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Araştırma Makalesi / Research Article

# EVALUATION OF POTENTIAL FLOOD AREAS IN THE BASIN OF LAKE LADİK THROUGH AHP AND GIS INTEGRATION, (SAMSUN, TÜRKİYE)

## Ladik Gölü Havzası'ndaki Potansiyel Taşkın Alanlarının AHP ve CBS Entegrasyonu ile Değerlendirilmesi (Samsun, Türkiye)

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ÖZET

Taşkınlar küresel ölçekte birçok ülkenin sorunudur. Türkiye'de özellikle yaz aylarında Karadeniz Bölgesi kıyı kuşağında büyük taşkınlar meydana gelmektedir. Yaşanılan taşkınların sayısı ve tahrip etme güçleri her geçen gün artmaktadır. Taşkınların oluşumunu engellemek mümkün değildir. Ancak bir afet karakterine dönüşmesini engellemek için gerekli önlemleri almak mümkündür. Taşkın ve benzeri doğal afetler için son zamanlarda duyarlılık analizleri gerçekleştirilmekte ve sonuçları karar vericilere yardımcı olmaktadır. Bu çalışma kapsamında Karadeniz Bölgesi'nde yer alan Samsun iline bağlı Ladik Gölü Havzası'nda birden çok coğrafi faktörün bir arada kullanılmasıyla taşkın duyarlılık analizi gerçekleştirilmiştir. Çalışmada çok kriterli karar verme yöntemlerinden olan Analitik Hiyerarşi Prosesi (AHP), Coğrafi Bilgi Sistemleri (CBS) ve Uzaktan Algılama (UA) teknikleri kullanılmıştır. Bu kapsamda dokuz (9) faklı coğrafi faktör (eğim, bakı, litoloji, toprak, havza boyutu, arazi kullanımı, yeryüzü şekilleri, yağış ve drenaj yoğunluğu) kullanılarak havzanın taşkın duyarlılık analizi gerçekleştirilmiştir. Çalışma sonucunda taşkın için düşük, orta, yüksek ve çok yüksek olmak üzere dört (4) farklı düzey belirlenmiş ve havzanın %36,77'si düşük, %30,03'ü orta, %11,43'ü yüksek ve %21,77'si çok yüksek düzeyde gerçekleşmesi muhtemel taşkınlara karşı duyarlı çıkmıştır. Ayrıca elde edilen taşkın duyarlılığı sonuçları ile daha öncesinde yaşanmış olan taşkın olaylarının karşılaştırılması yapılmıştır. Böylece analiz sonuçları ile doğal gerçeklik korele edilmiştir. Çalışmanın sonuç kısmında ise sahada taşkın afeti öncesinde alınması gereken önlemler ve risk yönetimine yönelik yaklaşımlar sunulmuştur.

ABSTRACT

Floods are a problem in-many countries on a global scale. In Türkiye, especially in the summer months, large floods occur in the Black Sea Region coastal belt. The number and the destructive power of experienced floods are increasing day by day. It is not possible to prevent the occurrence of floods. But it is possible to take the necessary measures to prevent it from turning into a disaster. Recently, susceptibility analyses have been carried out for floods and similar natural disasters and the results help decision-makers. Within the scope of this study, flood susceptibility analysis was carried out by using multiple geographical factors together in the Basin of Lake Ladik of Samsun Province in the Black Sea Region. In the study, Analytical Hierarchy Process (AHP), Geographic Information Systems (GIS), and Remote Sensing (RS) techniques were used, which are multi-criteria decision-making methods. In this context, flood susceptibility analysis of the basin was carried out by using nine (9) different geographical factors (slope, aspect, lithology, soil, basin size, land cover, landforms, precipitation, and drainage density). As a result of the study, for floods, there were identified four (4) different levels as low, medium, high, and very high; 36.77% of the basin was found to be low, 30.03% was medium, 11.43% was high and 21.77% was found to be susceptible to possible floods at a very high level. The results of the study are also important for decision-makers make in flood risk planning.

## 1.INTRODUCTION

In the last few decades, natural disasters such as climate change, floods and flash floods, earthquakes, tsunamis, typhoons, volcanic eruptions, and landslides due to the negative effects of anthropogenic activities have caused serious losses of life and property all over the world (Parker et al., 2007; Gashaw & Legesse, 2011; Stefanidis & Stathis, 2013; Singh et al., 2020; De Risi et al., 2022; Singh et al., 2020). The increase in natural disasters has revealed the necessity of examining disasters separately, taking different measures according to their type, and improving existing disaster prevention studies. Especially in natural disaster management studies, where a holistic approach is exhibited, this distinction becomes important in terms of evaluating natural disasters within themselves.

While various natural disasters with different effects occur in different places around the world; among these natural disasters, floods cause the most destruction, and loss of life and property after earthquakes. According to the International Emergency Events Database (EMDAT), 2023 data managed by the Centre for Research on the Epidemiology of Disasters (CRED), 399 natural disasters occurred, 86,473 people lost their lives and 93.1 million people were affected globally. In 2023, 41% of these disasters (164) were floods. After the flood disaster, 5,022 people lost their lives and 22.1 million people were affected. Again, according to CRED's 2023 disaster report, 2,970 people lost their lives in the Democratic Republic of Congo because of floods and landslides caused by heavy rains in South Kivu province in May. Floods in northeast Nigeria in October killed 275 people. In January, 52 people were killed and 2.1 million people were affected by floods and landslides across the country in the Philippines. Monsoon rains between April and July caused floods in Pakistan and India, killing at least 1,529 people and affecting 10.2 million people in India between June and September. In addition to these disasters, Yemen experienced a long and intense period of rainfall between March and September, during which 248 people lost their lives. In Guatemala, 78 people lost their lives because of floods and landslides. The floods that occurred in the Emilia-Romagna region of Europe in May were among the costliest floods of 2023 with an economic loss of US$ 9.8 billion, in addition to claiming the lives of 15 people (CRED, 2023).

In the last few decades, natural disasters have increased significantly for reasons such as the degradation of the natural balance of geography, especially for anthropogenic reasons, the increase in precipitation, and the occurrence of sudden downpours due to climate change and the temperatures reaching higher averages every year. Floods are one of the most destructive natural disasters that occur all over the world and the extent of the damages they cause is great and should be controlled with appropriate management activities (Köroğlu & Akıncı, 2023). Floods are one of the natural disasters encountered both in the world and in our country and their destructive effects are quite high. According to 2023 EMDAT data, it is the most common disaster in the world and has affected more than 22 million people (CRED, 2023). The fact that the effects of floods are so great is mostly related to the fact that they occur in people's living areas (Dilley et al., 2005). The ever-increasing population around the world has led to the shrinking of people's living spaces, which in turn has caused people to concentrate in certain areas, and these areas are mostly floodplains and river valleys close to water (Utlu, 2023). Again, people have preferred to build settlements along the banks of rivers in the historical process due to the fertile and rich biodiversity of the riverbanks (Girayhan, 2015). In addition to wrong location choices, the increasing pressure of people on the natural environment due to population growth, and mistakes in land cover make new settlements established without engineering measures more resistant to possible floods.

While it is not possible to prevent natural disasters from occurring, it is possible to keep their effects to a minimum. The best example of this situation is floods, which can be predicted for a certain period. Floods are one of the natural disasters whose damages can be reduced, if necessary, measures are taken (Köroğlu & Akıncı, 2023). In cases where there is healthy meteorological data and infrastructure, the impact of floods can be minimized. However, a positive approach and a specific system are needed to combat natural events such as floods or flash floods (Ballesteros-Cánovas et al., 2013; Hong et al., 2018). From this point of view, it is an extremely important approach to address the susceptibility assessment of floods with spatial data and within a certain system. One of the frequently used methods for flood management and disaster preparedness is to simulate floods based on experimental or computer models and to take various measures according to the results obtained (Uysal & Taşçı, 2023). Among these methods, hydraulic, hydrological, and morphometric approaches play an important role in preventing floods and reducing damage. These approaches are used to understand and manage the movement, quantity, and impact of water in the natural environment. Hydraulic approaches to flood prevention provide engineering solutions to direct the flow of water, control water levels, and reduce the impact of floods. These solutions include dams, levees, flood weirs, and channels. For example, dam gates can be opened to safely divert water during floods, or dikes can be built to retain water in flood zones. Hydrological approaches enable flood risks to be identified in advance by forecasting rainfall and runoff. This method helps to develop pre-flood warning systems and take preventive measures in areas of high flood risk. For example, by analyzing the annual rainfall in a region, it can be predicted in which periods the risk of flooding will increase, and water management strategies can be implemented in these periods. Morphometric analyses are used to identify areas at risk of flooding. For example, the slope and drainage density of a river basin can affect the flow rate of water and flood potential. These analyses help to determine how vulnerable the basin is to flooding and which areas need more protection. Again, such approaches enable risk planning before natural disasters, to propose solutions to problems that may occur during and after disasters and identify the least vulnerable areas in advance. Such approaches enable risk planning before natural disasters, propose solutions to problems that may occur during and after disasters, and identify the least susceptible areas in advance. Again, such systematic approaches also help in using the spatial relationship between geographical factors used in susceptibility assessment.

One of the systematic approaches that has an important place in natural disaster susceptibility assessments is the Analytic Hierarchy Process (AHP), which allows multiple factors to be evaluated together and the weight ratios of the factors to be calculated. AHP is one of the most frequently used Multi-Criteria Decision-Making Analysis methods in the literature (Köroğlu & Akıncı, 2023). AHP was first created by Saaty in 1980 (Saaty, 1980) and developed by Saaty and Alexander in 1989 (Saaty & Alexander 1989) and by Saaty and Forman in 1993 (Saaty & Forman 1993), respectively. AHP ensures that there is a mutual correlation between the factors used and that the factors that are important/unimportant relative to each other are expressed with numerical values. AHP is the most preferred multi-criteria decision-making analysis because it is both easy and straightforward to use and provides a simple, uncomplicated correlation between factors. Flood studies often involve complex data and models. AHP simplifies this complexity, allowing decision-makers to reach more easily understandable conclusions. Its hierarchical structure allows the decision process to be followed step by step. With this aspect, it has become a technique used in decision-making throughout the world in flood management and susceptibility studies (Pereira & Duckstein, 1993; Turoğlu & Özdemir, 2005; Turoğlu, 2005; Saaty & Vargas, 2006; Chandran & Joisy, 2009; Thilagavathi et al., 2011, Chiadikobi et al., 2011; Saini & Kaushik, 2012; Özşahin, 2016; Ocak, 2018; Işık et al., 2020; Ocak & Bahadır, 2020; 2021; Ocak et al., 2021a; Ocak et al., 2021b; Arya & Singh, 2021; Göztepe et al., 2022; Özşahin, 2022; Köroğlu & Akıncı, 2023; Fıçıcı, 2024; Köse et al., 2024; Yurteri, 2024). In conclusion, the use of AHP in flood studies is an effective approach to structure complex decision processes, compare different criteria and identify the most appropriate flood management strategies. The AHP method was preferred due to the features and because the study aims to identify areas susceptible to flooding.

Today, in flood studies; in addition to the use of high-resolution satellite images in the detection of water and wetland presence, determination of possible flood areas and modeling of the hydrological behavior of waters (Lin et al., 1997; Horritt et al., 2001; Özdemir, 2007; Sinha et al., 2008), Geographic Information Systems (GIS) have also been among the important tools used to make various plans and develop regional strategies in flood studies for the last few decades (Warner, 2001; Sanjay & Goel, 2002; Gupta & Srivastava, 2010; Patel & Srivastava, 2013; Özşahin, 2016; El-Haddad et al., 2020; Balogun et al., 2020; Swain et al., 2020; Ocak & Bahadır, 2020; 2021; Oğuz et al., 2022; Tariq et al., 2022; Majeed et al., 2023; Bozdoğan & Canpolat, 2024; Altın et al., 2024). Furthermore, in this type of susceptibility assessment of natural disasters, it is necessary to determine the impact areas and reveal the weight ratios determined for the factors used spatially. This need is met by AHP, which is used to determine the superiority of geographical factors used in many different subjects such as natural disasters susceptibility analysis, determination of the most suitable location, determination of agricultural product potential, obtaining the most suitable agricultural products and determination of discharge points for solid waste storage facilities. As a result of combining the numerical results obtained with AHP with GIS techniques, spatial expression of geographical factors is provided. Thanks to GIS, the susceptibility of a place to flooding can be determined by the flood susceptibility maps produced. Flood susceptibility maps are maps that show the location of flood-prone areas under current anthropogenic activities and environmental and climatic conditions, especially in urban environments (Ouma and Omai, 2023). Flood susceptibility mapping is recognized in the literature as a necessary first step in flood hazard mitigation and flood management (Termeh et al., 2018; Zhao et al., 2020). In this study, the flood susceptibility status of the Basin of Lake Ladik, which is in the Central Black Sea Region of the Black Sea in the north of Türkiye and has a tectonic origin, and the precautions to be taken are emphasized.

### 1.1. Study Area

The study area is in the central part of the Black Sea Region of Türkiye. The area administratively located within the borders of Samsun province is a lake basin. This basin includes a lot of small streams that take their sources from the masses of the big mountains in the south and have a total length of 118,07 km. Also, the mountains Akdag and Karaömer, which are settled in the south and covered with snow for a long period of the year, cause an increase in the flow rates of these rivers, which are relatively high in number in the basin, during the period when the snow starts to melt. Additionally, the sudden and heavy rains are also one of the important reasons for increasing the flow rates. However, the main reason why floods have been on the agenda in recent years and their numbers are increasing day by day is human intervention (Mohan, 2018; Singh et al., 2020; Singh et al., 2020). Anthropogenic activities carried out not only in the basin of Lake Ladik but also in many different places (changes in land cover and land cover by human intervention, destruction of the forests, concreting of residential areas, etc.) are the main factors triggering the formation of floods. The basin of Lake Ladik with an area of 147.8 km² has increased in the direction of urbanization in recent years (Bahadır & Uzun, 2021). At the same time, this situation has created pressure on the basin in terms of construction. Therefore, the risk of floods affecting this area has started to increase due to anthropogenic effects in the basin. In addition, large areas of agricultural land (31.14%) and alluvial materials (28.76%) in the basin create suitable and risky environments for floods. Especially since alluvial materials are saturated with water, they cause the basin floor to stay underwater during periods of heavy rainfall. In such a case, losses of life and property become unavoidable. At the same time, human beings who cause the recognition of natural disasters within their activities also undertake an important task in terms of performing natural disaster susceptibility analyses and establishing a sustainable system (Singh et al., 2015). Within the scope of this task, people have to take into account the geographical factors of the site to be used in a systematic approach to the susceptibility assessment for floods. When all these explanations and reasons are considered together, it is aimed to carry out flood susceptibility analysis in the basin of Lake Ladik by using different geographical factors such as slope, aspect, lithology, soil, land cover, drainage density, and to help decision-makers to take precautions by determining the susceptibility classes (Figure 1).

### 1.2. Flood Characteristics of the Study Area

Natural disasters are increasing day by day around the world. Among these natural disasters, it is the floods that cause the most loss of life and property after earthquakes. Floods, which have become an important problem on a global scale, occur frequently in Türkiye, especially in summer. According to the disaster records of Türkiye in 2020, 177 of the 905 natural disasters that occurred are floods (Table 1). Türkiye is a country where floods are experienced intensely, especially in the Black Sea Region. Although the floods that occur in our country occur at different times regionally, the common feature of all of them is the large-scale material and moral damage they have caused, especially in the last 5-10 years.

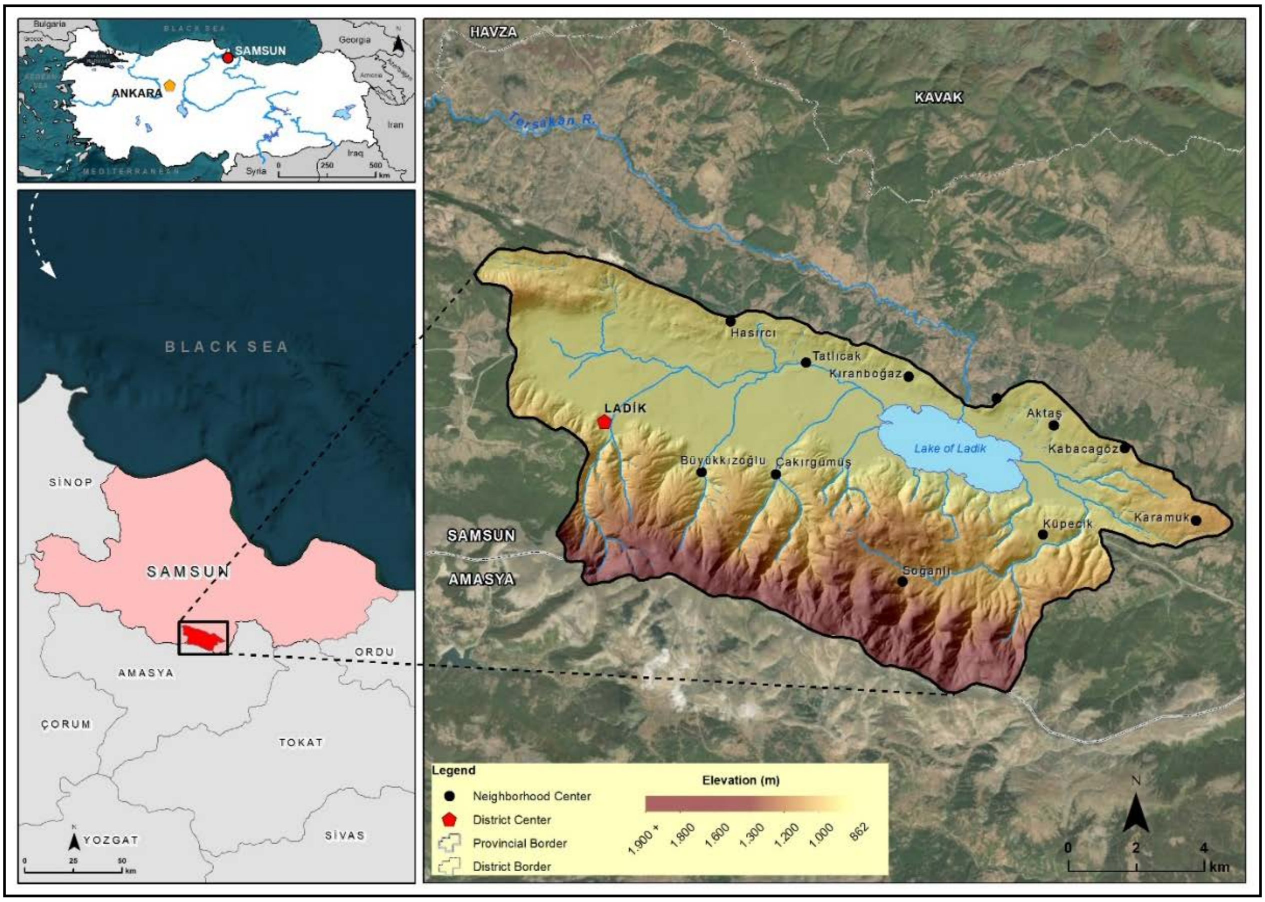


**Figure 1:** Location map of the study area.

**Table 1:** Natural events that took place in Türkiye in 2020 (AFAD, 2022; Ocak & Bahadır, 2022).

| Natural Events | Number | Percentage (%) |
|---|---|---|
| Avalanche | 11 | 1,22 |
| Earthquake | 321 | 35,47 |
| Other (Storm, Hail, etc.) | 270 | 29,83 |
| Landslide | 107 | 11,82 |
| Rockfall | 17 | 1,88 |
| Sinkhole | 2 | 0,22 |
| Flood/Inundation | 177 | 19,56 |
| **TOTAL** | **905** | **100** |

Even though in Türkiye the Black Sea Region has an active period in summer in terms of floods, the basin of Lake Ladik remained the quiet area of this active region in the historical process and witnessed a total of two (2) floods, one (1) on June 8th, 1971 (URL-1), and one (1) whose location could not be determined in the 1983-2022 disaster records (Samsun Provincial Directorate of Disaster and Emergency, 2022). No other information has been encountered in the literature regarding this flood, which took place on the Değirmen Stream, which passes through the district center of Ladik. Although the basin of Lake Ladik has a quiet history in terms of flooding, the fact that flood events do not occur/are very rare in a particular region does not mean that the region is completely exempt from flood risk. Factors such as land cover, climate change, urbanization and water management can increase flood risk over time, and therefore continuous assessment and planning is required for each region. Human-induced changes can increase flood risk over time and lead to flooding events in an area that has not previously experienced flooding. Human use of land for agriculture, industry or urban development can alter natural watercourses and drainage systems. Deforestation, agricultural expansion and urbanization increase surface runoff by reducing the soil's capacity to absorb water. This can lead to flooding in areas that have never experienced flooding before. Again, increasing construction and concretization in urban areas reduces the natural absorption areas of water. Rainwater flows faster on concrete floors, which can cause flash floods. Inadequate infrastructure and drainage systems can also increase flood risk. Climate change can lead to changes in rainfall patterns and intensity. This can lead to sudden and intense rainfall even in areas that were not previously prone to flooding. However, probably, the rivers morphologically overflow from the flat and shallow valley where the slope decreases and the stream spreads to the plain. In addition, during the field investigations, settlements established at the mouth of the short seasonal streams opening into the plain were identified (Figure 2). Considering these two morphological factors, it is estimated that a possible flood in the basin may cause serious problems in these settlements.

The fact that the artificial channel created around the bed of Değirmen Stream, which passes through the district center and flows into Ladik Lake in the rural area, is narrow in the city center (Figure 3A) and wider (Figure 3B) in the rural area, may put the district center where the population is densely at risk in a possible flood (Figure 3). Also, the fact that Değirmen Stream passes through the Ladik district center and its bed is used as a domestic waste discharge channel, and the plants such as reeds formed are not cleaned, seem to be the most basic problems for the overflow of the stream in case of a possible flood (Figure 4A, 4B).

**Figure 2:** Settlements established at the mouths of streams in the south of the study area.

**Figure 3:** The channel structure in different parts of the Değirmen Stream, which passes through the district center.

**Figure 4:** Domestic waste and formed reeds in Değirmen Stream passing through the district center.

## 2. MATERIAL AND METHODS

The flood susceptibility analysis carried out in the basin of Lake Ladik consists of three different stages (Figure 5); data generation with GIS, field observations and AHP. In the study, firstly, the geographical factors to be used in the analysis were decided, a geographical database was designed with GIS techniques, and data on geographical factors (slope, aspect, lithology, soil, basin area size, land cover, landforms, precipitation, and drainage density) were produced. In this context, the Digital Elevation Model (DEM) is the leading data used in spatial analysis and it is a source for many geographical factors (slope, aspect, elevation, etc.) used in spatial analysis. Due to this strong feature, first, DEM data with a resolution of 10 m of the basin of Lake Ladik was produced from 1/25.000 topography maps with GIS techniques and then used as a base to produce slope, aspect and landform data of the basin. Again, with GIS techniques, lithology data was produced from 1/100,000 scaled geological maps, and soil data were downloaded and simplified via the TAD Portal (Non-Agricultural Authorization and Soil Survey Portal). Furthermore, the precipitation map of the area was produced by; land cover with a controlled classification method from Sentinel-2 satellite images of the years 2017-2021 (Esri, 2022), linear density analysis and drainage density, which are among the GIS techniques, watershed analysis with hydrology tool (detection of micro-basin boundaries and determination of stream network for drainage density) and finally, using the precipitation data obtained from the Directorate General of Meteorology, with interpolation techniques. Field studies were carried out to check both the accuracy of the data during data production and the accuracy of the analysis results after the susceptibility analysis. In this way, the effect scores to be given to the parameters were decided more clearly, and probably mistakes were prevented. Through field studies, the reliability and accuracy of the study were increased.

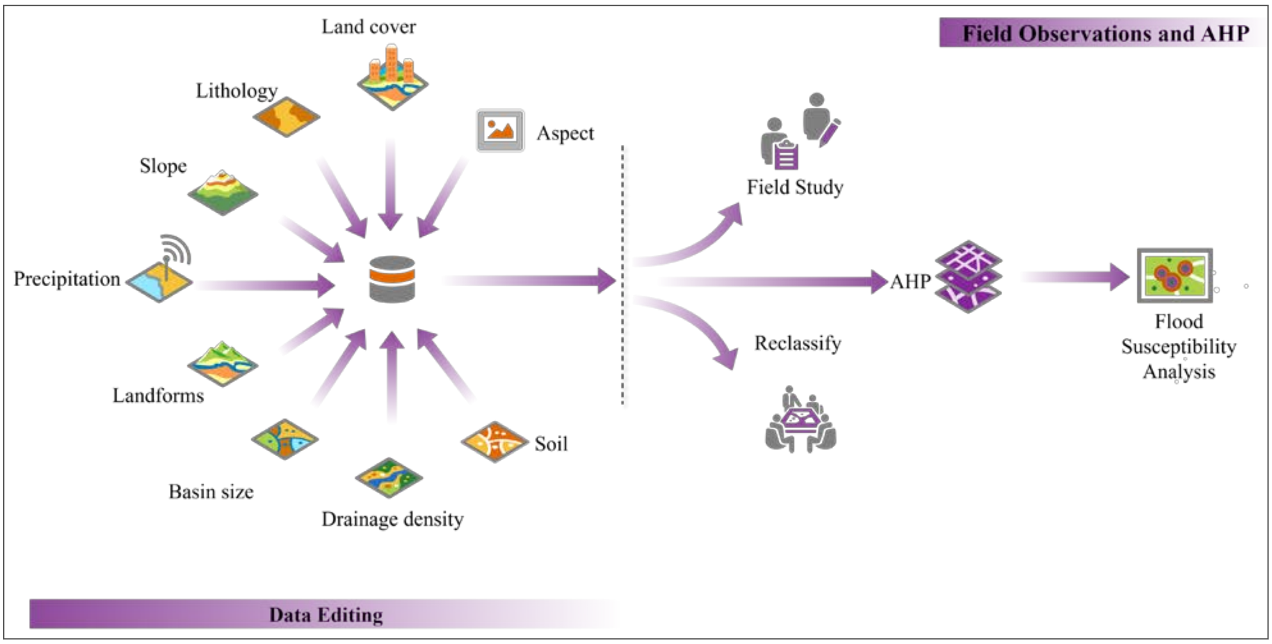


**Figure 5:** Flood susceptibility analysis workflow chart.

Immediately after data production, geographical factors were divided into sub-criteria, and each of them was evaluated according to the Pairwise Comparison Matrix on the Saaty (1989) scale by means of AHP. With the AHP, many factors or criteria are scored between 1-9-1/9 (Saaty, 1989; Table 2) according to the purpose of the study, weight ratios and a consistency ratio are calculated to understand the accuracy of the scoring. According to Saaty (1989), this consistency ratio should be ⩽10% (Saaty 1989), so that AHP can guide decision-makers in identifying vulnerable areas and determining measures before natural disasters. Again, it is possible to come across studies that say that the consistency rate varies according to the number of geographical factors used. According to the studies of Franci et al. (2016), the consistency rate should be ⩽5% for 3*3 matrices and ⩽9% for 4*4 matrices (Franci et al., 2016). These values are categorized in this way so that the study can give precise results.

**Table 2:** Analytical Hierarchy Process (AHP) importance scale (Saaty, 1989; Ocak & Bahadır, 2022).

| Importance Scale | Definition | | Importance Scale |
|---|---|---|---|
| 1 | Equally important | | 1 |
| 3 | Moderately more important | Moderately less important | 1/3 |
| 5 | Strongly more important | Strongly less important | 1/5 |
| 7 | Very strongly more important | Very strongly less important | 1/7 |
| 9 | Highly more important | Highly less important | 1/9 |
| 2, 4, 6, 8 | Intermediate values | | 1/2, 1/4, 1/6, 1/8 |

All parameters were scored between 1 and 9 according to their estimated importance in causing flooding and according to the importance scale (Table 2). The weight ratio of each upper and lower criterion was calculated (Table 3). The importance scores given to calculate the weight ratios in the flood susceptibility analysis were determined according to field observations, expert opinion (20 experts) and studies carried out in the literature. All these processes with AHP techniques were carried out using the 15.09.2018 version of the program designed by K. D. Goepel (Goepel, 2013). Various spatial analysis processes (data transformation, reclassification, cell size, extent adjustment, etc.) were carried out by using GIS techniques again for all top and bottom geographical factors whose weight ratios were calculated with AHP. Finally, all data were converted to raster data format for flood susceptibility analysis. Each resolution was set to 10 m, and flood susceptibility analysis of the field was performed with a weighted overlay tool. The result was divided into four (4) different classes low, medium, high, and very high.

## 3. RESULTS AND DISCUSSION

In this study, flood susceptibility analysis of the basin of Lake Ladik was carried out with AHP and GIS techniques by calculating the weight ratios of geographical factors consisting of nine different thematic data elements including slope, aspect, lithology, soil, basin area size, land cover, landforms, precipitation, and drainage density.

### Slope

In flood susceptibility analysis studies, the slope conditions of the land come first among the geographical factors to be considered. The slope is an important criterion due to its effect on the velocity of surface waters. Because the velocity of the water mainly depends on the slope of the land (Nsangou et al., 2022). In places where the slope values are high, rainwater quickly passes to the surface flow with drainage channels and is drained in a short time, while in places where the slope decreases, a longer time is needed for the water to drain. This situation causes surface water storage and increases the effect of the flood.

The slope values in the basin of Lake Ladik vary between 0-58° degrees (Figure 6a). Due to the tectonic origin of the basin, the slope values are quite low at its base, but they increase gradually from the northern and especially the southern shores of Ladik Lake. Especially the mountain masses (Akdağ and Karaömer Mountain) in the south of the basin constitute the units with the steepest slopes. Since the slope of the basin varies so much and to obtain more precise results within the scope of the study, the slope was divided into five (5) different groups: flat and nearly flat, slightly sloping, sloping, moderately steep, and very steep slopes.

In the pairwise comparison matrix performed with AHP within the scope of flood susceptibility analysis, in terms of the effect of water on the velocity of water; flat and nearly flat, slightly sloping places were given high scores, moderately sloping slopes where the slope is relatively increased were given low scores and the slopes with the highest slope value were given the lowest importance scores. These values were correlated with field studies and morphological dynamics were taken into consideration in scoring.

### Aspect

It is a factor that indirectly affects the occurrence of floods. This aspect affects the formation of many geographical factors that affect local flooding. Especially the local climate and vegetation come first among these conditions (Ocak et al., 2021a; Ocak et al., 2021b). For example, the northern sector slopes receive more precipitation than the southern sector slopes, and if other conditions are suitable, they create a more favorable environment for flood formation. Again, the northern sector slopes have more dense vegetation than the southern sector slopes. Since this will increase infiltration, it has a positive effect by slowing down the formation of floods on the northern sector slopes.

Within the scope of the flood susceptibility analysis conducted for the basin of Lake Ladik, the aspect is divided into five (5) different classes as flat surfaces, northern sectors (N, NE, NW), eastern, southern sectors (S, SE, SW) and west (Figure 6b). Flat surfaces are given high importance scores, such as slopes with low slope values. The northern sectors were also considered to be of high importance, while other sectors were given low scores because their relative importance had decreased.

### Lithology

Another natural factor affecting the formation of floods is lithological features. Lithology has an effect on the flood due to the permeability of the soil. The fact that the soil consists of loose materials or exhibits a water-saturated structure ensures rapid infiltration of the surface water and a significant reduction in the amount of water passing to the surface flow occurs. In lithological units where the ground is hard and impermeable, the opposite happens. Areas with resistant rocks have a lower flood risk or less drainage density (Srivastava et al., 2014; Feizizadeh et al., 2020). In these units, most of the water that enters the surface runoff flows without being infiltrated and causes an increase in the amount of water that causes flooding.

**Table 3:** Geographical factors and numerical values used in flood susceptibility analysis.

| Geographical Factor | Sub-Criteria | Area | | | Sub-Criteria Weight (%) | Consistency (%) | Weight (%) |
|---|---|---|---|---|---|---|---|
| | | km² | | % | | | |
| **Slope (°)** | 0-2 (Flat and Nearly Flat) | | 39,87 | 26,98 | 50,3 | **8** | **17,7** |
| | 2-5 (Slight Sloping Slope) | | 18,56 | 12,56 | 26,0 | | |
| | 5-15 (Sloping Slopes) | | 43,45 | 29,40 | 13,4 | | |
| | 15-35 (Moderately Steep Slope) | | 44,16 | 29,88 | 6,8 | | |
| | 35 + (Very Steep Slope) | | 1,76 | 1,19 | 3,5 | | |
| **Aspect** | Flat | | 22,57 | 15,27 | 54,2 | **7** | **2,5** |
| | Northern Sectors (N, NW, NE) | | 70,01 | 47,37 | 29,1 | | |
| | East (E) | | 13,93 | 9,42 | 6,9 | | |
| | Southern Sectors (S, SW, SE) | | 30,99 | 20,97 | 3,9 | | |
| | West (W) | | 10,30 | 6,97 | 5,9 | | |
| **Lithology** | Schist, phyllite, calcschist, limestone | ZA | 0,65 | 0,44 | 6,7 | **4** | **3,8** |
| | Limestone | | 15,18 | 10,27 | | | |
| | Pebble, sandstone, claystone, limestone | ZB | 7,25 | 4,91 | 6,7 | | |
| | Serpentinite, sandstone, agglomerate, tuff | | 0,93 | 0,63 | | | |
| | Limestone, claystone, marl | | 59,51 | 40,26 | | | |
| | Pebble, sandstone, marl, mudstone | ZC | 2,70 | 1,83 | 6,7 | | |
| | Conglomerate, sandstone | | 10,30 | 6,97 | | | |
| | Pebble, mudstone | ZD | 8,77 | 5,93 | 11,8 | | |
| | Alluvium | ZE | 42,51 | 28,76 | 68,1 | | |
| **Soil** | Alluvial Soils | | 26,82 | 18,15 | 37,2 | **5** | **8,2** |
| | Hydromorphic Soils | | 9,17 | 6,20 | 37,2 | | |
| | Brown Forest Soils | | 86,03 | 58,21 | 3,2 | | |
| | Chestnut Soils | | 25,10 | 16,98 | 6,1 | | |
| | Colluvial Soils | | 0,68 | 0,46 | 16,3 | | |
| **Basin Size (km²)** | 0,31-1,00 | | 1,80 | 1,22 | 35,0 | **4** | **8,6** |
| | 1,01-2,00 | | 14,78 | 10,00 | 23,7 | | |
| | 2,01-3,00 | | 32,18 | 21,77 | 15,9 | | |
| | 3,01-4,00 | | 41,76 | 28,25 | 10,6 | | |
| | 4,01-5,00 | | 13,51 | 9,14 | 7,0 | | |
| | 5,01-6,00 | | 16,57 | 11,21 | 4,6 | | |
| | 6 + | | 27,20 | 18,40 | 3,2 | | |
| **Land Cover** | Wetlands | | 11,71 | 7,92 | 30,0 | **2** | **9,2** |
| | Forests | | 58,47 | 39,56 | 3,0 | | |
| | Agricultural Areas | | 46,02 | 31,14 | 29,8 | | |
| | Settlement Areas | | 7,69 | 5,20 | 29,8 | | |
| | Bare Land | | 0,52 | 0,35 | 3,0 | | |
| | Rangeland | | 23,39 | 15,83 | 4,4 | | |
| **Landforms** | Mountain | | 4,12 | 2,79 | 5,2 | **2** | **9,2** |
| | Plateau | | 40,01 | 27,07 | 4,1 | | |
| | Plain | | 38,76 | 26,22 | 45,4 | | |
| | Slope | | 60,86 | 41,18 | 4,5 | | |
| | Fault Slope | | 0,48 | 0,32 | 4,5 | | |
| | Debris Cone | | 3,57 | 2,42 | 36,3 | | |
| **Precipitation (mm)** | 600-700 | | 80,59 | 54,53 | 26,1 | **5** | **27,4** |
| | 700-900 | | 48,01 | 32,48 | 32,8 | | |
| | 900 + | | 19,20 | 12,99 | 41,1 | | |
| **Drainage Density (Dd)** | 0,57-1,57 | | 12,18 | 8,24 | 6,2 | **2** | **13,5** |
| | 1,58-2,05 | | 17,21 | 11,64 | 9,9 | | |
| | 2,06-2,37 | | 62,05 | 41,98 | 16,1 | | |
| | 2,38-2,82 | | 47,09 | 31,86 | 26,2 | | |
| | 2,83-3,80 | | 9,27 | 6,27 | 41,6 | | |

There are lithological units with different characteristics in the basin of Lake Ladik (Figure 6c). Within the scope of the study, lithological units were classified according to the permeability of the ground. In the grouping of lithological features, the Turkish Earthquake Building Regulations published by AFAD in 2018 were considered (AFAD, 2018). The class with the strongest rocks and ground was given the highest score in the pairwise comparison matrix, while the lowest score was given to the class in which the ground consists of weak and loose materials. In addition, among the lithological units, Quaternary alluviums are the most abundant in the basin and cover 28.76% of the area. This lithological unit, which is located at the bottom of the basin and at the mouths of the rivers, is important because it has a water-saturated structure. At the same time, most of the settlements were built on this ground. In this aspect, the highest score in terms of flood susceptibility was given to Quaternary alluviums.

### Soil

Soils are effective in the formation of floods because of their properties such as moisture, permeability, porosity, thickness, and texture. Especially the moisture holding capacity, permeability and porosity of the soil are the most obvious features that affect the formation of floods. The soil type directly affects the type of drainage. The more permeable and porous the soil is, the more moisture and water holding capacity it has, and the rapid infiltration of runoff water increases accordingly. (Mojaddadi et al., 2017). In this way, it slows down the formation of floods. Also, the texture characteristics of soils such as clayey, sandy, and loamy also affect flood formation. Sandy soil is significantly more porous and permeable than both loam and clay soil (Arya & Singh, 2021). Therefore, sandy soils exhibit a stronger resistance to flooding than loamy and clayey soils.

There are alluvial, hydromorphic, brown forest, chestnut and colluvial soils in the study area (Figure 6d). Soils are directly proportional to the lithological features of the field and whether they are important against flooding or not is closely related to the lithology on which they are located. Quaternary-aged alluvial units, which have a rate of 28.76% in the basin, are also units where alluvial and hydromorphic soils are found. Therefore, alluvial, and hydromorphic soils always received the highest score in terms of flood susceptibility in the pairwise comparison matrix due to their water saturation. Again, the brown forest soils, which form the sub-forest layer, are of the lowest importance in the pairwise comparison matrix since they are both covered with vegetation and have relatively high permeability properties. On the other hand, chestnut soils were scored as moderately important compared to other soil groups due to their vegetation cover consisting of sparse forests and shrubs. Again, considering that it cannot withstand the destructive effect of water because it is composed of loose materials, although there are very few in the basin, high scores were assigned to colluvial soils.

### Basin Size

The size of a catchment, i.e. its area, determines its level of resilience to flooding. Small-sized micro-basins are more vulnerable to flooding than large-sized basins, and often a short runoff period is sufficient for rainwater to turn into floods in basins with small drainage networks, while a longer runoff period is required for flooding to occur in basins with large drainage networks (Ajin et al., 2013).

For a basin to have the character of a micro basin, its area must be between 0.031-190 km² (Arya & Singh, 2021). The area of Basin of Lake Ladik, which is determined as the study area, is 147.8 km². In other words, the study area exhibits a complete micro basin feature. In this aspect, there is a short flow period for flood formation in the basin. This time, known as the time of concentration, was calculated as 6.30 minutes according to the Kirpich (1940) equation explained below (Kirpich, 1940).

$Tc = 0{,}0078 * L0{,}77 / S0{,}385$
*Tc = time of concentration*
*L = mainstream length (m)*
*S = basin slope (m/m).*

Although the study area exhibits the characteristics of a micro-basin, to obtain more accurate results, the micro-basin boundaries of the area with smaller dimensions were determined by using the basin of Lake Ladik

DEM data (Figure 6e). In this context, high importance scores were given to micro basins with smaller areas and low importance scores to basins with large areas.

### Land Cover

In the Basin of Lake Ladik, six (6) different classes have been identified for land cover with controlled classification using Sentinel-2 satellite images from 2017−2021 (Figure 6f). These are wetlands, forests, agricultural areas, settlement areas, bare land, and rangeland. Among the identified land classes, wetlands are less resistant to flooding than other classes. Settlement areas and agricultural areas constitute the most susceptible areas for flooding after wetlands. The reason for this is that settlements are mostly established in places with low slope values and have more impermeable surfaces and agricultural areas are the main basis of the economy in the basin. Apart from these land cover types; rangeland areas are considered a low-importance land class due to their high location. The basin is covered with dense forest cover. Forests are important in terms of preventing floods. Forests constitute the most resistant land cover class to floods. In areas covered with forests, rainwater is retained by plants, which reduces the rate of falling to the ground. In this way, rainwater loses its power and can be easily infiltrated by both plants and soil. Therefore, there is a decrease in the amount of water that passes into the surface flow. Accompanied by all these explanations, by comparing with the literature information in the pairwise comparison matrix and correlating with the field observations; high scores were assigned to wetlands, residential areas and agricultural areas, high scores were assigned to rangeland areas, low scores were assigned to forest areas, and moderate scores were assigned to bare lands.

### Landforms

Landforms have a susceptible role in the formation of floods. Because landforms affect the speed, direction, and strength of water. For this reason, landforms are a geographical parameter that cannot be ignored in hydrological studies (Sherman, 1932; Horton, 1945; Strahler, 1964; Baker et al., 1988; Özdemir, 2007; Özdemir & Bayrakdar, 2014; Özşahin, 2016; Ocak et al., 2021a). In the Basin of Lake Ladik, main geomorphological units such as mountains, plateaus, plains, slopes and debris cones have been identified (Figure 6g). Among these morphological units, especially the plains are the most vulnerable landform in terms of flood susceptibility. Both the low slope values and their suitability for settlement increase the importance of the plains in terms of flood susceptibility. Since the settlements on the debris cones are very dense in the Anatolian geography and these morphological units are located at the mouth of the rivers, the debris cones are very risky areas in terms of flood susceptibility. Although they are located on high plains, plateaus are morphological units of low importance in terms of flooding because they have good drainage. Again, due to the rapid flow of surface waters on units such as mountains and slopes where the slope is high, these morphological units were also evaluated as units of low importance. Therefore, in the pairwise comparison matrix, the highest scores were given to the plain and debris cones, and lower scores were given to the mountain, plateau, and slopes.

### Precipitation

The main factor in the formation of floods is precipitation. The shape and amount of precipitation trigger the formation of floods. Especially rapid and heavy rainfall can cause flooding. Again, precipitation is effective in the saturation of the ground by causing an increase in the groundwater level (Ekinci, 2004; Özşahin, 2016). In such a case, a suitable environment for flooding is prepared.

The average precipitation in the study area is 743 mm. Precipitation increases significantly from the basin floor towards the southern slopes and exceeds 1150 mm. (Figure 6h). To reveal the effect of precipitation on the flood, the basin precipitation characteristics are divided into three (3) classes: 600-700 mm, 700-900 mm, and 900+ mm. Higher scores were assigned to places with more precipitation and lower scores to places with less precipitation.

### Drainage Density ($D_d$)

Drainage density (Dd) is obtained by dividing the total length of all streams in a basin by the area of the basin (Horton, 1945). It is important in terms of determining how susceptible the basins are to floods. The higher the drainage density in a basin, the less infiltration of water there is in that area and the basin exhibits a structure that is less resistant to flooding; but, in basins with low drainage density, surface waters infiltrate more quickly, and these basins exhibit a more resistant structure to flooding (Patton & Baker, 1976). To put it numerically, the drainage density value is expressed as high if it is greater than 1.75 and as very high if it is greater than 2.5 (Reddy et al., 2004). Whether the drainage network in a basin is resistant to floods is directly related to the drainage density of that basin (Altıparmak & Türkoğlu, 2018). The average drainage density in the basin of Lake Ladik was calculated as 0.80. In other words, the study area has a low drainage density. This value shows that the infiltration in the basin is rapid, and that the basin is of low importance in terms of flood susceptibility. In addition, different drainage density classes have been identified in the basin and five (5) different drainage classes have been established (Figure 6i). In the pairwise comparison matrix for flood susceptibility analysis, score assignments were made by considering these classes, and low scores were assigned to classes with low drainage density, and high scores were assigned to classes with high drainage density.

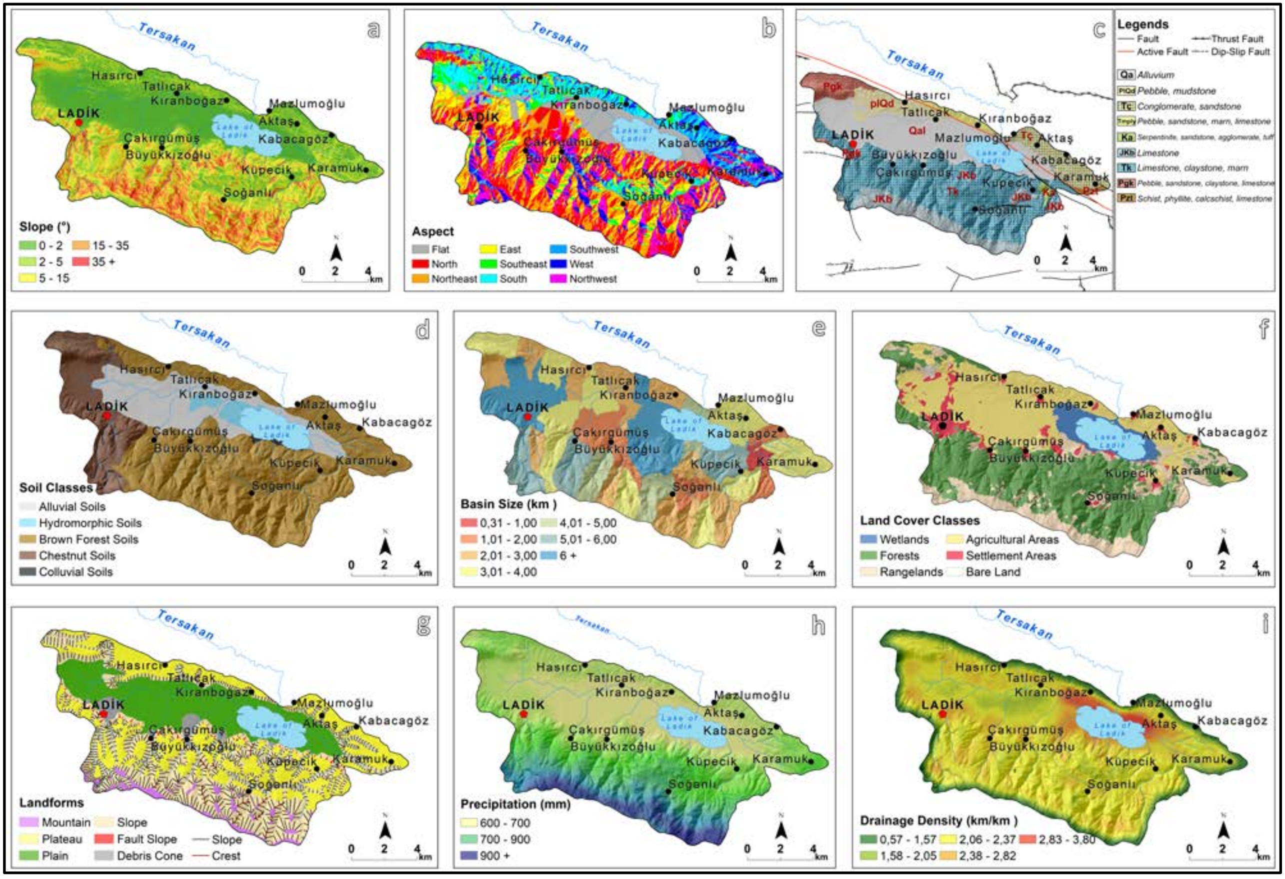


**Figure 6:** Maps of geographical factors used in flood susceptibility analysis in the study area; a) Slope map, b) Aspect map, c) Lithology map, d) Soil map, e) Basin size map, f) Land cover map, g) Landforms map, h) Precipitation map, i) Drainage density map.

### 3.1. Analysis and Evaluation

To analyze flood susceptible areas in the basin of Lake Ladik, a multi-criteria decision-making analysis was carried out with AHP using nine (9) main criteria (slope, aspect, lithology, soil, basin size, land cover, landforms, precipitation, and drainage density) and 51 sub-criteria based on these main criteria. By establishing a bilateral correlation between all the upper and lower criteria, scores between 1 and 9 were assigned according to the Saaty (1989) importance scale, and the weight ratios of all criteria were calculated (Figure 7; 8).

As a result of the multi-criteria decision-making analysis carried out for the flood susceptibility analysis, the consistency rate was calculated as 9% according to the nine (9) main geographical factors used in the basin of Lake Ladik.

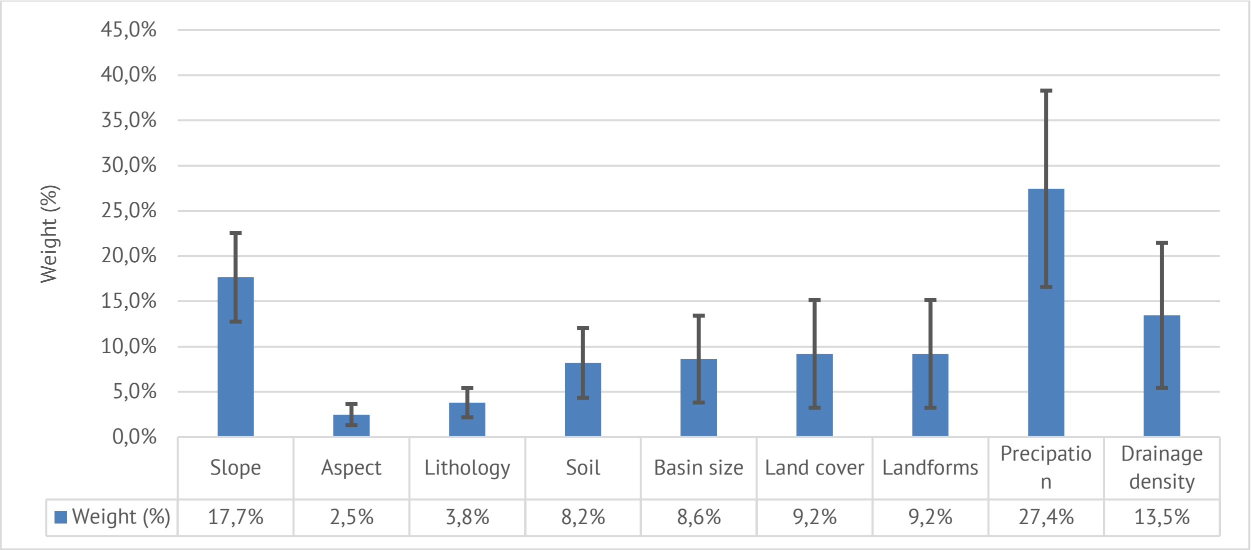
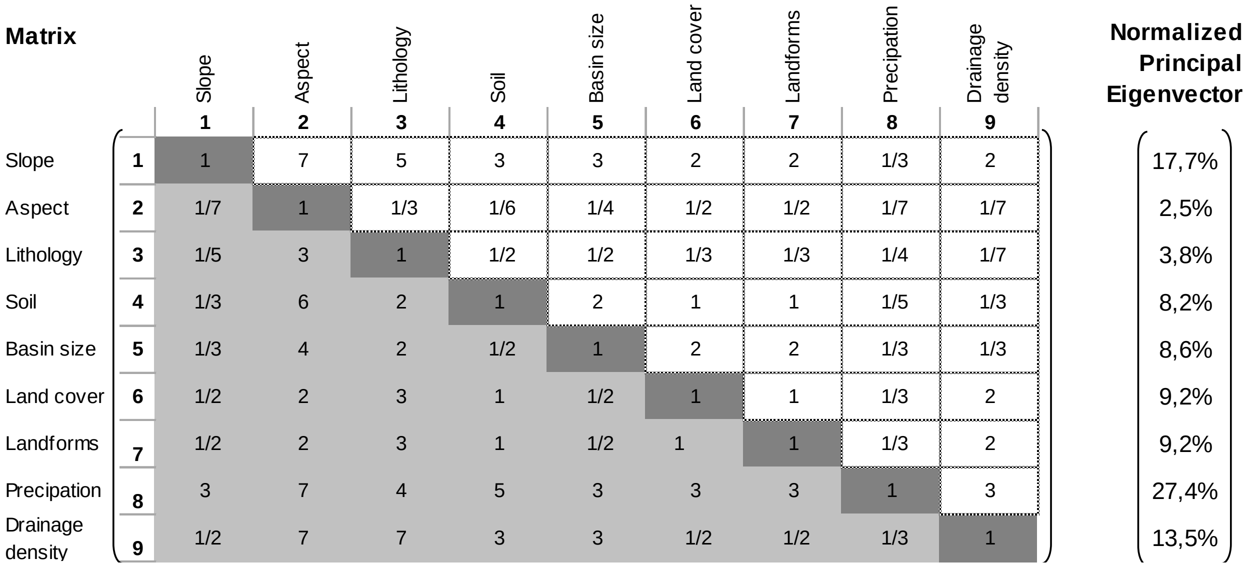


**Figure 7-**Distribution of weight ratios of the main geographical factors.



| Matrix | | Slope 1 | Aspect 2 | Lithology 3 | Soil 4 | Basin size 5 | Land cover 6 | Landforms 7 | Precipation 8 | Drainage density 9 | Normalized Principal Eigenvector |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Slope | 1 | 1 | 7 | 5 | 3 | 3 | 2 | 2 | 1/3 | 2 | 17,7% |
| Aspect | 2 | 1/7 | 1 | 1/3 | 1/6 | 1/4 | 1/2 | 1/2 | 1/7 | 1/7 | 2,5% |
| Lithology | 3 | 1/5 | 3 | 1 | 1/2 | 1/2 | 1/3 | 1/3 | 1/4 | 1/7 | 3,8% |
| Soil | 4 | 1/3 | 6 | 2 | 1 | 2 | 1 | 1 | 1/5 | 1/3 | 8,2% |
| Basin size | 5 | 1/3 | 4 | 2 | 1/2 | 1 | 2 | 2 | 1/3 | 1/3 | 8,6% |
| Land cover | 6 | 1/2 | 2 | 3 | 1 | 1/2 | 1 | 1 | 1/3 | 2 | 9,2% |
| Landforms | 7 | 1/2 | 2 | 3 | 1 | 1/2 | 1 | 1 | 1/3 | 2 | 9,2% |
| Precipation | 8 | 3 | 7 | 4 | 5 | 3 | 3 | 3 | 1 | 3 | 27,4% |
| Drainage density | 9 | 1/2 | 7 | 7 | 3 | 3 | 1/2 | 1/2 | 1/3 | 1 | 13,5% |

**Figure 8:** Pairwise comparison matrix of the main geographical factors.

To spatially apply the results of the pairwise comparison matrix performed with AHP, the calculated weight ratios were processed into the attribute tables of all geographical factors with GIS techniques. Then, according to the calculated weight ratios, the sub-criteria were first reclassified with GIS techniques, and in the last step, the weight ratios of the main geographical factors calculated with AHP were transferred to the map according to the equation below, and the flood susceptibility analysis of the basin of Lake Ladik was carried out (Figure 10).

**Flood Susceptibility Analysis**=(*Slope*0,177*) + *(Aspect*0,025)* + *Lithology*0,0038)* + *(Soil*0,082)* + *(Basin Size*0,086)* + *(Land Cover*0,092)* + *(Landforms*0,092)* + *(Precipitation*0,274)* + *(Drainage Density*0,135)*.

To determine the accuracy of the sensitivity analysis conducted within the scope of the research, it was aimed to use the ROC (Receiver Operating Characteristic Curve) method, which gives numerical values. However, since there is not enough flood inventory in the study area, it was not possible to verify the results of the analysis with the ROC curve method. Again, for the accuracy analysis, it was not possible to spatially determine the locations where the floods affect because of both satellite data and field studies. For these reasons, the accuracy and reliability of the results of the flood susceptibility analysis in the study were ensured by the location of the floods in the basin. Historically, only two major floods have occurred in the basin. One of them was on June 8, 1971, and the other one was on June 4, 2023, which was effective mostly in the west of the basin. Although the fact that only 2 floods occurred in the field seems to be insufficient for statistical accuracy analysis, it is accepted as a basis for accuracy and reliability since the locations of the floods occurred in both residential centers and many neighborhoods. When the locations of these floods are overlapped with the flood susceptibility map, it is seen that the floods occurred in areas with high and very high susceptibility (Figure 10).

As a result of the field studies carried out after the June 4, 2023, flood, it was determined that the 2023 flood caused many houses and workplaces to be flooded in Aşağıgölyazı, Tatlıcak and Saray neighborhoods, animals to perish in Tüfekçidere Neighborhood, and material damages in Sanayi, Akpınar, Çakırgümüş, Hacıalipınar, İskaniye, Kızılsini, Koğa, Şehreküstü, Yenicami and Bahşi neighborhoods. When these data obtained through field observations are compared with the table of the susceptibility levels of the settlements in the conclusion part of the study, it is seen that they overlap with the settlements most affected by the June 4, 2023, flood (Table 5). In this table where the susceptibility of settlements to flooding is presented, the settlements affected by the June 4, 2023, flood are in the first 4 places. According to the inventory data, 13 out of 14 settlements have both high and very high flood susceptibility. In other words, when the results of the flood susceptibility analysis are compared with the inventory data, it is determined that 93% of the settlements identified to be affected by the June 4, 2023, flood have high and very high flood susceptibility. This result shows that the results of the flood susceptibility map produced within the scope of the study are reliable and that this map can be used to reduce future damages due to flooding in the basin.

## 4. CONCLUSIONS

The Basin of Ladik Lake is highly susceptible to flooding due to high sediment and channel instability (low discharge in dry seasons and high discharge in rainy seasons) of short streams originating from the southern slopes. A significant flood occurred in Ladik on June 4, 2023, causing both material and life losses. This flood coincided with the results of the flood susceptibility analysis conducted within the scope of the study. In this flood that occurred in Tüfekçidere Neighborhood, 1 person lost his life, many houses were evacuated, and significant material damage occurred (Figure 9). The flood susceptibility classification produced by this study will enable decision-makers or planners to take precautions against possible flood events in the basin and put forward healthier plans.

**Figure 9:** Images from the June 4, 2023 flood.

In order to most accurately represent the spatial distribution of sensitivity classes in the final map, the natural break method was preferred. This method provides a classification based entirely on the available data by grouping similar values in the data in the most appropriate way. In this way, natural boundaries are determined more accurately and meaningful differences between classes are revealed (ArcGIS Pro Help, 2024).

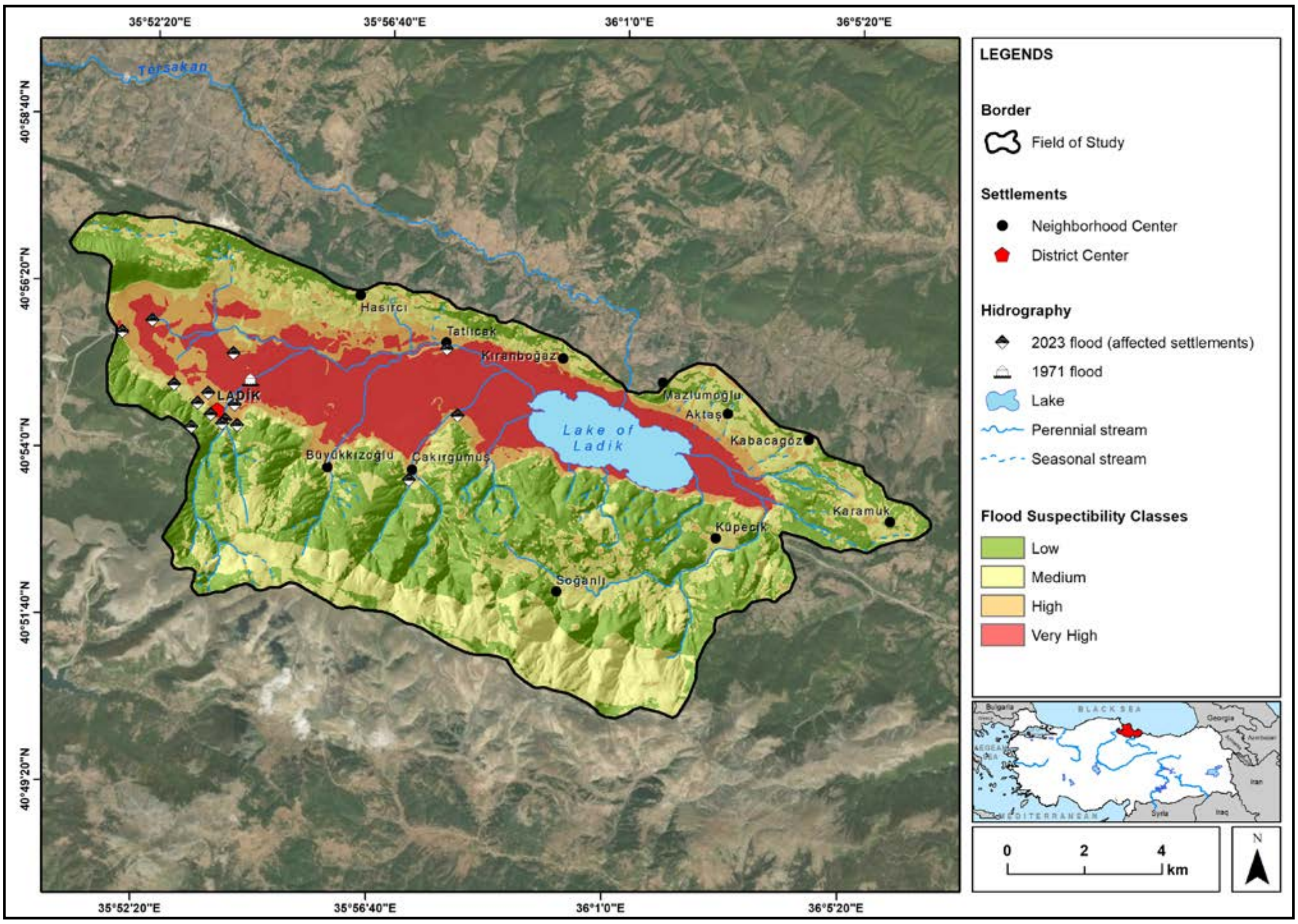


**Figure 10:** The flood susceptibility analysis map of in the study area.

## Low Level Flood Susceptibility Areas

The rate of places with low flood susceptibility in the basin of Lake Ladik is 36.77% (Figure 11). These areas with low flood susceptibility are the mountainous areas in the south of the basin and the forested areas throughout the basin. In these areas, either the slope values are high or there is dense vegetation. Small streams originating from high areas provide rapid drainage of water due to the high slope values. In addition, vegetation also contributes to the infiltration of water. For these reasons, flood susceptibility in these areas is low.

## Intermediate Flood Susceptibility Areas

In the basin of Lake Ladik, the rate of places with moderate flood susceptibility is 30.03% (Figure 11). The medium-level flood susceptibility class is generally seen in the basin, starting from the rangeland areas and the edges of the basin depression area. It is possible to say that the flood susceptibility remains at a moderate level due to the relatively low slope in this area, the transformation of the soil type to brown forest and chestnut soils, and less vegetation cover.

## High Level Flood Susceptibility Areas

The rate of places with high flood susceptibility in the basin of Lake Ladik is 11.43% (Figure 11). The high-level flood susceptibility class is seen in the basin where there are debris cones and settlement areas established. Ladik district center is also located in the area with high flood susceptibility. The Değirmen Stream flood that took place on 8 June 1971 still exemplifies the high susceptibility of this area. The fact that the district center is built in this area, that most of the economic activities take place here and that the construction increases day by day; are the parameters that will further increase the effects of a possible flood.

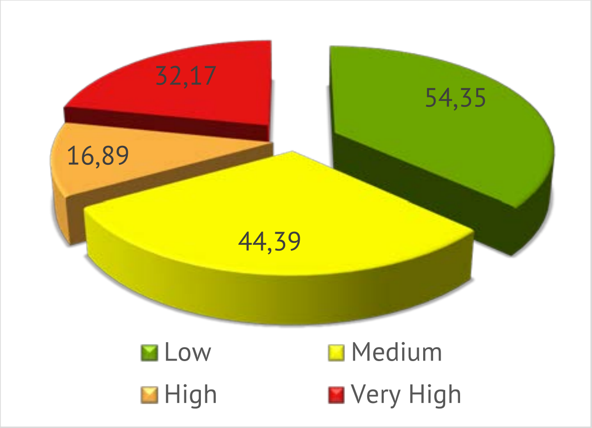


**Figure 11:** Distribution rates of flood susceptibility classes in the study area.

### Very High Flood Susceptibility Areas

In the basin of Lake Ladik, the rate of places with very high flood susceptibility is 21.77% (Figure 11). This rate is more than double in the area with high flood susceptibility and reveals the importance of the field in terms of flooding. This very high flood susceptibility is closely related to the presence of flat and nearly flat areas in the basin. These flat areas with slight or very slight slopes cover almost half of the basin. Quaternary-aged alluvium, hydromorphic and alluvial soils, drainage density and the presence of agricultural lands in the basin are the main factors in the very high flood susceptibility. Areas with very high flood susceptibility coincide exactly with these areas at the base of the basin.

The flood susceptibility analysis for the basin of Lake Ladik shows that this basin has an important potential for flooding. While three (3) of the settlements in the basin (Çakırgümüş, Büyükkızoğlu, Küçükkızoğlu) are located in areas with very high flood susceptibility, four (4) settlements (Tatlıcak, Bolat, Aşağıgölyazı), including the Ladik town center, are located in areas with high flood susceptibility, while the other settlements are located in areas with medium and low flood susceptibility. In addition, it has been determined that approximately 60% of the buildings (2,683 units) in the study area are located in areas with high and very high flood susceptibility (Table 4). 91% of the population (10,824 people) lives in these settlements. This shows how big the risk can be in a possible flood. For this reason, the new buildings and settlement areas to be built should be built according to the results of the flood susceptibility analysis. In addition, pre-disaster, during and post-disaster should be considered as a whole, and risk and crisis management plans should be created accordingly.

**Table 4:** The susceptibility of the buildings in the study area to floods.

| Susceptibility Classes | Area | | Number of Buildings |
|---|---|---|---|
| | km² | % | |
| Low | 54,35 | 36,77 | 531 |
| Medium | 44,39 | 30,03 | 1.335 |
| High | 16,89 | 11,43 | 1.926 |
| Very High | 32,17 | 21,77 | 757 |
| **TOTAL** | **147,80** | **100** | **4.549** |

Basin of Lake Ladik is an area where the materials carried by the rivers are abundant because it is a small and heavily drained basin. For this reason, the basin exhibits a structure that is susceptible to flood risks. The flood susceptibility analysis showed that more than 30% of the field has high and very high susceptibility (Figure 10; 11).

The result obtained because of the flood susceptibility analysis performed by using AHP and GIS techniques together was divided into four (4) different classes: low, medium, high, and very high (Figure 11). Considering the high and very high classes within the scope of the flood susceptibility analysis, it is seen that the five (5) settlements with the highest risk in the basin are Aşağıgölyazı, Tatlıcak, Sanayi, İskaniye and Büyükkızoğlu (Table 5). Inventory data obtained through field observations also show that 13 of the 14 neighborhoods within the basin boundaries and affected by the June 4, 2023, flood have high and very high flood susceptibility and only 1 (Tüfekçidere Neighborhood) has low flood susceptibility. The most important reason for this is that the settlement center of Tüfekçidere Neighborhood is located outside the basin boundaries, not within them.

**Table 5:** Susceptibility levels of settlements according to flood susceptibility analysis.

| ***Name*** | ***Population (2021)*** | ***Low*** | ***Medium*** | ***High*** | ***Very High*** | ***Area (km$^2$)*** | ***High + Very High*** |
|---|---|---|---|---|---|---|---|
| ***Aşağıgölyazı*** | 123 | 0,80 | 0,57 | 0,52 | 3,35 | 5,24 | 3,87 |
| ***Tatlıcak*** | 249 | 0,39 | 0,94 | 1,63 | 2,18 | 5,14 | 3,81 |
| ***Sanayi*** | 744 | 0,78 | 1,33 | 1,33 | 2,15 | 5,59 | 3,48 |
| ***İskaniye*** | 142 | 1,98 | 0,59 | 1,99 | 1,32 | 5,88 | 3,31 |
| ***Büyükkızoğlu*** | 240 | 5,09 | 3,20 | 0,40 | 2,83 | 11,52 | 3,23 |
| ***Hamitköy*** | 273 | 3,51 | 1,08 | 0,46 | 2,62 | 7,67 | 3,08 |
| ***Bolat*** | 399 | 5,46 | 4,18 | 0,84 | 2,16 | 12,64 | 3,00 |
| ***Mazlumoğlu*** | 124 | 0,36 | 0,49 | 0,45 | 2,51 | 3,81 | 2,96 |
| ***Çakırgümüş*** | 142 | 5,52 | 3,41 | 0,47 | 2,14 | 11,54 | 2,61 |
| ***Akpınar*** | 1573 | 0,55 | 0,69 | 1,39 | 1,06 | 3,69 | 2,45 |
| ***Bahşi*** | 2391 | 0,21 | 0,22 | 0,66 | 1,76 | 2,85 | 2,42 |
| ***Aktaş*** | 105 | 0,29 | 1,01 | 0,75 | 1,56 | 3,61 | 2,31 |
| ***Kıranboğaz*** | 131 | 0,27 | 0,46 | 0,37 | 1,81 | 2,91 | 2,18 |
| ***Cüce*** | 106 | 4,64 | 3,18 | 0,54 | 1,53 | 9,89 | 2,07 |
| ***Küçükkızoğlu*** | 131 | 1,96 | 1,26 | 0,41 | 1,21 | 4,84 | 1,62 |
| ***Hasırcı*** | 163 | 0,37 | 1,37 | 1,01 | 0,48 | 3,23 | 1,49 |
| ***Kabacagöz*** | 156 | 2,18 | 2,52 | 0,68 | 0,54 | 5,92 | 1,22 |
| ***Hacıalipınar*** | 559 | 0,72 | 0,52 | 0,36 | 0,47 | 2,07 | 0,83 |
| ***Küpecik*** | 270 | 4,72 | 3,57 | 0,48 | 0,32 | 9,09 | 0,80 |
| ***Kızılsini*** | 46 | 0,02 | 0,06 | 0,47 | 0,08 | 0,63 | 0,55 |
| ***Soğanlı*** | 97 | 2,69 | 5,49 | 0,28 | 0,00 | 8,46 | 0,28 |
| ***Ayvalı*** | 244 | 1,29 | 1,09 | 0,25 | 0,00 | 2,63 | 0,25 |
| ***Şıhlı*** | 291 | 0,29 | 0,72 | 0,25 | 0,00 | 1,26 | 0,25 |
| ***Karamuk*** | 115 | 1,75 | 1,04 | 0,20 | 0,00 | 2,99 | 0,20 |
| ***Saray*** | 344 | 5,38 | 3,91 | 0,17 | 0,00 | 9,46 | 0,17 |
| ***Yenicami*** | 612 | 0,29 | 0,09 | 0,08 | 0,09 | 0,55 | 0,17 |
| ***Deliahmetoğlu*** | 177 | 0,20 | 0,05 | 0,14 | 0,00 | 0,39 | 0,14 |
| ***Koğa*** | 910 | 0,04 | 0,08 | 0,09 | 0,04 | 0,25 | 0,13 |
| ***Yukarıgölyazı*** | 57 | 0,82 | 0,46 | 0,09 | 0,00 | 1,37 | 0,09 |
| ***Arslantaş*** | 18 | 0,65 | 0,27 | 0,08 | 0,00 | 1,00 | 0,08 |
| ***Şehreküstü*** | 737 | 0,18 | 0,17 | 0,05 | 0,00 | 0,40 | 0,05 |
| ***Tüfekçidere*** | 248 | 1,18 | 0,10 | 0,00 | 0,000 | 1,28 | 0,00 |
| ***Total Population*** | **Total Area (km$^2$)** | 54,58 | 44,12 | 16,89 | 32,22 | 147,80 | 86,47 |
|  | **%** | 36,93 | 29,85 | 11,43 | 21,80 | 100 |  |
|  | **11.917** |  |  |  |  |  |  |

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This article is derived from a part of his doctoral dissertation titled "Smart Natural Disaster Management in Basin of Lake Ladik Basin (Samsun)". Within the scope of the thesis, a holistic disaster management system application that can be used before, during and after a disaster has been designed. The application is both web and mobile based. This article constitutes only a part of the related doctoral dissertation. You can access the application designed to make the article more understandable: https://arcg.is/081azy

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