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AN APPLICATION OF THE RISK-CONSEQUENCE ROCKFALL HAZARD RATING SYSTEM FOR THE "MIRAWA" MAIN ROAD ROCK CUTS, KURDISTAN REGION, NORTH IRAQ

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ABSTRACT

In this work, the Missouri Rock Fall Hazard Rating System (MORFH RS), named as Risk-Consequence rockfall hazard rating system, was used as an attempt to assess the rockfall hazards of the road rock cuts along the "Mirawa" main road, especially, after the population and urban growth witnessed in the area in the last decade. The MORFH RS is a risk-consequences-based classification system that includes 22 factors, including 9 factors for risk, 10 factors for consequence, and 3 adjustment factors.

Seven (7) sites of rock cuts along 2.36 Km of the Mirawa main road have been studied in detail. These road cuts consist of the clastic rocks (sandstone, siltstone, and claystone) of the Injana Formation of the Late Miocene age. The Mirawa main road is located to the north of Shaqlawa summer resort, between Darband village (in the southeast) and Mawaran–Ulia village (in the northwest), within Erbil Governorate, Kurdistan Region, N-Iraq.

The used risk-consequence rockfall rating system diagram shows that; five-rock cuts (S-6, S-10, S-11, S-14, and S-22) have High risk-High consequences, and only two rock cuts (S-18 and S-22) have "Low risk-High consequences".

The risk-consequence rockfall hazard rating diagram shows that; the rock cuts (S-6, S-10, S-11, S-14, and S-22) are within the "High Hazard Zone" (Zone A), while the rock cuts (S-18 and S-20) are within the "Moderate Hazard Zone" (Zone B). Accordingly, the "Mirawa" main road is high to moderate rockfall hazards for vehicles and road users, and two maps related to the "risk-consequence" rockfall ratings were prepared.

استخدام نظام تصنيف "مخاطر – عواقب" السقوط الصخري لقطوعات صخور طريق "ميراوة" الرئيس، اقليم كردستان، شمال العراق

لؤي داود يوسف وعمار محمود شاكر

المستخلص

في هذا العمل استخدم نظام تخمين مخاطر السقوط الصخري لولاية ميزوري كمحاولة لحساب مخاطر السقوط الصخري على القطوعات الصخرية لطريق ميراوة الرئيسي، وخصوصاً بعد النمو السكاني والعمراني الذي شهدته المنطقة في السنوات العشر الأخيرة.

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ان نظام ميسوري لتخمين مخاطر السقوط الصخري يعتمد على حساب الخطورة وعواقبها (نتائجها) ويتضمن 22 معامل، 9 معاملات للمخاطر و10 معاملات لعواقبها، مع 3 معاملات تعديلية.

تم دراسة سبع قطوعات صخرية ضمن مسافة 2.63 كم على طريق ميراوة الرئيسي تفصيليا. تتكون هذه القطوعات من تتابعات من صخور رملية وطينية وغرينية لتكوين "إنجانة" بعمر المايوسين المتأخر. حيث يقع طريق ميراوة شمال مصيف شقلاوة، بين قرية دربند (الى الجنوب الشرقي) وقرية ماوران العليا (في الشمال الغربي)، ضمن محافظة اربيل، اقليم كردستان، شمال العراق.

اظهر مخطط تصنيف المخاطر - العواقب المستخدم في العمل الحالي ان خمس قطوعات صخرية (6 و 10 و11 و 14 و 22) ذات "مخاطر عالية- عواقب عالية" (H.R-H.C) واثنين من القطوعات الصخرية (18 و 20) ذات " مخاطر واطئة- عواقب عالية" (L.R-H.C).

مخطط انطقة مخاطر "Rockfall Hazard" للسقوط الصخري على الطريق كانت متواجدة في المواقع (6 و 10 و11 و14 و22) والتي تقع ضمن نطاق " المخاطر العالية (نطاق- A) والموقعين (18 و 20) واقعة ضمن نطاق الخطورة المتوسطة (نطاق-B).

وعلى هذا الأساس، اعتبر طريق ميراوة الرئيسي ذو مخاطر سقوط صخري عالية ومتوسطة على المركبات ومستخدمي الطريق، وتم اعداد خريطتين وفق نظام تقدير "مخاطر-عواقب" سقوط الصخور على الطريق.

INTRODUCTION

Every year, rockfalls take place on both natural and man-made slopes, especially, along the road cuts of the hilly areas, during the rainy and freeze-thaw seasons (Maerz *et al.*, 2004). These rockfalls may cause block roads, damage infrastructures, and even injuries and fatalities (Maerz, 2000). The safety and comfort of cars and passengers require cutting rock masses along the highways be stable and safe.

Rockfalls usually occur when rock or debris is falling from a road cut or nearby steep slope by processes such as planar sliding, wedge failure, toppling, differential weathering, and raveling onto the catchment and/or road (Norrish and Wyllie, 1996).

For determining the level of hazard and prioritizing remedial works, it is required to evaluate rockfall hazards along road cuts. Rock-slope geometry, vehicle traffic patterns, and roadway geometry are all included in the characterization (Wyllie and Norrish, 1996).

Recently, several rockfall hazard rating systems have been proposed and implemented by the Department of Transportation in the USA (Youssef *et al*., 2003), and the Missouri Rock Fall Hazard Rating System (MORFH RS) is one of them.

The MORFH RS has been developed for Missouri highways (Maerz *et al*., 2005 and Youssef *et al*., 2007). MORFH RS is based on the rating of the 22 parameters of the risk-consequence factors in rating the rockfall hazards on the highway rock cuts. "MORFH RS" uses; digital highway video logs, imaged at highway speeds for pre-screening, using the RockSee program and facilitating data entry of rating data, storing, printing, and transferring reports to a GIS system, via a personal computer attached to GPS device.

In the current work, due to the lack of the above-mentioned devices and requirements, the authors used the risk-consequence factors in rating the rockfall hazards of the rock cuts along the Mirawa main road manually. However, this system is based on separating the risk of failure and the consequences of failure from each other. The ratings for the risk and consequence categories are simple to calculate and more objective.

The main aim of the current study is to assess the rockfall hazards of the road cuts along Mirawa main road and rank them according to risk-consequence rating, then to draw a risk–

consequence rockfall hazard map that can be used to protect vehicles and road users, and any infrastructure that may be constructed close to those road cuts, which are vulnerable to such risks.

It is also can be used to determine the need and priority of maintenance and remediations on the road cuts.

The Google Earth Pro Image (8/2020), using ArcGIS 10.8.1 software, was used to demonstrate the location map of the studied area, and the Caltopo sheet (FS Topo 2013, White) map was used to draw the topographic and geological maps. The Digital Elevation Model (DEM-30 m resolution) of the studied area was used to draw the contour lines and both the risk-consequence rockfall rating and the risk-consequence rockfall hazard zonation maps of this work.

- **Previous Works**

There are several rockfall hazard rating systems proposed or in use today, such as;

- Oregon's RHR system (Pierson and Van Vickle, 1993), which is used 10 categories with 4 nominal rating criteria and scores.
- Ontario's RHR system is a modification of the Oregon RHR system (Franklin and Senior, 1987) in which the authors add five new parameters to Oregon's system and several parameters are redefined.
- The New York Department of Transportation (1996) for the rock slope rating system, uses three factors for computing the relative risk of a rockfall; a geological factor (GF), a section factor (SF), and a human-exposure factor (HEF).
- The "Landslide Possibility Index (LPI)" system (Bejerman, 1994). This estimation system considers characteristic features of the slope estimated in the field and then applied them in the chart included in Bejerman (1995).
- The slope stability probability classification (Hack *et al.*, 2003), is based on the probabilistic assessment of independently different failure mechanisms in a slope.
- Tennessee rockfall hazard rating system (Bellamy *et al.*, 2003), which is also a modification of Oregon's RHR System.
- With regard to the area of the current study, the area and its surroundings have undergone many studies in many geological aspects. Among those studies, which are related to the subject of the current work are;
- Sissakian and Youkhana (1979), reported the regional geological survey for the Erbile-Shaqlawa-Quaisinjag-Raidar area, which involve the current study area, for the benefit of the Iraq Geological Survey (GEOSURV).
- Shakir (2006), assessed the stability of rock slopes around Mirawa valley and kinematically analyzed the stability of rock slopes and stated that most of these rock slope failures are of wedge sliding in addition to a few planes sliding, toppling, and rockfall, respectively.
- Yousif and Shakir (2015), implemented the rockfall hazard rating system (RFHRS) along Mirawa main road and drew a landslide hazard map on a scale of 1:10000, according to the LPI of Bejerman (1994 and 1998) and the landslide hazard effects on roads by Barison and Conteduca (1998) in (Barahim, 2005). They showed that most of the studied rock cuts are classified as moderate hazard and needs remedial measures with moderate urgency because their rockfall hazard rating values are between 300 and 500.

STUDY AREA

The Mirawa main road is located north of Shaqlawa summer resort, in Erbil Governorate of Kurdistan region, North Iraq. Mirawa main road runs from Darband village (in the southeast) to Mawaran Ulia village (in the northwest) of the area, almost parallel to the axis of the syncline northeast Safin Anticline. It is bounded by the coordinates: 44°18'– 44°21'E and 36°24'–36°27'N (Fig.1). Seven rock cuts on the Injana Formation rock slopes had been studied along 2.63 km road distance between S-6 in the southeast and S-22 to the northwest had been studied. The coordinates of the studied seven sites are listed in Table (1).

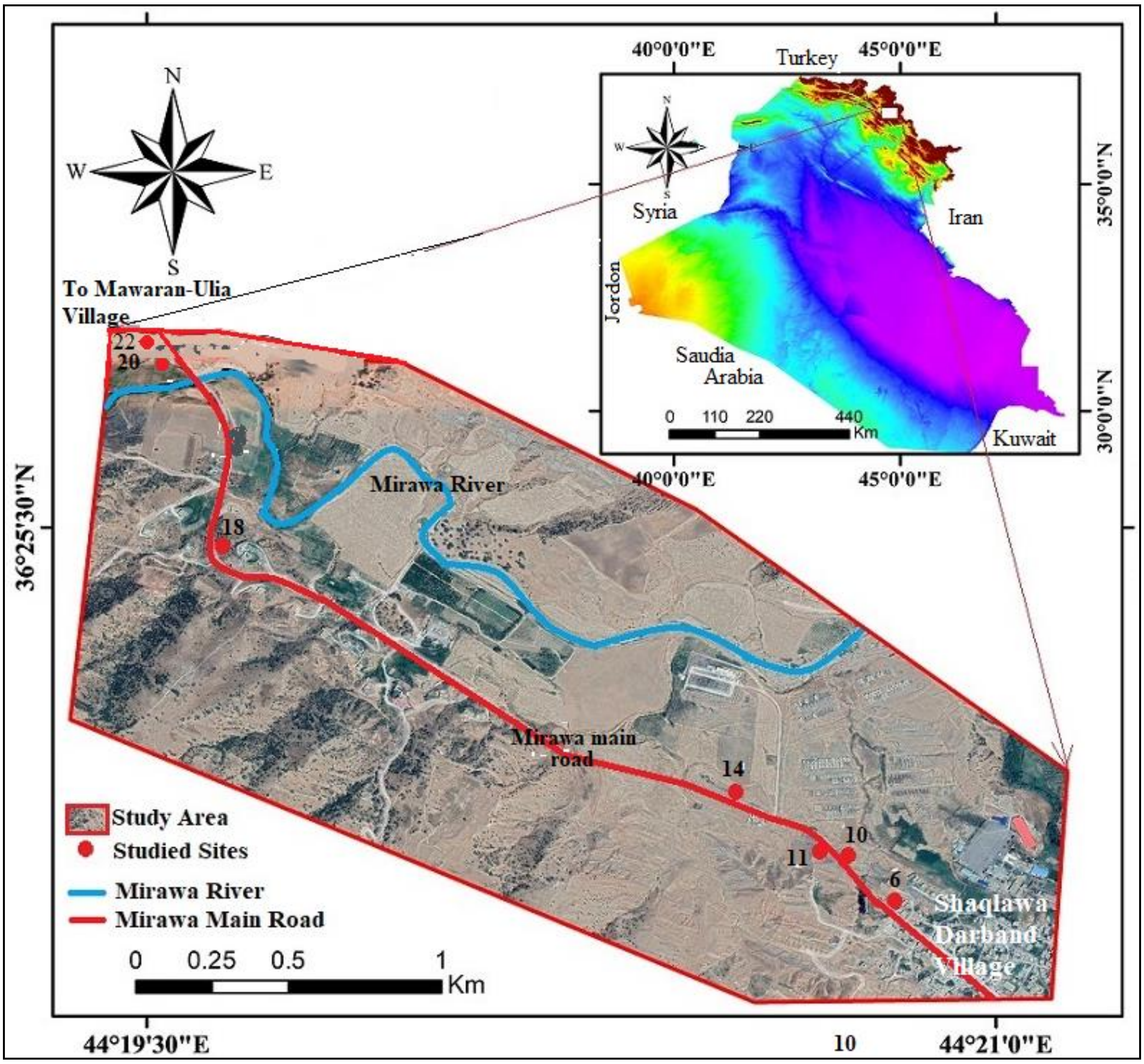

Fig.1: Google Earth Pro image shows the location of the studied area

Table 1: The coordinates of the studied rock cuts

Site No.	Latitude – N	Longitude – E	Elevation
S-6	36°24'49.29"	44°20'47.91"	791 m
S-10	36°24'54.53"	44°20'42.74"	780 m
S-11	36°24'55.87"	44°20'40.80"	786 m
S-14	36°24'59.39"	44°20'28.13"	760 m
S-18	36°25'26.14"	44°19'38.04"	772 m
S-20	36°25'48.24"	44°19'32.50"	741 m
S-22	36°25'53.39"	44°19'27.38"	745 m

GEOLOGICAL SETTING

The geological map of the studied area was drawn according to Shakir (2006) using Caltopo topographic map (FS Topo 2013, White) in a geographical Information System (GIS) environment (Fig.2).

The Mirawa main road follows approximately parallel towards the Mirawa valley, which is a strike valley that runs from SE to NW. The strike valleys and hills are the dominant geomorphological features in this area, which were formed by differential erosion of the Injana Formation weak siltstone and claystone rocks, while the harder sandstone rocks formed the isolated hills. These hills often have two asymmetrical slopes: gentle slopes on the southwestern side of the road, which act as the back slope, and steep slopes on the northeastern side of the road, which occasionally form overhanging slopes. A High frequency of rockfalls is frequently developed along the steeper slopes, due to their steepness (Shakir, 2006).

The Injana Formation of the Late Miocene age is exposed along the investigated road, and it constitutes the rock slopes on both sides of the main road (Fig.2). The Injana Formation is mainly composed of clastic rocks deposited in a fluviatile environment, such as relatively hard sandstone and soft siltstone and claystone. The Injana Formation in the Mirawa valley is underlain by the Fat’ha Formation (exposed out of the studied area) separated by the first thick reddish-brown sandstone horizon (Jassim *et al.*, 1984 and Al-Rawi *et al.*, 1992), and overlain by unlithified Quaternary sediments along the axis of the syncline (Shakir, 2006).

The studied 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 syncline, north Safin Anticline (out of the studied area, to the south), with a NW – SE trend. The northeastern limb of the Mirawa syncline is relatively steeper than the southwestern limb (Sissakian and Youkhana, 1979 in Shakir, 2006). The studied area is characterized by the Savanna climate and is 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%.

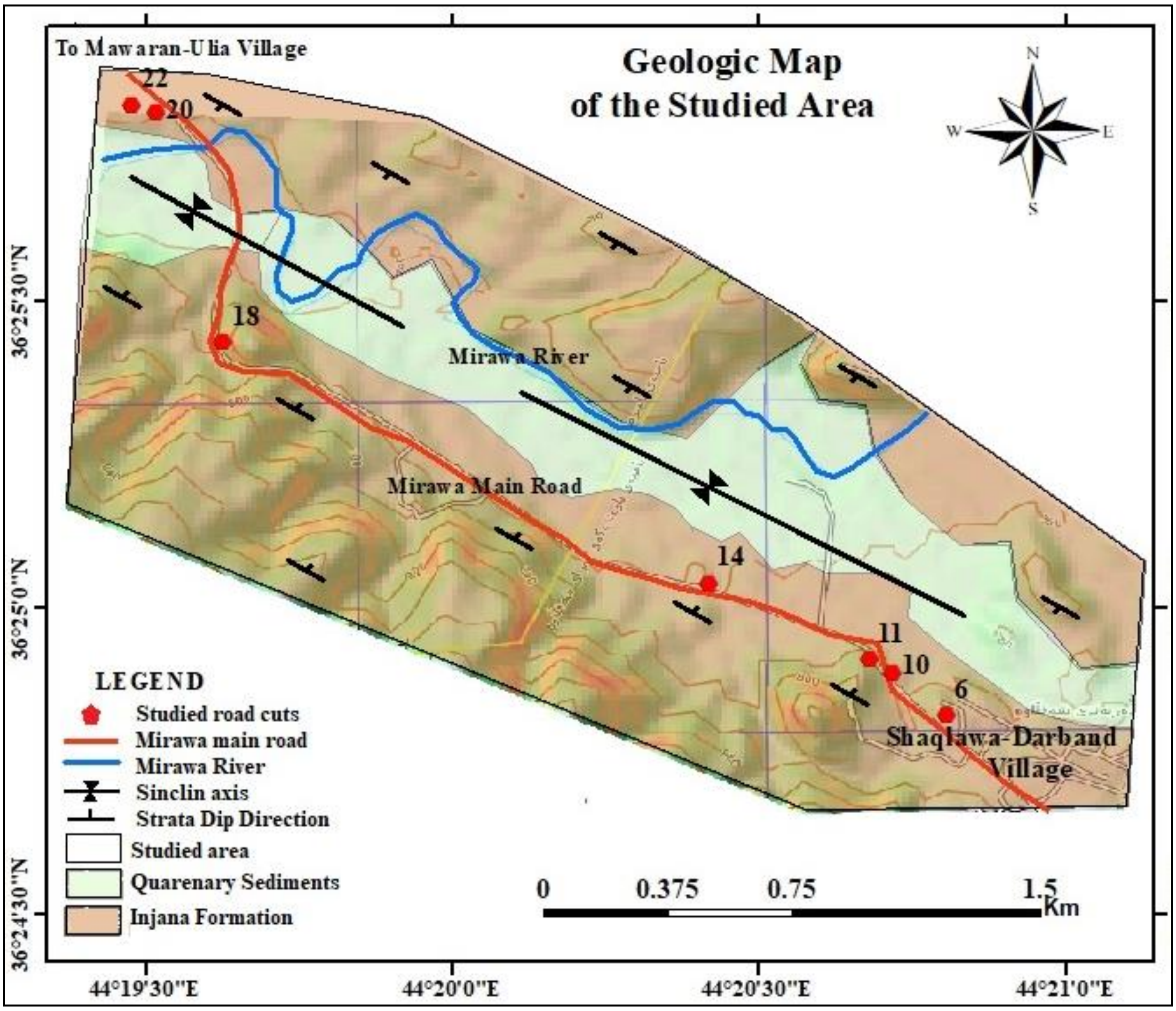

Fig.2: Geological map of the studied area drawn using a Caltopo topographic map (FS Topo 2013, White) in the GIS environment

STUDIED SITES CONDITIONS

This main road extends from Shaqlawa-Darband village in the southeast to Mawaran-Ulia village in the northwest. The two sides of this main road consist of road cuts along the Injana Formation. Seven rock cuts (Sites; 6, 10, 11, 14, 18, 20, and 22) were studied along this road. Generally, these seven road cuts are considered as; rock cut slopes less than (85°), one lane width for each direction through the cut, water on the face during the rain showers and snowy days, average vehicle daily traffic < 5000 car/day and no karst (sinkhole) features. In addition, they have a very small and narrow ditch and relatively small shoulders on each side.

- **Site-6**

This site is a road cut through the right side of the road and consists of siltstone and claystone beds of the Injana Formation. The blocks of the relatively harder siltstone beds form the potential rockfall after the differential erosion of the underlying weaker claystone beds. The fallen rock blocks are about 0.5 m in size. The shoulder in this site is relatively wider (Fig.3A), which may reach 2.5 m, compared to the other sites, and not ditch. This rock cut has previously been subjected to rockfall and potential subsequent rockfalls.

Fig.3: Side and front views for the rock cuts in (S-6 A) and (S-10 B), respectively

- **Site-10**

Site-10 is a road cut located at the right side of the road, through the weak claystone (2 – 3 m thick) bed at the lower part overlain by the hard sandstone (3 – 3.5 m thick) layer (Fig.3B), with the relatively small shoulder (not more than 1.5 m), small ditch (about 0.5m width and 0.3m deep) and adequate sight distance.

This road cut is vulnerable to later potential rockfall of large blocks of the sandstone bed can affect and threaten the road users, after the removal of the underlying supports due to the differential erosion of the underlying claystone bed.

- **Site-11**

It is located on the left side of the main road and totally consists of a relatively hard sandstone bed of dip slope toward the road (Fig.4A). It has a limited sight distance due to the curved road and relatively high slope height. This site is vulnerable to later plain sliding with different block sizes.

Fig.4: Side views for the rock cuts for (S-11A) and (S-14B)

- **Site-14**

This site is on the right side of the road, it consists of a relatively thick and hard sandstone bed that overlies the softer claystone bed (1.5 – 2 m thick). Although the sandstone bed dipped against the slope (rock cut), it forms an overhanging slope due to the deferential erosion of the underlying soft claystone and potentially failed by wedge sliding and/or toppling (Fig.4B).

- **Site-18**

This road cut is on the right side of the road and has a 4.5m height, almost consisting of a relatively thick claystone bed underlying a thinly bedded sandstone layer. The harder sandstone bed is very blocky and failed downslope due to the deferential erosion of the underlying softer claystone by the rainwater (Fig.5A).

Fig.5: Side views for the rock cuts in (S-18A) and (S-20 B)

- **Site-20**

This road cut is located on the northeastern limb of the syncline and the left side of the road. It has an irregular slope face of claystone bed (7.5 m thick) containing two thin beds of sandstone (0.3 m thick for each) in its middle part. The claystone bed is an underlying 3.5 m massive hard sandstone bed at the top of the road cut (Fig.5B). The massive sandstone layer was previously subjected to rockfall by wedge sliding due to the removal of the underlying support by deferential erosion.

- **Site-22**

This road cut is located at the northeastern limb of the syncline and the left side of the road. It is totally consisting of hard and massive and thinly bedded sandstone succession. Although, the sandstone bedding dip against the road cut, some large masses potentially fall by toppling or wedge sliding along the discontinuity intersection lines (Shakir, 2006), which have unfavorably dipped towards the road cut (Fig.6).

Fig.6: Side view for the rock cut in (S-22)

METHODOLOGY

A risk-consequence classification system called the MORFH RS has been developed for Missouri highways. The MORFH RS system was first described by Maerz *et al.* (2003) and is more fully described by Maerz *et al.* (2004). The Missouri rockfall hazard rating system uses; digital highway video logs, imaged at highway speeds for pre-screening, using the RockSee program and facilitating data entry of rating data, storing, printing, and transferring reports to a GIS system, via a personal computer attached to GPS device.

Due to the lack of the aforementioned devices and equipment, the current work adopted the field and office observations and measurements to calculate the factors of the risk-consequence rockfall hazard rating system manually.

The current work depends on the field observations and measurements by Shakir (2006) and Yousif and Shakir (2015), Google earth image (8-2020), caltopo topographic map, and the new audit field observation in 2022, using GIS environment.

The “Risk-Consequence” rock all hazard rating system includes 22 factors. The system includes 9 factors for risk, 10 factors for consequence, and 3 adjustment factors. These factors are organized into risk and consequence categories and identified based on how the factors are evaluated (Maerz *et al*., 2005). There are two ways to supply data to the system: using a class number corresponding to descriptive ratings or providing a real measured or estimated value. In the case of descriptive ratings, there are five ratings or class numbers indicated as 0 – 4 (Maerz and Yousef, 2004). In the current work, the descriptive rating was adopted in the rating for both the risk and consequence factors, according to the Missouri Department of Transportation (MODOT) records in Maerz and Youssef, (2004).

For each of the risk and consequence factors, the ratings are summed and divided by the maximum total ratings to give a value in percent. Adjustment factors must be added afterward. These range from 0 to 12 for the risk and from 0 to 15 for the consequence adjustment factors and are added directly to the rating system, i.e., not averaged in with the rest of the parameters (Youssef *et al*., 2003).

- **Rating of the Risk Parameters**

Risk factors are defined as measurable (or estimable) parameters that can be used as a predictor of the likelihood of failure. These are nominally geologic factors and the site’s history of rockfalls (Maerz and Youssef, 2004).

The input data is used to produce nine fundamental parameters with a rating of 0 – 12 using the procedures described in "MORPH RS parameters description and values"(Maerz *et al.,* 2005), except for weathering, which is 0–24 weighted double because of its importance. The results of all nine criteria are summed together and adjusted to a percentage to obtain a risk rating between 0 and 100.

The adjustment factors are similarly calculated on a scale of 0 to 12 using the formula described in the “MORPH RS parameter descriptions and values”. These values are simply added as the risk rating, where the highest risk rating is 100 (Maerz *et al.,* 2005).

1. Slope height (SH): High slopes are more likely to fail than lower slopes. The height of the vertical slope should be measured from the pavement level to the highest point on the rock slope where rockfall is likely. A linear approach was adopted, where slopes were rated between 0 and 12, for heights of 0 to 60 ft. Slopes above 60 ft are rated at the maximum "12" value (Maerz *et al.*, 2004).

Slope height (SH) rating can be calculated by equation (1) or as described in Table (2).

Rating = Slope Height * 0.2 …….. (1)

Table 2: Slope height rating

Slope height (ft)	10	20	30	40	50	60
Rating	2	4	6	8	10	12

2. Slope Angle (SA): The slope angle is the angle between the horizontal plane and the mean plane of the rock face/slope. The slope angle is important because the risk of failure is greater as the slope angle is increased (Maerz *et al.*, 2004). The slope angle (SA) is rated by equation (2) and Table (3).

Rating = 0.2 * Slope Angle – 6 ………… (2)

Table 3: Slope angle rating

SA (°)	30	40	50	60	70	80	90
Rating	0	2	4	6	8	10	12

3. Rockfall Instability (RFI): This factor is determined from the observation, evidence of blocks in the ditch, and loose blocks on the face of the rock cut. It is rated according to equation (3) or as described in Table (4).

Rating = 3 * RFI class number …………. (3)

Table 4: Rockfall instability description (Maerz *et al*., 2004)

RFI	**Class no.**	**Description**	**R**
Completely Unstable	4	Rocks often fall in this area and there is considerable evidence for that in the ditch and from maintenance records; this will be in sites where severe rockfall events are common	12
Unstable	3	Rocks fall from time to time; the rockfalls will occur frequently during certain times of the year, but will not be a significant problem during other times; this also is used where significant rockfalls have occurred in the past	9
Partially Stable	2	Rocks fall occasionally; rockfalls can be expected several times per year, usually during storms.	6
Stable	1	Very few blocks fall during the year and only during a severe storm	3
Completely Stable	0	No rockfalls; no historical and physical evidence for any rockfall in the area	0

4. Weathering Factor (WF): Physical and chemical weathering are well known for increasing the instability of slopes in a variety of ways. In most cases, the weathering grade is descriptive (Maerz *et al.*, 2004), and the description can be turned into a rating. WF factor is rated by equation (4) and described in Table (5).

Rating = 6 * WF class number ……………….. (4)

Table 5: Weathering factor classification

WF	Class no.	Description	R
High	4	Major erosion features are present, there are many overhanging areas along the rock cut, and differential erosion is evident along the rock cut.	24
Moderate	3	Some erosion features are present, differential erosion features are large and numerous throughout the rock cut.	18
Low	2	Minor differential erosion features appear widely distributed throughout the area; the differential erosion rate is limited.	12
Slightly	1	Few differential erosion features and the erosion rate is very low.	6
Fresh	0	No evidence of weathering and the walls are smooth and planar.	0

5. Strength of Intact Rock (SIR): The compressive strength of intact rock materials on the face is a critical aspect in determining the durability of these materials. The strength of the weakest zone can be determined using a variety of approaches and the most popular ones are using a geological hammer and penknife according to the description of the MODOT manual (Maerz and Youssef, 2004). This factor can be rated by equation (5) or as classified in Table (6).

Rating = -3 * SOIR class number + 12 ………………. (5)

Table 6: Intact rock strength description

SIR	Class No.	Description	R
Very Strong	4	> 14504 psi, many blows by the hammer needed to fracture the rock (>100 MPa)	0
Strong	3	7252 – 14504 psi, several blows to fracture the rock (50 -100 MPa)	3
Moderate	2	3626 – 7252 psi, A firm blow is needed to fracture the rock (25- 50 MPa)	6
Weak	1	725 – 3626 psi, can indent the rock with a pick (5-25 MPa)	9
Very Weak	0	145 - 725 psi, can crumble by hand (1-5 MPa)	12

6. Slope Face Irregularity (FI): Face irregularity is a descriptive scale-based indication of unstable slopes. The following criteria are used to make the decision: The maximum depth of the overhang cut, the degree of differential erosion, the blasting method, and the distribution of discontinuities and rock units are all factors to consider (Maerz *et al.*, 2004). If there are many discontinuities in different directions typically the face will not be smooth and will be irregular because of the blocks that have previously fallen.

This factor has been rated by equation (6) and descriptive scale (Table 7).

Rating = 3 * FI class number ……… (6)

Table 7: Slope face irregularity (FI) description

FI	Class no.	Description	R
Very High Irregular face	4	There are many joints and overhanging features, irregular features everywhere throughout the site, the face is stepped everywhere	12
Highly Irregular face	3	Much of the face is irregular and there are many joints and stepped faces	9
Moderately Irregular face	2	There are many irregular areas in the face	6
Slightly Irregular face	1	There are some irregular areas along the face	3
Smooth Face	0	Very Smooth face	0

7. Face Looseness (FL): It is based on an estimation of the number of open discontinuities visible on the face and the looseness of the face's rock blocks. This is dependent on the type of rock, blasting history, and weathering degree. It is rated by equation (7) as described in Table (8).

Rating = 3 * FL class number …………. (7)

Table 8: Face looseness description

FL	Class no.	Description	R
Very highly loose material	4	The face is completely covered by loose blocks	12
Highly loose materials	3	Much of the face is covered by loose blocks	9
Moderately loose material	2	Some of the faces are covered by loose blocks	6
Low loose material	1	Little of the face is covered by loose blocks	3
No loose material	0	There is no loose material on the face	0

8. Block Size (BS): Small rock masses are inherently less stable and have a higher failure risk than bigger blocks. The distribution of discontinuities on the slope can be used to evaluate block size as a risk factor. The types of discontinuities may include joints, faults, bedding planes, and shear structures. Rocks with numerous discontinuities are more prone to rockfall than massive rocks. BS is rated according to Table (9).

Table 9: Block size (BS) factor description and rating (for Risk factors)

Block Size	Description	R
Massive	Blocks are large and the average joint spacing is 5 ft	0
Moderate Blocky	The average block size is 2.5 ft	4
Very Blocky	The average block size is 1 ft	8
Completely Crushed	Intact rock has the character of crushed run aggregates, joint spacing is less than 0.5 ft	12

9. Water on Face (WOF): During instances of high rainfall, many rockfalls occur. Weathering and instability are caused by water in combination with freeze-thaw cycles (Maerz *et al.*, 2004). This factor is rated by equation (8) and described according to Table (10).

Rating = 3 * WOF Class number ……….. (8)

Table 10: Water on the face (WOF) classification

WOF	Class No.	Description	R
Dry	0	There is no water on the face	0
Damp	1	There is evidence of water on the face	3
Wet	2	There is evidence of significant water on the face	6
Dripping	3	Water dripping from the face	9
Flowing	4	Water flows from the face	12

- **Adjustment Risk factors**

A. Adversely Oriented Discontinuities (AOD): This parameter is an attempt to deal with the effect of the discontinuities that have an adverse orientation toward the highway. The steeper the high angle with respect to the highway, the higher the risk of rock failure. The dip angle of the discontinuities along the face of the rock cut can be measured by using an inclinometer or Brunton compass in the field (Maerz *et al*., 2004). It is rated by equation (9) and described according to Table (11) according to Hoek and Bray (1981).

Rating = 4 * class number ……………… (9)

Table 11: Adversely oriented discontinuity risk rating

AOD	Favorable	Fair	Unfavorable	Very Unfavorable
Dip Angle of Discontinuity Towards the road (°)	< 20	20 – 45	45 – 65	65 – 90
Class number	0	1	2	3
Rating	0	4	8	12

B. Karst Effect (KE): If the karst feature (sinkhole) is filled with well-cemented materials the rater will consider it as a normal cut and not add any adjustment to the system. While, if the sinkholes are filled with an easily weathered material, a karst adjustment has to be made to the rating system (Maerz *et al*., 2004). KE is calculated by equation (10) and described in Table (12).

Rating value = 4 * class number …………… (10)

Table 12: Karst effects risk rating

Filled sinkhole description	Class no.	R
No sinkholes, or sinkholes filled with cemented materials, or Sinkholes filled with very loose materials like sand and clay	0	0
Small 50 ft wide filled with boulders and cobbles or undercut with weak materials	1	4
Medium 100 ft wide filled with boulders and cobbles with weak materials	2	8
Large 150 ft wide filled with boulders and cobbles with weak materials	3	12

- **Rating of the Consequence Parameters**

The term "consequence factors" refers to measurable (or estimable) parameters that can be used to predict the consequence of a failure. These are apparently roadway and human elements that would indicate the consequence of the failures. (Maerz and Youssef, 2004). A rating of 0–12 is calculated for 10 factors according to the formula described in the “MORFH RS parameters description and values”. The values of all parameters are summed and normalized to produce a consequence rating between 0 and 100 (Maerz *et al.*, 2005).

– **Ditch Width (DW):** The effectiveness of the ditch is measured by its ability to restrict the rock from reaching the roadway. There are two different ways to classify ditch width. If the Rock cut is vertical the following categories for ditch width are used as described in Table (13A) and calculated by equation (11A):

Rating = - 0.8 * DW + 12 ………….. (11A)

Table 13A: Ditch width (DW) factor rating for vertical rock cuts

DW (ft)	0	5	10	15
Consequence Rating	12	8	4	0

On the other hand, if the rock cut has a bench rated as bad, or the rock cut is non-vertical the following expanded categories for ditch width is used (Maerz *et al*., 2004). The DW is rated by the equation (11B) and described according to Table (13B).

Rating = - 0.4 * DW + 12 ………….. (11B)

Table 13B: Ditch width (DW) factor rating for rock cut slopes less than 85°

Ditch Width (ft)	0	10	20	30
Consequence Rating	12	8	4	0

– **Ditch Volume (DV):** Under normal circumstances (slope greater than 85° without bad benches), DW and DV are used. If there are non-vertical cuts or a bad bench, ditch shape (DS) is used in place of ditch volume. Ditch volume is rated by equation (12) and described as in Table (14).

$$\text{Rating} = -0.4 * DV + 12 \quad \ldots\ldots\ldots\ldots\ldots (12)$$

Table 14: Ditch volume (DV) factor rating

DV (ft^3/ft)	0	5	10	15	20	25	30
Rating	12	10	8	6	4	2	0

– **Ditch Shape (DS):** If the ditch shape (DS) is flat or has a low back slope angle, the blocks may reach the highway, but if the DS has a large back slope angle, the blocks may bounce and roll back toward the rock face.

Note: This factor is used only if a bad bench is identified or the slope angle is less than 90°, then the DW will be modified and the DS rating value is added to the rating system. In such cases, the Ditch shape is used in place of the ditch volume, as described in Table (15).

Table 15: Ditch (DS) shape factor rating

(DS)	Flat (0°)	Slight Back Slope (1V:8H) 7°	Moderate Back Slope (1V:6H) 9°	Large Back Slope (1V:4H) 14°
Class number	3	2	1	0
Rating	12	8	4	0

– **Expected Rock Fall Quantities (ERFQ):** This is a subjective quantitative factor, which is used to determine the ditch effectiveness, by calculating the ratio of expected rockfall quantity to the ditch volume (Maerz and Youssef, 2004). This factor is determined by measuring or estimating the area of the face that is unstable and estimating the depth of the loose zone (Maerz *et al.*, 2005). This factor is rated according to equation (13) and described in Table (16), according to (MODOT, in Maerz and Youssef, 2004) records.

$$\text{Rating} = 0.3 * RFQ \quad \ldots\ldots\ldots\ldots\ldots (13)$$

Table 16: Expected rock fall quantities (ERFQ) description

ERFQ	**Description**	**R**
> 40 cubic feet per linear foot	The face is completely loose and the expected volume of falling rocks will be about 40 cu ft/ft	12
30 cubic feet per unit foot	Most of the face is loose and the expected volume of falling rocks will be 30 cu ft/ft	9
20 cubic feet per linear foot	Many areas of the face are loose and the expected volume of falling rocks will be 20 cu ft/ft	6
10 cubic feet per linear foot	Few areas on the face are loose and the expected volume of falling rocks will be 10 cu ft/ft	3
Less than 5 cubic feet per unit linear foot	There is no expected rockfall (there are no loose materials on the face)	0

– **Slope Angle (SA) (consequence rating)**
For slope angle from 20 – 30°, Rating = 1.1913 * SA – 23.682 ……. (14)
For slope angle from 30 – 70°, Rating = -0.2569* SA + 19.55 ……. (15)
For slope angle from 70 – 85°, Rating = 0.7095* SA –48.453 …… (16)
For slope angle from 85 – 90°, Rating = -2.4 * SA + 216 ………. (17)
The descriptive value can be obtained from Table (17).

Table 17: Slope angle (SA) rating for consequence rating

SA (°)	20	30	40	50	60	70	80	85	90
Rating	0	12	10	6	3	2	4	12	0

– **Shoulder Width (SW):** If the shoulder width (SW) is small (narrow), the chance of fallen rock reaching the road is greater (Maerz *et al.*, 2004). Shoulder width can be measured by using a tape measure in the field. The SW is rated according to equation (18) and described in Table (18).

Rating = - SW +12 …………… (18)

Table 18: Shoulder width factor rating

SW (ft)	0	3	6	9	12
Rating	12	9	6	3	0

– **Number of Lanes (NOL):** If the highway has one lane, the ability of the driver to avoid the fallen rock is very low. But if there are multiple lanes, the driver has a better chance to avoid fallen rocks by swerving to an adjacent lane. The number of lanes can be determined from field observation or the Municipal local council (Maerz *et al*., 2004). The NOL rating is calculated by equation (19) and Table (19). This equation was derived in consultation with MODOT personnel (Maerz and Youssef, 2004).

Rating = -0.5* (NOL)^3 + 4.5* (NOL)^2-16*(NOL)+24 ……… (19)

Table 19: Number of lanes rating

NOL	1 Lane	2 Lanes	3 Lanes	4 Lanes
Rating	12	6	3	0

– **Average Daily Traffic (ADT):** This factor is important because the consequence of rockfall increases with increasing traffic. This factor can be rated by equation (20) and described in Table (20) respectively.

Rating = 0.0006 * ADT ……….. (20)

Table 20: Average daily traffic rating (MODOT, 2000 in Maerz *et al*., 2005)

ADT	5000 Car/Day	10000 Car/Day	15000 Car/Day	20000 Car/Day
Rating	3	6	9	12

– **Average Vehicle Risk (AVR):** AVR is a measure of the number of vehicles present in the hazard zone at any given time, or, when a fractional quantity, of the percentage of the time, that a vehicle is present in the rockfall hazard zone (Maerz *et al.*, 2005). This percentage is obtained by using a formula (equation 21) based on slope length, average daily traffic (ADT), number of lanes, and the posted speed limit through the hazard zone and described in

Table (21). In the current work, this equation (eq. 21) was used to determine the (AVR) factor rating values.

$$AVR\ \% = (NOV/day/lane) * (RCL\ ft) * (0.000189394) / (PSL\ m/hr) * 24 \quad \ldots\ldots (21)$$

This formula was modified after Pierson and Van Vickle (1993).
Where: NOV =number of vehicles per day and per lane, RCL =Rock cut length (hazard zone), and PSL= Posted Speed Limit

Table 21: Average Vehicles Risk rating (Maerz *et al*., 2005)

AVR	Description	R
Low Risk	25 % of the time the vehicle will be in the rock cut zone	3
Medium Risk	50 % of the time the vehicle will be in the rock cut zone	6
High Risk	75 % of the time the vehicle will be in the rock cut zone	9
Very High Risk	100 % of the time the vehicle will be in the rock cut zone	12

– **Decision Sight Distance (DSD):** It is a measure of the distance/reaction time from a hazard zone that a driver is first able to recognize the hazard, either a fallen rock on the highway or a falling rock on the slope. This system is calculated by equation (22) and a descriptive method is used to characterize the DSD as in Table (22).

$$(DSD)\ Rating = 4 * DSD\ class\ number \quad \ldots\ldots\ldots\ldots (22)$$

Table 22: Decision sight distance classification (AASHTO, 1990)

AVR	Class No.	Description	R
Very Limited	3	Distance is very small and there are many vertical and horizontal curves on the roads, vegetation obscures falling rock	12
Limited	2	There are some curves and obstacles on the road not giving the driver enough time to perceive that there are falling rocks on the road	8
Moderate	1	There are few curves and obstacles and the driver can control the vehicle easily because he sees falling or fallen rocks	4
Adequate	0	The road is completely straight without any obstacles or curves and the driver can see the entire rock face and road at any time	0

– **Block Size (BS) (consequence rating):** BS is also affecting the consequence factor in a different way, because large moving blocks have greater kinetic energy than smaller ones, meaning they will travel further down the inclined slope and cause more damage to road and vehicles (Maerz *et al.,* 2004). In MORF RS the average value of the block size from the rock cut face is used; this value represents the block size of the rock cut face. BS is rated by equation (23) and described as in Table (23).

$$Rating = (-0.0004*BS)^6 + (0.0023*BS)^5 + (0.0011*BS)^4 - (0.0267*BS)^3 + (0.5464*BS)^2 - (0.0208*BS) + 0.14 \quad \ldots\ldots\ldots (23)$$

Table 23: Block size factor rates for the consequence rating (Maerz and Youssef, 2004)

BS	Description	R
Massive	Blocks are large and the average joint spacing 5 ft	12
Moderately Blocky	The average block size is 2.5 ft	8
Very Blocky	The average block size is 1.0 ft	4
Completely Crushed	Intact rock has the character of crushed run aggregates, joint spacing is less than 0.5 ft	0

- **Adjustment consequence rating**

– Ditch Capacity Exceedance (ERFQ/DV): The value of the ditch capacity exceedance is internally calculated by dividing the expected rockfall quantity by the ditch volume (ERFQ/DV). It is rated according to equation (24) and described in Table (24).

Rating = 5 * Adjustment value – 5 …………. (24)

Table 24: Ditch capacity (DC) rating (Maerz and Youssef, 2004)

ERFQ/DV	1	2	3	4
Rating	0	5	10	15

If ERFQ/DV = 1 that means the ditch will contain all the fallen rocks.
If ERFQ/DV = 2 that means the ditch will completely fill and a large amount spill over.
If ERFQ/DV = 3 that means the fallen rock will spill over to the shoulder of the road.
If ERFQ/DV = 4 that means the fallen rocks will spill over to the road.

RESULT AND DISCUSSION

In the current work, because the program of the original system, in addition to the devices does not available for the authors, this paper used the available factors that are required for site assessment and based on the data collected during the fieldwork and office calculation of Shakir, (2006) and Yousif and Shakir (2015), by the benefit of the last Google Earth Pro image of (8/2020) and the caltopo topographic map of the area, in addition to the new audit field observation in 2022.

The studied road cuts are considered as; one lane width for each direction through the cut, wet rock cut face during the rain showers and snowy days, moderate intact rock strength, and average vehicle daily traffic < 5000 cars/day. In addition, they have no ditch, relatively narrow shoulders and the slopes are less than 90°. Although the studied road cuts are less than 85° slope, the ditch shape (DS) was rated and used in place of the ditch volume (DV), according to Maerz and Youssef (2004).

The current work is based on the detailed measurements and observations of (7) seven rock cuts (S-6, S-10, S-11, S-14, S-18, S-20, and S-22) along the main road of the Mirawa area. Four rock cuts on the right side of the road (S-6, S-10, S-14, and S-18) and three road cuts (S-11, S-20, and S-22) on the left side of this road (See Figs.1 and 2). The calculations have been done manually using class numbers corresponding to the descriptive ratings (from Table 2 to Table 24), and the results are listed in Tables (25A and B).

A. The Risk-Consequence Rating

Table (25 A) shows that the normalized risk rating values for five studied rock cuts (S-6, S-11, S-14, S-18, and S-20) are less than 50% (between 33.3% and 47.2%), whereas, the rock cuts (S-10 and S-22) are more than 50%. Note, the risk rating values for these two rock cuts are so close (50.9% for both) to the low-risk rating. The relatively "high risk" rating of (S-10 and S-22 are due to; high slope angles (SA), relatively high weathering grade (WF), and rock face irregularities (FI).

The total risk rating values, after adding the AOD adjustment risk factor values, the rock cuts (S-6, S-11, and S-14), became more than 50% (51.8, 50.3, 55.2, respectively). Accordingly, in the studied road, five rock cuts are rated as "High-Risk" rockfall rock cuts, and only two rock cuts are rated as "Low-Risk" rockfall rock cuts.

Note; that the studied rock cuts are formed of the clastics of the Injana Formation, which have no karst (sinkhole) features, and it was not taken into account (as an adjustment factor).

Table (25B) demonstrates that the normalized consequence rating values for the studied rock cuts are more than 50% for all the rock cuts, except the rock cut (S-1) is less than 50% (44.3%). While, after adding the ditch capacity exceedance (D.C.E.) factor, the total consequence rating for the rock cut (S-6) rais3ed to more than 50%, as an adjustment consequence factor, all the studied rock cuts are rated as "High-Consequence" rockfall.

The high consequence rating values are because;

- The small ditch width and nearly flat ditch shape of none vertical slopes (less than 85°) made the blocks may reach the road.
- The nearly flat ditch made the ditch shape factor gain the high rating class.
- The massive block size, make the large moving blocks have greater kinetic energy, making them will travel further down the inclined slope and cause more damage to road and vehicles.
- The relatively small road shoulder makes the chance of fallen rock reaching the road greater.

Table 25A: Risk factors rating for the studied road cuts

Site no. / Parameters	S-6	S-10	S-11	S-14	S-18	S-20	S-22
1-Slope Height (ft) **(SH) Rating**	27 5	17 3	50 10	17 3	16 3	21 4	40 8
2- Slope Angle (°) **(SA) Rating**	65 7	85 10	60 6	60 6	40 2	50 4	85 10
3- Slope Instability (SI) **Class no.** **Rating**	Partially stable 2 6	Partially stable 2 6	Partially stable 2 6	Partially stable 2 6	Stable 1 3	Stable 1 3	Partially stable 2 6
4-Weathering Factor (WF) **Class no.** **Rating**	Slightly 1 6	Low 2 12	Slightly 1 6	Low 2 12	Slightly 1 6	Slightly 1 6	Low 2 12
5-Intact Rock Strength (MPa) **Class no.** **Rating**	Moderate (25 – 50) 2 6	Moderate (25 – 50) 2 6	Moderate (25 – 50) 2 6	Moderate (25 – 50) 2 6	Moderate (25 – 50) 2 6	Moderate (25 – 50) 2 6	Moderate (25 – 50) 2 6
6- Rock Face Irregularity **Class no.** **Rating**	Slightly 1 3	Moderate 3 9	Slightly 1 3	Moderate 3 9	Slightly 1 3	Moderate 2 6	High 3 9
7- Rock Face Looseness **Class no.** **Rating**	None 0 0	Low 1 3	Low 1 3	Low 1 3	Low 1 3	Moderate 2 6	Moderate 2 6
8- Block Size (BS) (ft^3) **Rating**	Moderate 4	Massive 0	Moderate 4	Massive 0	Moderate 4	Massive 0	Massive 0
9- Water on Rock face **Class no.** **Rating**	Wet 2 6	Wet 2 6	Wet 2 6	Wet 2 6	Wet 2 6	Wet 2 6	Wet 2 6
Normalized Risk Rating	39.8%	50.9 %	46.3%	47.2 %	33.3%	38%	50.9%
A-Adversely Dip orientation of Discontinuity **Class no.** **Rating**	65 3 12	50 2 8	30 – 35 1 4	50 – 60 2 8	40 1 4	30 1 4	40 – 45 1 4
Total Risk Rating	51.8 % = High	58.9% = High	50.3 % = High	55.2 % = High	37.3 % = Low	42.0 % = Low	54.9 % = High

Table 25 B: Consequence factors rating for the studied road cuts

Site no. / Parameters	S-6	S-10	S-11	S-14	S-18	S-20	S-22
1- Ditch Width (ft) **Rating**	0 12	0 12	0 12	0 12	0 12	0 12	0 12
2- Ditch Shape **Rating**	3 12	3 12	2 8	0 – 2 10	1 4	1 4	3 12
3- Expected Rockfall Quantity (ft3) **Rating**	10 3	20 6	10 3	20 6	10 3	10 3	20 6
4- Slope Angle (°) **Rating**	60-65 3	85 12	60 3	75-85 3	40 10	60 3	85 12
5- Block Size **Rating**	Blocky 4	Massive 12	Massive 12	Massive 12	Blocky 4	Massive 12	Massive 12
6- Shoulder Width (ft) **Rating**	10 2	3 9	8 4	3 9	10 2	10 2	3 9
7-Number of Lanes **Rating**	1 12	1 12	1 12	1 12	1 12	1 12	1 12
8-Average Daily Traffic (car/day) **Rating**	< 5000 2	< 5000 2	< 5000 2	< 5000 2	< 5000 2	< 5000 2	< 5000 2
9-Average Vehicle Risk (%) **Rating**	29% 3	32% 4	23% 5	38% 5	24% 3	47% 6	28% 4
10-Sight Distance Decision (ft) **Rating**	Adequate 0	Adequate 0	Limited 8	Adequate 0	Adequate 0	Adequate 0	Limited 8
Normalized Consequence Rating	44.2%	67.5%	56.7%	59.2%	43.3 %	46.7 %	72.5 %
A-Adjustment Factor: Ditch Capacity Exceedance (D.C.E) **Rating**	3 10	6 15	3 10	6 15	3 10	3 10	6 15
Total Consequence Rating	54.2% = High	82.5% = High	66.7% = High	74.2% = High	53.3% = High	56.7% = High	87.5% = High

Because of the near or no ditches at the studied rock cuts, the ditch volume values are (0.0) making the capacity exceedance (DCE) factor to gained high ratings. The high consequence rating values for the studied rock cuts are because;

- The none ditch or very small ditch width and nearly flat ditch shape of none vertical slopes (less than 85º) made the blocks may reach the road.
- The nearly flat ditch made the ditch shape factor gain the high rating class.
- The massive block size, make the large moving blocks have greater kinetic energy, making them will travel further down the inclined slope and cause more damage to road and vehicles.
- The relatively small road shoulder makes the chance of fallen rock reaching the road greater.
- Because of the near or no ditches at the studied rock cuts, the ditch volume values are (0.0) making the capacity exceedance (DCE) factor gain high ratings.

The aforementioned results were plotted on the Risk–Consequence rating diagram (Maerz and Youssef, 2004), which shows that; four rock cut (S-6, S-10, S-14, and S-22) has high risk-high consequence (H.R-H.C) rockfall ratings and tow rock cuts (S-18 and S-20) have a low risk-high consequence (L.R-H.C), but only one rock cut (S-11) is at the contact between the (H.R-H.C) and the (L.R-H.C), and for more safety, it considered within the (H.R-H.C) rockfall rating (Fig.7).

- According to the "risk – consequence" diagram (Fig.7), the rock cuts (S-18 and S-20) have a low risk- high consequence (L.R – H.C) rockfall rating due to the low rating of the; Expected rockfall quantities (ERFQ), relatively wide road Shoulder (SW) and adequate decision sight distance (D.S.D).
- (ERFQ) were rated as low (3), which means few areas on the rock cut face are loose and the expected volume of falling rocks will be 10 ft^3/ft.
- The relatively wide road shoulder was rated as (2) because the shoulder width is about 10ft in length, in which the chance of fallen rocks reaching the road will be low.
- The adequate decision sight distance (0.0 rating), makes the driver able to recognize the hazard of falling rocks and maneuver his vehicle to safety.

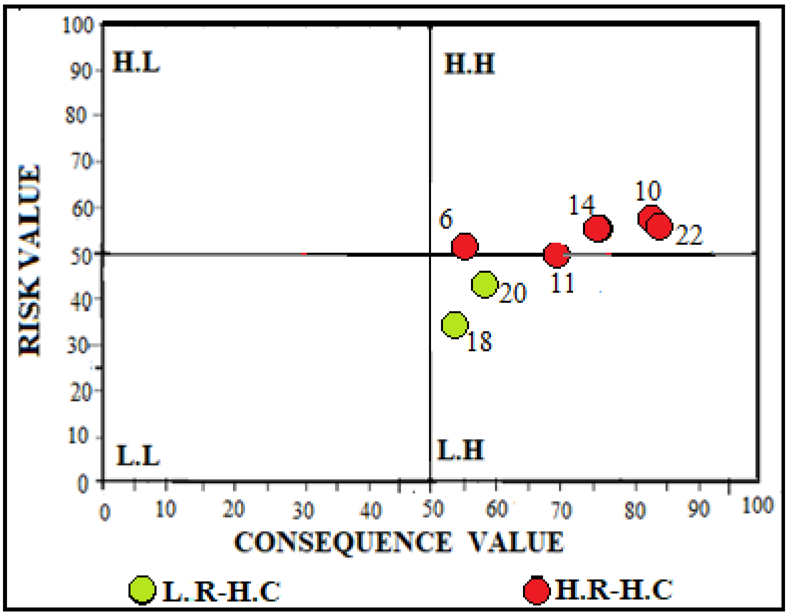

Fig. 7: The results of the Risk – Consequence diagram for the rock cuts along Mirawa main road (After Maerz and Youssef, 2004)

On the other hand, the high risk- high consequence (H.R-H.C) rating is due to the following;

1- The high slope angle (SA) on the rock cuts (S-6, S-10, S-11, S-14, and S-22)
2- No ditch or nearly flat ditch made the ditch shape rating high on the rock cuts (S-6, S-10, S-11, S-14, and S-22) cannot contain all the fallen rocks.
3- Massive blocks have greater kinetic energy and travel further down the inclined slope and cause more damage to the road and vehicles.
4- The relatively narrow road shoulders on rock cuts (S-10, S-14, and S-22)
5- The limited decision sight distance (D.S.D) on the rock cuts (S-11 and S-22), does not allow the driver to avoid the fallen rocks, because there are some curves and obstacles on the road not giving the driver enough time to perceive that there are falling rocks on the road.

6- The ditch capacity exceedance (D.C.E. = 15), on the rock cuts (S-10, S-14, and S-22), which means the fallen rock will spill over to the road shoulder.

Note that, the risk-consequence rating of the rock cuts (S-6 and S-11) is located at the contact between the (H.R-H.C) and the (L.R-H.C), due to its relatively low-risk rating (51.8% and 50.3%, respectively).

These results were used to develop the risk-consequence rockfall rating map for the "Mirawa" main road, using the GIS 10.8.1 system (Fig.8).

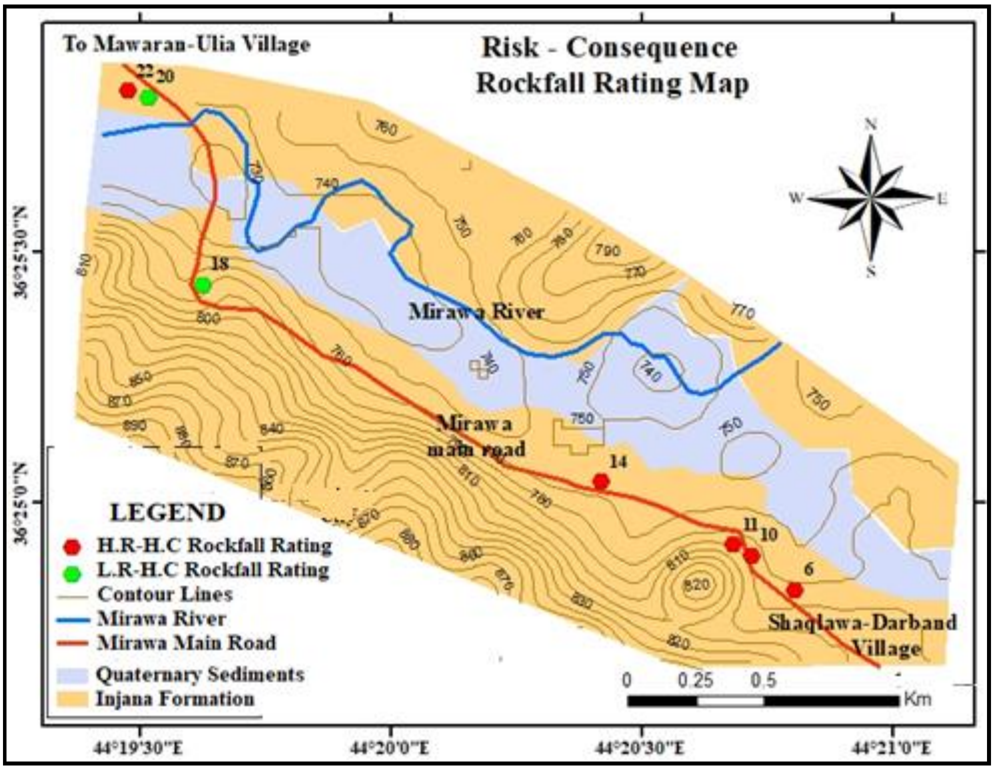

Fig.8: Risk-Consequence rockfall rating map for the studied rock cuts

B. The Risk-Consequence Hazard Zonation

In order to produce the "Risk-Consequence" rockfall hazard map for the studied rock cuts, the total risk-consequence rating values were plotted on the rockfall Risk-Consequence Hazard Zones diagram (Maerz *et al*., 2004), which shows that five-rock cuts (S-6, S-110, S-11, S-14, and S-22) are within the "High Hazard Zone" (Zone A), and two rock cuts (S-18 and S-20) are within the "Moderate Hazard Zone" (Zone B), as shown in Fig. (9). Note, that the rating of the rock cuts (S-18) is located at the contact line between the "Moderate Hazard" and "Low Hazard" zones, and considered within the "Moderate Hazard Zone" for the most safety.

The "High Hazards" of the rock cuts (S-6, S-10, S-11, S14, and S-22) are due to the high consequence ratings (54.2%, 82.5%, 66.7%, 74.2%, 53.3%, and 87.5%, respectively), although the relatively low total risk ratings (37.3% and 42.0%) for the rock cuts S-18 and S-20.

The "Moderate Hazards" of the rock cuts (S-18 and S-20) are due to; the low-risk ratings (less than 50%) and the relatively low values of the consequence ratings (53.3% and 56.3%, respectively), as shown in Tables (25A and 25B) and Fig. (9).

Accordingly, the aforementioned results, were used to develop the "Risk-Consequence" rockfall hazard map for the studied area (Fig.10). This map can be used to protect vehicles, road users, and any infrastructure that may be constructed close to those road cuts, which are vulnerable to such risks. It is also can be used to determine the need and priority of maintenance and remediations on the road cuts.

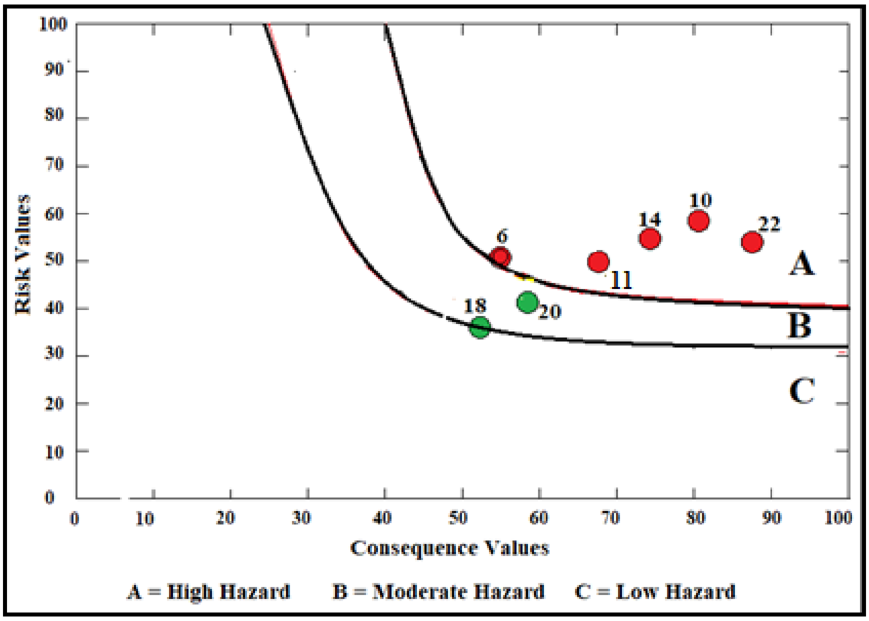

Fig.9: Risk – Consequence hazard diagram for the rock cuts along Mirawa main road (after Maerz and Youssef, 2004)

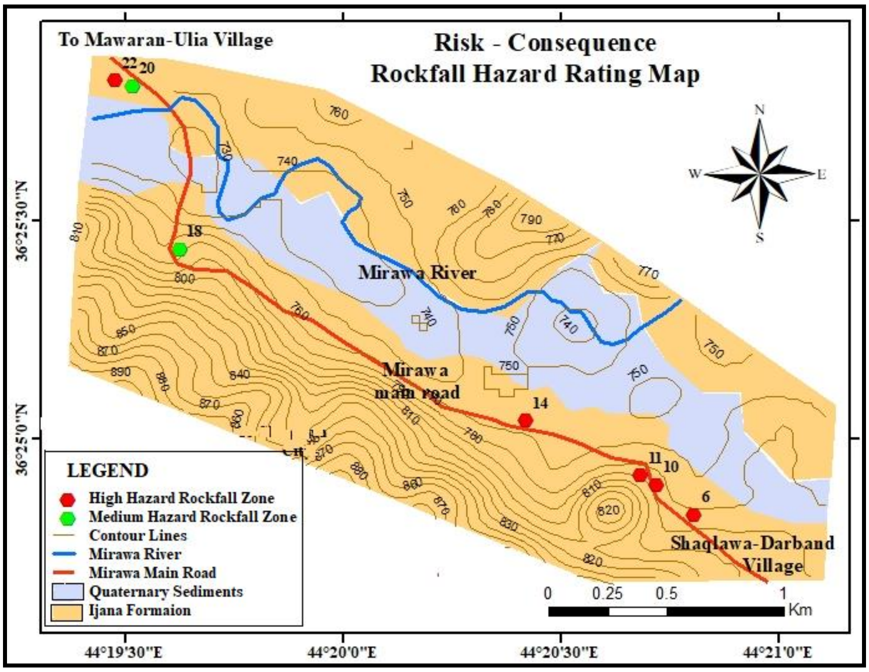

Fig.10: Risk -Consequence rockfall hazard map for Mirawa road cuts.

CONCLUSIONS AND RECOMMENDATIONS

- The risk-consequence rockfall rating diagram showed that most of the studied rock cuts have “high risk” ratings and “high consequence” ratings (except for S-18 and S-20) when the rockfall reaches the road. These consequences results are due to; (30° – 45°) slope angles **(SA)** because of rolling and bouncing rocks, one lane width road for each side (in which case, the ability for the driver to avoid fallen rocks is very low), none ditch or very small ditch width (**DW**) and Ditch shape (**DS**) cannot contain all the fallen rocks, Massive to moderately blocky block size **(BS)** have greater kinetic energy made the fallen rocks travel further down the inclined slope and cause more damage to the road and vehicles.
- The Risk-consequence rockfall hazard rating diagram for the studied rock cuts, because of the above reasons, showed that five-rock cuts (S-6, S-10, S-11, S-14, and S-22) are within the “high hazard zone” (Zone A) and two rock cuts (S-18 and S-22) are within the “moderate hazard zone” (Zone B).
- It is worth to notice, that the ratings of the rock cut (S-18) are very close to the “low hazard zone” and the rock cut (S-6) is close to the “moderate hazard zone”. These results made the “Mirawa” main road threatened by rockfalls and poses hazards to the road and vehicles.
- Accordingly, the following works are recommended;
  - Installing traffic signs to limit the speed of cars passing along this road.
  - Installing traffic signs before and near the high and moderate hazardous rock cuts to indicate the potential rockfall taking place, in order to attention and avoid the rockfall.
  - Digging an adequate ditch to contain all the rockfall to prevent it from reaching the road.
  - Widened the road shoulders for the same purpose.

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