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Determination of Rockfall Risk Using Fine-Kinney Methodology for Bitlis Downtown Area, Eastern Türkiye

Ercan Işık[1], Aydın Büyüksaraç[2*], Yunus Levent Ekinci[3] and Mehmet Cihan Aydın[4]

1 Bitlis Eren University, Department of Civil Engineering, Bitlis, Turkey, ercanbitliseren@gmail.com https://orcid.org/0000-0001-8057-065X

2 Canakkale Onsekiz Mart University, Çan Vocational School, Canakkale, Turkey, absarac@comu.edu.tr https://orcid.org/0000-0002-4279-4158

3 Department of Archaeology, Bitlis Eren University, Bitlis-Turkey, ylekinci@yahoo.com https://orcid.org/0000-0003-4966-1208

4 Bitlis Eren University, Department of Civil Engineering, Bitlis, Turkey, mcydin@beu.edu.tr https://orcid.org/0000-0002-5477-1033

Abstract

One of the important natural hazards arising from topographic, morphological and meteorological conditions in Bitlis city in Eastern Turkey is rockfall. As one of the natural hazards, rock falls damage settlements and cause significant loss of life and property. There are many inclined and steep slopes along the Bitlis river valley in the city. The urban and intercity roads were designed parallel to these slopes, while many neighbourhoods of the city have been built on these slopes. The ground snow load also contributes significantly to the rockfall hazard in Bitlis where the highest snowfall was observed in Turkey. In addition to these unfavourable conditions, random structuring was also added, on the other hand, topographic and morphological conditions and the hazard of rockfall were almost never taken into account. The risk of rockfall, which is observed intensely in seven neighbourhoods in Bitlis downtown, was investigated by Fine-Kinney Method within the framework of this study. In the frame of Fine-Kinney Method, damage probability rating, hazard exposure frequency rating, impact rating of hazard on human and environment were calculated and action planning table was prepared to define the risk of the rockfall in Bitlis downtown.

Keywords: Rockfall, East Anatolia, Fine-Kinney method, Risk, Natural disaster

1. Introduction

In particular, natural disasters experienced in recent years and the loss of life and property that are the result of these disasters have revealed the importance of studies, research and measurements taken on the agenda. Determination of risky area before possible event is important in terms of reducing damages and to take the necessary precautions before the disasters. However, the large number of risky regions negatively affects the evaluation and decision-making process. For this reason, use of practical methods is seen as a suitable solution to determine risky areas quickly and correctly. One of the important steps for any natural hazard is to identify risky areas. In these regions, it is possible to identify the areas of priority risk and the evaluation process in which the natural hazard risks are calculated. As a result, a number of determinations can be made according to the hazard levels. In general, for each type of natural hazard, risk identification and priorities can be obtained by using the methods in the literature. There are many studies on risk assessment for natural hazards such as earthquakes, avalanches, landslide floods (Işık and Kutanis, 2015; Aydın and Yaylak, 2016; Işık, 2013; Šipoš and Hadzima-Nyarko, 2017; Nikoo et al., 2016; Hadzima-Nyarko et al., 2017; Fuchs et al., 2017; Osipov et al., 2017; Aydin and Işık, 2015; Mitra et al., 2018; Bai et al., 2017; Murillo-García et al., 2017; Elshorbagy et al., 2017; Mojaddadi et al., 2017; Rilo et al., 2017; Forino et al., 2017; Ntajal et al., 2017; Djalante et al., 2017; Armaş et al., 2017; Islam et al., 2017). Such studies have uneconomical consequences both in terms of time and

*Corresponding author: absarac@comu.edu.tr

personnel. Natural hazards of nature-based causes can occur in different forms. One of the natural hazards is rockfall due to rock stability problems. Rock stability problems can be expressed as a fall by moving downward along the slope of the rocks in time, separated by natural or artificial reasons from the main mass, or by the effect of gravity as a whole. Rockfall has a negative impact on human life, especially in transportation (roads, railways) and urban areas.

An investigation to estimate the rockfall potential in the California Yosemite Valley was conducted based on physical evidence of rockfall travel to the base of the slope and theoretical potential energy assessments. It has been revealed that the size of the rockfalls in the valley ranges from 1 m^3 single rocks to medium sized falls with a volume of 100,000 m^3 (Wieczorek et al., 1999). Rockfall was triggered in 1997 after moderate earthquakes in the Umbria and Marche regions of central Italy. Observations obtained were used to investigate the correlation that existed between rockfalls and various causal factors such as slope angle, geology, and strong ground motion parameters. All data, multiple regression, were used to formulate a prediction rule that could be used to construct a rockfall susceptibility map in the event of an earthquake in regions with similar geological and geomorphological features (Marzorati et al., 2002). Rock slope failures were investigated using 3D reconstruction from image sets obtained by observations in three selected regions in the French Alps over a period of 6 years (Voumard et al., 2017).

Rockfalls occur in almost every city in Turkey. Rockfalls have led to the loss of more than 20,000 lives in Turkey so far. While Kayseri is the province with the highest number of rockfalls in our country, Erzurum, Nevşehir, Adıyaman, Sivas, Niğde and Karaman are the other provinces where rockfalls are experienced a lot. In Turkey, where rockfall events are observed a lot, many studies have been carried out on this subject. Some of these studies are mentioned in this section. In Boğaziçi village (Kemah, Erzincan), which is located on the lower parts of a high sloping slope, very steep, 25-30 m high cliffs of fractured and fissured basaltic rocks up to 6 m^3 have been found to have broken off. Kinetic energy, jump height, horizontal position of rock endpoints and velocity of rocks along each section were evaluated using Rockfall V.4.0 software along the selected profiles (Keskin, 2013). A similar study was conducted by Polat et al. (2016) in Sarıca Village (Gürün, Sivas), located at the foot of very steep cliffs and crushed sedimentary and volcanic rocks, in order to prevent the risk of rockfall, and a map and charts containing the possible falling rock blocks in the region and the relevant residential area at risk. It was determined that previously falling rock blocks with field observations made in some parts of the D-350 highway between Isparta-Egirdir-Konya were observed in areas that are high and moderately susceptible to rockfall, and the general rock structure was found to consist of limestone blocks with discontinuity planes (Hepdeniz 2019). Rockfall analyzes were carried out in Kavak village, which is located in the west of Sivas city center. Properties such as kinetic energy values, jump heights and reach distances of rock blocks that are likely to fall have been successfully calculated (Polat 2020). The use of unmanned aerial vehicles (UAV) is also frequently used in rockfall assessment studies. In particular, identifying areas with difficulty in transportation and mapping studies are carried out quite easily (Polat and Keskin, 2017; Şener, 2019; Utlu et al., 2020).

Rockfall potentials were evaluated by different researchers using different methods. For example, Evans and Hungr (1993) suggested that the angle between the far edge of the rock shadow and the crest of the slope should be at least 27.5°. They stated that this would be beneficial in rockfall vulnerability studies at the base of the slopes. Dussauge-Peisser et al. (2002) analyzed data on rockfalls in the calcareous cliffs around Grenoble in the French Alps, granite cliffs in the Yosemite Valley in the USA, and metamorphic and sedimentary rocks in the Arly gorges of the French Alps. They used statistical distribution of past events to estimate rockfall occurrence rates, as an alternative to deterministic approaches that have proven unsuccessful in predicting individual rockfalls. As an alternative, they suggested evaluation with a probabilistic approach. Binal and Ercanoğlu (2010) investigated the rockfall potential in the Kula geopark through experimental investigation and numerical analysis. They carried out extensive field studies including determination of soil column locations, geological descriptions of soil columns, scanline studies of discontinuities, determination of slope profiles, measurement of actual falling block sizes and sampling. Ali et al. (2021) rated the rockfall hazard on the Pakistan-Karakoram Road using Pierson's modified Rockfall Hazard Rating System for Pakistan (RHRSP). The area is divided into four zones as very high, high, medium and low risk. Akın et al. (2021) evaluated the effectiveness of a rockfall trench through 3D probabilistic rockfall simulations and automatic image processing. Keskin and Polat (2022) performed the kinematic analysis and rockfall assessment of the rock slope in the UNESCO World Heritage list (Safranbolu/Turkey). Especially the historical castles in urban area are dangerous in terms of rockfall. The best examples of these are the Ankara and Afyon castles in our country. Evaluation and improvement studies were carried out in these castles (Topal et al., 2007; San et al., 2020). A similar study was carried out in our study area, Bitlis Castle. However, no scientific publication related to this study could be found. In the castle, the weathered rocks were filled with filling materials and many rocks were connected to each other with metal bonds.

The Analytical Hierarchy process (AHP), based on multi hazard factors such as rockfall risk, slope, lithology, soil, altitude, precipitation, fragility factors, land use and population covering the whole of Bitlis province, was made according to multiple decision-making criteria. Geographic Information System (GIS) was used to visualize the result maps. The study revealed that rockfall risks are mostly concentrated in mountainous and rugged southwest and partially southeast regions, including city and district centers (Aydın et al., 2022).

In this study, Bitlis downtown was as an example for rockfall risk assessment and grading. Seven different locations where the risk of rockfall was the highest in Bitlis downtown were studied. The number of structures to be affected due to the risk of falling rock, along with the line length, geological features, observed damages and characteristics were found for each location. Information was given about the local geology of the region studied. Risk values for each location were determined according to the action planning table by determining the probability scale (I), frequency (exposure) scale (F), effect/damage-result scale (D) values. Risk ratings for seven locations were performed with the calculated risk values. The obtained results were interpreted and recommendations were made.

2. Study Area

Bitlis downtown was taken into consideration in this study. Bitlis province settles in Lake Van Basin in the East Anatolian Region of Turkey, which is one of the important provinces of the strategic corridor of Turkey. Bitlis city with 70.000 inhabitants (including surrounded villages) is located at an elevation of 1,400 meters, 15 km from Lake Van, in the steep-sided valley of the Bitlis River, a tributary of the Tigris River (Işık and Kutanis, 2015). The location map of the study area is shown in Figure 1. Mountains have been formed 90% of Bitlis. Plateaus and plains have been formed only 10% of Bitlis. The important mountain in Bitlis known as Nemrut Mountain exceeds 3.000 m high.

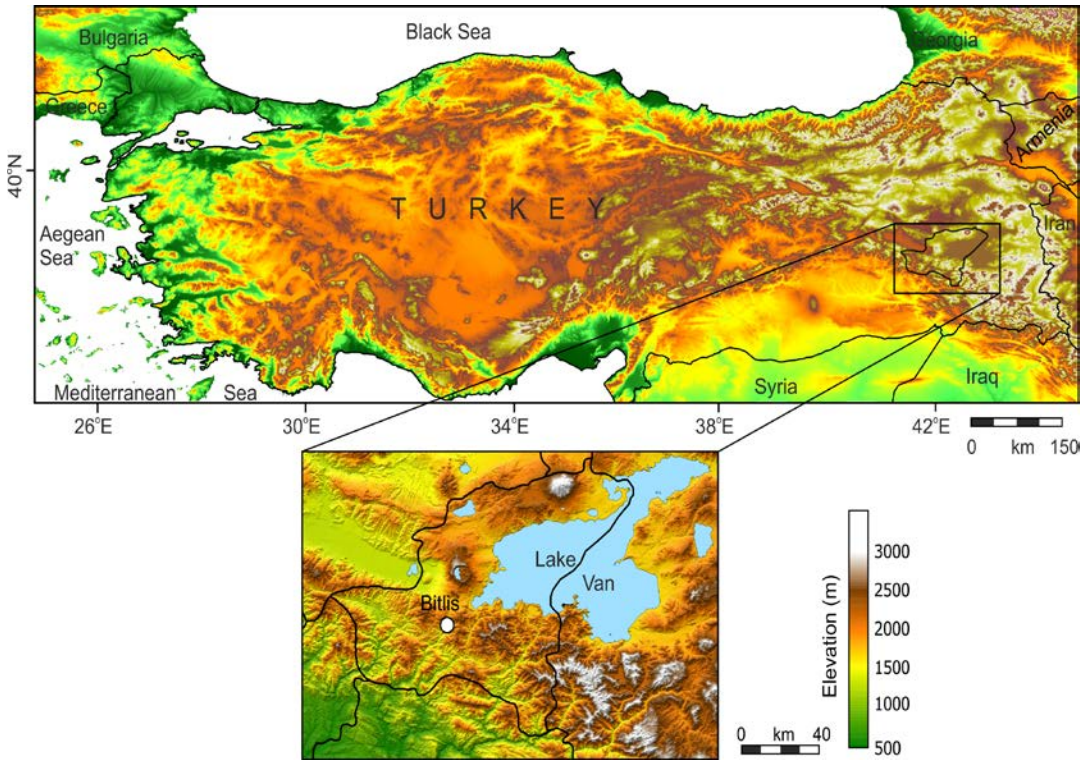

Figure 1. Location of study area

2956 rockfall events had been held across the country in 2008, corresponds to 10% of disasters occurring in Turkey (Figure 2). The reason for 7% of the total number of people affected by disasters are rock falls (Gökçe et al., 2008). Bitlis is one of the top ten provinces of Turkey in terms of rockfall. There were 67 rockfall events in Bitlis province between 1965 and 2010 (Ekinci et al., 2020) and also 9 events in Bitlis downtown between 1965 and 2020 (Bulut et al., 2018).

Due to the unfavourable geological and morphological characteristics of Bitlis province, the settlement of rockfall events is important in terms of loss of life and property. In general, many of the settlement provinces where the city is founded have very sloping and steep slopes. This increases the risk of rockfall and its risks (Işık and Özlük, 2012). In addition to this, many factors can be considered as risky zones due to these factors which are not taken into account during construction. The passage of Bitlis-Diyarbakır-Van highway through the city center increases the risk of damage.

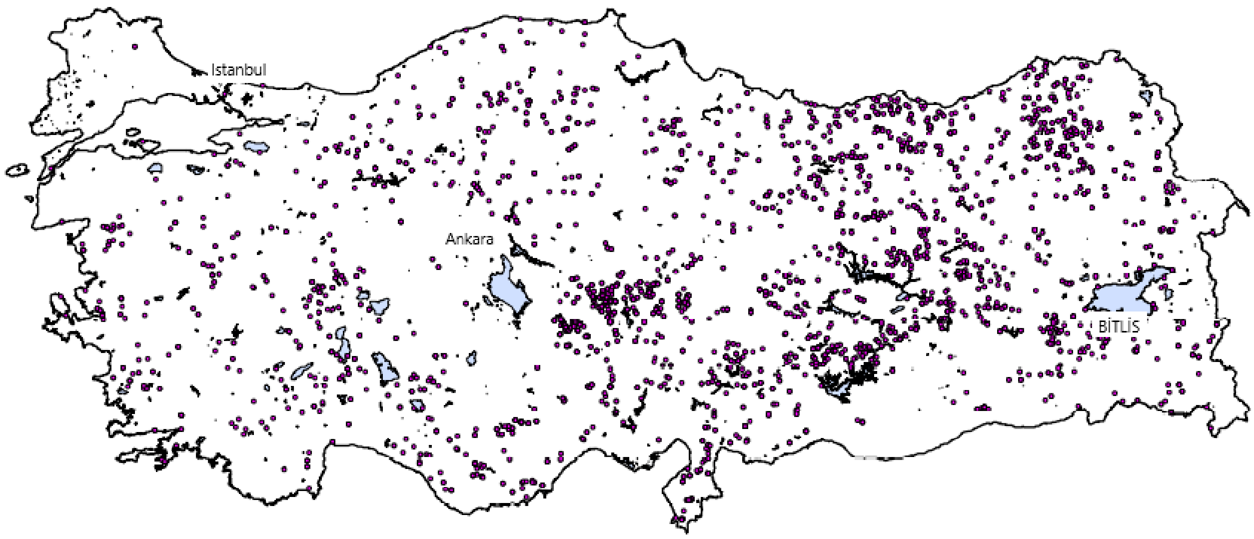

Figure 2. Spatial distribution of rockfall events observed in our country (modified from Gökçe et al., 2008).

The eastern Anatolian region where Bitlis province is in the region where the snow is observed the most. Bitlis is one of the first three provincial centers in Turkey in terms of snowfall. Bitlis downtown experiences a very different microclimate in terms of snowfall in an area of approximately 1500-2000 km^2. Bitlis is the city most avalanche occurred with more than 200 avalanches in Turkey between the 1965-2010. Excess rainfall and avalanche events will increase the risk of possible rockfall. When the 50-year average return period of 14 provinces in Eastern Anatolia is examined, it is seen that Bitlis is exposed to a significantly high ground snow load (Terzi, 2011; Aydın and Işık, 2014) (Figure 3).

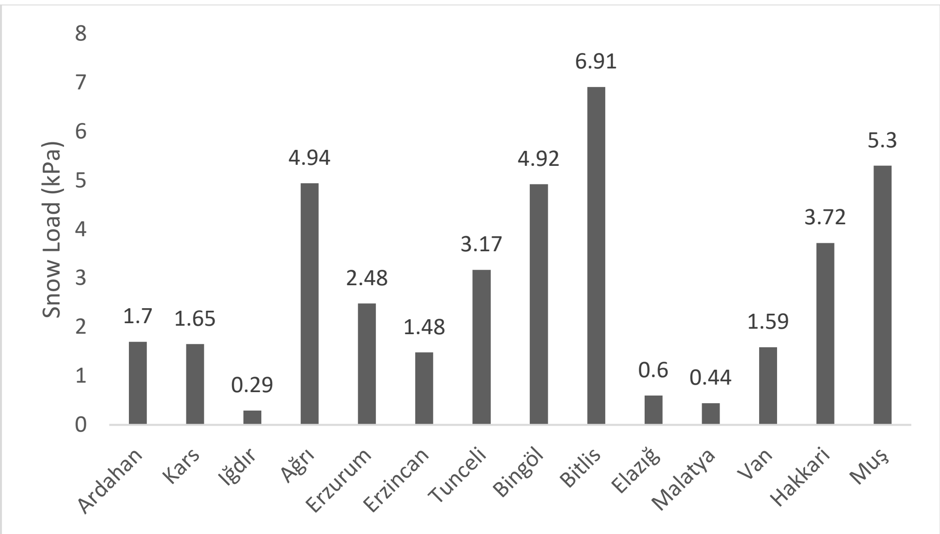

Figure 3. Normalized ground snow loads (kPa) with the 50-year return period in the Eastern Anatolia region in Turkey (Terzi, 2011).

2.1. Local Geology of Bitlis Province

Eastern Anatolia is a region with an average height of 2000 m and actively under the influence of compression regime in the north-south direction (Koralay et al., 2014). The geological map of the area (1:10.000 scaled) was made by Boray (1975) in order to identify the different rock types to shed light on the structure and metamorphism of the Bitlis massif (Figure 4). Most of the rock units in the study area are metamorphic. The rock assemblages observed in the Eastern Anatolian region are from old age to young; Paleozoic-Lower Mesozoic metamorphic rocks (Boray, 1975;

Perinçek, 1980; Perinçek and Özkaya, 1981; Yılmaz et al., 1981; Göncüoğlu and Turhan, 1983; Çağlayan et al., 1983). Upper Cretaceous ophiolitic rocks (Demirtaşlı and Pisoni, 1965; Ketin, 1977; Yılmaz et al., 1981), Eocene-Lower Miocene sedimentary rocks and Upper Miocene-Quaternary terrestrial sediments and volcanic rocks (Figure 4). The rock units in the study area consist of an almandine-amphibolite facies metamorphized core into which Precambrian granites are introduced, and the surrounding greenschist facies metamorphism of Paleozoic-Mesozoic cover rocks. Tertiary cover rocks, most of which are clastic and volcanic alternations, are located on all these units. Mesozoic units, Triassic variegated shale and limestone alternation; Jura - Lower Cretaceous dolomite, recrystallized limestone and limestone; It is represented by the Upper Cretaceous aged volcanic limestone alternation and micrites. Tertiary rock units include Paleocene-Eocene turbiditic sandstones, limestones and volcanics alternating with them, and Miocene aged sandstone-claystone intercalated clastics and limestone. Metamorphism is very low-low level at the peaks and adjacent parts of the main structure; In the wings and towards the structural core, it reaches the conditions of almandine - amphibolite facies. Widespread volcanic activity took place between the Pleistocene and Quaternary periods in the region of Eastern

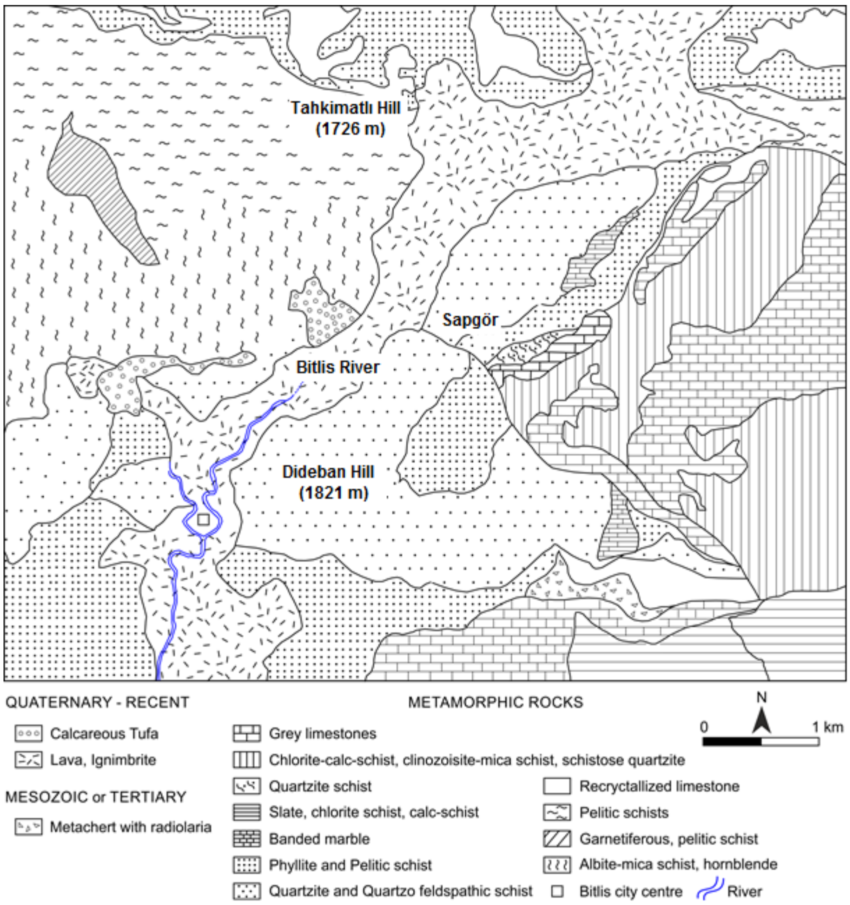

Figure 4. Geological map of study area (Scale 1:10.000) (changed from Boray, 1975).

Anatolia Volcanic Area (EAVA) that one of the important volcanic areas of Turkey (Koralay et al., 2014). Fossils were not found in other rocks except the Radiolarian metachert. It has been revealed that the stacking of the units on a large scale has taken place with tectonic events. In this case, metamorphic rocks of unknown age are distinguished by metamorphism grades and petrographic features. The lower union, which is more metamorphic than these associations, and the less metamorphic union that is preserved in sedimentary structures in some rock units within it, is called upper union. Bitlis downtown is located at steep slopes on both sides of Kışla and Güzeldere. It is located in the steep-sided valley of both these rivers. Generally, basalts columns have been found in slopes of rivers (Tabban, 2000). Two clear basalt flows and terrace levels formed by these flows have been observed in Bitlis Valley. The fluvial sediment deposits and other current flows overlies in most place has been observed (Biçek, 2006). The Bitlis ignimbrite is seen in three levels in the form of valley deposit deposits, with an average thickness of 30-50 m, welded at different degrees. At the bottom, there is a well-welded base level with a homogeneous appearance, with dark brown surfaces in contact with the atmosphere, fresh fractured surfaces in black. The average thickness of the floor level seen in the glassy structure varies between 5-8 m. Within the basement level, rock fragments of round and/or angular shapes, mostly with metamorphite composition, varying in size from 0.5 to 2.5 cm are observed. Above the ground level is a reddish pinkish colored, homogeneous inner structure, very well welded middle level, which is seen as an indentation in morphology. The intermediate level contains smaller, relatively rounded rock fragments and abundant fiamme structures. At the top of the Bitlis ignimbrite, there is a gray colored, less welded ceiling level. The ceiling level, which contains abundant rock fragments, pumice and voids, has a thickness of approximately 5-10 m. In this level, which can be broken and crumbled more easily than the other two levels, grayish white, porous, 1.5-5 cm in size, pumice type components with low flattening rate are seen. Tuffs which were formed by basaltic flows has been observed in Bitlis Valley and in Rahva Plateau (Altınlı, 1966).

3. Rockfall in Downtown of Bitlis

Rockfall is a rock movement that is the result of continuing to move downward from the incline of the rock on a steep slope. The movement of the rock is observed in parallel with the increase in the slope angle shown in Figure 5, for example, rolling at a slope angle of 30 degrees, rolling faster at an angle of 45 degrees, bouncing at 60 degrees, and free falling at an angle of 90 degrees. Rockfalls occur due to freezing-thawing, earthquakes, explosion vibrations, precipitation, tree roots, joints in the rock mass, excavation, weathering, pore pressure changes due to rainfall leaks, surface water flow, root growth or slope disturbance caused by leverage (Ritchie, 1963; Hoek, 2007; Şaroğlu and Bar, 2017). In this study, risky regions in Bitlis downtown were prioritized in terms of rockfall using the Fine-Kinney method after observational evaluations on the field.

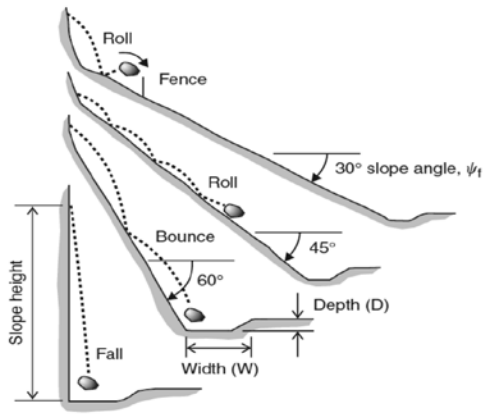

Figure 5. Rock fall movement types (Ritchie, 1963; Şaroğlu and Bar, 2017)

Landslides or rockfalls are also a problem in some slopes, especially when the volcanic origin of the beams is cut or destroyed, as human activities such as the creation of new road routes in the city and the change of slope slopes are carried out uncontrollably. There are twelve neighbourhoods in Bitlis (Figure 6). Six different locations in these neighbourhoods, with the risk of rockfall, form the subject of that study. The specifications for six locations are given in Figure 7.

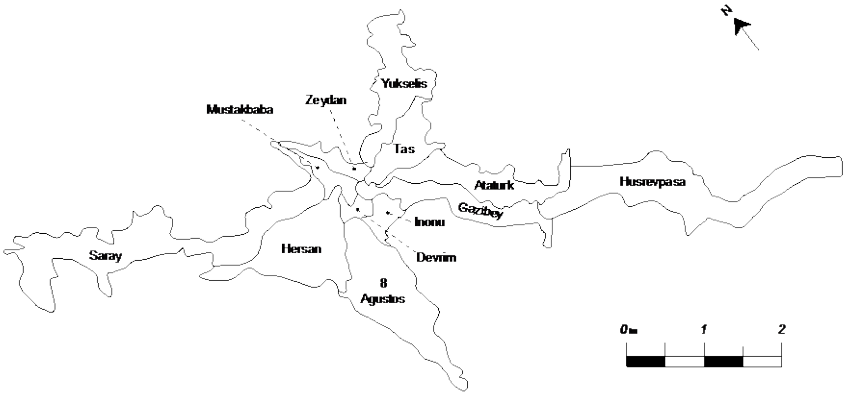

Figure 6. Twelve neighbourhoods of Bitlis downtown (Işık et al., 2017)

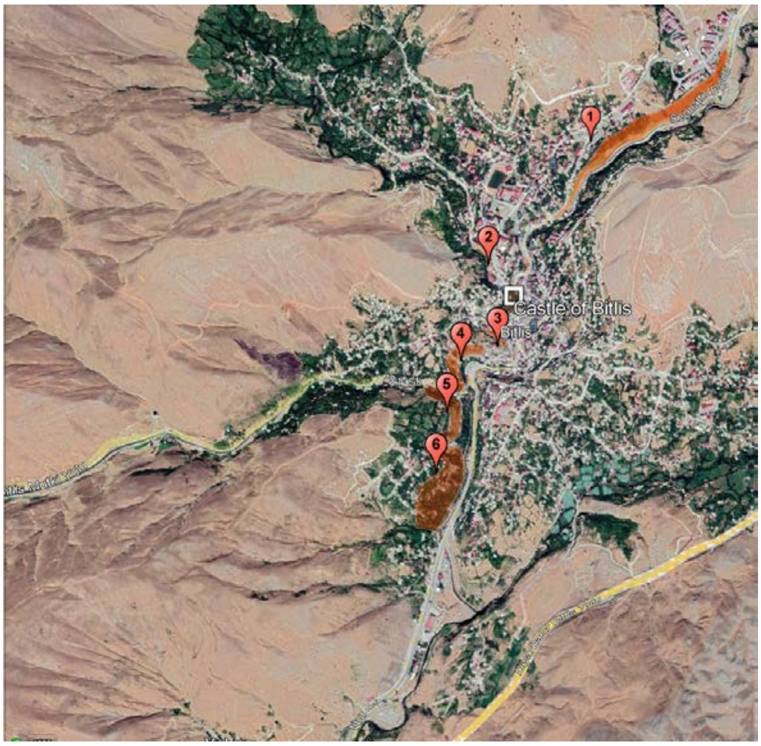

Figure 7. Display of six locations where rockfalls were observed. (1) Selahattin Eyyubi Street, (2) Zeydan District Area, (3) Muştakbaba District Area-1, (4) Muştakbaba District Area-2, (5) Saray District Area-1, (6) Saray District Area-2,

3.1. Location-1

The area along the road between Tatvan and Bitlis is about 1400 m length on the right side towards the Bitlis direction. This area is composed of volcanic units (basalt columns) of the Nemrut volcanism (Figure 8). Segregations along the discontinuity planes was observed in the rocks. The discontinuity ranges from 10-15 cm in some places. There is no housing that can be affected by the rockfall incident, but the event will seriously affect the roadway located in the main artery and the pedestrian path under the slope. There is danger of loss of life and property.

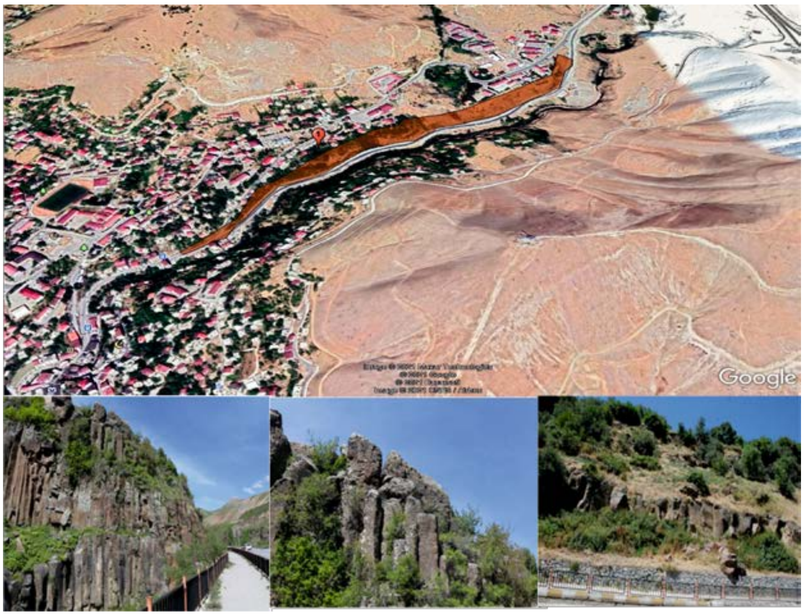

Figure 8. Position and visuals of Location-1

3.2. Location-2

There are ignimbritic rocks along Mermutlu Street, which is approximately 250 m in line length (Figure 9). Segregation along the discontinuity planes was observed in the rocks. The discontinuity ranges somewhere between 1-3 cm. There is no housing to be affected by the rockfall event, but the event has a serious effect on the main arterial roadway and on the pedestrian path under the slope (Figure 9). There is danger of loss of life and property.

3.3. Location-3

According to Diyarbakır direction of the street passing through the city center, there are ignimbrites on the slope to the left of the volcanic units about 50 m in length (Figure 10). The discontinuity ranges from 0.5 to 3 cm in some places. There is no housing to be affected by the rockfall incident, but the event seriously affects the main arterial roadway and the pedestrian path under the slope (Figure 10). There is danger of loss of life and property.

Figure 9. Position and images of Location-2

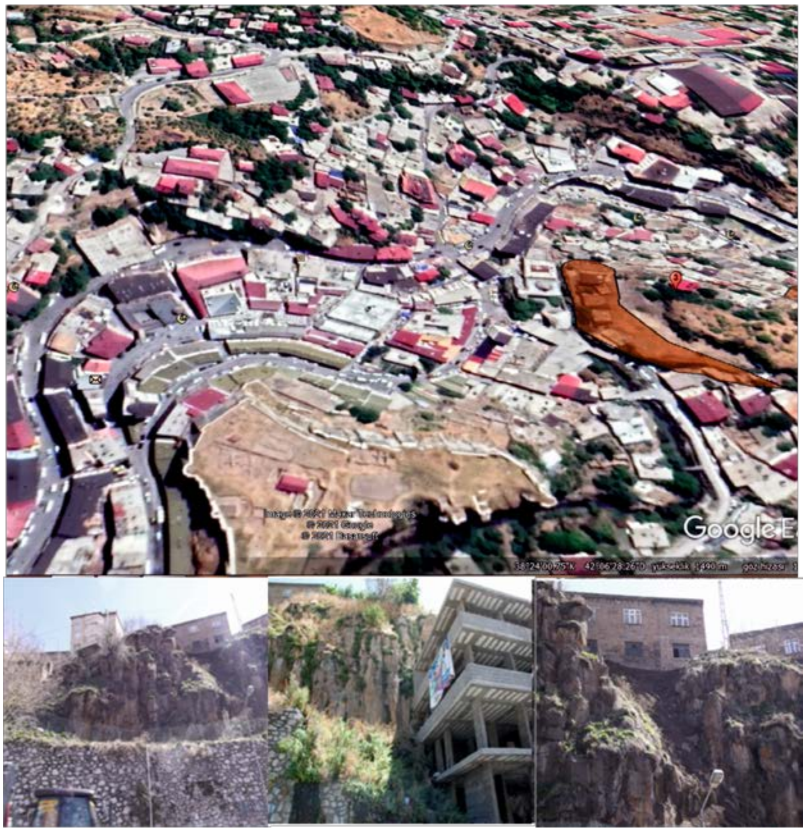

Figure 10. Position and images of Location-3

3.4. Location-4

The area behind of the Şerefiye Külliye was named as Muştakbaba District Area 1 with an approximate length of 140 m (Figure 11). This area contains ignimbrites from the volcanic units which are the product of the Nemrut volcanism. The area with a line length of approximately 140 m was observed along the planes of discontinuity in the rocks. The discontinuity ranges from 5-10 cm in some places. There are 2 shops with about 12 buildings that can be affected by the rockfall incident at the first degree. There is danger of loss of life and property.

Figure 11. Position and images of Location-4

3.5. Location-5

Alemdar Street, approximately 468m long, located behind of the old industrial area, was named as Mustakbaba District Area 2 (Figure 12). There are ignimbrites from volcanic units of the Nemrut volcanism. Segregation along the discontinuity planes was observed in the rocks. The discontinuity ranges from 20-30 cm in some places. There are about 42 buildings that can be affected by rockfall incident (Figure 12). There is danger of loss of life and property.

Figure 12. Positions and images of Location-5

3.6. Location-6

The Lower Tahtisit Street, 500 m long of the Saray Neighborhood is named as Saray District Area 2 (Figure 13). There are ignimbrites from volcanic units of the Nemrut volcanism. Segregation along the discontinuity planes was observed in the rocks. The discontinuity ranges somewhere between 1-3 cm. There are about 32 buildings that can be affected by rockfall incident (Figure 13). There is danger of loss of life and property.

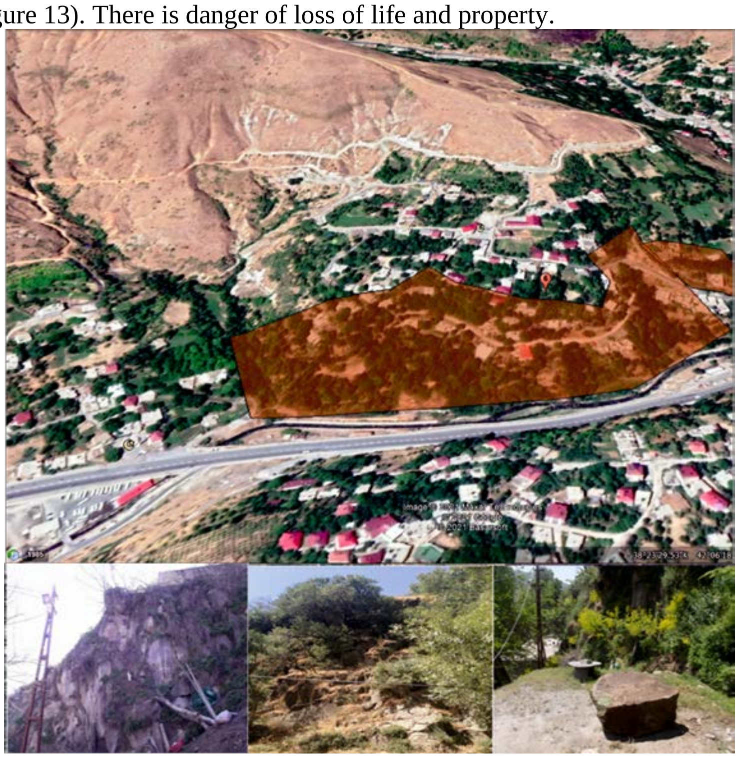

Figure 13. Position and images of Location-6

4. Risk Analysis of Rockfall Hazard

Fine-Kinney method is widely used by different researchers in different sectors. It is widely used in factories, construction sector, cement sector, occupational health and safety risk analysis (Kinney and Wiruth, 1976; Erzurumluoğlu et al., 2015; Oturakçı et al., 2015; Kokangül et al., 2017; Gül et al., 2017; Birgören, 2017). It is generally used to rank and prioritize the risks identified in the workplaces (Babut et al., 2017). What makes this study different from other studies is that the Fine-Kinney method is used to rank and prioritize the risks of rockfall, which is a natural hazard, for a particular area. This study aims to create a model for predicting risk for other natural hazards. Risk analysis is required to estimate the magnitude of the risks caused by hazards, to rate them and to decide whether the risk is acceptable according to the resulting risk value and to offer solutions to reduce the risks.

Although there are many risk assessment methods, Fine Kinney Method, one of the most effective methods, was used in this study. The Fine-Kinney method was first proposed at the Naval Weapons Center in California (Kinney and Wiruth, 1976). In the method, risk is seen as the occurrence of hazards (Stankovic and Stankovic, 2013). Briefly, risk assessment is evaluated using the product of the probability of an accident or damage, the severity of consequences in case of hazards and frequency of occurrence of hazards (Babut et al., 2011). Thus, it is clear that the easy-to-use method employed to mathematically assess accident control requires probability, frequency and severity parameters and scale tables of each parameter (Oturakçı et al., 2015).

In this method, besides the probability of the event and the intensity (Outcome Level), the frequency plays a role in determining the risk. In this method, the risk value is calculated according to the following Eq. 1.

$$\text{Risk} = P \times F \times I \qquad (1)$$

P = Possibility (between 0.2 – 10)
F= Frequency (between 0.5 – 10)
I= Intensity

4.1. Probability Scale (P)

The probability of occurrence of damage in time is rated in Table 1.

Table 1. Damage probability rating

Value	Category
0.2	Practically Impossible
0.5	Low possibility
1	Very Low possibility
3	Rare but Possible
6	Strongly Possible
10	Very Strong Possible

4.2. Frequency (Exposure) Scale (F)

Frequency (F) is defined as the frequency of exposure to hazard and is rated as in Table 2.

Table 2. Hazard exposure frequency rating

Value	Explanation	Category
0.5	Very rare	Once a year or less
1	Quite rare	Once or several times a year
2	Rare	Once or several times a month
3	Sometimes	Once or several times a week
6	Frequently	One or more days
10	Continously	Continuous or multiple times per hour

4.3. Impact / Damage-Result Scale (I)

It is defined as a scale of impact, damage on human and environment in case of danger, and it is rated as in Table 3.

Table 3. Impact rating of hazard on human and environment

Value	Explanation	Category
1	Should be Considered	No damage or not important
3	Important	Minor or slightly damage
7	Serious	Moderate damage and significant loss
15	Very Serious	Major damage and environmental impact
40	Very Bad	Death/Injuring and heavy damage and heavy environmental impact
100	Disaster	Multiple deaths and collapse and major environmental disaster

4.4. Decision-Action Table According to Risk Value

According to the Risk Value calculated from the formula given in Formula (1), the decisions in Table 4 should be taken and action plans should be prepared.

Table 4. Action planning table

Rank	Risk Value	Decision	Action
1	R<20	Acceptable Risk	Emergency measures may not be necessary
2	20<R< 70	Exact Risk	Action plan must be taken
3	70 <R<200	Important Risk	Must be monitored carefully and removed by annual action plan
4	200 <R< 400	High Risk	Should be eliminated by considering short-term action plan
5	R>400	Very High Risk	Immediate action must be taken

4.5. Risk Analysis

Risk describes the losses that can occur under a certain risk factor over a certain period (Coburn et al., 1994). Risk is the resultant of the likelihood of any hazard and the consequences of this danger. The level of risk is proportional to the size of the danger and the vulnerability of the affected members (Kundak and Türkoğlu, 2007). The level of damage that the risk element will generate can be measured in terms of the expected economic loss or loss of life and property. In general, the risk calculation formula can be given in Eq.2:

$$[Rij] = [Hj] \times [Vij] \quad (2)$$

where, [Rij] is the risk that an item (*i*) at risk would create on element *i* in a given unit of time due to a hazard of significance *j*. [Hj] is the hazard with the probability (*j*) of experiencing a dangerous event of severity. [Vij] is vulnerability, indicating the levels of loss that can occur in element *i* as a result of experiencing a hazard of severity *j* (Coburn et al., 1994; Kundak and Türkoğlu, 2007; Hadzima-Nyarko et al., 2015). The total risk for any element can be obtained by summing the risks from all hazard levels, ($\min \leq j \leq \max$) (Coburn et al., 1994).

Disaster exposure for residential units that are exposed to any natural hazards is part of modern disaster management with emergency procedures being organized during and before disasters. One of the most effective ways to reduce natural hazard losses is to reduce the most possible losses with disaster-free practices and risk mitigation practices. A number of methods are needed to identify natural hazard risks and to measure these risks. Since there are a large number of risky regions, it is not possible to apply these methods and to get results in terms of time and personnel.

Therefore, sorting risky regions within themselves and ranking them among risky regions can be seen as an appropriate solution. Faster solutions can be achieved by using fast and practical solutions in determining risky areas. For this, the Fine-Kinney method, which is widely used in risk analysis, is generally preferred. Bitlis province, which frequently experienced rockfall events, was chosen as an example for the application of this method. Evaluations were made for seven different locations selected for the province of Bitlis.

In this study, the areas that are in hazard of falling rocks in Bitlis downtown were determined firstly as a result of in situ observations and examinations. Risk scores were then calculated for each region according to the Fine-Kinney method, by determining the probability, frequency, and magnitude of the effect / damage outcomes according to the given scales. The risk level is determined according to the obtained risk value and the recommended actions to take the risk or withdraw it to the acceptable level are given in the risk analysis table (Table 5). Risk grading has been done for six different locations. Location-5 (Mustakbaba Neighbourhood) was obtained as the riskiest area.

Table 5. Risk analysis of rockfall in Bitlis downtown (**(Risk Value=I× F×P)**

Location	Hazard	Possibility (P)	Frequency (F)	Intensity (I)	Risk Value	Result	Suggestion
1	High slope, large and medium size rockfall and roll	6	1	40	240	High risk	A short-term action plan must be prepared and a solution must be found. Application projects should be prepared
2	Medium-high slope, medium and small rockfall and roll	3	1	7	21	Absolute Risk	In the medium-term action plan to be taken. Application projects should be prepared
3	High slope, small and medium-sized rockfall	6	2	40	480	Very high risk	Very urgent measures should be taken and an action plan should be prepared. Application projects should be prepared immediately
4	High slope, rockfall and roll in large and medium size	6	1	40	240	High risk	A short-term action plan must be prepared and a solution must be found. Application projects should be prepared
5	High slope, large and medium size rockfall and roll	6	1	100	600	Very high risk	Very urgent measures should be taken and an action plan should be prepared. Application projects should be prepared immediately
6	High slope, rockfall and roll in large and medium size	3	1	40	120	Important Risk	It should be carefully monitored and removed by taking into consideration the annual action plan. Application projects should be prepared

5. Discussion and Conclusions

Determination studies for a solution and more importantly, to what extent the existing conditions affect the safety of life and property have been examined due to the existing rockfall problem in Bitlis downtown. The recent study of Aydın et al. (2022), which covers the entire province of Bitlis, and this study, the studies carried out by the relevant organisations in Bitlis, try to draw attention to the problem of rockfall in Bitlis. Some prevention studies have yielded positive results and led to the evaluation of rockfall as a preventable type of disaster. If the rockfall event is considered in terms of the places where it is dangerous, it can be mentioned that the problems encountered on the roads are much easier to solve than the life-threatening dimension in the city and it is possible to keep them under control. However, in terms of the consequences of rockfall events in the city, disasters and very difficult problems emerge. The area where this study was carried out is the area where Bitlis has been settled for a very long time, and rockfall events resulting in death are encountered from time to time. Within the scope of this study, the boundaries of the regions experiencing the rockfall problem, which poses a great danger in the city, were determined and the risk of each region was calculated. Thus, the priority of taking precautions has been tried to be revealed.

Six different locations where the risk of rockfall was the highest in Bitlis downtown were studied. Risk ratings for six locations were performed with the calculated risk values. The Fine-Kinney method is used as a quick and practical solution for risk rating. According to the risk analysis of the Fine-Kinney method, six locations were found to be high and very high risk. Life and property safety is seriously threatened in the investigated areas. Urgent measures should be taken and action plan should be prepared. From the locations examined, *Location-3* and *Location-5* should be recovered immediately action plan. *Location-1* and *Location-4* should be recovered by the short-term action plan. *Location-2* should be recovered by the medium-term action plan. It should be carefully monitored and taken into the annual action plan in the *Location-6* from the examined locations. The results of the study are preliminary evaluation results, revealing that detailed studies should be done. Risk grading is made by the study and ranking has been created the examined six different regions. This study can be used as a model for other hazard types. This order must be considered in order to determine the exact risks.

Rocks and stones with falling potential in natural or later formed slopes should be safely cleaned using specialized equipment and blasting methods. It is possible to apply different types of wire network (steel grid - steel composite grid) against superficial rocks and stone falls that may occur along the slope surface. High energy absorbing panels are fixed to the solid floor of block rocks that comprise the risk of locally taper surface may be one solution. Anchorage and floor nails can be applied in addition to surface measures with geotechnical approach against rock slope stability problems in some regions. Rock barriers or barrier walls can be installed in large, high slopes or in areas where superficial precautions are not possible. The method to be used should be decided by making on-site and detailed analyzes.

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