مجلة الدراسات التربوية والعلمية - كلية التربية - الجامعة العراقية
العدد الثالث والعشرون - المجلد السابع - علم الجغرافيا - تموز 2024م
doi.org/10.52866/esj.2023.07.23.16

Modify Rockfall Hazard Rating System RHRS by incorporating road slope steepness hazard in Sargelu Village, northeastern Iraq

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Abstract :

Rockfall, a common mountain hazard, poses significant risks to human lives and infrastructure. This study focuses on a region in northeastern Iraq, characterized by steep slopes and active tectonic activity, making it susceptible to rockfalls. The Rockfall Hazard Rating System (RHRS) is a widely used tool for assessing rockfall hazards. Still, this study proposes an enhancement by incorporating road slope steepness as a factor in the study area.

Two sectors of the study area were analyzed. In sector 1, the slopes were classified as moderately hazardous (Level 3) initially. However, when considering road slope steepness, the risk level increased to Level 2. This calls for warning signs, speed limits, daily road checks, and detailed slope studies. In sector 2, the slopes were initially classified as highly hazardous (Level 2). With the inclusion of road slope steepness, the risk level escalated to Level 1, signifying very high risk. Stopping vehicle traffic, detailed slope studies, and direct interventions to address potential rockfalls are recommended.

This study highlights the significant impact of road slope steepness on the RHRS, emphasizing the need to incorporate this factor for more accurate risk assessments in areas with steep terrain.

Keywords: Sargelu; RHRS; Sulaymaniyah; Road Slope Steepness hazard .

تعديل نظام تصنيف مخاطر الانهيارات الصخرية RHRS عن طريق اضافة عامل انحدار الطريق في قرية سركلو، شمال شرق العراق

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بحث مستل من رسالة ماجستير للباحث الاول

مستخلص:

تساقط الصخور، وهو خطر شائع في المناطق الجبالية، يشكل مخاطر كبيرة على حياة الإنسان والبنية التحتية. يركز هذا البحث على منطقة في شمال شرق العراق، تتميز بالمنحدرات الحادة والانشطة التكتوني نشطة، مما يجعلها عرضة لسقوط الصخورمن المنحدرات العالية. نظام تصنيف مخاطر الانهيارات Rockfall hazard rating system (RHRS) هو أداة مستخدمة على نطاق واسع لتقييم مخاطر تساقط الصخور. ومع ذلك، يقترح هذا البحث تحسينًا عن طريق إدراج انحدار الطريق كعامل في منطقة الدراسة. تم تحليل مقاطعتين من منطقة الدراسة. في مقاطعة الاولى، تم تصنيف المنحدرات على أنها خطيرة بشكل معتدل (المستوى 3). ومع ذلك، عند النظر في مستوى انحدار الطريق، ارتفع مستوى الخطر إلى المستوى 2. وهذا يستدعي علامات تحذير، وتحديد سرعة السيارات المارة، وفحوصات يومية للطريق، ودراسات تفصيلية للمنحدر. في المقاطعة الثانية، تم تصنيف المنحدرات على أنها خطيرة للغاية (المستوى 2). مع اضافة خطورة انحدار الطريق، ارتفع مستوى الخطر إلى المستوى 1، مما يدل على وجود مخاطرة كبيرة جدًا. يُوصى بوقف حركة المركبات، ودراسات تفصيلية للمنحدرات، وتدخلات مباشرة للتعامل مع تساقط الصخور المحتملة. يسلط هذا البحث الضوء على التأثير الكبير لانحدار الطريق على RHRS، مشددًا على الحاجة إلى إدراج هذا العامل لإجراء تقييمات مخاطر دقيقة أكثر في المناطق ذات التضاريس الحادة.

كلمات مفتاحية: سركلو؛ RHRS؛ السليمانية؛ مخاطر الانهيارات الصخرية .

1. Introduction

Rockfall is a prevalent mountain hazard where various-sized masses descend from cliffs or slopes, typically considered rapid or extremely rapid, often remaining near their original location [1,2,3,4]. In contrast, toppling occurs in natural rock slopes, characterized by forward rotation under gravity, adjacent cracks, or fluids [5,6]. Fractures, especially in extreme conditions like freeze-thaw cycles, are a major cause of rockfall [7]. Additionally, human activities such as road construction undercutting and deforestation contribute to increased rockfall and landslides [8]. The consequences of these events are significant, affecting human lives and economic elements like livestock, settlements, infrastructure, and transportation [9,10].

Over the years, several models have been developed for assessing rockfall hazards, including the Rockfall Hazard Rating System by the USA Federal Highway Administration and the Canadian National Railway Corporation model [1,11,12,13]. These models have been widely adopted and customized by different countries for assessing rockfall hazard and risk [14,15,12,16,17]. Modified methods like the Rock Slope Rating Procedure (RSRP), Italian Modification of RHRS (mRHRS), Pakistan Modification of RHRS (RHRSP), and others serve various purposes, from evaluating transportation corridors to open-pit quarries. These model adaptations consider unique topographic, geological, and climatic conditions and rely on data collected through historical databases, in-situ measurements, trajectory modeling, and laboratory tests.

Geotechnical field investigations encompass various factors such as rock strength, weathering degree, discontinuity characteristics, and more. All these parameters are integrated into the Rockfall Hazard Rating System, which accounts for risk consequences [18,12]. The system's importance is underscored by its role in evaluating the elevated risk posed by steep road inclines, particularly in regions like Sargalu village in northeastern Iraq. Situated at the convergence of active tectonic plates, this area features towering mountains, and its road network includes exceptionally steep sections with gradients reaching up to 38 degrees. This study's objective is to enhance the RHRS by incorporating road slope risk, revealing its impact on overall risk levels, potentially necessitating additional safety measures.

1. Study area

The study area is located administratively within the Sulaymaniyah Governorate in northeastern Iraq, southwest of Sulaymaniyah city center. It is situated in the Jafaty Valley, approximately 60 kilometers from the center of the Sulaymaniyah governorate, delimited by latitudes (45° 10' 35.9"- 45° 09' 58.55") east and longitudes (35° 50' 23.08"- 35° 52' 39.77") north, refer to the below figure-1.

(a)

(b)

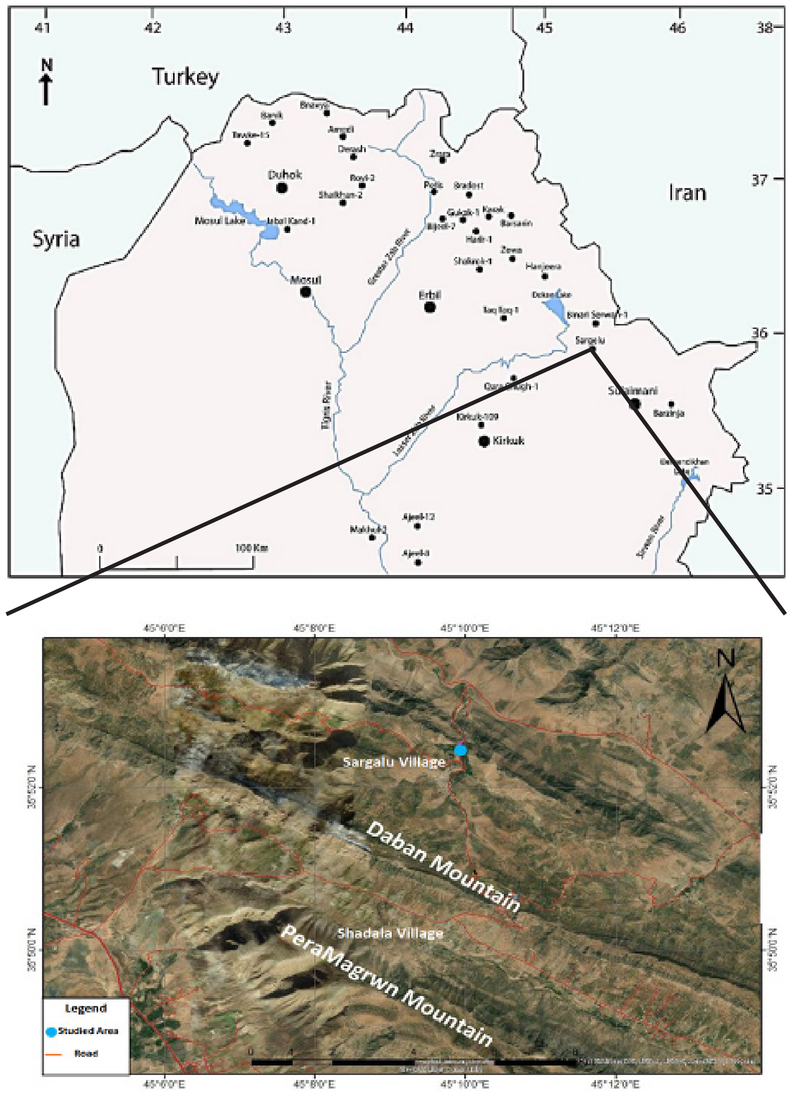


Fig. 1 Map of the study area:
(a) The upper part of the map of Iraq. (b) Visual image of the study area.

2. Aim:

The current study aims to underscore the significance of incorporating road slope steepness as a factor in the Rockfall Hazard Rating System (RHRS) and to elucidate its impact on modifying risk levels for roads with differing degrees of slope. Such modifications can lead to variations in the stability of the slopes along the road and its supporting elements.

3. Stratigraphic of the Study Area:

The stratigraphy of the study area stands as a crucial facet warranting in-depth examination, given its paramount importance in engineering studies. It encompasses the geological formations exposed at the surface and the recent deposits that overlay the region. By delving into these formations, we gain insights into the relationships between rock types, their distribution, and the geological phenomena within the area. Furthermore, we can discern the influence of these formations on variations in rock type and nature, which subsequently impact slope stability. The stratigraphic sequence in the study area, from the oldest to the recent, includes:

Sargelu Formation (Middle Jurassic): This formation is comprised of black bituminous limestones and Dolomitic limestones, interbedded with brown shales. It also contains brownish chert zones in the upper part. In the study area, the Sargelu Formation exhibits a thickness ranging from 40 to 130 meters [19].

Naokelekan Formation (Middle Jurassic): The Naokelekan Formation consists of thin layers of argillaceous material, overlaid by alternating thin layers of bituminous limestone, shaley limestone, and shale. Its thickness in the study area ranges around 20 meters [19]. The contact between Sargelu and Naokelekan formations is sharp and conformable and characterized by black thin bedded, highly bituminous shales with thin bands of black chert at the top of the Sargelu Formation [20]

Barsarin Formation (Middle Jurassic): This formation is composed of stromatolitic dolostone and stromatolitic dolomitic limestone, with a thickness of about 20 meters in the study area.

Chia-Gara Formation (Late Jurassic): Characterized by thin layers of limestone and marly limestone, this formation's thickness in the study area falls within the range of 100 to 200 meters.

Sarmord Formation (Early Cretaceous): Comprising light gray Marly Limestone and bluish gray Marl, the Sarmord Formation in the study area has a thickness of approximately 450 meters [19].

Qamchuqa Formation (Early Cretaceous): This formation consists of large blocks of dark gray limestone and Dolomitic Limestone, featuring Very Coarse Gray and Yellowish Green Marl and Gray Limestone. In the study area, its thickness varies from 300 to 600 meters.

Kometan Formation (Late Cretaceous) (Lawa and Gharib, 2009): This formation comprises well-layered Globigerinal limestone, characterized by its white color, and Oligostigina limestone. Its thickness in the study area ranges from 150 to 175 meters [19].

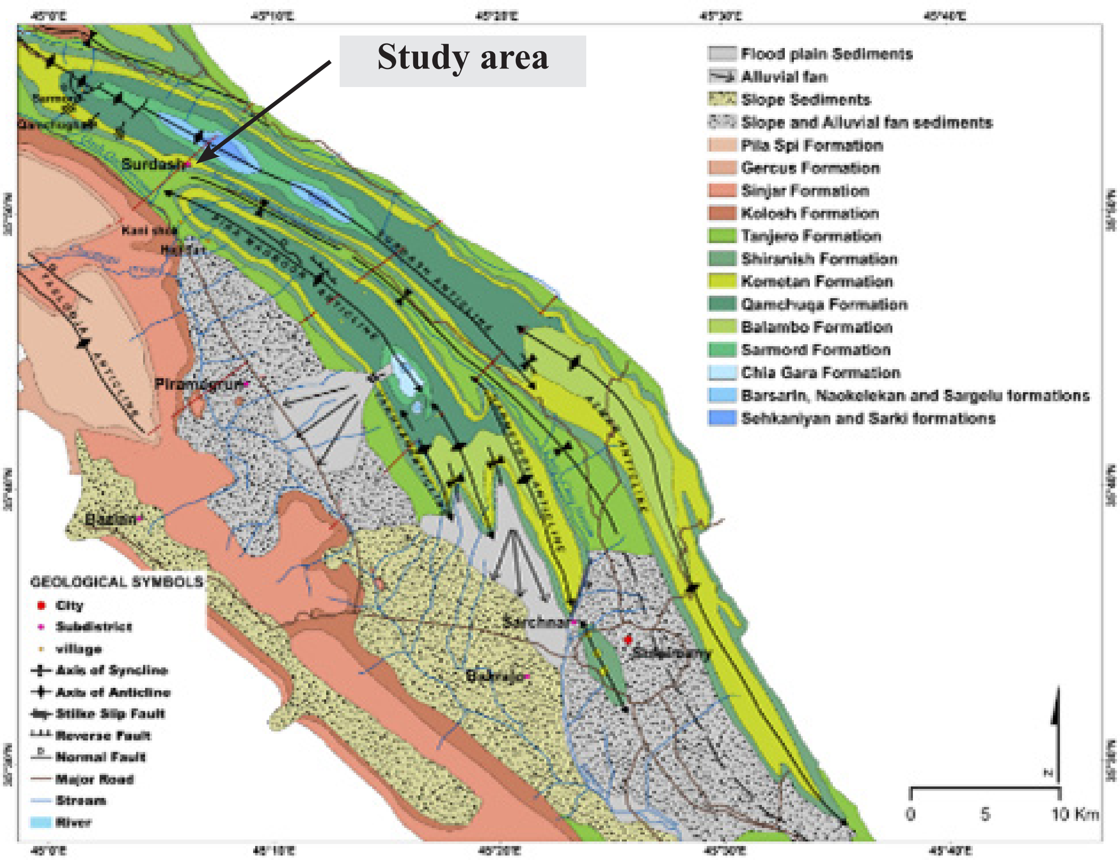


Fig 2. A geological map showing of the exposed formations (modified by Sissakian and Fouad,2014)

4. Methodology

In this stage, two sectors along the road leading to Sargelu were identified through numerous reconnaissance surveys of the study area. A comprehensive geological engineering survey was conducted to assess the prevalent collapses along the road and the contributing factors. The locations were determined using GPS devices and marked on the map. The risks associated with these collapses were evaluated using a global system known as the Rockfall Hazard Rating System (RHRS) [1]. A study of the elements and categories of the RHRS, as shown in Table (1), was carried out to quantify the extent and nature of collapses on the slopes and the associated risks in the two sectors, the RHRS elemints are detailed in the below:

1. Describing the slope by measuring the Slope Height, the slope face, and the direction of inclination. Slope height is the highest point at which rocks are expected to fall if the rocks from the natural slope are above the cut slope, Slope height is one of the major factors affecting rockslide risk, It is calculated using a clinometer and tape measure.

2. Evaluating the effectiveness of ditches (Ditch Effectiveness).

Ditch Effectiveness is the ability of the pavement to prevent fallen rocks from reaching the paved road. The hazards associated with a particular slope section depend on how well the paver performs at picking up the rocks. When a small rock hits the road, no matter how much of the rock falls from the slope, evaluating the effectiveness of the pavement in preventing fallen rocks from reaching the road is of great importance in determining the extent to which users and pedestrians are protected from hazards from falling rocks

3. Assessing the average risk to vehicles (Average Vehicle Risk).

Refers to an estimate of vehicle exposure to road rockslide hazards. Depending on the length of the ramp face, the number of passing cars and the speed limit of the road, It is calculated through the following equation: AVR=(ADT.SL)/PSP.100

4. Determining the percent of Decision Sight Distance for visibility. The percentage reduction in decision sight distance (DSD) needed for a driver to make a complex or immediate decision. The percentage of decision sight distance PDSD is obtained by:

PDSD=(ASD/DSD).100%. where PDSD = % sight distance, ASD = Actual Sight Distance, and DSD = Decision Sight Distance.

5. Measuring the roadway width, including paved shoulders.

Paved Roadway Width is the vertical measure that is measured on the center line of the paved road from one edge of the pavement to the other, and includes sidewalks, and the importance of determining this width lies in the event that if the driver notices the presence of rocks in the road or falling rocks, he can interact and take evasive measures to avoid them . The more room available for this maneuver, the greater the likelihood that the driver will be able to successfully pass the rock without hitting other roadside hazards or oncoming vehicles.

6. Taking measurements of the geometrical dimensions of unstable or collapsed blocks within the slope.

7. Assessing the Geologic Character, which can be divided into two conditions.

Case (1) : When structural geological conditions dominate the landslides, the evaluation includes the assessment of the structural geological conditions and the nature of discontinuity surfaces.

Case (2) : When geological conditions resulting from weathering and exposure dominate the landslides, the evaluation includes assessing variations in rock type and the degree of differential weathering.

8. Evaluating the size of the collapsed rock blocks (Block Size).

It is the process of identifying large rocks and rock blocks of large size that are likely to fall and their potential impact in the event of a landslide. The size of the fallen rock blocks is an important factor in estimating the risks of rockslides. The size of the rock masses, the greater the possibility of large rockslides,

9. Identifying previous failure events (Previous Failures)

It is the activity of rockfall at a location and the history of previous landslides is important and vital to identify and estimate the risks of current and future landslides as it is considered as an indicator of future rockfall events. History of previous avalanches helps to understand avalanche patterns and to identify areas that have been at risk in the past and where they will be most vulnerable in the future [21].

10. Assessing the climate and the presence of water on the slope (Climate and Presence of Water on Slope).

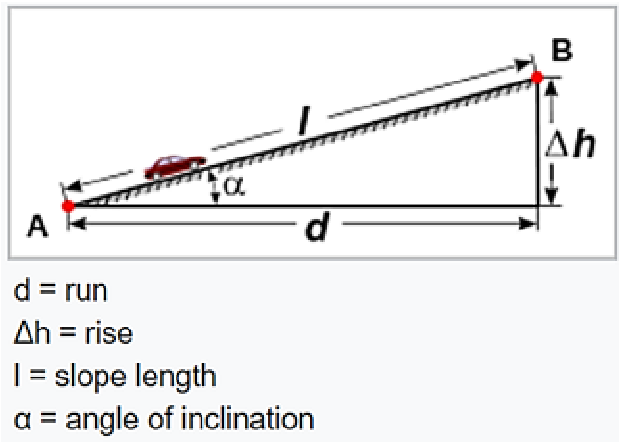
The study of the climate is important in estimating the risks of rockslides, as climate changes and the presence of water can contribute to an increase in the risk of landslides and their impact on neighboring areas. Where [22] confirmed the effect of climate changes on the frequency of occurrence of rock-slides with high strength, as the results showed that an increase in temperatures may lead to an increase in rock-slides due to changes in geological and hydrogeological conditions, especially in water melting, and that a decrease in temperatures leads to freeze this water,

Table 1. A summary sheet of Rockfall Hazard Rating System (after Pierson et al., 1990)

<table>
<tr><th colspan="3" rowspan="2">Factors</th><th colspan="4">Rank</th></tr>
<tr><th>3 Points</th><th>9 Points</th><th>27 Points</th><th>81 Points</th></tr>
<tr><td colspan="3">Slope Height (m)</td><td>7.5 - 15</td><td>15 - 23</td><td>23 - 31</td><td>> 31</td></tr>
<tr><td colspan="3">Ditch Effectiveness</td><td>Good catchment</td><td>Moderate catchment</td><td>Limited catchment</td><td>No catchment</td></tr>
<tr><td colspan="3">Average Vehicle Risk (AVR)</td><td>25%</td><td>50%</td><td>75%</td><td>100%</td></tr>
<tr><td colspan="3">Percent of Vision Sight Distance</td><td>100%</td><td>75%</td><td>50%</td><td>25%</td></tr>
<tr><td colspan="3">Paved Roadway Width (m)</td><td>> 13</td><td>13 - 11</td><td>11 - 8.5</td><td>< 8.5</td></tr>
<tr><td colspan="3">Rock Diameter or Quantity of Rockfall Event (m)</td><td>< 0.3
or
< 0.9</td><td>0.3 – 0.6
or
0.9 – 2.7</td><td>0.6 – 1.5
Or
2.7 – 9.1</td><td>> 1.5
Or
> 9.1</td></tr>
<tr><td rowspan="4">Geologic characteristics</td><td rowspan="2">Case 1</td><td>Structural Condition</td><td>Discontinuous fractures, favorable orientation</td><td>Discontinuous fractures, random orientation</td><td>Discontinuous fractures, adverse orientation</td><td>Continuous fractures, adverse orientation</td></tr>
<tr><td>Rock Friction</td><td>Rough Irregular</td><td>Undulating, smooth</td><td>Planar</td><td>Clay, gouge infilling, or slickensided</td></tr>
<tr><td rowspan="2">Case 2</td><td>Structural Condition</td><td>Few differential erosion features</td><td>Occasional erosion features</td><td>Many erosion features</td><td>Major erosion feature</td></tr>
<tr><td>Difference in Erosion</td><td>Small difference</td><td>Moderate difference</td><td>Large difference</td><td>Extreme difference</td></tr>
<tr><td colspan="3">Climate and Presence of Water on Slope</td><td>Low to moderate precipitation; no freezing periods; no water on slope</td><td>Moderate precipitation or short freezing periods, or intermittent water on slopes</td><td>High precipitation or long freezing periods or continual water on slope</td><td>High precipitation and long freezing periods, or continual water on slope and long freezing periods</td></tr>
<tr><td colspan="3">Rockfall History</td><td>Few falls (< 2/yr)</td><td>Occational falls (<2 to12/yr)</td><td>Many falls (>1/month but <1/week)</td><td>Constant falls (> 1/week)</td></tr>
</table>

in addition to the factors mentioned in the global RHRS, we have identified and recognized a road slope factor in the study area. This factor can have a negative impact on the associated risk in the area, prompting us to modify the RHRS by incorporating this element. We aim to assess how it affects the system and increases the risk level to a higher degree. The road slope disturbs the load distribution of slope base rocks, causing them to shift in another direction. Furthermore, this factor plays a significant role in propelling fallen rocks downhill, increasing their speed due to gravity and posing an increased risk to passers-by. Road slope steepness, in general terms, refers to the angle at which a road or surface tilts concerning the horizon. It represents the degree of incline or slope of the road or surface, known as the road slope ratio. The value zero signifies horizontality, while higher numbers indicate steeper or more intense inclines. Slope is often calculated as a ratio of vertical height (h) to horizontal run (d), expressed as the 'rise over run' fraction. In this equation, 'run' represents the horizontal distance (not the distance along the slope), and 'rise' signifies the vertical distance. The slope ratio is determined using the following formula:

$$Road\ grade = \frac{\Delta h}{d}$$



And the given risk points will be as follows:

- 3 points when the slope degree is from 0 to 10 degrees.
- 9 points when the slope degree is from 10 to 20 degrees.
- 27 points when the slope degree is from 20 to 30 degrees.
- 81 points when the slope degree is 30 degrees and above.

According to the total points obtained, the sector's risk level is identified based on the table below.

Table (2) Risk Assessment Levels Classification according to [23].

Risk Level	Total points	Nature of Risks in Slopes
Level 4	199 >	.Low-risk slopes / Slopes do not require detailed studies
Level 3	200 – 399	Moderate-risk slopes / Slopes require warning signs and routine .monitoring along the road weekly
Level 2	400 – 599	High-risk slopes / Slopes require warning signs, speed limit designation on the road, daily patrols, some treatments to avoid the effects of collapses, and recommendations for detailed slope .studies
Level 1	600 ≤	Very high-risk slopes / Vehicle traffic on the road must be stopped, detailed studies of the slopes need to be conducted, measuring the nature of occurring and potential collapses, and .direct intervention to address potential collapses

5. Discussion

5.1 Sector-1:

The length of the road in this sector is 138.5 meters, and it is located on the road leading to Sargelu village at coordinates (N 35° 50' 23.08") (E 45° 10' 35.9"). This sector is situated in the southwestern flank of the Sardasht Fold, in the southwestern part of Daban maontain, and towards the village of Shaddala. It's noteworthy that this sector lacks rockfall protection measures and is characterized by steep slopes. The road features sharp turns, significantly reducing the line-of-sight distance in this section. The values of the parameters of the Rockfall Hazard Rating System (RHRS) are summarized in Table (3).

Fig 3. Illustrates the absence ditch in sector-1.

Fig 4. displays the road slope steepness percentage in the study area within

The values of the parameters of the Rockfall Hazard Rating System (RHRS) for sector-1 are summarized in Table (3),

Factor			Point
Slope Height (m)			81
Ditch Effectiveness			81
Average Vehicle Risk (AVR			3
Percent of Vision Sight Distance			81
Paved Roadway Width (m)			81
Geologic Characteristic	Case (1)	Structural Condition	3
		Rock Friction	3
	Case (2)	Structural Condition	3
		Difference in Erosion	3
Rock Diameter or Quantity of Rockfall Event (m)			3
Climate and Presence of Water on Slope			3
Rockfall History			3
Total points			**348**

Therefore, the road slope in sector-1 posed risks at the third level according to Table (3), based on the classification of risk assessment levels. These risks are categorized as moderate. In this context, the steepness of the road equals (38.26). When adding the points for the road slope steepness attribute, the total points reach (429) (348 + 81 = 429). Consequently, the risk level moves to the second level, where the hazards to drivers increase.

Here, we recognize the significance of incorporating this attribute into the Rockfall Hazard Rating System (RHRS) for this section. Its substantial impact on elevating the road's risk levels underscores the need for additional measures to ensure the safety of drivers and prevent accidents on the road.

5.2 Sector-2:

The length of the road in this sector is approximately (112 meters), and it is located at coordinates (N 35° 52' 39.77") (E 45° 09' 58.55"). This sector is situated in the northeastern limb of the Sardasht anticline and is considered one of the riskiest sections in the study area due to the narrow paved road, almost no protection measures, and reduced line-of-sight distance. Geological characteristics play a crucial role in this section, including structural conditions and the nature of discontinuity surfaces that contribute to rockfalls.

Despite the mentioned risks in this section, it is noteworthy that there are tourist residential houses on the terraces of the slopes without taking the safety of the residents into consideration, as seen in Figure (5). Additionally, rockfall incidents have been observed near these houses. The values of the parameters of the Rockfall Hazard Rating System (RHRS) are summarized in Table (4).

Fig 4.
shows a general view of the slopes and the paved road and sidewalk related to rockfall in Sector-2

Fig 5.
illustrates the falling of rock blocks near the tourist houses built on the slopes of sector-2.

The values of the parameters of
the Rockfall Hazard Rating System (RHRS) for sector-2 are summarized in Table (4).

<table>
<tr><th colspan="3">Factor</th><th>Points</th></tr>
<tr><td colspan="3">Slope Height (m)</td><td>81</td></tr>
<tr><td colspan="3">Ditch Effectiveness</td><td>81</td></tr>
<tr><td colspan="3">Average Vehicle Risk (AVR</td><td>3</td></tr>
<tr><td colspan="3">Percent of Vision Sight Distance</td><td>81</td></tr>
<tr><td colspan="3">Paved Roadway Width (m)</td><td>81</td></tr>
<tr><td rowspan="4">Geologic Characteristic</td><td rowspan="2">Case (1)</td><td>Structural Condition</td><td>81</td></tr>
<tr><td>Rock Friction</td><td>27</td></tr>
<tr><td rowspan="2">Case (2)</td><td>Structural Condition</td><td>9</td></tr>
<tr><td>Difference in Erosion</td><td>18</td></tr>
<tr><td colspan="3">Rock Diameter or Quantity of Rockfall Event (m)</td><td>81</td></tr>
<tr><td colspan="3">Climate and Presence of Water on Slope</td><td>9</td></tr>
<tr><td colspan="3">Rockfall History</td><td>27</td></tr>
<tr><td colspan="3">Total points</td><td>579</td></tr>
</table>

In this regard, the slopes in sector-2 were found to have risks at the second level, which means they are highly hazardous slopes according to Table (4). The road’s slope steepness measures (24.1), and when adding the points for the slope steepness property, the total score becomes (606) (579+27=606). This transition shifts the risk level from the second level to the first level, indicating that these slopes are extremely high-risk. Thus, we observe the specific impact of the road slope steepness property on the Rockfall Hazard Rating System and its significant role in assessing the risk levels in sectors of the study area.

6. Conclsion:

This study concluded that slopes in sector-1 were classified as moderately hazardous (Level 3) according to Table 3 of the Rockfall Hazard Rating System (RHRS). These slopes require warning signs, routine monitoring, and possibly some mitigation measures due to a road slope value of 38.26 degree. When these points are added, the total score reaches 429 (348+81), moving it to Level 2, signifying higher risk. This calls for warning signs, speed limits, daily road checks, and detailed slope studies to prevent incidents. This highlights the importance of adding road slope steepness to the RHRS in this county.

In sector 4, slopes were categorized as highly hazardous (Level 2) in Table 2 of the RHRS, requiring warning signs, speed limits, daily road checks, and possible mitigation measures due to a road slope value of 24.1. When slope steepness points are added, the total score becomes 606 (579+27), shifting the risk level to Level 1, indicating very high risk. Stopping vehicle traffic, detailed slope studies, measuring and addressing potential rockfall incidents directly are recommended. This underscores the impact of road slope steepness on the RHRS and its role in assessing risk levels in the study area.

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