ASSESSMENT OF ROCKFALL HAZARDS ON MIRAWA – MAWARAN MAIN ROAD, KURDISTAN REGION, N IRAQ

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ABSTRACT

This study includes the implementation of a method for the analysis of rockfall hazard along roads and motorways. The method is the Rockfall Hazard Rating System (RHRS) developed by the Oregon State Highway Division. This method was implemented on rock cuts along Mirawa main road, north of Shaqlawa summer resort, in Kurdistan Region, north Iraq.

Seven road cuts are rated according to RHRS and the results showed that most of the studied rock cuts of Mirawa area are classified as moderate hazard and needs remedial measures with moderate urgency, because their rockfall hazard rating values are between 300 – 500. The other two rock cuts (Sites 1 and 6) are classified with low hazard and needs remedial measures with low urgency, because their RHR values are less than 300. Accordingly, a geological map with rockfall hazard sites was prepared for Mirawa main road.

تقدير مخاطر الإنهيار الصخري لطريق ميراوة – ماوران الرئيسي، اقليم كردستان، شمال العراق

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المستخلص

تتضمن الدراسة استخدام طريقة تحليل مخاطر الإنهيار الصخري على مسار المركبات وطرق المرور السريعة. الطريقة المتبعة هي RHRS المعدة من قبل قسم طرق المرور السريع لولاية اوريغون في الولايات المتحدة الأمريكية. استخدمت هذه الطريقة على القطوعات الصخرية على طول طريق ميراوة – ماوران الرئيسي الواقع شمال مصيف شقلاوة، في اقليم كوردستان، شمال العراق.

تمت دراسة سبعة قطوعات صخرية بموجب RHRS وأظهرت النتائج ان أغلب القطوعات الصخرية لطريق ميراوة – ماوران تصنف متوسطة الخطورة وتحتاج الى إجراء بعض المعالجات وأعمال الصيانة من وقت لأخر، وذلك لكون قيم تقدير مخاطر الإنهيار الصخري لخمس محطات تتراوح بين 300 – 500، في حين ان قطعي الطريق في الموقعين (1 و 6) قد صنفت واطئة المخاطر ولاتحتاج الى معالجات وأعمال صيانة ضرورية، وذلك لكون قيم تقدير RHR فيها اقل من 300. وبموجب تلك النتائج تم رسم خريطة جيولوجية لمخاطر الإنهيار الصخري على طريق ميراوة الرئيسي.

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INTRODUCTION

Transportation systems, such as highways are vulnerable to rockfall wherever they cut across or skirt along mountains, plateaus, ridges and similar topographic features (Bunce *et al*., 1997 and Hungr *et al*., 1999). In the context of highway rock slopes, potentially unstable slopes present hazards and pose risks to the traveling public, to the transportation infrastructures, to local economies and to the environment.

Varnes (1978) considered that both rockfall and rockslide are forms of landslides. It was updated by Cruden and Varnes, (1996) classification systems, where the first term (rock) indicates type of material and the second term (fall or slide) indicates type of movement. The State Transportation Agencies and the Federal Highways Administration (FHWA) have adopted 5 simpler nomenclatures for rock slope failures affecting highways and referring to all such failures as rockfall.

Transportation contractors usually work with as low cost as possible, without any consideration to the safety of the road users, especially in Iraq. The safety of the road users is made more difficult when the highways pass through terrain requiring rock cuts (Pierson *et al*., 1990). In mountainous regions such as Kurdistan, many kilometers of roadways pass through steep terrain, where rock slopes adjacent to the highway are common. Some of these man-made slopes (road cuts) may reach up to hundred meters of hight. There is an inherent rockfall potential at such slopes.

There are many standardized methodologies developed in the world which provide programs that include inspection of all rock slopes along highway system to identify where rockfall would most likely affect the roadway. One of these methods is the Oregon Rockfall Hazard Rating System (RHRS). This system is adopted in the present study to assess the rockfall hazards of the rock cut slopes along the main road of Mirawa valley area. The basic data of the current study are obtained from a study of rock slope stability of the Fatha and Injana formations in the area around Mirawa valley (Shakir, 2006).

The main aim of this study is to assess the rockfall hazards along Mirawa – Mawaran main road and draw a map that can be used to protect vehicles, road users and any infrastructure that may be constructed close to those rock slopes which are vulnerable to such risks.

The area is located north of Shaqlawa resort. The main road runs from Darband to Mawaran Ulia, almost parallel to the synclinal axis of the area. It is bounded by the coordinates: 44° 18' 00" – 44° 21' 00" E and 36° 24' 00" – 36° 27' 00" N (Figs.1 and 2).

The studied area was previously studied by Shakir (2006) who assessed the stability of rock slopes around Mirawa valley and by Al-Obaidy (2005), who analyzed the stability of rock slopes around Shaqlawa area. They analyzed kinematically, those rock slopes and stated that most of the rock slope failures are of wedge sliding in addition to few plane sliding, toppling and rockfall, respectively. They drew landslide hazard maps, scale 1: 10 000, according to Landslide Possibility Index of Bejerman (1994 and 1998) and landslide hazard effects on roads by Barison and Conteduca, (1998 in Barahim, 2005).

GEOLOGICAL SETTING

Mirawa main road extends nearly parallel to Mirawa valley, which is a strike valley, runs SE – NW. The main geomorphological features within this area are the strike valleys and hills. These features were developed due to differential erosion of the incompetent (siltstone and claystone) rocks of the Injana Formation, forming the valleys, while the harder (sandstone) rocks form the hills. These hills usually have two asymmetrical slopes; gentle slopes on the southeastern side of Mirawa main road making the back slope, and the steep slopes on the northwestern side of the main road, representing the scarp, which occasionally form overhanging slopes. The later steeper slopes have high rockfall frequency due to its steepness. Only the Injana Formation is exposed and forms the rock slopes of the two sides of Mirawa – Mawaran main road, (Shakir, 2006).

The Injana Formation is composed of clastic rocks, such as the relatively hard sandstone and the soft siltstone and claystone, deposited in fluviatile environment. The Injana Formation in the Mirawa valley is underlain by the Fatha Formation, separated by a thick limestone bed, and overlain by unlithified Quaternary sediments along the axis of the syncline (Fig.2).

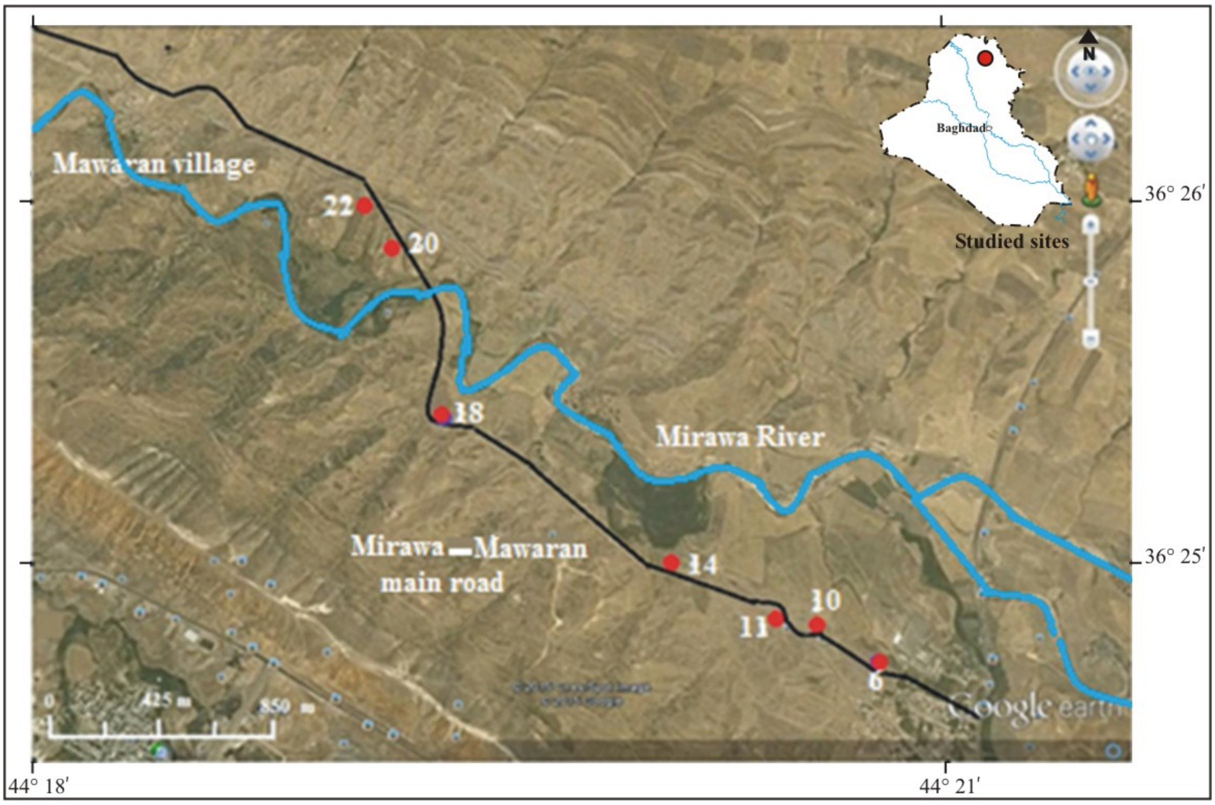

Fig.1: Satellite image showing the location of the studied sites along Mirawa – Mawaran main road

From the tectonic point of view, Mirawa area is located within the High Folded Zone of the Zagros Fold – Thrust Belt of the Arabian Platform (Fouad, 2010). Mirawa valley runs along the axis of an asymmetrical synclinal fold, with NW – SE trend. The northeastern limb is relatively steeper than the southwestern limb (Sissakian and Youkhana, 1979).

The studied area is characterized by the Savanna climatic conditions and close to the semi arid conditions (Al-Obaidy, 2005), due to the moderate annual rates of rainfall (650 mm) and few snowy days (< 6 days/year) in winter, and hot in summer (may reach up to 40 °C), according to I.M.O. (2000). The mean annual temperature in winter for the last twenty years is 18 °C and the annual humidity is 48%.

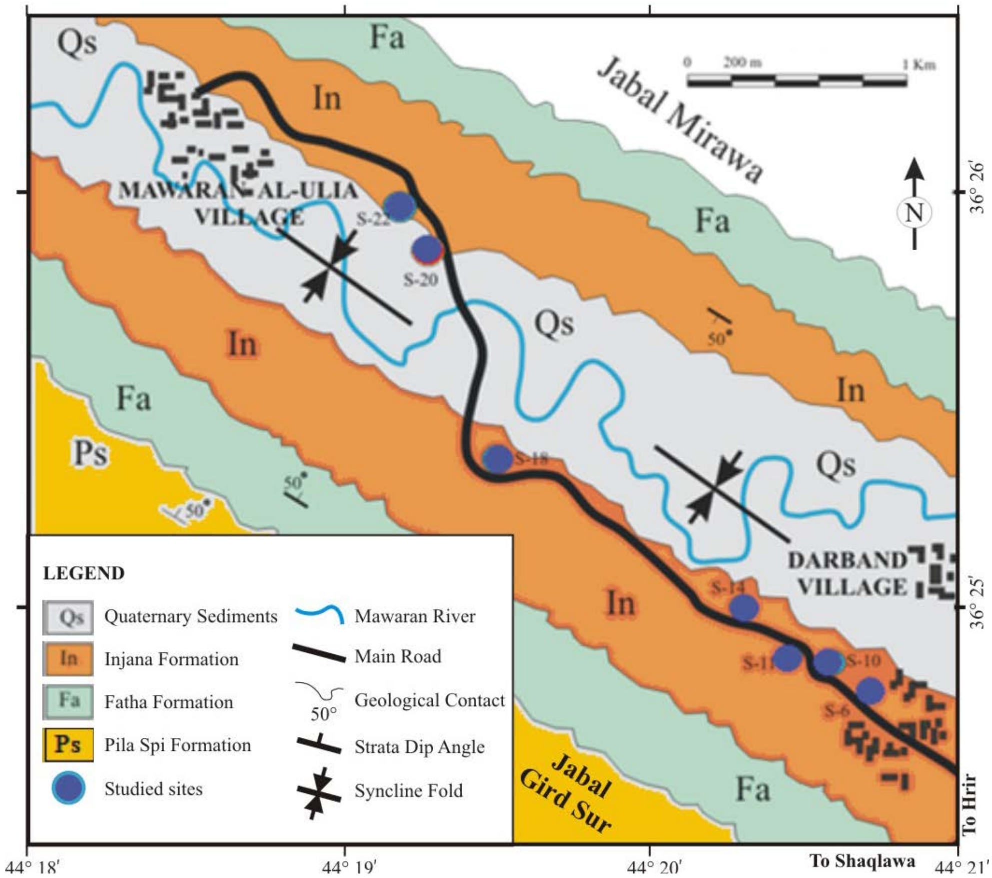

Fig.2: Geological map of the studied area (after Shakir, 2006)

METHODOLOGY

In order to assess the exposition to the risk associated with rockfall, and to prioritize budget allocations for maintenance and remediation works, the Oregon Department of Transportation (USA) has developed a classification scheme, designed specifically for motorway cuts, named the Rockfall Hazard Rating System (Pierson *et al.*, 1990 and Scesi *et al.*, 2001) to identify dangerous slopes, that require urgent remedial work. This is best summarized in Table (1). This method includes all the elements regarding rockfall hazard (slope height, geologic character, volume of the rockfall/ block size, climate and presence of water on slope and rockfall history) and the vehicle vulnerability (ditch effectiveness, average vehicle risk, percent of decision sight distance, roadway width). The resulting total score assesses the degree of the exposition to the risk along roads.

The first step in this process is to make an inventory for the stability conditions of each slope; so that they can be ranked according to their rockfall hazard. Then, the rockfall areas identified in the inventory are ranked by scoring the categories, as shown in Table (1). Some categories require a subjective evaluation, whereas others can be directly measured and then scored. The rating criteria scores increase exponentially from (3 to 81) points and allow quick distinguishion of more dangerous sites (Budetta, 2004). The category scores are then added together for an overall rockfall site score.

The field observations and measurements, used in the current study, were obtained from Shakir (2006). Seven sites were used, for the road cut and rock slopes in order to estimate their rockfall hazards on Mirawa main road.

The geological character (character No.6) of each site is assessed as part of the detailed rating and is classified as either **Case 1)** Structural Condition or **Case 2)** Differential Erosion Condition. When both are present, both are rated and the Case that provides the highest score is used in the rating (Pierson *et al*., 1990).

In the RHRS's original method, the slopes with scores lower than 300 are classified for remedial works with low urgency, whereas those higher than 500 are in need of immediate stabilization measures.

Table 1: Summery sheet of Rockfall Hazard Rating System
(after Pierson *et al*., 1990)

Category			Rating criteria by score			
			Point 3	**Point 9**	**Point 27**	**Point 81**
1	**Slope height**		7.5 m	15 m	22.5 m	> 30 m
2	**Ditch effectiveness**		Good	Moderate	Limited	No Catchment
3	**Average vehicle risk (% of time)**		25	50	75	100
4	**Decision sight distance (%)**		Adequate (100%)	Moderate (80%)	Limited (60%)	Very limited (40%)
5	**Roadway width (including paved and shoulders)**		13.20 m	10.80 m	8.40 m	6 m
6	**Case 1**	**Structural condition**	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		Friction	Rough, irregular	Undulating	Planar	Clay filling or slickenside
Or 6	**Case 2**	**Structural condition**	Few differential erosion	Occasional erosion	A lot of erosion	Major erosion
		Difference in erosion rates	Small	Moderate	Large	Extreme
7	**Block size**		0.3 m	0.6 m	0.9 m	1.20 m
8	**Volume of rockfall per event (m^3)**		2.3	4.6	6.9	9.2
9	**Climate and presence of water on slope**		Low to Moderate precipitation; no freezing periods; no water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope and long freezing periods	High precipitation and long freezing periods or continual water on slope
10	**Rockfall history**		Few falls	Occasional falls	Many falls	Constant falls

ROCKFALL HAZARD ON THE MIRAWA – MAWARAN MAIN ROAD

Seven rock cuts have been studied along Mirawa – Mawaran main road in order to estimate their rockfall hazards and to draw rockfall hazard map for remediation works and protect the road users against these hazards that can help in the designing plans for future urban development.

Shakir (2006) studied 23 sites for rock slope stability analyses in Mirawa area, but only seven of which (sites No: 6, 10, 11, 14, 18, 20 and 22) are road cuts. These road cuts are rock slopes subjected to previous and later potential rockfall and may affect and threat road users. Most of these rock slopes are cut through the Injana Formation, in which the rockfall from the sandstone beds have taken place, after the removal of the underlying supports by either differential erosion of the claystone or by the road cut works. Most of the rock failures are defined as plane sliding, especially in the sites 6, 14, 18 and 20; as demonstrated in Figs. (3 and 4) and wedge sliding in sites 10, 11 and 22; as shown in Figs. (5 and 6).

The studied rock slopes are kinematically analyzed and represented by the stereographic projection in Fig. (7), which shows the potential plane sliding that has taken place along the slopes of sites 6, 14 and 18. The slopes of sites 10, 20 and 22 have the probability to wedge sliding, in addition to toppling, while along the slope of site No.11 only wedge sliding is probable.

The rockfall hazard ratings of the studied road cut slopes, according to RHRS, are listed in Table (2). Most of the studied rock cut slopes (Sites 10, 11, 14, 18 and 22) are classified for remedial measurements with moderate urgency, because their rockfall hazard rating values are more than 300, but less than 500, while the other two rock cut slopes (Sites 6 and 20) are classified for remedial measurements with low urgency, because their RFHR values are less than 300, as shown in Table (2).

Accordingly, a rockfall hazard map at scale of 1: 10 000 for Mirawa – Mawaran main road is prepared to be used in warning and remedial measurements and protection works against these rockfall hazards, as shown in Fig. (8).

Fig.3: Side views of sites 11 **(A)** and 14 **(B)**; showing the blocks vulnerable to rockfall on Mirawa road

Fig.4: Side and frontal views of sites 18 and 20 respectively, of potential plane sliding

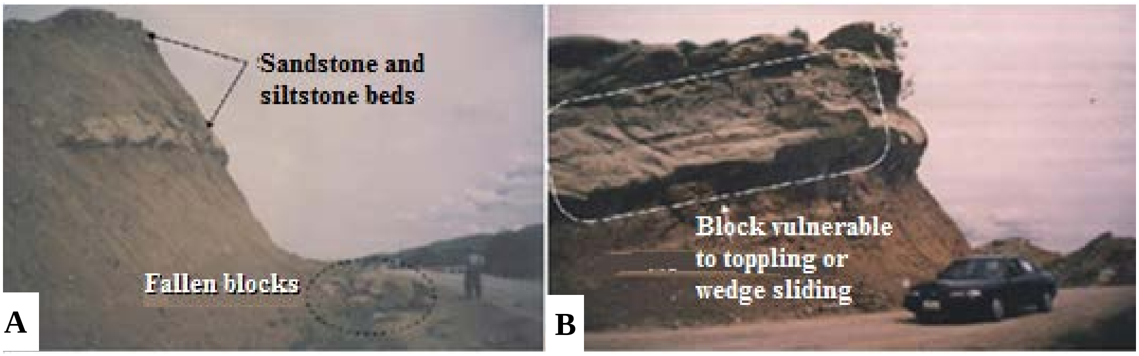

Fig.5: Side views of sites No.6 **(A)** and 10 **(B)**; showing the blocks vulnerable to rockfailure

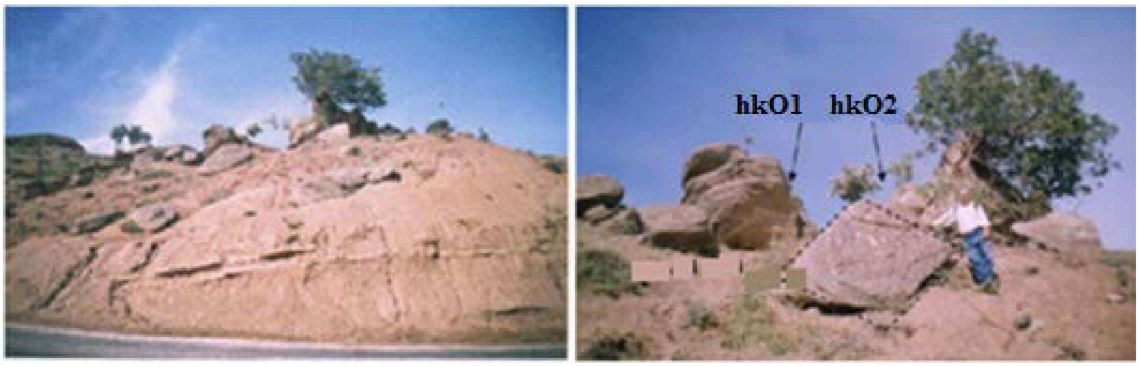

Fig.6: Side and frontal views of the site No.22 showing the detached blocks due to differential erosion

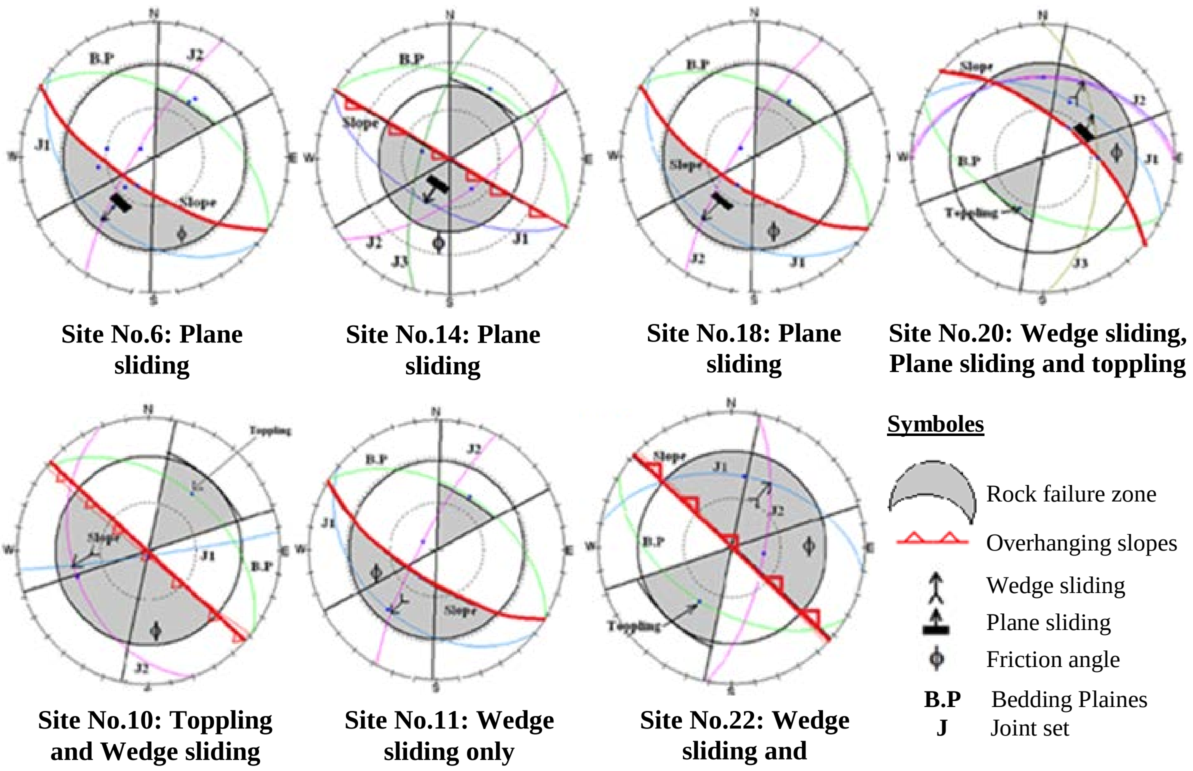

Fig.7: Stereographic projection of rock failure types of the studied road cuts

Table 2: Rockfall hazard rating of the studied rock slopes

Parameters		Site no.	6	10	11	14	18	20	22
Slope height (m)		Value	10	10	15	4	4	6	10
		Score	3	3	9	3	3	3	3
Ditch effectiveness		Value	M	No	Li	Li	No	Li	M
		Score	9	81	27	27	81	27	9
Average vehicle risk %		Value	25	75	50	50	50	50	25
		Score	3	27	9	9	9	9	3
Decision sight distance %		Value	M	V – Li	V – Li	M	V – Li	M	V – Li
		Score	9	81	81	9	81	9	81
Roadway width (m)		Value	7	7	7	7	7	7	7
		Score	81	81	81	81	81	81	81
Geological character	**Structural condition**	Value	Adverse	Adve.	Adve.	Adve.	Adve.	Adve.	Adve.
		Score	27	27	27	27	27	27	27
	Rock friction	Value	Plan.	Und.	Plan.	Plan.	Plan.	Undu.	Plan.
		Score	27	9	27	27	27	9	27
	Structural condition	Value	Occas.	Many	Few	Many	Occas.	Many	Occas.
		Score	9	27	3	27	9	27	9
	Difference in erosion rates	Value	Moderate	Large	Small	Large	Moder.	Moder.	Moder.
		Score	9	27	3	27	9	9	9
Block size		Value	0.6 m	0.9 m	0.9 m	1.2 m	1.2 m	0.6 m	0.9 m
		Score	9	27	27	81	81	9	27
Volume of rockfall per event (m³)		Value	4	6	6.5	7.5	7.5	2	6
		Score	9	27	27	27	27	3	27
Climate and presence of water on slope		Value	9	9	9	9	9	9	9
		Score	9	9	9	9	9	9	9
Rockfall history		Value	Many	Many	Occa.	Occa.	Many	Occas.	Occas.
		Score	27	27	9	9	27	9	9
Total Rating		Score	212	416	332	308	452	194	302

The yellow color indicate values within moderate rockfall hazards category

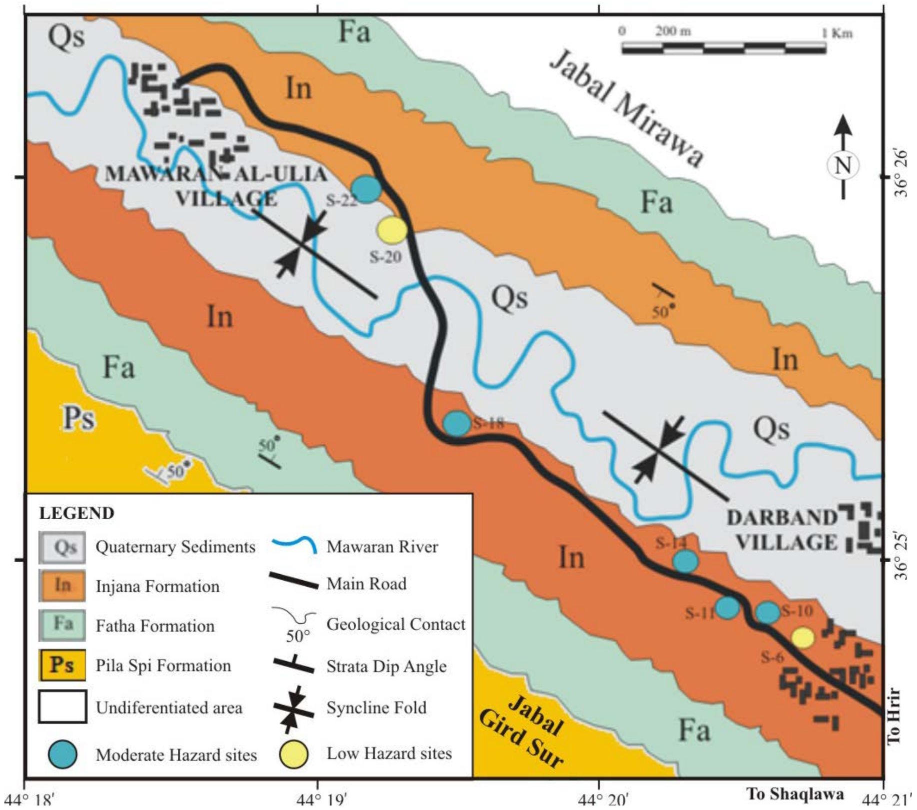

Fig.8: Rockfall hazard map of Mirawa – Mawaran main road

CONCLUSIONS

- Rockfall Hazard Rating System (RHRS) is used successfully to assess seven problematic rockfall sites affecting the main road connecting Mawaran village with other surrounding villages and towns.
- Most of the studied rock cut slopes have an adverse geological factors that contribute to create potentially unsafe ground above the main road. Most of the studied road cuts are classified as moderate rockfall hazard on Mirawa – Mawaran main road, because the main road has one lane width, relatively short sight distances due to the abrupt meanders relatively with medium to large block sizes and medium volumes of rockfall per each events. These moderately hazardous rock slopes need a detailed remedial measures and warning indicators close to them.
- The low rockfall hazard of two sites (6 and 20) are due to the low values of the sight distance, the block size and the volume of the rockfall per event.
- The application of the RHR system is proved accurate and, if used with the field observations, can be successfully applied in rockfall hazard on road cuts estimations elsewhere.
- Six of the ten categories rated are objective categories and can be directly measured, while the remaing four categories are subjective categories; therefore, the scores are based on comparison and judgment.

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