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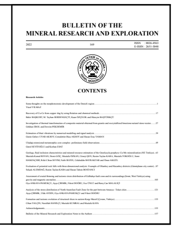

Evaluation of potential rock falls with three-dimensional analysis: Example of Oltanbey and Hasanbey districts (Gümüşhane city center)

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Research Article

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ABSTRACT

The central district campus of Gümüşhane, located on the Trabzon-Erzurum Highway, has a steep topography, and because of the effect of climatic and morphological structure, frequent rockfall events can cause loss of life and property from time to time. For these reasons, the slopes in some parts of the Oltanbey and Hasanbey districts of the central district of Gümüşhane, which pose a great threat in terms of rockfall potential, were chosen as the study area. In this study, three-dimensional rockfall analyzes were carried out using the RocPro3D program on the lines determined in the rockfall source zones with a high probability of rockfall. As a result of the analysis, it was determined that the rock blocks rolled from the O1, O2 and H1 source rock lines determined at the upper elevations of the study area threaten the settlements and road networks in Oltanbey and Hasanbey districts. With the 3D rockfall analysis, steel barrier was applied as a precautionary structure in the areas determined to be under the risk of rockfall, and the analyzes were carried out again considering the precautionary structures. By examining the results of the analyzes, the safest and most economical different barrier types have been proposed to eliminate the danger of rockfall.

1. Introduction

Due to its geological and geomorphological features, our country has many rockfall events, especially in the Black Sea Region. Gümüşhane city center (Figure 1), located on the Trabzon-Erzurum Highway in the Eastern Black Sea Region and located in the southern zone of the Eastern Pontide belt, is one of the places where rockfall events occur frequently.

In this study, rock masses on free, suspended or high steep slopes that threaten some parts of Oltanbey and Hasanbey districts in the central district of Gümüşhane were examined and a rockfall inventory map was created according to the locations of the fallen blocks. Three-dimensional rockfall analyses were carried out using RocPro3D (2014) computer program in areas with high rockfall probability considering the identified source rock areas, suspended discontinuity-controlled rock masses and rockfall inventory map. According to the data obtained; rolling trajectories of rock blocks, optimum steel barrier design was made considering the maximum span distances and kinetic energies of the rolling blocks, and barrier types were determined, and precautionary structures

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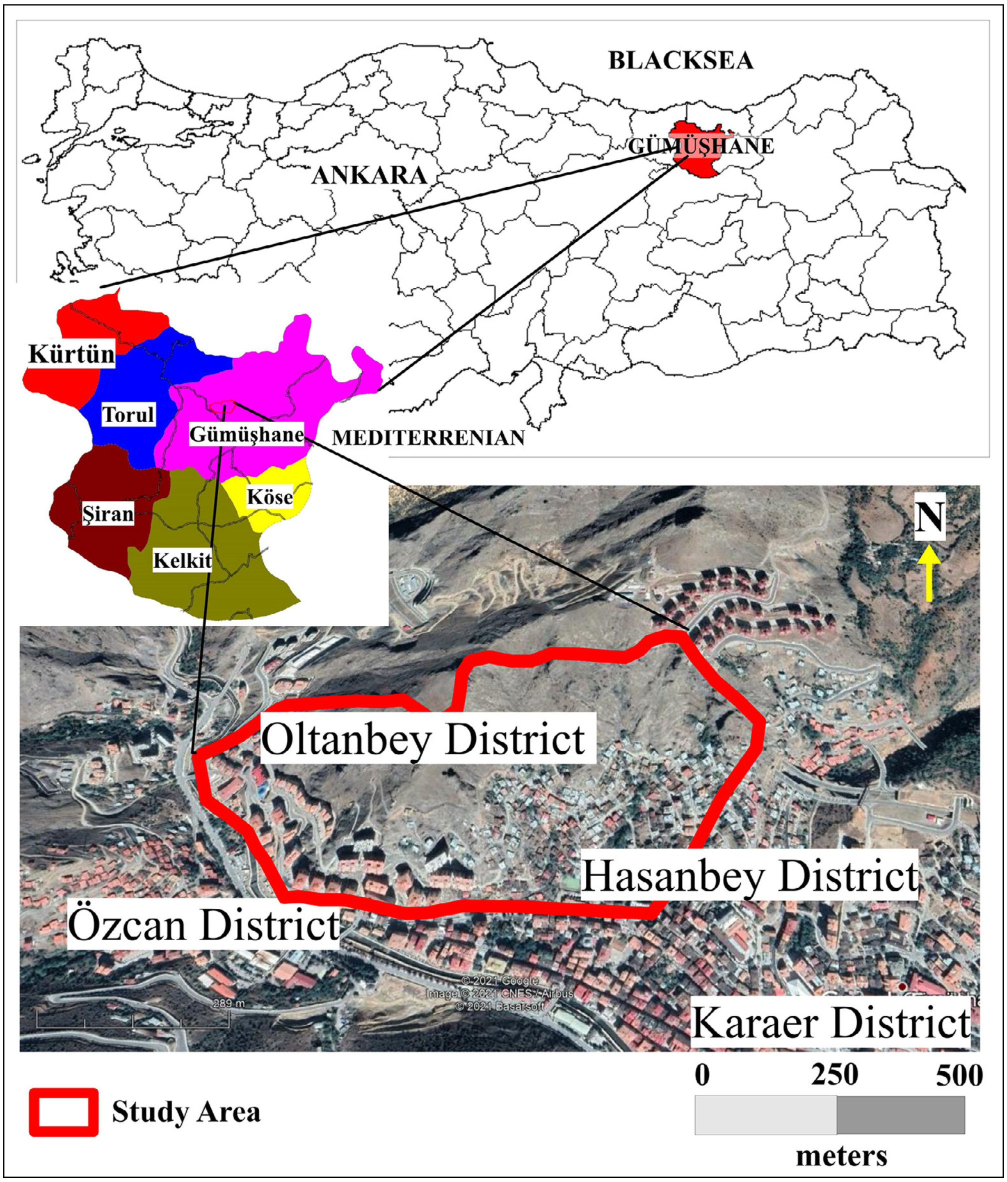

Figure 1- Location map of the study area.

were proposed considering the European Technical Approved Guide for Rockfall Prevention Kits (ETAG 27).

Many rockfall cases have been encountered in the study area so far. Although there have been loss of life and property due to rockfalls in Gümüşhane city center in the past, rockfall inventory map of Oltanbey and Hasanbey districts in Gümüşhane city center has been produced for the first time in this study, and three-dimensional rockfall analysis have been made and precautionary structures in potentially dangerous areas have been proposed.

In the region, which includes the study area, many engineering geology-based studies have been carried out so far (Tüdeş, 2001; Alemdağ vd., 2011; Tüdeş vd., 2012; Alemdağ vd., 2014; Gürocak vd., 2017).

Tüdeş (2001), in his PhD thesis study in the city center of Gümüşhane, examined the engineering properties of the rocks spreading in the settlement area. The researcher transferred parameters such as classification of rock masses, excavability, bearing capacity, seismicity of residential areas, flood assessments to the Geographical Information Systems (GIS) environment. He prepared the relevant maps in the GIS environment and evaluated the suitability of the study area for settlement.

Alemdağ et al. (2011), the excavability properties of the Late Carboniferous aged Gümüşhane Granitoid cropping out in Gümüşhane, and its vicinity were examined and classified in terms of excavability. According to the classifications made, it was determined that moderately weathered rock masses were removable, while highly weathered rock masses were excavated. In the excavations carried out in the study areas, it was determined that moderately weathered rock masses were removed using a hydraulic breaker, while highly weathered rock masses were excavated using a shovel.

Tüdeş et al. (2012), in their study in Gümüşhane city center, are considering the engineering characteristics of the rock masses outcropping in the study area and the seismicity and flooding conditions at the regional scale, they prepared a suitability map for the city center to assist the planners in site selection and the decisions to be taken regarding land use and emphasized the importance of creating a database.

Alemdağ et al. (2014) produced a solution by using different failure methods for the formation mechanism and rehabilitation of the landslide that occurred in the Gümüşhane Granitoid located in the Mordut region of Gümüşhane city center.

Gürocak et al. (2017), to determine the possible instability mechanism due to discontinuities in the rock mass in the area where the Gümüşhane Granitoid Complex spans, by kinematic analysis method and for the subsequent instability models, the creation of GIS-based maps in ArcGIS program and by using fuzzy interpretation method, the final instability map for the study area was produced.

Three-dimensional studies on rockfall analysis have started to increase in the last ten years in the literature, and some of these studies are summarized below.

Tonini and Abellán (2014), in the study titled the use of three-dimensional (3D) point clouds in geological hazards, obtained digital elevation models with point cloud data and evaluated the importance of these high-resolution data for the detection of geological hazards. In Lato and Vöge (2012), by using automatic mapping of rock discontinuities in 3D lidar and photogrammetry models, fracture and fracture systems of rocks and their mapping were provided. Topal et al. (2012), in their study, determined the spreading areas of the rocks that are likely to fall by performing two-dimensional (2D) RocFall analysis to determine the rockfall risk areas on the 17 profile lines selected around Kastamonu Castle (Türkiye). In Keskin (2013), the kinetic energy of the falling rocks, the distance they can travel, the jump height and speed were determined by modelling the cross-section lines created in the areas that are ruptured and in danger of rupture in the steep cliffs in the Boğaziçi (Erzincan, Türkiye) region, by modelling in the RocFall computer program. In Sarro et al. (2014), in the Son Poc rockfall (Mallorca, Spain) study, the geometry and parameters of the blocks in the existing rockfall area were revealed, all coefficients were calculated by back analysis method, and the areas at risk as a result of new rockfall events that may occur with 3D simulation were revealed. In Riquelme et al. (2015), by using 3D data, characterization of rock slopes with slope mass grading was revealed by numerical data of point clouds. In Yakar et al. (2015), they created three-dimensional, digital terrain model, orthophoto and vector maps of rockfall regions with Unmanned Aerial Vehicle (UAV) photogrammetry. As a result of the study, they have seen that high accuracy and precision data can be obtained with UAVs, they can be used for imaging hard-to-reach areas and measurements can be made in a short time. Therefore, they say that UAVs can be used in rockfall events and will play an active role in producing the necessary data for modelling the terrain. Wang et al. (2017), for automatic exposure fracture extraction from a 3D point cloud, developed different algorithms in the light of the data obtained from the lidar images and determined the areas of rockfalls that occurred or could occur. In Akın et al. (2019), in the study of evaluating the rock holding trench performance with 3D rockfall analysis; for the digital surface model, point cloud data obtained from photogrammetric images taken with an unmanned aerial vehicle created and 3D rockfall analysis were performed in RocPro3D software. It has been revealed that in general, the falling blocks were held by the trench excavated between the source zone and the settlement, but in some parts these blocks could continue to roll past the rock holding trench. Şener (2019), according to the results of GIS-based 3D modelling of possible rockfalls using unmanned aerial vehicles around Kasımlar Village (Isparta), determined the maximum kinetic energy, maximum jump height and maximum fall speeds in possible rockfalls and prepared the base data for the design of engineering structures to prevent possible rockfalls or to minimize their effects. In Alptekin and Yakar (2020), in their study of obtaining the 3D point cloud of rock blocks using terrestrial laser scanner, laser scanning of the rock falling from a rough terrain and threatening a house was performed to obtain the 3D model in high resolution and showed that these data can be used in 3D rockfall simulations.

2. Geology of the Study Area

The Alibaba Formation (Figure 2), which spreads in the city center of Gümüşhane (Hasanbey, Oltanbey and Özcan Districts), starts with a thin basal conglomerate and nummulitic sandy limestones and has the characteristics of a volcano sedimentary succession that continues with andesitic-basaltic pyroclastics (Tokel, 1972). Macroscopically, basic, and intermediate volcanic rocks are gray-green in color and occasionally porphyritic, with fractures and cracks, and intense silicification, argillization, pyritization and current alterations are observed along the fractures. Alibaba Formation overlies the Kermutdere Formation with an angular unconformity (Kaygusuz and Şen, 2011). Over these, bedded tuffs alternate with andesitic breccias. Andesite, basalt and pyroclastics, which are the subject of the study, are generally observed at the upper levels in the field (Figure 3). Considering the fossil determination of the samples taken from the clastics in the formation, the age of the unit was determined as Ypresian and Lutetian (Aydınçakır, 2014). The apparent thickness of the formation is approximately 400 m, and it was deposited in shallow marine and terrestrial environments, accompanied by intense volcanic activity.

3. Digital Terrain Models

Topography and vegetation have a significant influence on the orientation of rockfall lines and the rolling distance of falling blocks. The main advantage of 3D analysis over 2D analysis is that the possible rolling of the falling rock blocks is determined on the digital terrain model, not on a topographic section. This feature is very useful in determining which route a block to be rolled from the source rock area can actually follow and in determining the areas where improvement methods will be applied.

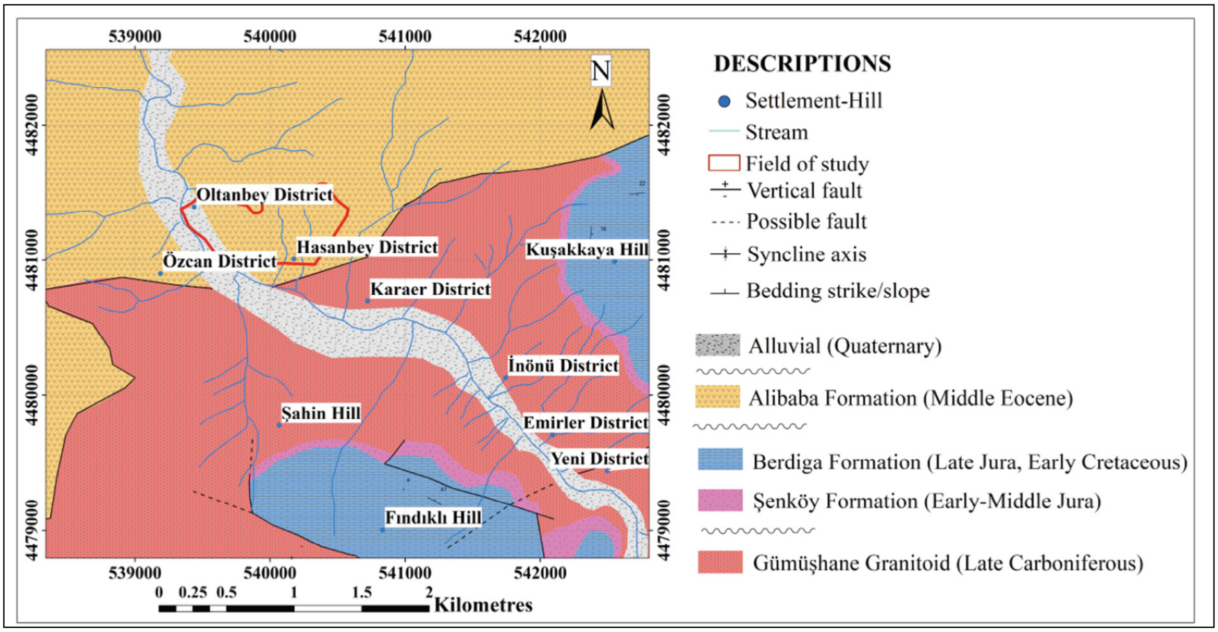

Figure 2- Geological map of the study area (modified from Kandemir, 2004).

Figure 3- a, b) Oltanbey District. Aydınlık Houses Sites Road andesites belonging to the Alibaba Formation in the field (view direction from north to south; c) Oltanbey District. Aydınlık Houses Sites and Afet Houses Sites andesites belonging to the Alibaba Formation in the field (view direction from west to east); d) Oltanbey District. Field view of andesites belonging to Alibaba Formation from Aydınlık Houses, Museum Houses Sites (view direction from south to north).

In the digital terrain model of the study area, vegetation, buildings, etc. to show small topographic changes with details and to determine healthier rolling routes, data to be obtained from medium-sized maps such as 1/25000 scale topographic maps and digital elevation models are extremely inadequate. In this study, high resolution orthophoto images and a high resolution (0.18 x 0.18 m) digital elevation model (DEM) produced from the point cloud (594.000 points) obtained in this context were used (Figure 4). The slope map (Figure 5) produced on the DEM was used to determine the source rock areas in 3D rockfall analysis, and the relief map (Figure 6) was used to visualize the areas threatened by the rolling trajectories determined in the RocPro3D program and all rasters are produced in the Turef TM39-Gauss-Krüger (ITRF 96/GRS 80) projection system.

4. Rockfall Analysis

To analyse the potential rockfall areas in the Oltanbey and Hasanbey districts, which are the subject of the study area, the source rock areas should be determined. The source rock areas where rockfall can occur were determined (on the slope map) based on equation 1, which considers the resolution of the digital terrain model.

$$a = 55 x RES^{-0.075} \quad (1)$$

The value (a) in the equation is the boundary slope value in degrees and RES is the resolution “in meters” of the digital elevation model. Considering these parameters, a value was found to be 62°. However, to stay in a safer area in terms of rockfall hazard, areas with a slope of more than 60° were accepted as the source rock area and the slope map was reclassified

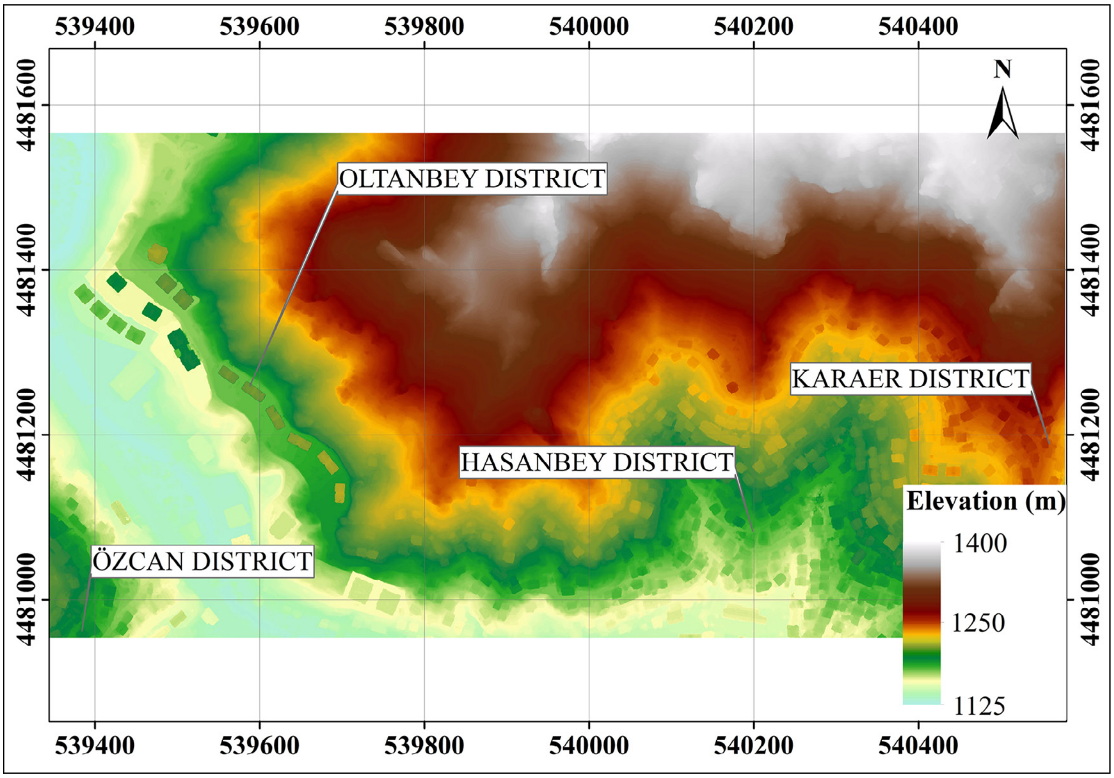

Figure 4- Digital elevation model of the study area.

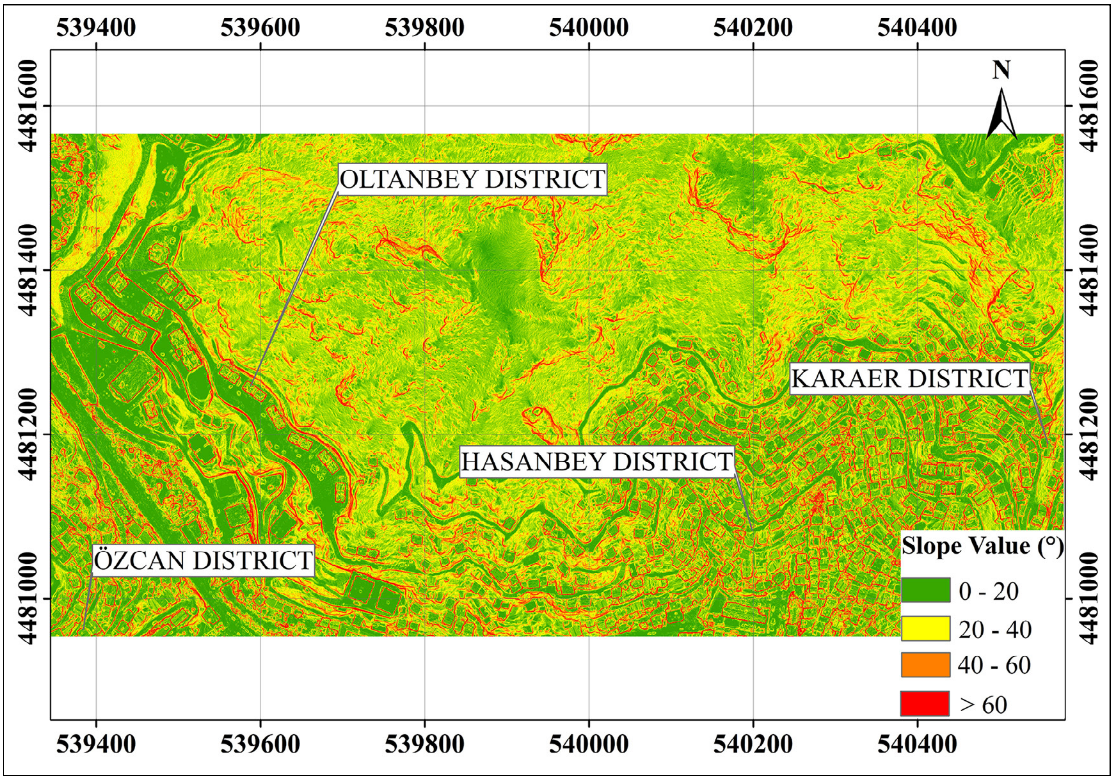

Figure 5- Slope map of the study area.

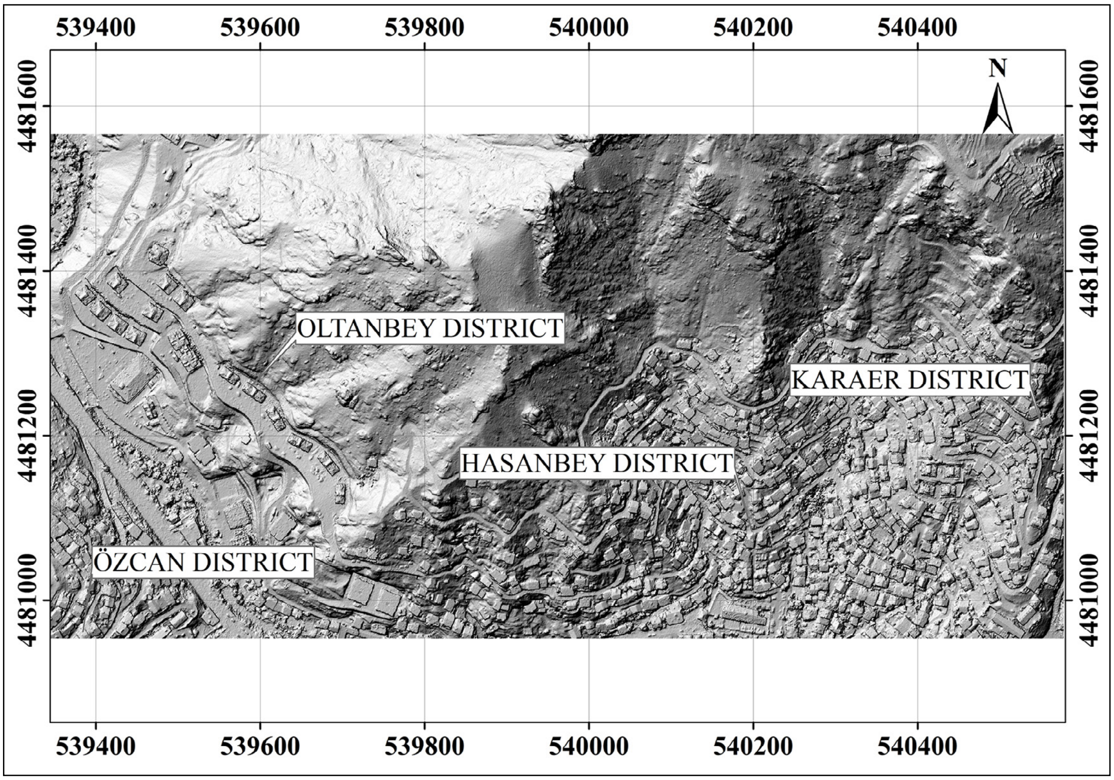

Figure 6- Relief map of the study area.

and a map showing the source rock areas was produced by transferring the borders onto the orthophoto.

By using 50 years of Disaster and Emergency (AFAD) data of the study area, orthophoto image and digital elevation model, suspended rock blocks in the active source rock areas and fallen rock blocks at lower elevations were determined and marked on the orthophoto by being detected in situ (Figure 7). In addition, rockfall events obtained through written and visual media were investigated and recorded from the past to the present, and a rockfall inventory map was obtained by processing on digital maps (Figure 8, URL-2, 2015; URL-6, 2016; URL-3, 2019; URL-5, 2019; URL-4, 2020; URL-1, 2020).

In order to model possible rockfalls in three dimensions in the study area, the locations, shapes and dimensions of the blocks were determined by considering the areas determined in the inventory map and the suspended blocks determined by field observations as well as the fallen blocks (Table 1).

Normal Return (Rn) and Tangential Return (Rt) parameters were obtained by trying different parameter data input variations and simulations by back analysis method for 10 fallen blocks whose coordinates were determined by selecting on the rockfall inventory map (Figure 9). In the light of back analysis and field observations in the study area, the most suitable parameters for the study area were determined by taking the average of the values obtained from 10 andesite blocks.

The parameters to be used in the analysis of possible blocks to fall in the Alibaba Formation were determined by retrospective analysis and by using the parameter bases of the RocPro3D program using 10 block samples that had previously fallen in the field and are given in Table 2. The parameters used in Table 2 belong to the probabilistic method selected in 3D rockfall analysis, and it is the preferred method for areas where variables such as lithological, slope, and roughness conditions differ in the rolling trajectory of the rock. Based on the assumption that the values assigned to the parameters used here can change during the analysis, the software defines the range in which these values can change, and the first value assigned is changed in line with the probabilistic

Figure 7- a) Oltanbey District Museum Houses Site. Andesite blocks that have broken off from the source rock areas (view direction from southeast to northwest), b) Oltanbey District Museum Houses Site. The building hit by the andesite block from the source rock areas (view direction from north to south), c) Oltanbey District Museum Houses Site. The building hit by the andesite block from the source rock areas (view direction from west to east).

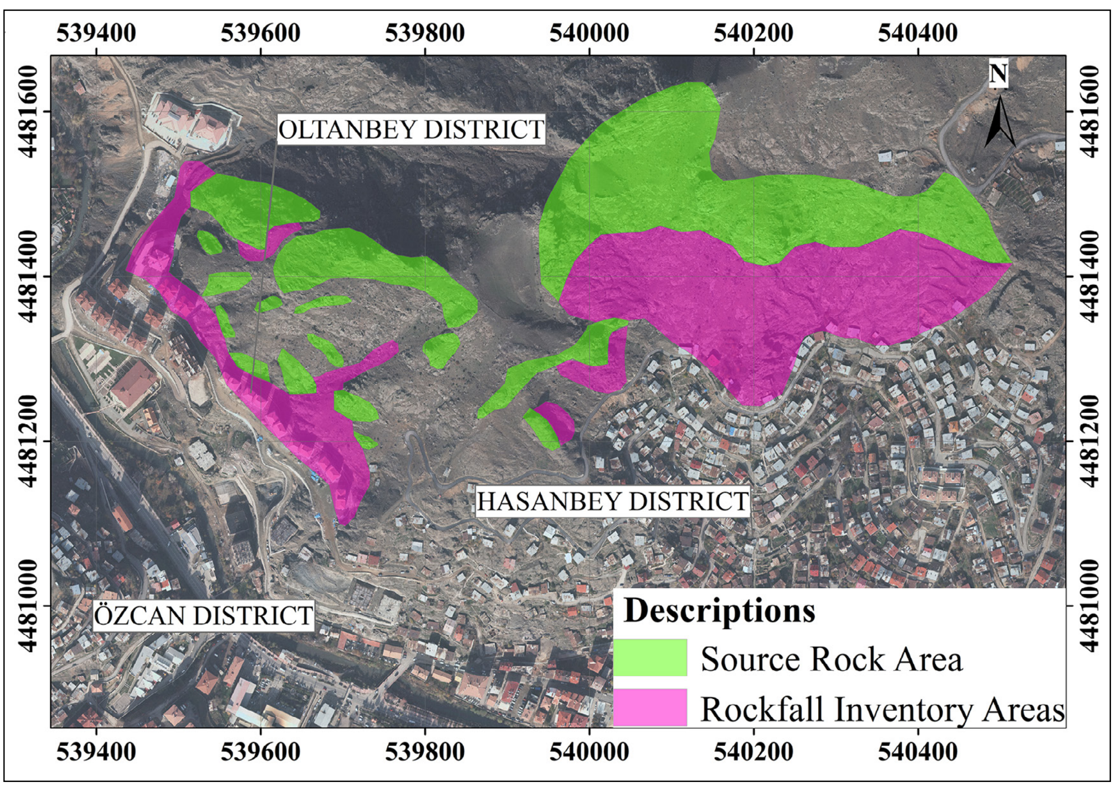

Figure 8- Source rock and rockfall inventory map determined in the study area.

Table 1- Shape and dimensions of fallen rock blocks.

Lithology	Andesite					
Sample	Falling Block Dimensions			Block Volume (m^3)	Block Shape	Density (kg/m^3)
	x (m)	y (m)	z (m)			
1	1.65	1.15	1.2	2.28	Quadrangular	2570
2	2.10	1.75	1.3	4.78	Quadrangular	2570
3	0.75	0.95	0.45	0.32	Quadrangular	2570
4	1.15	1.87	1.22	2.62	Quadrangular	2570
5	2.25	1.98	1.55	6.91	Quadrangular	2570

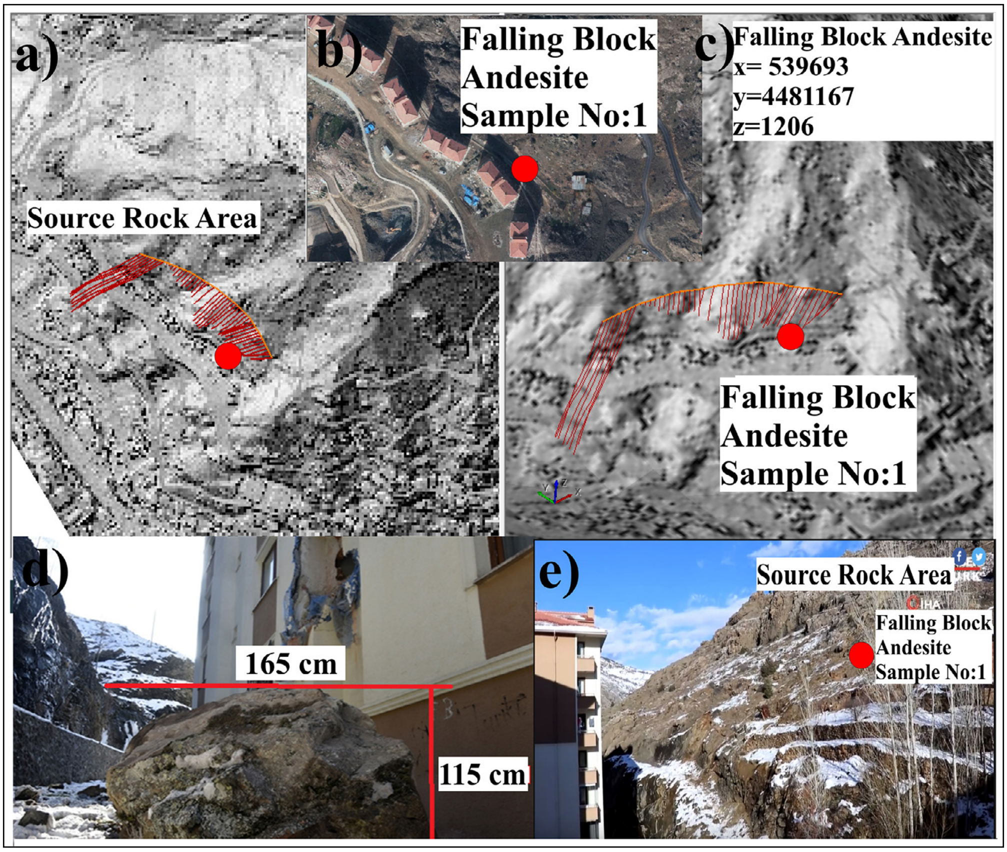

Figure 9- a) Relief map appearance of Source Rock Fields, b) orthophoto image of the fallen andesite block, c) the fallen block appears on the relief map, d) Oltanbey District. View of the andesite block striking the Museum Houses Site (view direction from west to east), e) Oltanbey District. View of the source rock areas at the upper level of the Museum Houses Site (view direction from east to west).

variables during the analysis, thus ensuring that the uncertainties arising from reasons such as speed, friction and surface heterogeneity are included in the analysis.

In the study area, the joint feature of the rock mass within the source rock areas of the Alibaba Formation and therefore the rapid development of weathering processes caused block ruptures of different sizes in many areas in the rock mass. 3D rockfall simulation was carried out with 3 (O1, O2, H1) fall line sections created in the study area, especially in areas where the slope is high. Parameters obtained from the analysis made; are the rolling energy, jump heights and span distances of the blocks and are given in the form of graphics (Figure 10-12).

Table 2- Input parameters used in RocPro3D program.

Andesite Rock Mass	Sample No: 1	Sample No:2	Sample No:3	Sample No:4	Sample No:5	Sample No:6	Sample No:7	Sample No:8	Sample No:9	Sample No:10	Average
Rn	0.50	0.51	0.52	0.48	0.49	0.50	0.52	0.50	0.52	0.48	0.50
Rt	0.80	0.81	0.78	0.83	0.79	0.81	0.82	0.78	0.79	0.81	0.80
Variability Δ_R %	10	10	10	10	10	10	10	10	10	10	10
Limit Speed V_R(lim) [m/s]	10	10	10	10	10	10	10	10	10	10	10
Limit Variable Δ_R (lim) %	2.1	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Lateral Deviation											
Variability Δ_Qh (°)	20	20	20	20	20	20	20	20	20	20	20
Limit Speed V_Qh (lim) [m/s]	10	10	10	10	10	10	10	10	10	10	10
Limit Variable Δ_Qh (lim) (°)	10	10	10	10	10	10	10	10	10	10	10
Bounce Back											
Variability Δ_Qv (°)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Limit Speed V_Qv (lim) [m/s]	10	10	10	10	10	10	10	10	10	10	10
Limit Variable Δ_v (lim) (°)	4	4	4	4	4	4	4	4	4	4	4
Coefficient of Friction											
k value	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Variability Δ_k (%)	10	10	10	10	10	10	10	10	10	10	10
Limit Speed V_k (lim) [m/s]	10	10	10	10	10	10	10	10	10	10	10
Limit Variable Δ_k (lim) %	10	10	10	10	10	10	10	10	10	10	10
Transition Parameters											
Angle β_lim (sudden event) (°)	2	2	2	2	2	2	2	2	2	2	2
Angle β_lim (inclined position) (°)	25	25	25	25	25	25	25	25	25	25	25

4.1. Source Rock Line No. O1

50 fallible rock blocks were identified for the O1 line selected in the source rock area with a high probability of rockfall from the upper elevations of Oltanbey District. As a result of the 3D analysis performed on 50 rock blocks on the O1 line, the blocks where andesite blocks move along the drainage networks show a maximum spread of around 148 m, the jump height is at most 7.5 m (Figure 10), and the highest kinetic energy generated by the rolling blocks. It was determined to be 1062 kJ. Andesite blocks approaching the settlements for the O1 line pose a high danger to the existing structures and the falling blocks spread into the settlements located at the lower levels and directly threaten the residences.

4.2. Source Rock Line No. O2

50 fallible rock blocks were defined for the O2 line selected in the source rock area with a high probability of rockfall from the upper elevations of the Oltanbey district. As a result of the 3D analysis performed on 50 rock blocks on the O2 line, it was determined that the andesite blocks moved along the drainage networks, the blocks spread out around 198 m at the most, the jump height was at most 6.5 m, and the largest kinetic energy created by the rolling blocks was 1161 kJ (Figure 11). The andesite blocks approaching the settlements for the O2 line pose a high danger to the existing structures and the falling blocks spread into the settlements located at the lower levels and directly threaten the residences.

4.3. Source Rock Line No. H1

As a result of the 3D analysis performed on 50 rock blocks defined for the H1 line selected in the source rock area with a high probability of rockfall from the upper elevations of Hasanbey neighbourhood, the andesite blocks move along the drainage networks,

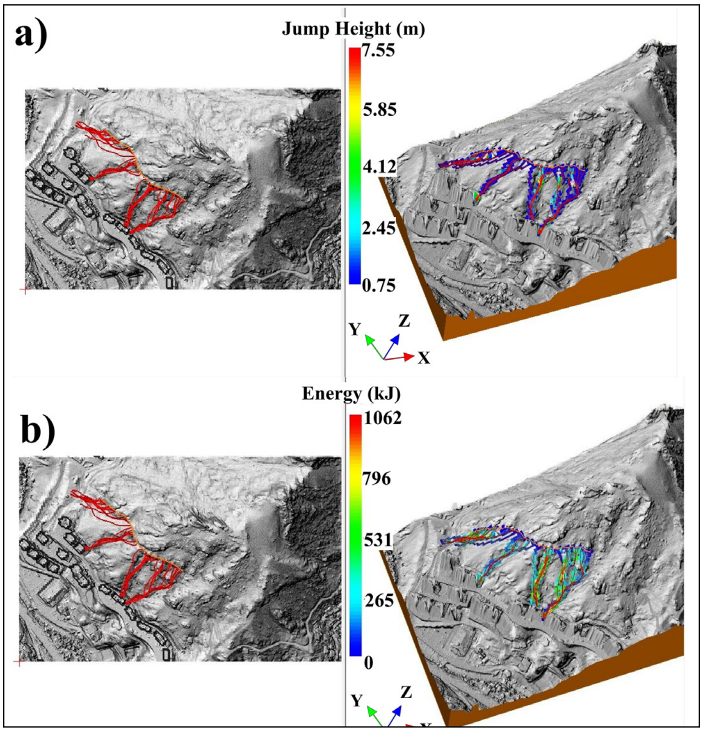

Figure 10- a) 2D, 3D maps showing the jump height and spreading route of 50 rock blocks rolled from the O1 source rock area, and b) 2D, 3D maps showing the energy and propagation route of 50 rock blocks rolled from the O1 source rock area.

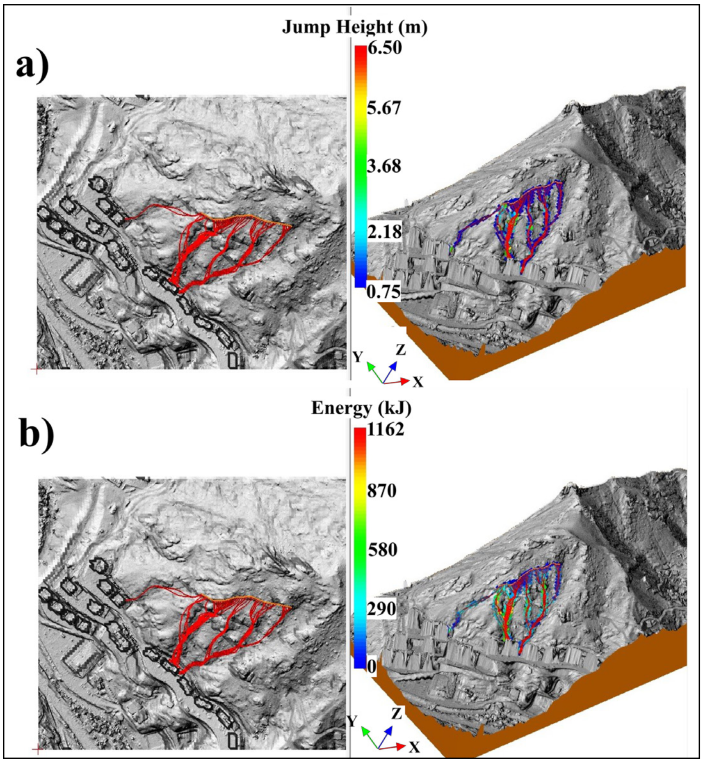

Figure 11- a) 2D, 3D maps showing the jump height and spreading route of 50 rock blocks rolled from the O2 source rock area, and b) 2D, 3D maps showing the energy and propagation route of 50 rock blocks rolled from the O2 source rock area.

the blocks spread around 176 m at most, the jump height is at most 5.35 m, and the largest kinetic energy formed by the rolling blocks was determined to be 999 kJ (Figure 12). Andesite blocks approaching the settlements for the H1 line also pose a high danger to the existing structures and threaten the residences.

5. Precautionary Structure Applied in Rockfall Areas

In the literature, many improvement methods (steel barrier, earth concrete embankment, combined net, trench, etc.) are applied to prevent rock blocks with high rolling probability that threaten residential areas and road routes. In this study, it was thought that the steel barrier application would be more accurate and practical due to the steep and high slope of the study area, the area to be treated consists of several source rock areas and the lack of a road network to which the construction machinery can access the improvement area. For this reason, by determining the appropriate areas in the topography where barrier application can be made, because of the rockfall analysis made, the barrier types were determined in ETAG 27 (Maximum Energy) standards by choosing meters with the lowest bounce height and energies of the tumbling blocks and at which they are damped (Figure 13).

As a result of the rockfall analyses made on the O1, O2, H1 lines in the three source rock areas determined in the Alibaba Formation, the routes followed by the blocks falling from the O1, O2, H1 lines in the areas affecting the settlement and road networks were considered. In the selection of the barrier type and location, the locations determined by considering the topographic slopes of the spreading rolling profiles, optimum kinetic energy and jump height parameters were checked in the field and the most suitable location was determined.

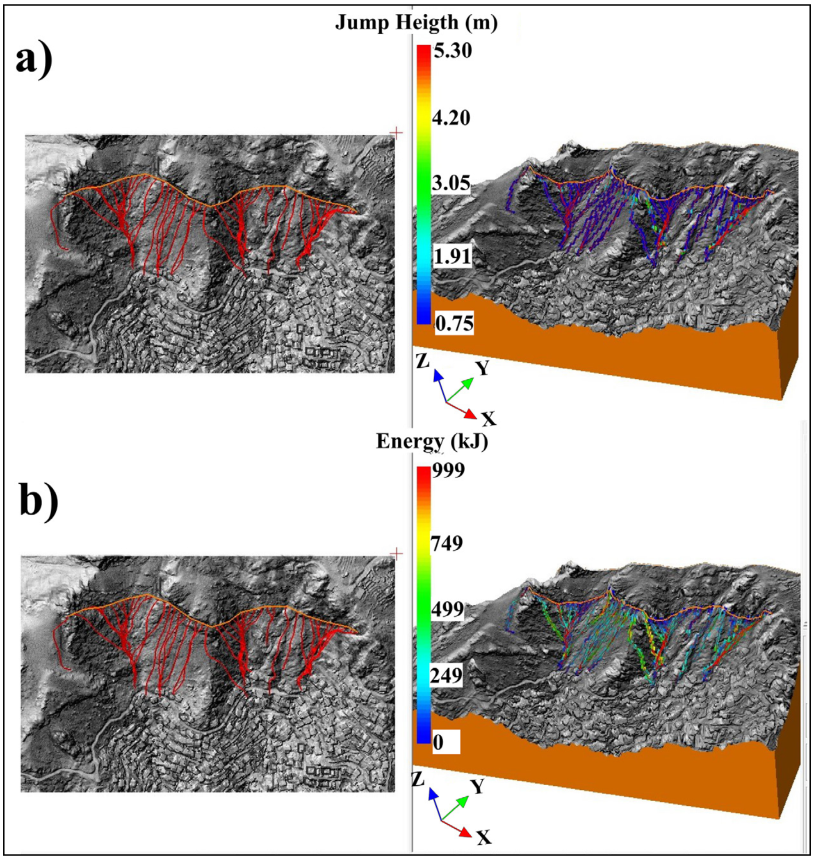

Figure 12- a) 2D, 3D maps showing the jump height and spreading route of 50 rock blocks rolled from the source rock area H1, and b) 2D, 3D maps showing the energy and propagation route of 50 rock blocks rolled from the source rock area H1.

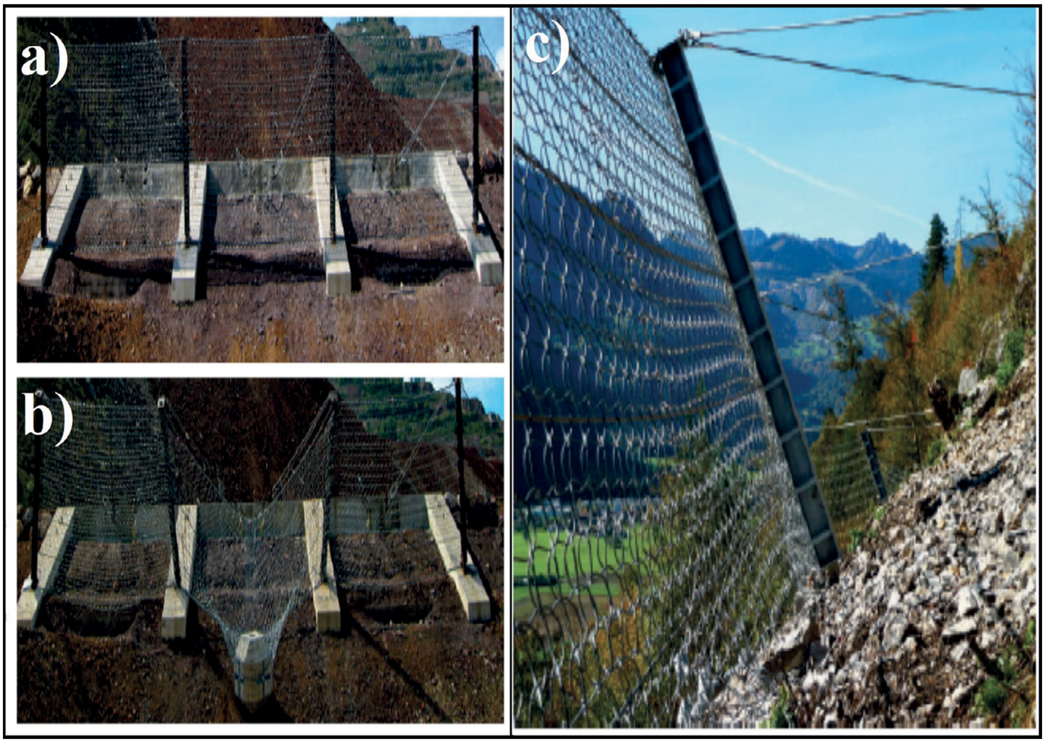

Figure 13- a) Steel barrier application example in ETAG 27 (ME) Standards (Trumer Rockfall), b) steel barrier example of preventing falling rock block in ETAG 27 (ME) standards (Trumer Rockfall), and c) steel barrier example in ETAG 27 (ME) standards (Trumer Rockfall).

5.1. Barrier Analysis for Blocks Falling from the O1 Source Rock Area

It was determined by the rockfall analysis that the blocks falling from the O1 source rock area threatened the settlement and road networks in the Oltanbey District. From the analysis results obtained, considering the bounce height and energy along the rolling line of the blocks, steel barrier types produced in ETAG standards; by applying the 2 m high and 500 kJ capacity class 2 barrier type in ETAG 27 (ME) standards, it was reanalysed, and it was observed that the rolling blocks were damped (Figure 14). The barrier line O1, which was applied in 3 different areas and with a total length of 238 m in sections, approximately 40 m below the source rock area in the study area, was applied to the area where the energies and jump height of the blocks falling from the source rock area were most appropriate (Figure 14). The jump height and energy graphs obtained from this analysis show that the selected barrier type is suitable and reliable for the precautionary structure.

5.2. Barrier Analysis for Blocks Falling from the O2 Source Rock Area

It was determined by the rockfall analysis that the blocks falling from the O2 source rock area threatened the settlement and road networks in Oltanbey District. In the light of the data obtained from the analysis results, considering the bounce height and energy along the rolling line of the blocks, from the steel barrier types produced in ETAG standards; with the application of the 3rd class barrier type with a height of 2 m and a capacity of 1000 kJ in ETAG 27 (ME) standards, it was reanalysed, and it was observed that the rolling blocks were damped (Figure 15).

The barrier line, which was applied in one piece and with a total length of 110 m, approximately 115 m below the source rock area in the study area, was applied to the area where the energies and jump height of the blocks falling from the O2 source rock area were most appropriate (Figure 15). The jump height and energy graphs obtained from this analysis show that the selected barrier type is suitable and reliable for the precautionary structure.

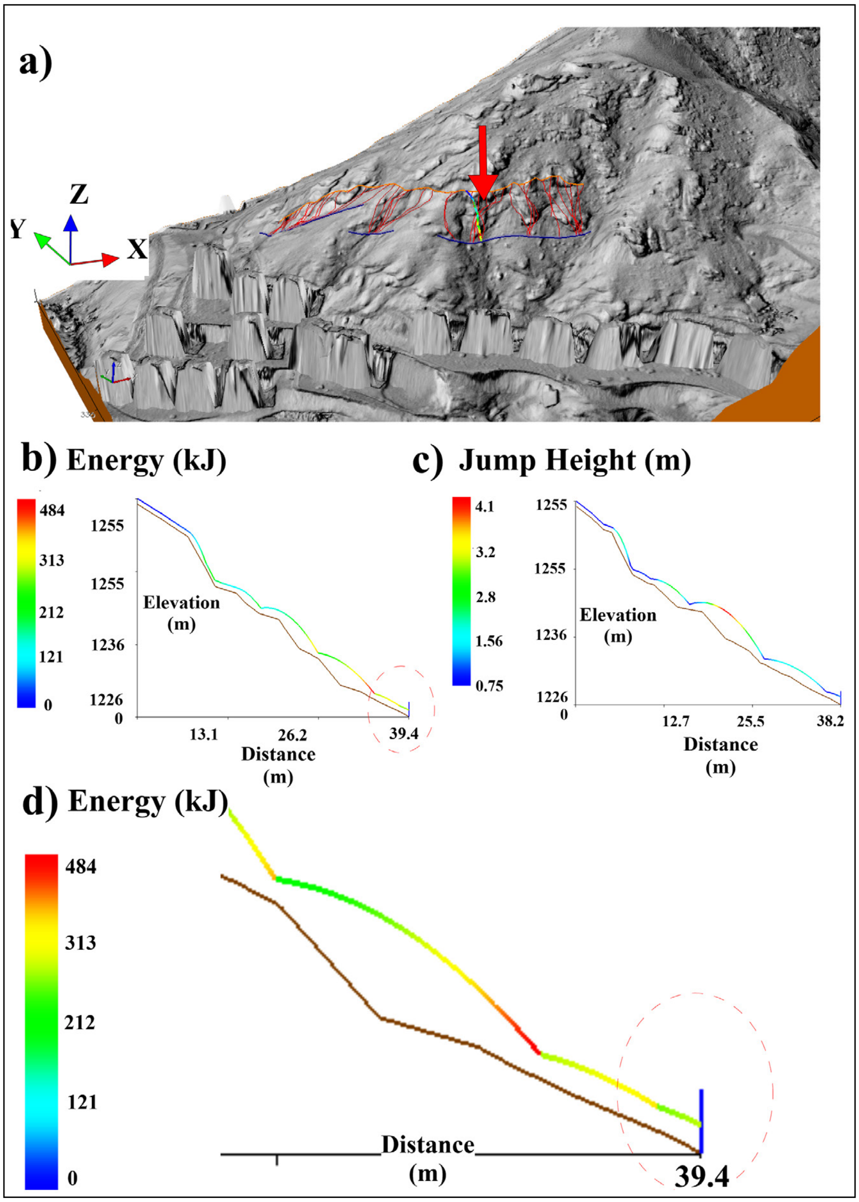

Figure 14- a) Steel barrier location and 3D rolling trajectories image at O1 rockfall line, b) barrier application energy graph on a single trajectory, c) barrier application jump height on a single trajectory, and d) close-up view of applying ETAG 27(ME) barrier to a single orbit.

5.3. Barrier Analysis for Blocks Falling from the H1 Source Rock Area

It was determined by the rockfall analysis that the blocks falling from the H1 source rock area threatened the settlement and road networks in Hasanbey District. From the results of the analysis, considering the bounce height and energy along the rolling line of the blocks, steel barrier types produced in ETAG standards; With the application of the 3rd class barrier type with a height of 2 m and a capacity of 500 kJ in ETAG 27 (ME) standards, it was reanalysed, and it was observed that the rolling blocks were damped (Figure 16).

The barrier line, which was applied approximately 120 m below the source rock area in the study area, in four parts and with a total length of 300 m, was applied to the area where the energies and jump height of the blocks falling from the H1 source rock area were most appropriate (Figure 16).

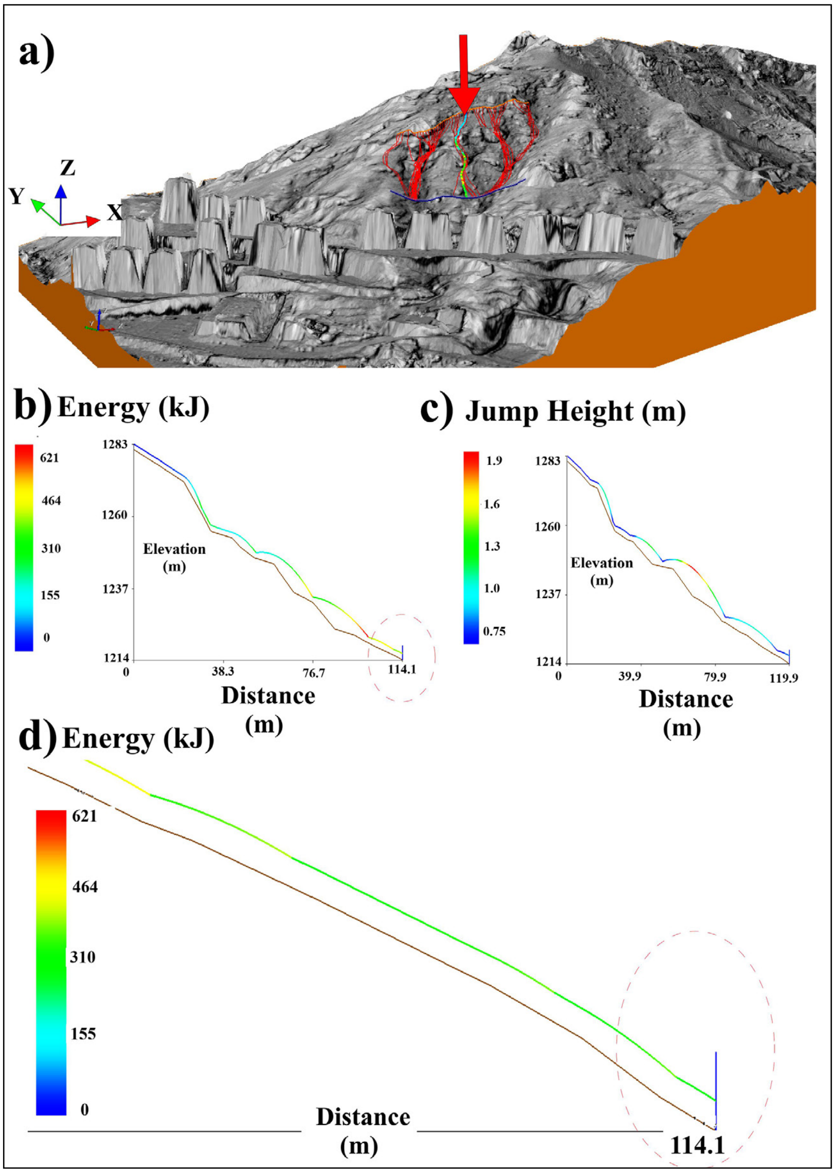

Figure 15- a) Steel barrier location and 3D rolling trajectories image at O2 rockfall line, b) barrier application energy graph on a single trajectory, c) barrier application jump height on a single trajectory, and d) close-up view of applying ETAG 27(ME) barrier to a single orbit.

The jump height and energy graphs obtained from this analysis show that the selected barrier type is suitable and reliable for the precautionary structure.

6. Results

In this study, the source rock areas on the high steep slopes that threaten some parts of the Oltanbey and Hasanbey districts of the central district of Gümüşhane province, along with the fallen and suspended blocks, were determined and a rockfall inventory map was created by considering the locations of the fallen blocks. Rockfall analysis were made using the RocPro3D program on the lines determined in the source rock areas with a high probability of rockfall, and the following results were obtained.

The blocks falling from the source rock areas in the study area consist of andesite rock masses belonging to the Alibaba Formation.

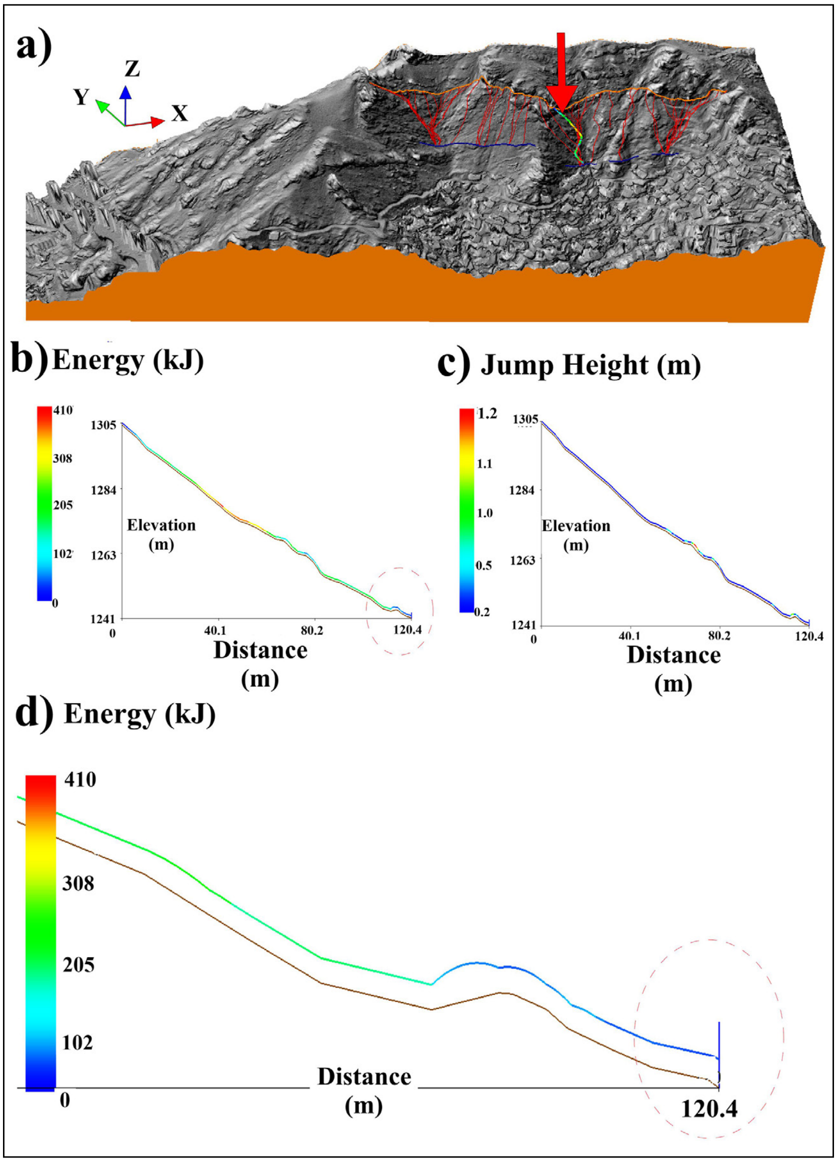

Figure 16- a) Steel barrier location and 3D rolling trajectories view at the H1 numbered rockfall line, b) barrier application energy graph on a single trajectory, c) barrier application jump height on a single trajectory, and d) close-up view of applying ETAG 27(ME) barrier to a single orbit.

In the creation of the digital terrain model of the study area, vegetation, buildings, etc. high resolution orthophoto images, digital elevation model, slope map and relief maps were used in order not to overlook the details and topographic details and to determine healthier rolling routes. All generated digital maps were produced on the Turef TM39-Gauss-Krüger (ITRF 96/GRS 80) projection system.

Based on the findings obtained from the examination of orthophoto images, the source rock areas where potential rockfall can occur for the study area were determined as areas with a slope of 60° and higher, and areas with a slope of 60° or more on the orthophoto were limited and a map showing the source rock areas was produced.

As a result of the field studies, the locations and geometries of the fallen rock blocks were determined in the field and a rockfall inventory map was created by comparing them with the digital terrain model and orthophoto image produced previously for the study area.

It was determined that the rock blocks rolled from the O1 source rock area showed a maximum spread of 148 m, the jump height was at most 7.5 m, and the maximum kinetic energy of the rolling blocks was 1062 kJ. It has been determined that the andesite blocks rolling from the source rock area pose a high danger for the Oltanbey District at the lower elevations and the secondary road networks providing access to the district, and the falling blocks have spread into the settlements at the lower elevations. As a result of the improvement analysis, the rockfall cross-section lines were re-analysed, and it was observed that the rolling blocks were damped by applying a 2 m high and 500 kJ capacity 2nd class steel barrier in ETAG 27 (ME) standards as the barrier type.

It has been determined that the rock blocks rolled from the O2 source rock area move along the drainage networks and the blocks have a maximum spread of 198 m, the jump height is up to 6.5 m and the greatest kinetic energy created by the rolling blocks is 1161 kJ. It has been determined that the rolling andesite blocks threaten some sites and road networks in Oltanbey District and sometimes roll into the site. As a result of the improvement analysis, the rockfall cross-section lines were re-analysed, and it was observed that the rolling blocks were damped with the application of a 3rd class steel barrier with a height of 2 m and a capacity of 1000 kJ in ETAG 27 (ME) standards.

It was determined that the rock blocks rolled from the source rock area H1 move along the drainage networks, the rock blocks spread around 176 m at most, the jump height is maximum 5.35 m, and the greatest kinetic energy created by the rolling blocks is 999 kJ. It has been determined that the rolling andesite blocks threaten some sites and road networks in Hasanbey District and spread to the site from time to time. As a result of the improvement analysis, it was determined that the rolling blocks were damped in the re-analysis of the rockfall section lines with the application of a 3rd class steel barrier with a height of 2 m and a capacity of 500 kJ in ETAG 27 (ME) standards.

The rockfall source and inventory areas determined because of this study, the spreading zones of the falling blocks and the improvement results obtained by 3D rockfall analysis which must be considered in the Gümüşhane province revision and implementation zoning plan changes will minimize and prevent future loss of life and property.

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