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ORIGINAL ARTICLE

Monitoring mass movements using Network-RTK measurement technique and producing potential rockfall scenarios in a paleo-landslide area

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Abstract

Mass movements resulting from landslides cause significant losses in terms of lives and property. Periodic observations of these movements using geodetic measurement techniques help to prevent these losses. Network-RTK measurement technique produces real-time location with centimeter accuracy, based on phase observations using a network of reference stations. In this study, the paleo-landslide area in the Işıklar location of Trabzon province, Esiroğlu district, Turkey, was chosen as the application area. This study aims to measure the application area between 2019 and 2021, using the Network-RTK technique to determine the mass movements. Additionally, there is a rock block in an area with a steep slope. The possible movement of this rock block is a threat to infrastructure facilities, residential areas, agricultural areas, and life safety if the mass movement continues. Within this scope, the potential movement scenarios of the block were produced using RocPro3D software and UAV photogrammetry. Scenarios following an ongoing mass movements in the region triggering another mass movement are discussed. In the light of the results obtained, mass movements in the vertical direction of up to 28 cm were detected in the area where the rock block is located in the last 2 years. The periodic continuation of mass movements in the study area, declared a disaster-prone area, confirms the importance of the rock block in the region. In another phase of the study, possible movement scenarios of the rock block were examined using a rockfall analysis. In this context, with the help of an unmanned aerial vehicle, a digital elevation model and orthophoto map of the region where the rock block is likely to move was produced and a base map to be used in rockfall analysis was obtained. As a result of the rockfall analysis, maps showing the speed, energy, spread, possible impacts, and stopping points were produced. With the examination of these maps, it has been determined that residential areas, agricultural areas, and infrastructure facilities in the study area may be significantly damaged.

Key words: mass movement, landslide, Network-RTK, paleo-landslide, RocPro 3D

1 Introduction

A disaster is defined as the results of natural, human-induced, or technological activities that cause physical, and environmental losses and a disruption of the order of social life. Disasters usually cannot be overcome by people's own abilities (Ergünay, 2009). Many kinds of disasters cause loss of life and property. Mass movements and rockfalls are among the leading types of disasters with such catastrophic effects. In order to minimize the destructive effects of these disasters, mass movements from landslides should be monitored using various measurement tools, and the data obtained should be interpreted. Both mass movements and rockfalls are important research topics that attract researchers' interest. In this context, there are numerous studies in the literature, with different scope and focus, that include mass movement and rockfall analysis. Distinctive samples of these studies are mentioned below in a chronological order.

Gili et al. (2000) examined the usability of fast static and real-time kinematic measurement methods in monitoring landslide areas. The study area (Vallcebre region, Spain) has been periodically monitored by terrestrial photogrammetry and geodetic measurement techniques since 1987. Notably, changes of up to 1.6 m occurred during 1996 – 1997. Bayrak (2003) attempted to create a dynamic deformation model which considers mass movement in the study area with help of geodetic, geophysical, and geological methodologies. In this context, a geodetic deformation network consisting of fourteen points, four of which are fixed points, was designed in the study area. The dynamic deformation model was completed by considering the groundwater level changes calculated in light of the obtained results. Kalkan et al. (2003) used such geotechnical methods as inclinometer and piezometer together with the results obtained from satellite-based geodetic methods to monitor landslides. The maximum movement determined by GNSS measurements between February 2000 and September 2003 was 130 cm horizontally and 30 cm vertically. Abidin et al. (2004) used geodetic and geotechnical methods to precisely determine the mass movements occurring in the landslide area in the West Java region of Indonesia. Three groundbreaking measurements have been conducted at fourteen GPS points set up since 2002, revealing significant mass movements at the level of centimeters to decimeters, depending on locations and observation periods. Squarzoni et al. (2005) set up nine deformation points in the landslide area located in the Ubaye valley of the French Alps. Measurements were conducted between October 2000 and October 2002 in 8 periods, detecting Changes up to 3 m. Saleh and Al-Bayari (2007) designed a 56-point geodetic deformation network in a landslide area in Jordan. The measurements were conducted in two periods, before and after the rainy seasons, in a two-year period (2002 – 2004), and mass movements up to 0.5 m per year were detected. Wang (2011) conducted rapid static and continuous static GNSS measurements from March 2008 at the landslide area in Ponce, Puerto Rico confirming changes up to 1 m horizontally and 0.5 meters vertically. Yuceses et al. (2016) aimed to model mass movements resulting from landslides in their study area to determine the direction of movement and to produce risk maps. Vertical movement were shown to differ-between +4.89 m and −0.60 m during the 3-year period. Sarro et al. (2018) used the RocPro3D software to simulate rockfall damage in the village of Cortes de Pallas, a cultural heritage site. They used SfM (Structure from Motion) techniques to determine the geometric characteristics of rock blocks and ALS (Aerial Laser Scanning) to produce the digital elevation model (DEM) of the study area. Tiwari et al. (2018) collected data in a potential landslide area using terrestrial laser scanning, GNSS, and robotic measurements. In this context, six geodetic GPS points were installed in the study area. Changes up to 0.1305 m in the horizontal direction and −2.1315 m in the vertical direction were detected. Akin et al. (2021) adopted RocPro3D to assess the effectiveness of a rockfall ditch in Akköy village, located in the steeps of Cappadocia, Turkeyto perform 3-D probabilistic rockfall analyses to confirm if rock blocks can cross the ditch. Samardžić-Petrović et al. (2020) have performed a detailed analysis of mass movements in a landslide since 2018 with periodic measurements using a geodetic deformation network consisting of sixty-six points, four of which are fixed points. The detected mass movements including horizontal changes of approximately 21% of all installed points are 0 – 2 cm, 33% are 2.01 – 4 cm, 23% are 4.01 – 6 cm, and finally, 33% are greater than 6 cm. Li et al. (2020) established a GNSS-based automatic deformation monitoring and warning system in 2017 for real-time monitoring of mass movements in the Zhutoushan landslide areashowing deformations up to 80 cm in the horizontal direction and up to 15 cm in the vertical direction. Ozturk et al. (2022) adopted UAV photogrammetry to model rock blocks and to propose rockfall scenarios in Murtaza Village, Niğde, Turkey. Retaining walls with a length of 142 m and a width of 1.5 m were modelled to prevent potential rockfalls in the area where the risk is high. Leyva et al. (2022) investigated the correlation between rockfall probability and rainfall in Anaga Nature Reserve in Tenerife, Canary Islands, Spain. The data on rockfalls and rainfalls during the period 2010 – 2016 confirmed the correlation. The results show that intense rainfalls can trigger new landslides or reactivate old landslides and rockfalls.

Both terrestrial and satellite-based measurement methods for monitoring mass movements are described in the literature of the subject. Examples of terrestrial measurement methods include: robotic electronic rangefinders, terrestrial laser scanners, and the terrestrial synthetic aperture radar technique. Synthetic Aperture Radar Techniques, Unmanned Aerial Vehicle-based applications and GNSS measurement methods are examples of satellite-based measurement methods.

This study has two main purposes. The first is to measure the mass movements periodically in an old paleo-landslide area using a CORS compatible GNSS receiver with the Network-RTK technique. The second is to propose potential rockfall scenarios in the landslide area using the UAV photogrammetry technique. In this study, it has been possible to apply both landslide and rockfall analyses together in the same study area – an old landslide area that includes residential areas and agricultural land where mass movement has continued since 1952. A number of mass movements have occurred in the region from past to present. As a result of these mass movements, multiple residential and agricultural areas in the region have been damaged. Detection and investigations of mass movements in the region by authorized public institutions are limited to superficial observations devoid of scientific studies and field studies. Therefore, periodic monitoring of the mass movements in the region with modern measurement techniques and interpretation of the results will shed light on the analysis of these movements in a more meaningful and detailed way. Additionally, the presence of a rock block within the boundaries of the study area – a region with a high slope value and where mass movement is expected – shows how crucial the possible movement scenarios produced for the rock block are. The movement of the rock block as a result of the ongoing mass movements due to the landslide disaster in the region poses a significant threat to the residential areas and agricultural land within the study area. As a result of the rockfall analysis conducted in this context, the identification of risky agricultural and residential areas in the region is essential to plan precautionary measures.

2 Material and Methods

2.1 Study area

The study area is in the Işıklar location of Esiroğlu District, Maçka, East Black Sea Region and is located east of the Trabzon-Gümüşhane Highway. The area is also approximately 2 km away from Atasu Dam, which provides drinking water for Trabzon province. A large part of the study area is located in a region with a high slope up to 60% due to its topographic structure (Figure 1). This paleo-landslide area was selected in the process of the preliminary investigations (AFAD, 2016). Records and reports of mass movements from past to present in Maçka district, which is one of the districts where landslide disasters are experienced most frequently, were examinedleading to this old paleo-landslide area being declared a disaster-exposed area.

Although the study area is located on an old landslide area, it has been exposed to mass movements that have continued since 1952 for such various reasons as: a high precipitation potential, uncontrolled explosions, deterioration of the natural drainage structure, etc. According to the province directorate's disaster and emergency records, as a result of the said mass movements, many houses and

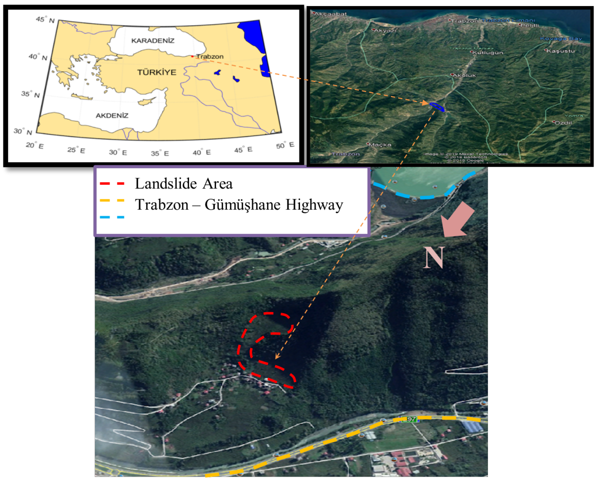

Figure 1. The study area

Figure 2. a) The mass movement-induced damage of the constructions in the study area. b) The surface cracks as a result of mass movements in the study area.

agricultural land in the region were destroyed. Within the scope of the measures taken as a result of these destructions, the region was declared a disaster area and the construction of new structures in this region was prevented in accordance with official procedures. These ongoing mass movements cause critical damage to habitation in the study area (Figure 2a), as well as changes in the land surface (Figure 2b). The high slope and intense rainfall in the region are the main triggers of the landslide hazard. Maçka district of Trabzon province is the district with the most frequent landslides observed both in the province and throughout the country. Esiroğlu Işıklar location is a region settled on a potential landslide area with a remarkably high slope. According to the damage assessment studies conducted by AFAD (Disaster and Emergency Management Authority), the landslide disaster has affected a total of fifty-seven houses in the region and four of these houses have been heavily damaged. This situation adversely affects the daily lives of the people in the region (AFAD, 2016).

2.2 Application of Network-RTK Measurement Technique

Network-RTK is a technique used for determining positions with centimeter precision and in real-time based on phase observations at longer base distances (50–100 km) compared to the Standard RTK measurement technique. In the Network-RTK technique, atmospheric modelling of a specific region is provided by the data of

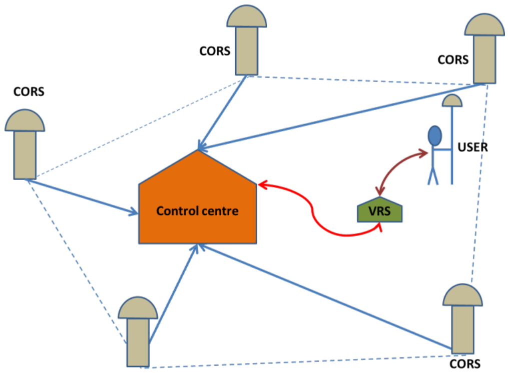

Figure 3. The demonstration of the Network-RTK's operating principle (Geo-matching, 2023)

Figure 4. CORS-TR system

multiple reference stations instead of depending on a single reference station (Kahveci, 2009) (Figure 3). The rover in a Network-RTK system can connect to the server in one of two ways: radio modems and GSM (Global System for Mobile Communications). The rover instantly calculates its location when it receives real-time kinematic. The method of transferring network data to the rovers depends on:

- corrections calculated at the network of reference station or rover,
- the content of the information to be sent,
- data transfer protocol and media (Pektaş, 2010; İnal et al., 2014).

The most frequent application of this measurement technique is fixed GNSS networks in today's conditions. The CORS technique is a widely used Network-RTK variant, which enables to calculate instantaneous location information in real time. For this purpose, the CORS-TR (Continuously Operating Reference Stations-TR) network consisting of 146 points has been established in Turkey (Figure 4). In this context, CORS stations covering the whole country are connected to a control center and the positions of the stations and atmospheric corrections can be calculated and modeled continuously.

For this study, a topographic survey of the study area was conducted using this measurement method, for two periods: September 2019 and September 2021. A dual-frequency Topcon GR-5 brand CORS-compatible GNSS receiver was used. This satellite receiver can receive signals from both GPS and GLONASS satellite systems. The workflow of this measurement technique, which was used in the process of detecting the mass movements occurring in the study area is shown in Figure 5.

First, the topographic survey of the study area was conducted using the CORS-TR technique with the GNSS receiver. The CORS-TR technique offers the accuracy of $\pm$ 4cm in seconds, and it does not need a second fixed GNSS receiver or a second operator. In addition, the time periods in which the satellites assumed the most suitable geometry were chosen as the measurement days. The study area was separated by virtual grids in a one-meter range, and the

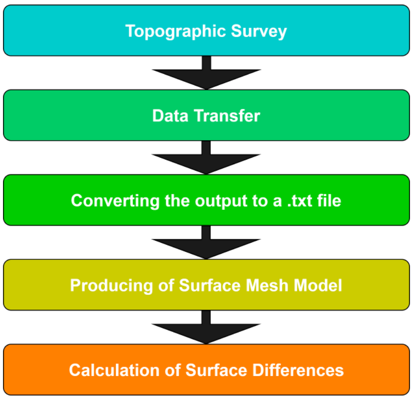

Figure 5. The workflow of the mass movement detection

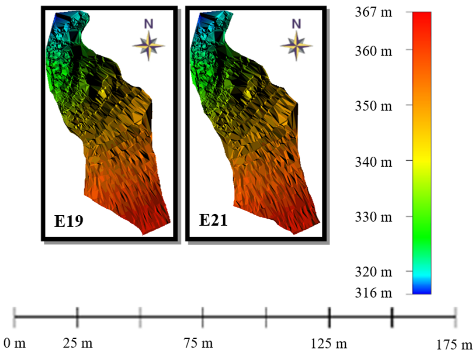

Figure 6. Surface mesh models of E19 and E21 measurement periods (Region-1)

location information of each grid was calculated using GNSS receiver. With the elimination of the phase-initial uncertainty, each point was measured three times at a recording interval of 5 seconds. The exact coordinate values of each point were calculated using the average of these three periods. Then, the spatial data of each survey point was transferred to CAD software. After the point data were converted into a .txt file using the CAD software, surface mesh models of the study area were produced for each period using photogrammetric software. Consequently, the surface differences between the periods were calculated by a spatial difference operation of GIS software.

A total of two periods (E19 (September 2019) and E21 (September 2021)) Network-RTK measurement processes were conducted in the study area, which was divided into two separate regions featuring different topographic structures and each region was evaluated separately (see Figure 16). Surface mesh models were produced from the measurement data collected for each period, and surface differences were calculated for the regions divided into two groups. The surface mesh models of these two regions for the two period measurement processes are shown in Figure 6 and Figure 7, respectively.

Surface differences of each region were alanysed with the help of surface mesh models belonging to regions 1 and 2 for different periods (E19 and E21), using the surface difference module of the ArcGIS program. This module has the principle of establishing a geometric correlation between the triangles of both surfaces of a region. First, one of the surfaces is used as the reference surface. Considering the positions of the triangle models on the first surface on the second surface, three different options emerge. These options can be above, below, or at the level of the intersection. Considering the surface difference data obtained between the E19 and E21 periods, significant changes in the vertical movement (Figures 8 and 9) were noticed.

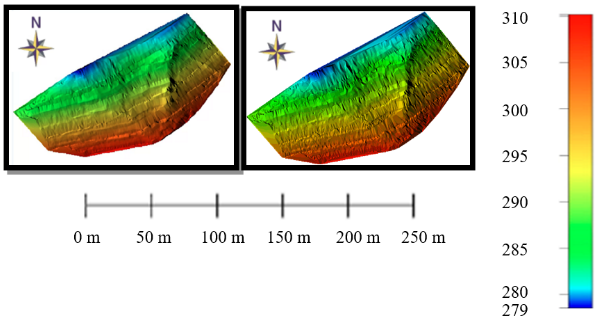

Figure 7. Surface mesh models of E19 and E21 measurement periods (Region-2).

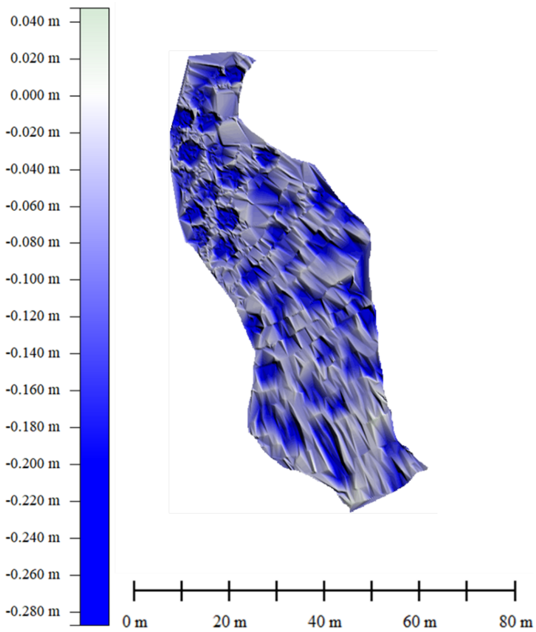

Figure 8. Surface differences of E19 and E21 measurement periods (Region-1).

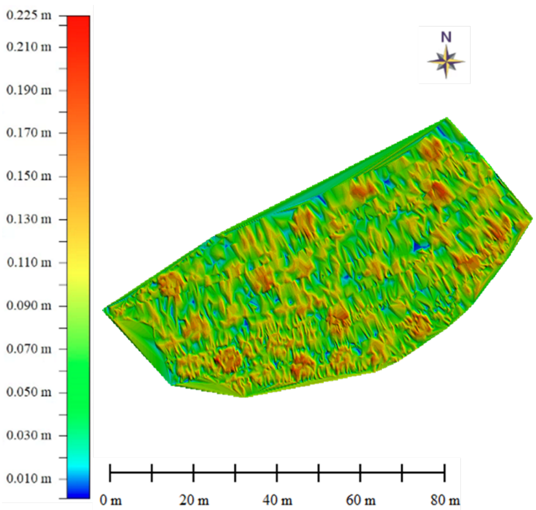

Figure 9. Surface differences of E19 and E21 measurement periods (Region-2).

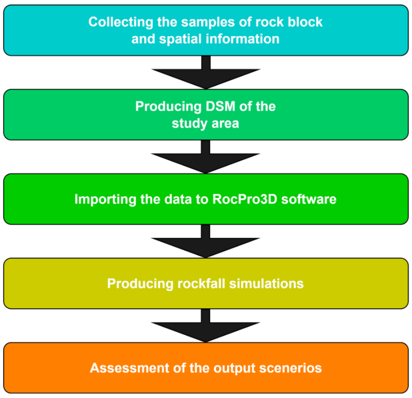

Figure 10. The workflow of the producing rockfall scenarios

2.3 Producing Potential Rockfall Scenarios Using UAV Photogrammetry

Rockfalls, being among the geologic-based natural disaster types, are defined as rapid and sudden movements of rock blocks along discontinuous surfaces on slopes as a result of the gravity force (Koçyiğit, 2019). This disaster causes serious losses of life and property due to its high speed and kinetic energy.

There is a need for 2D or 3D rockfall simulations to minimize the possible lossesby creating various types of maps such as fall trajectories, dispersion, kinetic energy, and velocity maps of the rock block (Şener, 2019). Using these parameters, it becomes possible to take various precautions (breaking in place, trenching, nailing, etc.) to prevent or reduce the hazard of a rockfall.

In this study, the scenarios that may occur as a result of a possible rock movement in the paleo-landslide area were described using the RocPro3D software. In RocPro3D software, different geological units can be defined on the 3-dimensional digital surface model on which the rockfall will be modeled, and different return coefficients (Rn and Rt) and friction coefficients can be assigned to these units. That is why this software has been chosen.

RocPro3D is a software tool that enables simulations of rockfall trajectories and safe zones in 3D space (RocPro3D, 2014). The software conducts analyses using heterogeneous rock blocks which have different geomechanical soil models over surface models. The required parameters are block parameters and soil parameters. The block parameters consist of starting position, mass and size of the block and starting velocity or falling height. The soil parameters include the dynamic friction coefficient, the normal and tangential restitution coefficients, the horizontal deviation, and the flattening of the rebound angle (Li and Lan, 2015). Using these inputs, 3D rockfall simulations can be obtained and the structures that are possibly damaged can be identified with a rigid body approach. There are many studies that use RocPro3D in the literature on rockfall analysis, for example, Sarro et al. (2018) and Akin et al. (2021). The workflow conducted for rockfall analysis using RocPro3D is presented in Figure 10.

2.4 Collecting the samples of the rock block and spatial information

At this stage, field surveys were conducted on the rock block (Figure 11). First, the position and volume of the rock block were determined. This detection was conducted with the help of a GNSS receiver. First, the volume of the rock was calculated by measuring the bottom, top and sides of the rock. In addition, for verification purposes, geophysical measurement data conducted within the scope of the project in 2019 in the region were used. In the light of the results obtained, the volume of the rock block was calculated as 18 m^3. In addition, a small piece of the block was broken, and laboratory samples were taken.

Figure 11. The rock block in the study area.

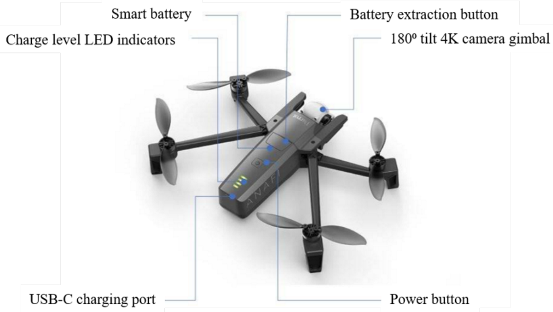

Figure 12. Anafi Parrot UAV (Parrot, 2018)

2.5 Producing DEM of the study area

At this stage, the digital elevation model (DEM) of the region where the rock is located and can be reached with its possible movement was created by adopting UAV photogrammetry with an Anafi Parrot UAV (Figure 12). The technical specifications of the unmanned aerial vehicle and its camera are given in Table 1 and Table 2, respectively.

Table 1. The technical specifications of Anafi Parrot (Parrot, 2018)

Features	Value
Total Weight	320 g
Controller Weight	386 g
Battery Weight	126 g
Number of Batteries	4
Flight time	25 min.
Max Horizontal Speed	15.2 m/s
Max Vertical Speed	4 m/s
Max Wind Resistance	13.9 m/s
Max Distance	4000 m
Operating Temperature Range	-10 – 40 C°

Table 2. The technical specifications of of the vehicle's camera (Parrot, 2018)

Features	Value
Built-in Camera	Yes
Lens aperture	2.4 /f
Sensor Type	CMOS
Sensor Size	1/2.4 inch
Active Pixel	21 MP
Video Resolution	4K
Video Frame Rate	30 fps
Optical Zoom	Yes
Zoom Ratio	2.8 x
Snapshot Transfer	Yes
Photo Resolution	5344x4016

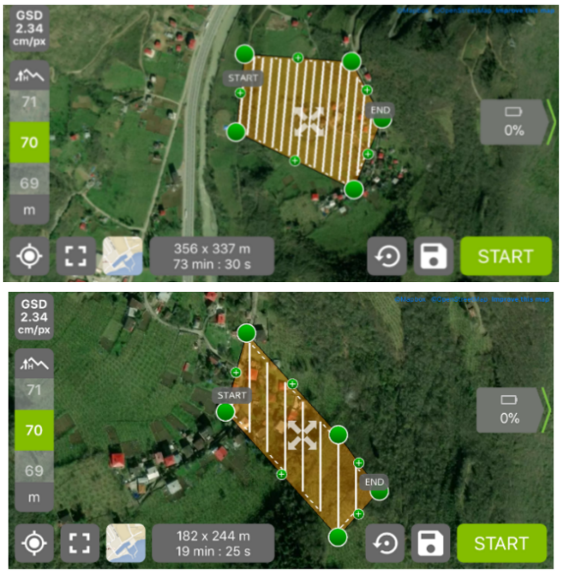

Figure 13. The flight plans on the study area

The missions created by arranging the flight plans for the area using the Pix4d Capture program were transferred to the UAV (Figure 13). Due to the size of the study area, the limited airtime of the unmanned aerial vehicle used, and the varying topographic structures of the region, the study area was divided into two different regions and two different flight plans were produced. Considering the topographic structure of the study area, the flight height was determined as 70 m and the overlap rates for both columns were determined as 80%.

For the digital elevation model and orthophoto map to be obtained with the help of the UAV, to have the real coordinates on the ground and to eliminate the errors that occur, there is a need for homogeneously distributed ground control points (GCPs) in the work area to be flown. In the production phase of the orthophoto and digital elevation model, which is a part of this study, a total of six ground control points were established in the terrain before the flight operation was performed (see Figure 15). These points were applied to the terrain with the help of spray paint and cardboard plates. In addition, the measurements of the ground control points in the terrain were taken with the help of the GNSS receiver, and the exact coordinate values of the points were calculated accordingly.

During the flight procedures, a total of 328 vertical aerial photographs of the study area were taken and processed with photogrammetric methods using Photoscan Agisoft Professional, commercial software that produces 3D data for different purposes. Thus, the DEM, orthophoto map and the general view of the study area were generated (Figures 14 – 16).

The ground sampling distance of the obtained DEM and orthophoto map was 2.34 cm/pixel, and a total of 17 871 410 points were captured.

Selected specifications of the camera used in the flights to generate the digital elevation model and orthophoto map is summarized in Table 3.

In addition, the root-mean-square values of the ground control points defined in the program during the creation of the orthophoto map and the digital elevation model are given in Table 4.

2.6 Importing the produced data to the RocPro3D Software

The dense point cloud data compiled in the previous step was converted into the .stl format with the help of Agisoft Metashape program and transferred to RocPro3D software. Hence, DEM of the

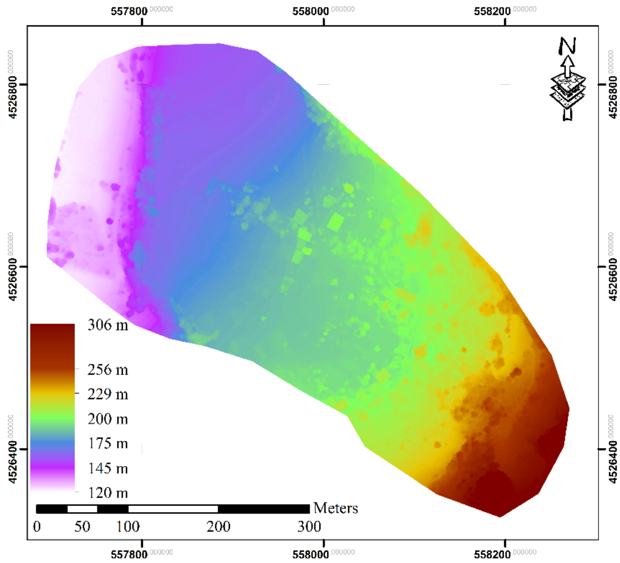

Figure 14. The DEM of the study area

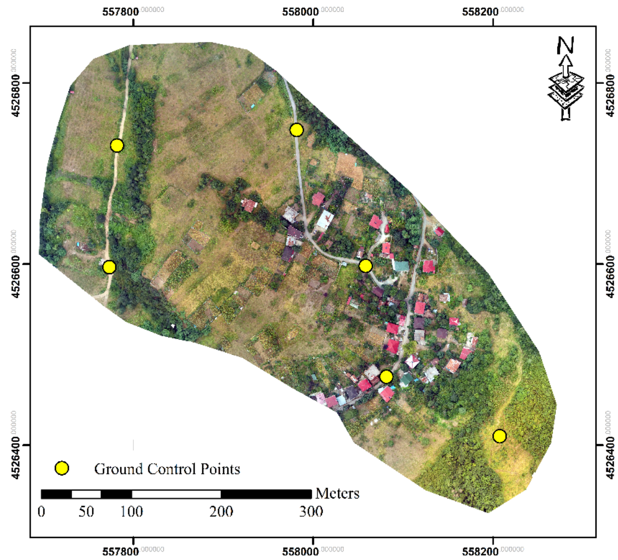

Figure 15. The orthophoto map of the study area

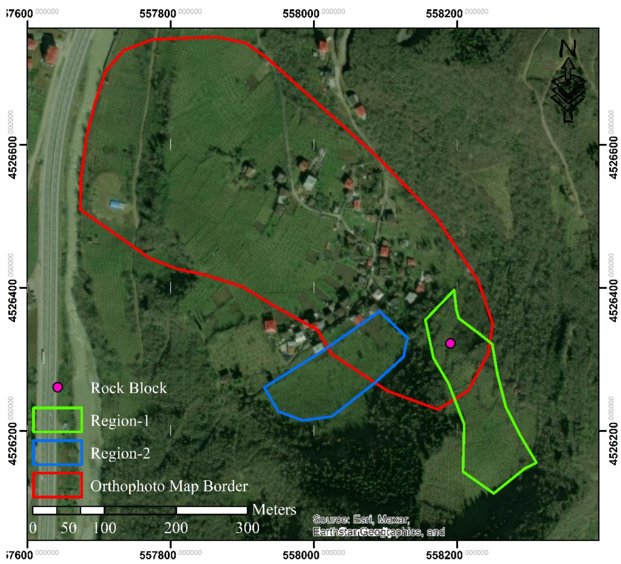

Figure 16. The general view of the study area and subregions.

Table 3. Camera locations and image overlap

Number of images	328
Resolution	4608 x 3456
Focal Length	4 mm
Pixel Size	1.34 x 1.34 µm
Flying altitude	70 m
Ground resolution	2.34 cm/pixel
Coverage area	0.185 km^2
Camera stations	328
Total points	17 871 410

Table 4. Root mean square error values of ground control points (GCP)

GCP	X (cm)	Y (cm)	Z (cm)	Total Error (cm)
1	1.04715	0.92147	0.74583	1.58174
2	1.47290	1.29389	0.98729	2.19507
3	2.08912	2.17021	1.97321	3.60108
4	0.92133	0.75219	1.08320	1.60871
5	0.56281	0.82375	0.96782	1.38996
6	1.75981	1.93721	2.14397	3.38324

terrain was defined to the RocPro3D software (Figure 17). In addition, to perform the analysis correctly, the parameters specified in the following paragraph were defined to the software.

The region where the block is likely to move and its surroundings are completely covered with talus and there is also vegetation. In the analyses, the region where the block will move was chosen as talus covered with vegetation. In this case, the normal rebound coefficient was set to 0.315, the tangent rebound coefficient was set to 0.80, and the internal friction angle was set to 12.78. The unit volume weight of the block that is likely to move was calculated as 2.6 g/cm^3. As a result of the analysis, the block's movement speed, energy, jump height, impact, and spread map were created.

2.7 Producing Rockfall Simulations

After defining the parameters and importing the solid model to the software, the simulation step was carried out. In this context, first, slope and aspect maps of the area were generated (Figure 18).

Next, regarding the rock block existing in the study area,

- Spread Map (Figure 19)
- Energy and Velocity Maps (Figure 20)
- Maps of the possible stop and impact points were created with the help of the RocPro3D software (Figure 21 and Figure 22).

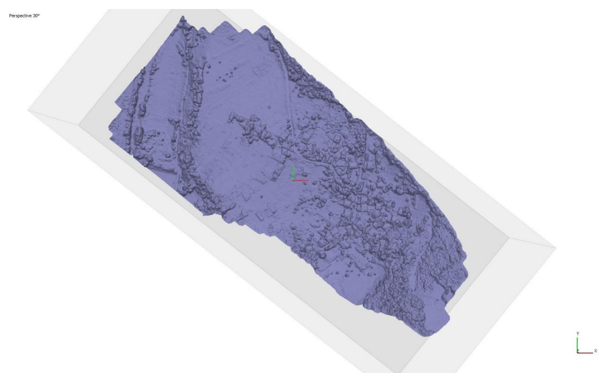

Figure 17. Solid model of the study area (region 3)

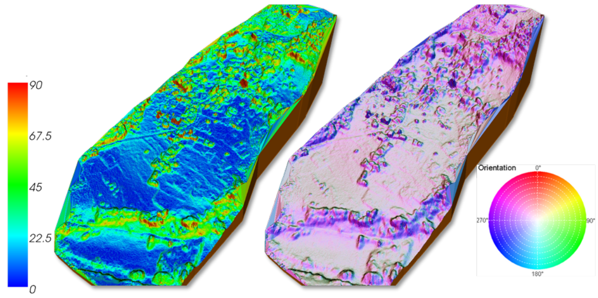

Figure 18. Slope and aspect maps of the study area (region 3)

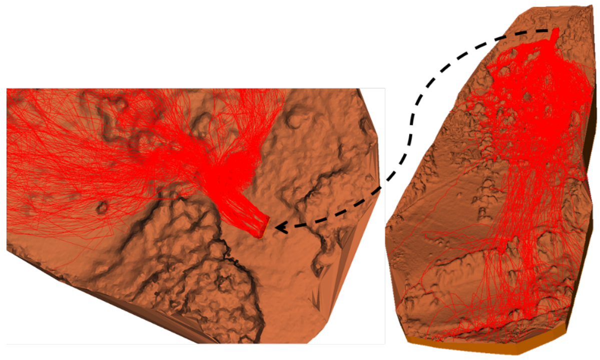

Figure 19. Spread Map

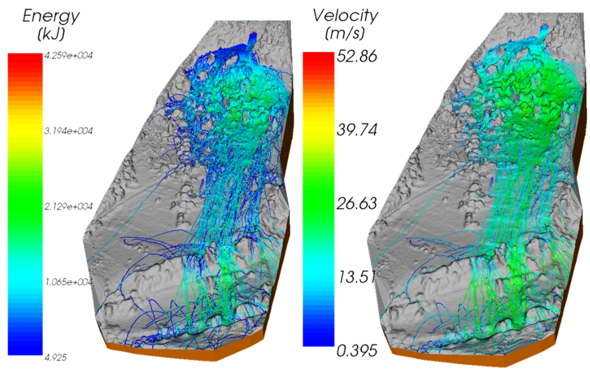

Figure 20. Energy and Velocity Maps

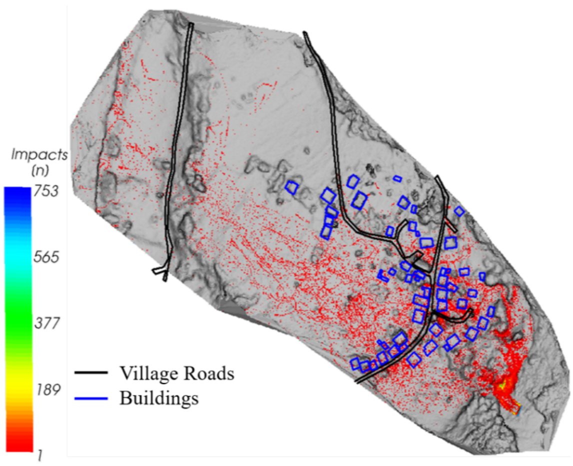

Figure 21. Location of village roads and buildings on the map which shows possible impact points

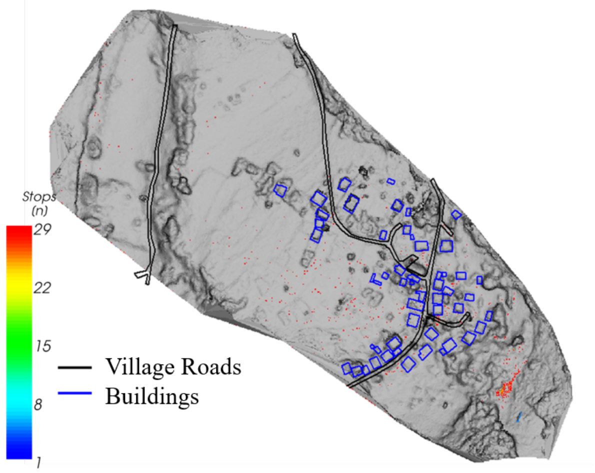

Figure 22. Location of village roads and buildings on the map which shows possible stop points

2.8 Assessment of the output scenarios

The rockfall analysis processes, which started with the obtained DEM, using an UAV, were completed with the generation of maps for the various purposes discussed above with the help of the Rock-Pro3D software. With this analysis, one thousand scenarios that may occur as a result of the movement of the mentioned rock due to the mass movements in the region were proposed using the software. For each scenario, spread of a 18 m^3 rock block on the terrain surface (Figure 19), stop and impact points (Figure 21 and Figure 22), the energy and velocity maps it has along the route it moves (Figure 20) were created in the previous step.

The spread map is a type of map that shows the possible movement routes of the rock in the study area in one thousand scenarios. The map showing possible impact points is a type of map showing the points where the rock fragments hit for each scenario. As seen in Figure 21, number n represents the numbers of the points where the piece of rock stood as a result of all scenarios. That is, if number n is equal to the number 189, it is interpreted that the rock impacts the same point 189 times. Finally, the map showing the possible stopping points of the rock is shown in Figure 22. This map represents the points where the boulder stood over one thousand scenarios. Similarly, the bar representing the stopping points is shown in Figure 22. The fact that number n is equal to the number 29 in this bar means that the boulder has stopped at that point twenty-nine times as a result of all scenarios.

Both the village roads and the buildings in the orthophoto map of the region created for this application were digitized with the help of various CAD software and converted into vector data and then integrated to the map that shows stop and impact points of the rock block. Hence, the risk status of buildings, agricultural areas and village roads was examined by considering the scenarios that may occur as a result of the movement of the rock block.

3 Results and Discussions

Landslide disaster is one of the most important disaster types that cause significant losses in terms of life and property. The deformations that occur as a result of this disaster negatively affect human life and comfort areas and can seriously damage arable lands and residential areas. Trabzon province, located in the Eastern Black Sea Region of Turkey, has been described by AFAD as 'the province where landslides and regional disasters are experienced most intensely' due to its annual rainfall amounts and its geological and geomorphological structure. The Maçka district of Trabzon province, which is located in the study area, has the characteristics of a district where the highest number of landslide disasters occur throughout the country.

A large number of mass movements have been detected as a result of observations made on different points in the study area until today. In the region where mass movements continue, the landslide events cause severe damage to many houses and result in deep cracks on the land surface. This study proposes a way of monitoring mass movements that occur as a result of a landslide disaster with the help of Network-RTK measurement technique to analyze the rockfall that may occur with the movement of a rock fragment as a result of the continuation of a possible mass movement. The topographic measurement of the land surface of the study area was conducted with the help of a CORS compatible GNSS receiver in two periods (E19, E21) using the Network-RTK measurement method. As a result of these measurements, the generated point data of the study area were evaluated by using various CAD software programs and surface mesh models of the region (regions 1 and 2) were generated for each period (Figure 6 and Figure 7). Using the differences between the surface mesh models produced for both periods, the vertical surface differences between the periods E19 – E21 were calculated (Figure 8 and Figure 9). Maps showing the surface differences produced for both regions (1 and 2) are evaluated separately below:

- In the surface difference model produced for region 1, vertical collapses up to 28 cm were detected (Figure 8).
- In the surface difference model produced for region 2, vertical collapses were not observed, and increases in elevations were detected in certain parts of the land. The maximum value of these changes in the vertical direction was calculated as 22 cm (Figure 9).

An additional application within the scope of the study is the rockfall analysis of the rock block located in region 1. In this context, the possible movement scenarios of the existing rock block in the region as a result of the effect of mass movements in the study area were examined.

Considering the map outputs extracted from one thousand different scenarios, it was observed that many agricultural areas, village roads and buildings in the region are at risk. Buildings at risk constitute approximately 80% of the total number of buildings in the region.

As a result of the process steps applied in this study area where a mass movement (terrain) triggers another mass movement (rock block) both types of movements were analyzed. In the light of the results obtained, it was revealed that the movement of the rock block in the region where the slope has remarkably high values poses a threat to the residential and agricultural areas in the region. The fact that the activities conducted in the study area, which is declared as a disaster-prone area, are limited to superficial observations and reports, is insufficient for a detailed and comprehensive understanding and interpretation of mass movements in the region. In this context, scientific studies conducted in the study area are crucial for the authorized local municipalities and institutions.

It has been determined that another type of disaster (rock fall) may be experienced in the region as a result of the evaluation of the mass movements through the Network-RTK measurement technique and the effect of this movement on the rock.

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