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Monitoring and Evaluation of 2015 Devrek Zonguldak Landslide within the scope of Flood Risk Assessment by Landsat-8 Satellite Data

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Abstract

The mass movement towards stream beds and their accumulation there may cause flood events as a result of landslide events. In this study, Devrek Landslide, which occurred in 2015, was investigated by using a remote sensing technique. The Çomaklar stream is located at the lower elevations of this landslide region. Çomaklar stream and surrounding settlements are at risk of flooding due to the probability of preventing the water flow in the stream because of the effects of the landslide. Devrek district is located in Zonguldak in the northern part of Turkey. LANDSAT-8 satellite images between the dates 27 January 2015 and 22 July 2015 were used to investigate the location and size of the Devrek district landslide. Satellite-derived remote sensing data have been widely used in recent years to monitor changes on the earth's surface and to provide information. In this study, the Spectral Angle Difference method was used to compare the images before and after the landslide event. A change detection analysis was conducted between pre-landslide and post-landslide images to investigate the area affected by the disaster. As a result, the landslide was determined as 1050 meters in length and 110 meters in width, and the landslide area was calculated as 10.87 ha.

Keywords
Flood Risk, Natural Disasters, Devrek Landslide, Landsat-8, Remote Sensing

Taşkın Riski Değerlendirmesi Kapsamında Landsat-8 Uydu Verileri ile 2015 Yılı Devrek Zonguldak Heyelanının İzlenmesi ve Değerlendirilmesi

Özet

Heyelan olayları sonucunda akarsu yataklarına doğru kütle hareketi olması ve orada yığılması taşkın olaylarına neden olabilmektedir. Bu çalışmada 2015 yılında meydana gelen Devrek Heyelanı uzaktan algılama tekniği kullanılarak incelenmiştir. Çomaklar deresi bu heyelan bölgesinin alt kotlarında yer almaktadır. Çomaklar deresi ve çevresindeki yerleşimler, heyelan ile hareket eden kütlenin dereyi kapatması ihtimali ve etkilerinden dolayı, taşkın riski altındadır. Devrek ilçesi, Türkiye'nin kuzey kesiminde Zonguldak'ta yer almaktadır. Devrek ilçesi heyelanın yerini ve boyutunu araştırmak için 27 Ocak 2015 ve 22 Temmuz 2015 tarihleri arasında LANDSAT-8 uydu görüntüleri kullanılmıştır. Uydu kaynaklı uzaktan algılama verisi, yeryüzü üzerindeki değişimleri izlemek ve bilgi temin etmek için son yıllarda yaygın olarak kullanılmaktadır. Bu çalışmada heyelan olayı öncesi ve sonrası görüntülerin karşılaştırılmasında Spektral Açı Farkı yöntemi kullanılmıştır. Afetten etkilenen alanı araştırmak için heyelan öncesi ve heyelan sonrası görüntüler arasında değişim tespit analizi yapılmıştır. Sonuç olarak heyelan uzunluğu 1050 metre, genişliği 110 metre, heyelan alanı ise 10.87 ha olarak hesaplanmıştır.

Anahtar Sözcükler
Taşkın Riski, Doğal Afetler, Devrek Heyelanı, Landsat-8, Uzaktan Algılama

1. Introduction

Hazards turn into disasters when they affect humans and the environment. The impact of natural disasters on humans and the environment is increasing dramatically and turning into more severe over the last decades. Disasters can be classified as; natural, human-made and human-induced disasters. Natural disasters are extreme events that result in death or injury to humans and environmental damage within the lithosphere, hydrosphere, biosphere or atmosphere as a result of purely natural phenomena (such as earthquakes, volcanic eruptions and tsunami). Human-made disasters are events that occur as a result of human activities (such as industrial accidents, and atmospheric pollution). Human-induced disasters are natural disasters that are accelerated by human influence (van Westen 2000). Natural disaster-related issues have been investigated by multiple disciplines on some issues such as floods (Akgül 2018; Akgül and Çetin 2019), tornadoes (Womble et al. 2018), tsunamis (Roemer et al. 2010), earthquakes (Theilen-Willige 2010), or landslides (Rai et al. 2014) in recent years.

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Due to the environmental effects of landslides, some researchers have evaluated the safety of engineering structures and environmental risks (Ersoy et al. 2020). Landslides may be purely natural as a result of an earthquake or a heavy rainfall or human-induced. Landslides can be classified as mixed natural/human-influenced disasters.

A landslide is one of the major disasters on the earth's surface that can cause huge damage on humans, nature, settlements and the environment (Dahal 2017). Landslides occur in a large variety depending on the type of movement (slide, topple, flow, fall, spread), the speed of movement, the material involved and the triggering mechanism (earthquake, human interaction) (van Westen 2000). Remote sensing data are important for mapping the size of landslide features. Monitoring landslide occurrence and progress stages by using satellite-based data was widely used in several types of research (Stumpf et al. 2017; Liu et al. 2019; Tajudin et al. 2020). Remote sensing (RS) and/or Geographic Information System (GIS) tools have the ability to provide monitoring and evaluation of the distribution of mass movements, landslide mapping and hazard assessment (Rai et al. 2014; Dahal and Dahal 2017). Tajudin et al. (2020) investigated land cover changes between the years 2005 and 2014 in Ulu Kelang, Selangor, in Malaysia by using satellite images to get information about the factor of landslide occurrences. Varangaonkar and Rode (2019) presented a review on landslide prediction and localization using GIS and remote sensing.

Devrek district of Zonguldak province, in the Western Black Sea region in Turkey, is a region with landslide risk. Several kinds of research were carried out using terrestrial measurements and remote sensing techniques related to the landslide event that occurred in Devrek district in 2015.

In the study conducted by Karakuş et al. (2016), the Devrek Landslide, which started in Zonguldak Devrek District on April 20, 2015 and continued until July 27, 2015, was examined; the landslide mechanism and landslide formation were investigated, and also the precautions taken in the study area were explained. In this study conducted by Karakuş et al. (2016), it was stated that the width of the landslide was approximately 100 m and its length was approximately 1000 m.

In the study conducted by Görmüş et al. (2018), the landslide disaster in Devrek on 16 July 2015 was investigated. Aerial photogrammetry, ground-based SAR, and local observations were used to observe the landslide. As a result of their study, the landslide route was determined as approximately 1300 meters by comparing the orthophoto images of the years 2011 and 2015. The depth of the landslide was also examined. It was evaluated as four individual landslides triggered each other.

In the study conducted by Eker and Aydın (2019), Devrek landslide on the 16th of July 2015 was investigated by using a total of 20 historical aerial photographs between 1944 and 2011, and also Unmanned Air Vehicles (UAV) data on landslide area on July 23, 2018 as remote sensing data.

In this study, we studied on the landslide that occurred on July 17, 2015 in Devrek district of Zonguldak City which is located in the Western Black Sea Region in northern Turkey. Flood control works have been carried out on Çomaklar stream which is located at lower elevations of the landslide before the landslide occurred in 2015. It has been evaluated that the mass movement caused by the landslide may affect the stream flow negatively by narrowing the cross-section. The aim of this study is to monitor the landslide and to detect the changes before and after the landslide by using satellite-based remote sensing data and Spectral Angle Difference method within the scope of flood risk assessment. In our study, the extent of this landslide was examined by using Landsat-8 satellite images for a period of approximately 6 months, in comparison with the studies given in the paragraphs above, which investigated the Devrek landslide that took place in 2015.

2. Material and Method

2.1. Study Area

The Western Black Sea Basin is one of Turkey's 25 basins and covers approximately 3.7% of Turkey's surface area, the basin is bounded by the Sakarya Basin in the southwest, the Kızılırmak Basin in the southeast, and the Black Sea in the north (SYGM 2019). Devrek district in Zonguldak City is located in the Western Black Sea Basin of Turkey (Figure 1). A typical Black Sea climate is observed in the study area; precipitation is seen in almost every season. The study area is located between 41°13′00″ and 41°14′00″N latitudes, and 31°56′0″ and 31°58′0″E longitudes in Devrek in Zonguldak City.

It was stated in the report of the Western Black Sea Basin Flood Management Plan that 225 flood events were recorded in the Western Black Sea Basin, and one of the biggest floods that caused loss of life in the basin occurred in 1998 in the Devrek District of Zonguldak (SYGM 2019). Devrek Stream and Çomaklar Stream, which pass through the Devrek District of Zonguldak, merge into the Devrek District. A devastating flood occurred in the town of Devrek in 1998. Due to the flood risk in this stream, hydrodynamic model studies were carried out, flood depth maps and flood hazard maps were prepared and flood risk assessment studies were conducted (SYGM 2019). Flood control facilities were built on the Çomaklar Stream and in the town center of Devrek Zonguldak (DSİ 2022). The importance of carrying out flood risk assessment studies and building flood control facilities was indicated in official reports (DSİ 2017; SYGM 2019).

As seen in Figure 2, the Turkey Landslide Intensity map prepared in 2008 by the General Directorate of Disaster Affairs, the landslide density situation in Devrek District in Zonguldak City was stated as "very high" (AFAD 2022).

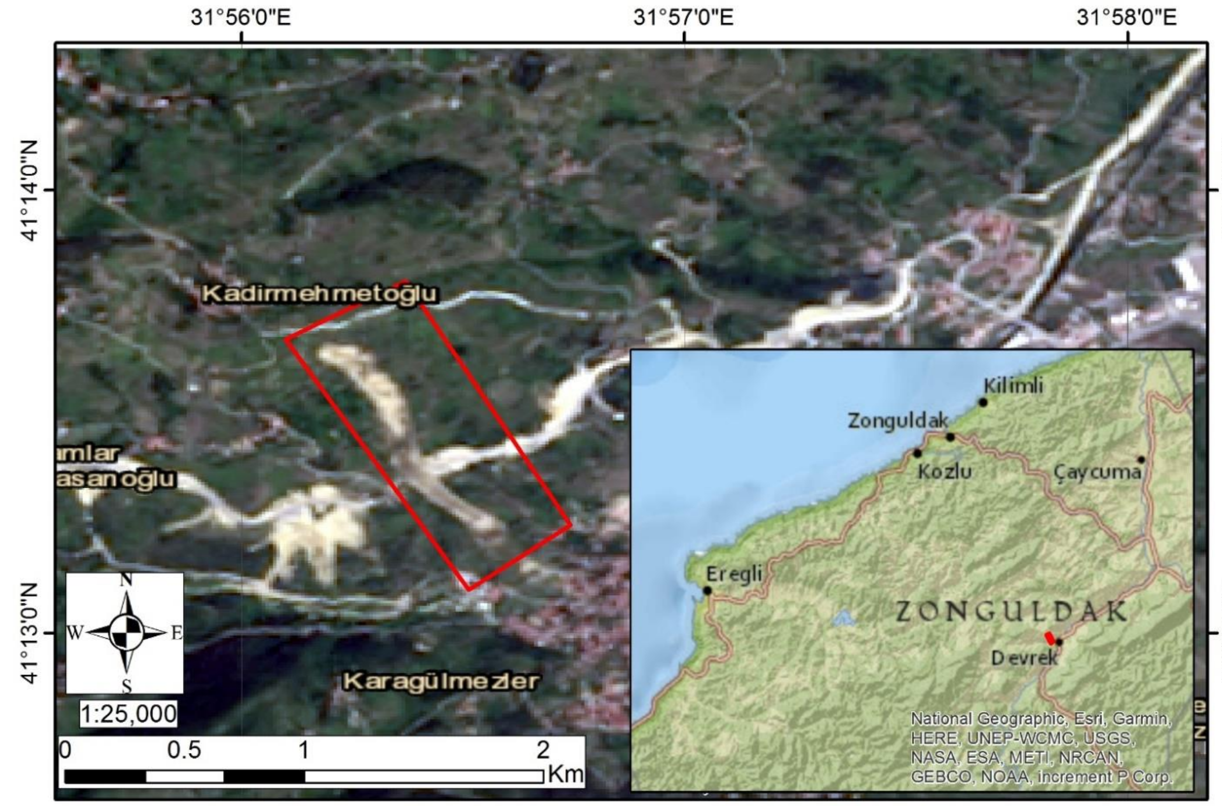

Figure 1: The study area

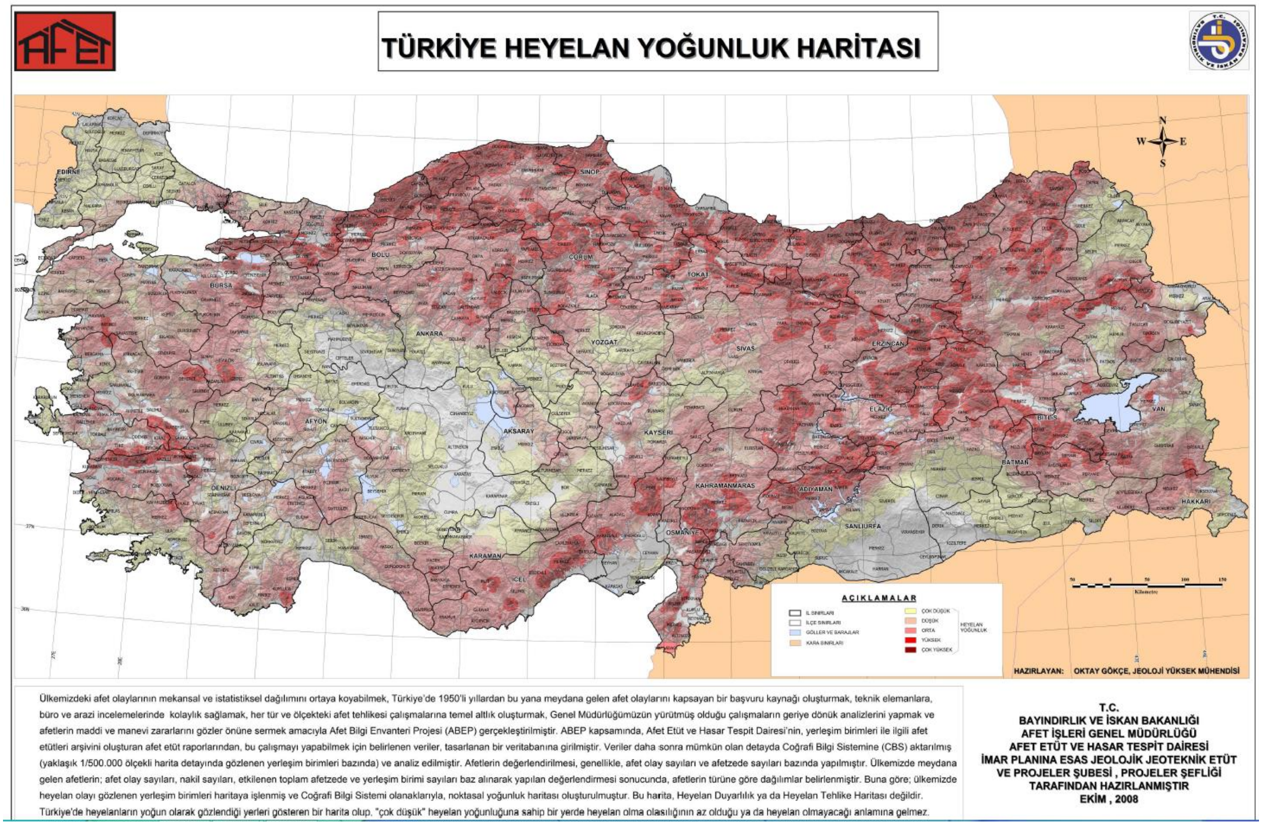

Figure 2: Turkey landslide intensity map prepared in 2008 by the General Directorate of Disaster Affairs (AFAD 2022)

2.2. Material

Landsat satellites have been providing space-based images of Earth's land surface since 1972 (USGS 2016). It was reported that Landsat 8 satellite has the capability to provide high-quality land-surface data having the compatibility with historical Landsat satellite data (USGS 2013). Landsat 8 satellite images were used in this study to evaluate the extent of the landslide.

Satellite images used in this study was selected taking into account the cloudiness in the archive scanning studies and the images dated 27 January 2015 and 22 July 2015 were found appropriate for the study (Table 1). Landsat 8 band specifications are given in Table 2. Landsat 8 Bands Wavelengths chart is given in Figure 3.

Table 1: Name and date of the image used in the study

Date	Name of the image
27 January 2015	LC08_L2SP_178031_20150127_20200909_02_T1
22 July 2015	LC08_L2SP_178031_20150722_20200909_02_T1

Table 2: Band specifications of Landsat 8 satellite (USGS 2022)

Band Number	Band name	Bandwidth (nm)	Resolution (m)
1	Coastal Aerosol	0.43-0.45	30
2	Blue	0.45-0.51	30
3	Green	0.53-0.59	30
4	Red	0.64-0.67	30
5	Near Infrared	0.85-0.88	30
6	SWIR1	1.57-1.65	30
7	SWIR2	2.11-2.29	30
8	Panchromatic (PAN)	0.50-0.68	15
9	Cirrus	1.36-1.38	30
10	TIRS 1	10.6-11.19	100
11	TIRS 2	11.5-12.51	100

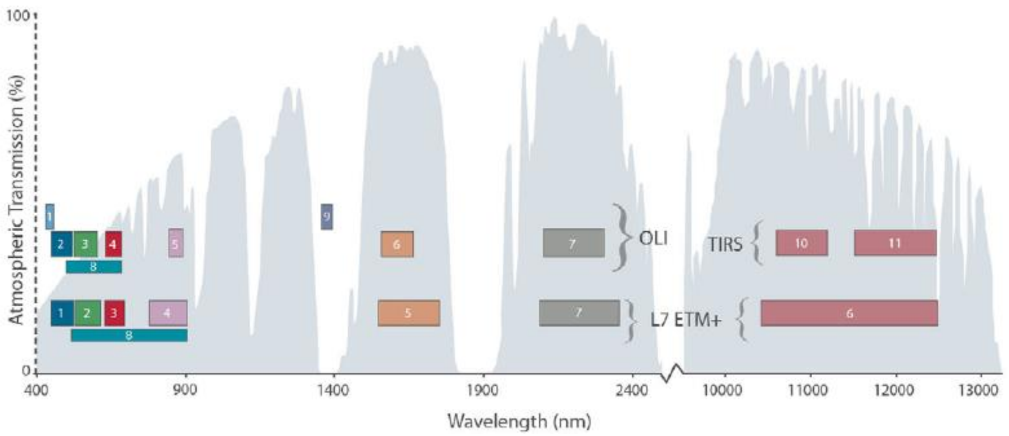

Figure 3: Landsat 8 bands wavelengths chart (USGS 2013)

2.3. Method

In the first step of the study, Landsat 8 data were pre-processed with radiometric calibration and atmospheric corrections. The raw images of the Landsat 8 satellite those dated 27.01.2015 before the landslide and 22.07.2015 after the landslide, which was used to determine the landslide area, were pre-processed with radiometric calibration and atmospheric corrections, and these corrections were made by using ENVI software.

QUAC (Quick Atmospheric Correction) is a method used for atmospheric correction and the QUAC module was developed by Spectral Sciences Inc. in cooperation with the US Air Force Research Laboratory (Bernstein et al. 2005; L3HARRIS 2022a). After making radiometric calibration, atmospheric corrections were made by using QUAC.

Satellite-derived remote sensing data have been primary sources for monitoring and obtaining information on the earth. Several change detection techniques have been developed to monitor and assess environmental changes using satellite image data. In this study, the Spectral Angle Difference method was used to compare the images of pre- and post-landslide events. A change detection analysis was performed between the images dated 27 January 2015 before the landslide and 22 July 2015 after the landslide to investigate the affected area by the disaster.

The Spectral Angle Difference method is recommended especially for hyperspectral images that are multi-band images (L3HARRIS 2022b; Kruse et al. 1993). In the study conducted by van Leeuwen et al. (2017), the Spectral Angle Difference method was used; in their study van Leeuwen et al. (2017) stated that *"the result classes are rated based on this difference: a smaller angle means higher similarity and vice versa"* (van Leeuwen et al. 2017).

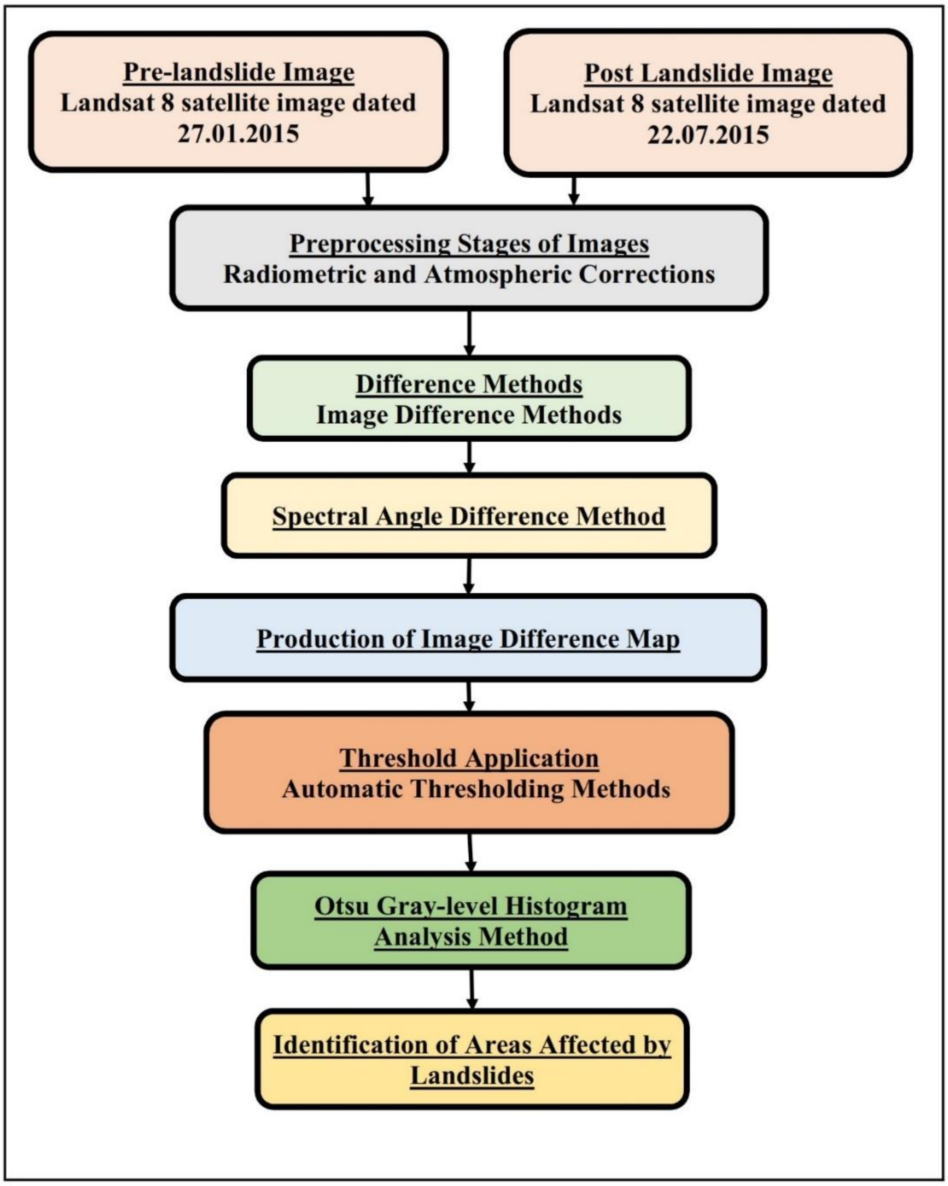

Figure 4: Working flow diagram

In our study, classes with the lowest spectral angle differences represent an area of mass movement. Spectral Angle Difference method has been a commonly used method as seen in previous literature (Lodhi et al. 2018; Ma et al. 2016). A threshold value according to Otsu's thresholding method was determined (Otsu 1979). The Otsu method calculates the threshold between two peaks on the histogram of the image using gray-level histogram analysis (Otsu 1979). The working flow diagram of this study is given in Figure 4.

3. Results and Discussion

Landslide occurrence is investigated by using Landsat-8 satellite images before the landslide and after the landslide between the dates of 27 January 2015 and 22 July 2015 (Figure 5).

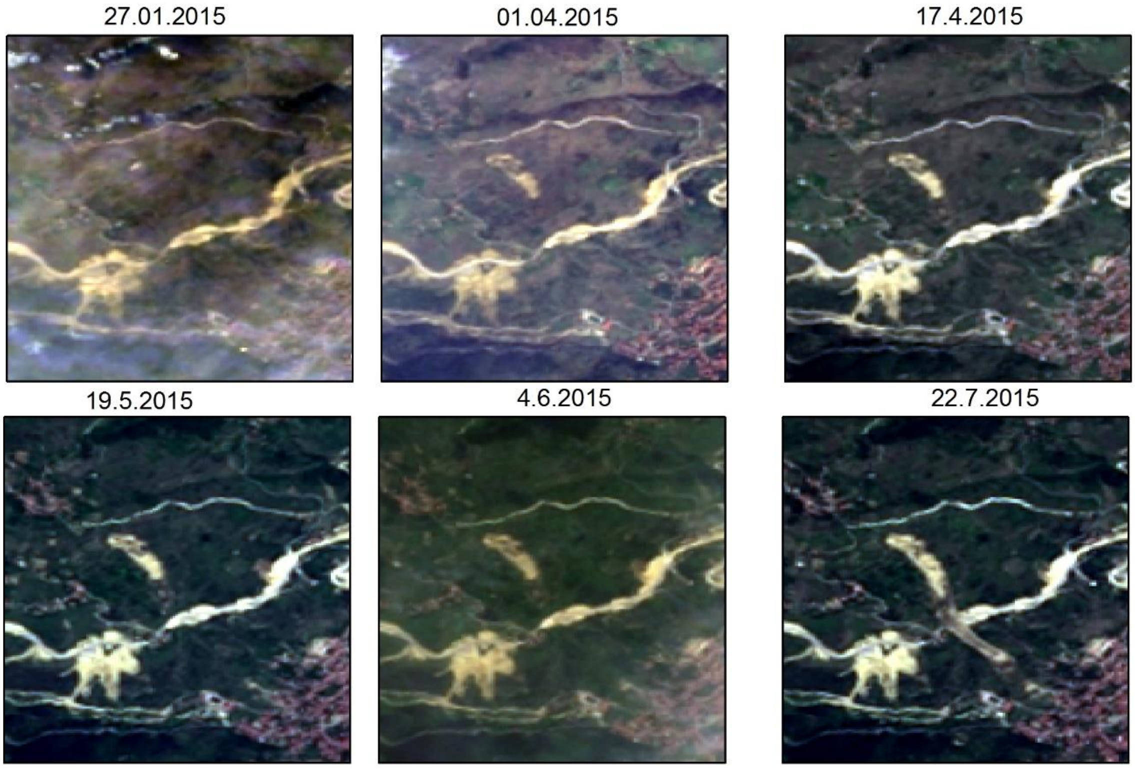

Figure 5: Landsat 8 images between 27 January 2015 and 22 July 2015

The extent of the landslide is determined by performing a change detection analysis between the images dated 27 January 2015 before the landslide and 22 July 2015 after the landslide (Figure 6).

Figure 6 was obtained using the Spectral Angle Difference method. As seen in Figure 6, the areas where the change is low have values close to 0, while the areas damaged by the landslide where the change is the most, have values close to the maximum value of 1.

In order to detect the landslide area in the change map, which has values between 0 and 1 (Figure 6), a threshold value was determined with the Otsu method within the Automatic Thresholding methods. By applying the Otsu method, the map divided into two classes landslide areas and non-affected areas, was transferred to ArcMap software and the size of the affected area was calculated.

As a result, the length of the landslide is determined as approximately 1050 meters, and the width at its widest point is determined as 110 meters. The S-shaped landslide area was calculated as 10.87 ha.

The Devrek landslide that occurred on July 17, 2015 caused damages to settlements and the environment with its devastating effects. Due to the landslide, it has been determined that the material flowing into Çomaklar Creek had largely blocked the stream. Çomaklar Stream is a tributary of Devrek Stream (Figure 7).

Because the water flow in Çomaklar stream, which is a branch of Devrek Stream, was likely to be blocked due to the landslide, it was necessary to determine the flood risk and the negative effects on the environment and the necessary measures to be taken.

Emergency measurements were carried out to prevent damages caused by the mass movement. Necessary precautions within the scope of flood control activities, were taken in case of flooding (Karakuş et al. 2016).

In this study, flood risk assessments were made and necessary measures to prevent damages caused by mass movement were evaluated using remote sensing satellite images.

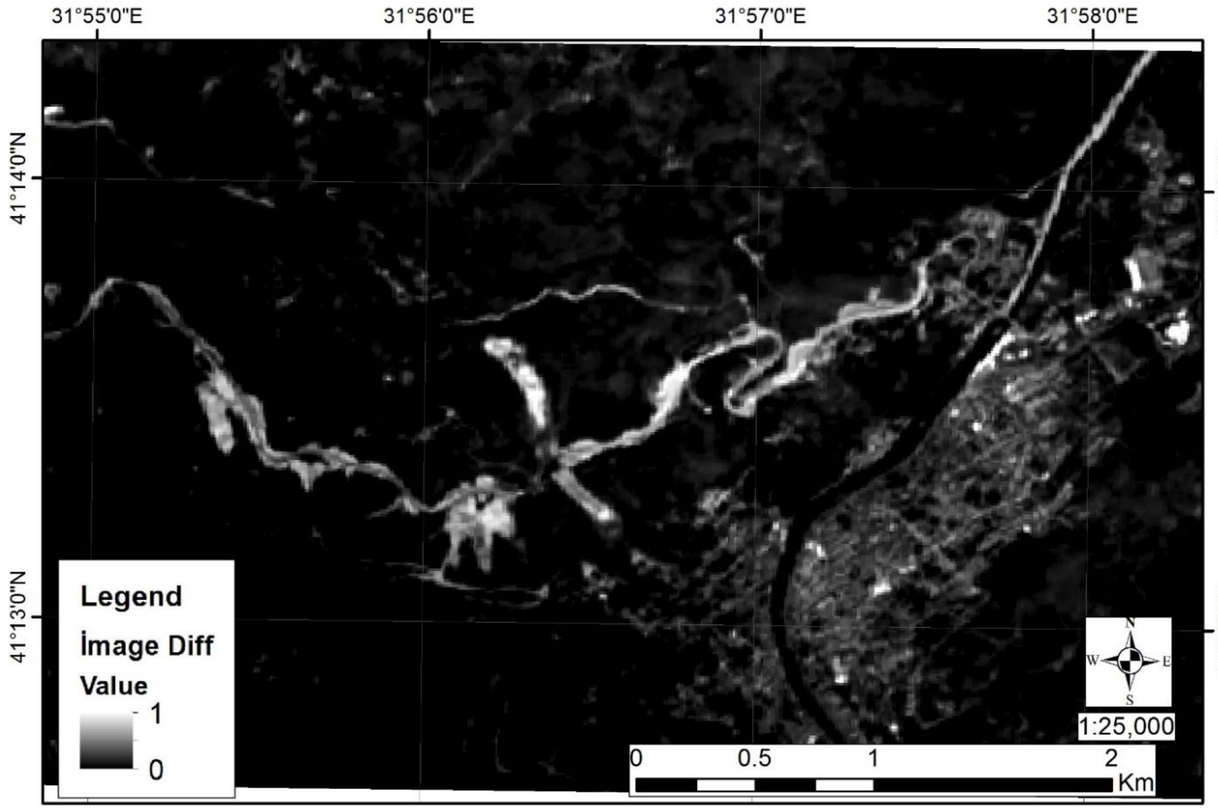

Figure 6: The extent of the landslide

Figure 7: The location of Çomaklar stream and the landslide

Satellite-based remote sensing is an effective technique for monitoring and evaluating disasters that supports decision-makers in the management process, as well as for the assessment of disaster damages. The remote sensing method has been used to detect the changes over time and to identify the impacts of natural events for many years around the world, even in remote and dangerous areas.

The use and contributions of satellite-based remote sensing techniques in landslide mapping were examined and evaluated by previous research. Qin et al. (2018) proposed a method for landslide inventory mapping using Sentinel-2 images in Western China and used pre-event and post-event satellite images for landslide mapping. In the study conducted in Ulu Kelang, Malaysia by Tajudin et al. (2020), monitoring of landslide by applying change detection of land cover by using satellite imagery for 2005 and 2014 were reported.

In this study, the extent and the impacts of the Devrek landslide that took place in 2015 were investigated by using Landsat-8 satellite images for a period of approximately 6 months in pre and post-event, for the first time. This study reveals the contribution of using remote sensing in the monitoring and evaluation of landslide-related flood risk assessments. The attention to the investigation of the landslide issue is not only drawn to the extent of the landslide, but also to its effects on vital issues such as water resources management and flood control.

4. Conclusion

The construction of the flood facilities on the Çomaklar stream started in 1982 (SYGM 2019). It is important to evaluate flood risk assessment in Çomaklar stream due to its topographic and climatic features. Several effects including effects of past and future floods, hydrological features, stream networks, properties of water and land resources, river basin features, topography, existing infrastructures, etc. are evaluated within the scope of flood risk assessments.

Flood control facilities were built due to the threat of flooding in Çomaklar Stream before the landslide occurred in 2015, on account of this mass movement caused by the landslide, flood risk has to be evaluated in addition. The residential areas in the area where Çomaklar stream meets Devrek stream can be affected if any flood occurs.

In comparison with the previous studies, this is the first study on the selected study area conducted by using the Landsat satellite data and the Spectral Angle Difference method.

The mass movement caused by the landslide was investigated by using a satellite-based remote sensing technique for a period of approximately 6 months.

The location and the size of the Devrek district landslide area is investigated by using LANDSAT-8 satellite images before the landslide and after the landslide between the dates 27 January 2015 and 22 July 2015. The Spectral Angle Difference method was used in the analysis of landslide extent area.

As a result, the length of the landslide is determined as approximately 1050 meters, and the width at its widest point is determined as 110 meters. The S-shaped landslide area was calculated as 10.87 ha.

Monitoring all stages of the progress and completion processes of landslide events contributes to taking technical measures to be developed within the scope of disaster management.

The narrowing of the stream cross-section in streams with flood risk is not technically appropriate in terms of project criteria. The narrowing of the cross-section is due to several events and environmental factors. There was a risk of narrowing the cross-section of Çomaklar stream by the mass movement caused by the landslide, therefore revision of the planning and project design studies for flood prevention is recommended.

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