Iraq, pp. 198. (2013).

[12] P. Budetta. *"Assessment of rockfall risk along roads. Natural Hazards and Earth System Science*", Copernicus Publications on behalf of the European Geosciences Union. Vol.4, No. 1, pp. 71-81. (2004).

[13] Palmström A. *"RMi - a rock mass characterization system for rock engineering purposes"*. Ph. D. thesis Univ. of Oslo, pp. 400, (1995). http://www.rockmass.net.

[14] Pierson, L. A., Davis, S. A., and Van Vickle, R. *"Rockfall Hazard Rating System – Implementation Manual*", Federal Highway Administration (FHWA), Report FHWA-OR-EG-90–01, FHWA,U.S. Dep. of Transp., 1990. Rotterdam, Vol.2, pp. 1175 – 1178. (1998).

[15] Sissakian, V. K., *"Geological map of Iraq*". Sheets No.1, Scale 1:1000000, State establishment of geological survey and mining. GEOSURV, Baghdad, Iraq. (2000).

[16] Stocklin, J. *"Structural History and Tectonic of Iran*", A Review. American Association of Petroleum Geologists Bulletin, USA, Vol. 52, pp. 1229-1258. (1968).

[17] Stille, H., Palmstrom, A., *"Ground behavior and rock mass composition in underground excavation"*. Tunnelling and Underground Space Technology Vol. 23, pp. 46–64. (2008).

[18] Wyllie, Duncan, C. and C. W. Mah, *"Rock Slope Engineering: Civil and Mining*". Fourth Edition, Spon Press, New York, pp.37-45. (2004).