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An Evaluation of the Causes and Consequences of the Flash Floods (5.9.2023) in the Degirmen River Basin in Igneada (Demirkoy/Kırklareli)

İğneada (Demirköy/Kırklareli) Değirmen Deresi Havzasında Meydana Gelen Selin (5.9.2023) Nedenleri ve Sonuçları Üzerine Bir Değerlendirme

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ABSTRACT

On 5.9.2023, flash floods occurred in Igneada town of Demirkoy district of Kırklareli province, which caused serious loss of life and property. Since this unfortunate event was a natural hazard with a hydro-meteorological characteristic, it occurred at the river basin scale. Therefore, the present study aims to systematically reveal the chain of events leading to the flash floods in the Degirmen River basin, where the natural hazard occurred. The study data were processed and interpreted in the light of the relevant literature within the framework of the findings obtained from office and field studies. At this stage, the Root Cause Analysis (RCA) method was used to determine how and why the event occurred and how to prevent similar problems from occurring again. As a result of the study, it was determined that flash floods caused by sudden torrential rains led to high-energy water flows on the slope lands depending on topographic features. Consequently, they forced the transportation of materials of various sizes. The materials coming from the river's upper basin with strong flash floods with irregularly changing flow rates triggered flooding in places where the slope of the river bed decreased. However, this natural event has become a natural hazard in the lower basin due to the wrong land use caused by the negative anthropogenic effects of human beings on the natural environment.

Keywords: Flash floods, inundation, natural hazard, Demirkoy, Igneada.

ÖZ

5.9.2023 tarihinde Kırklareli ilinin Demirköy ilçesine bağlı İğneada beldesinde ciddi can ve mal kaybına neden olan bir sel meydana gelmiştir. Bu elim olay hidro-meteorolojik karakterli bir doğal afet olduğu için akarsu havzası ölçeğinde meydana gelmiştir. Bu nedenle, bu çalışma doğal afetin meydana geldiği Değirmen dere havzasında sele yol açan olaylar zincirini sistematik olarak ortaya koymayı amaçlamaktadır. Çalışma verileri, ofis ve saha çalışmalarından elde edilen bulgular çerçevesinde ilgili literatür ışığında işlenmiş ve yorumlanmıştır. Bu aşamada olayın nasıl ve neden meydana geldiğini saptamak ve benzer problemlerin tekrar yaşanmasının nasıl önlenebileceğini tespit etmek için Kök Neden Analizi (KNA) yöntemi kullanılmıştır. Çalışma sonucunda aniden gelişen sağanak yağışların sebep olduğu sel olayının, topografik özelliklere bağlı olarak yamaç arazilerde yüksek enerjili su akımlarına ve buna bağlı olarak çok değişik boyutlardaki malzemenin taşınmasına sebep olduğu tespit edilmiştir. Akarsuyun üst havzasından debisi çok düzensiz bir şekilde değişen güçlü sel suları ile gelen malzemeler akarsu yatağında eğimin azaldığı yerlerde su baskınlarının yaşanmasını tetiklemiştir. Ancak bu doğal olay, özellikle insanın doğal ortam üzerindeki olumsuz antropojenik etkilerinin yol açtığı yanlış arazi kullanımıyla alt havzada afet karakteri kazanmıştır.

Anahtar Kelimeler: Sel, su baskını, afet, Demirköy, İğneada.

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Introduction

Natural hazards are extreme events whose consequences can damage both the natural and human-made environment (Bathrellos & Skilodimou, 2019). The most common of these natural hazards, which vary from region to region (Skilodimou & Bathrellos, 2021), are flash floods (Xiong et al., 2019), which are widespread around the world and are characterized by their negative impact on economic development (Skilodimou & Bathrellos, 2021). In recent years, flash floods caused by sudden torrential rains have become more common (Polat et al., 2023). These events, the frequency and severity of which increase day by day due to climate change and other environmental factors (Du et al., 2023), turn into hydro-meteorological natural hazards with the adverse effects of human beings on the natural environment (Özşahin, 2013). Flash floods are very fast-moving streams of water flowing with torrential rainfall in the upper and middle reaches of river basins, covering the slopes (Özcan, 2006). Flash floods, whose flow rate varies irregularly (Korkanç & Korkanç, 2006), become more destructive as they carry significant amounts of sediment and debris due to their high kinetic energy (Özdemir & Kaymak, 2022). These materials trigger an increase in the river load in the lower parts of the river basin, where the slope decreases, overflowing the river bed and flooding the surrounding areas (Özşahin, 2022).

Flash floods and subsequent inundations, which can cause damage anywhere, devastate agricultural areas, infrastructure, and human life, especially in areas close to rivers (Subraelu et al., 2023). To mitigate the effects of these natural hazards with dramatic consequences and to maintain healthy socio-ecological systems under changing basin or climate conditions, there is a need to investigate the root causes and impacts of the problem with scientific methods after natural hazards (Ren et al., 2023). This need is crucial for effective natural hazard management and mitigation (Taherizadeh et al., 2023).

Today, researchers from different disciplines, especially geographers, are working in every country to control and mitigate the effects of flash floods (Roy et al., 2020). In particular, what is known about areas vulnerable to natural hazards is largely based on general post-disaster assessment studies (Tate et al., 2021). However, in areas where flash floods are likely to occur, morphometric, hydrological, mathematical, statistical, machine learning, and hybrid methods are used to generate data about possible natural hazards (Liu et al., 2022; Liu et al., 2023). Therefore, pre- and post-natural hazard studies are generally based on Geographic Information Systems (GIS) techniques. Thus, a large amount of spatial and temporal data can be processed, and valuable information can be generated (Shahiri Tabarestani and Afzalimehr, 2021).

Türkiye is located in a geographical area where the main factors that trigger natural hazards, such as flash floods, are widely observed (Kamuş & Atalay Dutucu, 2023). This is evidenced by the frequent occurrence of similar events characterized as natural hazards almost every year (Özşahin, 2022). Therefore, many studies, especially by geographers, have been conducted on flash floods in Türkiye. While some of these studies have aimed to make a general evaluation of the causes and consequences of natural hazards (Bahadır, 2014; Fural et al., 2019; Karabulut et al., 2007; Korkmaz & Karataş, 2013; Özdemir & Kaymak, 2022; Sezer, 1997; Şahin, 2002; Şahinalp, 2007; Turoğlu, 2005; 2011a; 2011b; 2012; Uzun, 1995; Uzun, 2010; Zeybek, 2005; Zeybek et al., 2013a; 2013b; 2017), others have aimed to identify and map areas that have already experienced or are likely to experience disasters (Avci, 2023; Avci & Sunkar, 2015;2018; Avci & Ünsal, 2023; Avci et al., 2023; Cürebal et al., 2016; Ocak & Bahadır, 2020; Ocak et al., 2021; Özdemir, 2007; Özşahin, 2022; Özşahin & Kaymaz, 2013; Polat et al., 2023; Sunkar & Tonbul, 2010; Turoğlu, 2007; Turoğlu & Aykut, 2019; Turoğlu & Özdemir, 2005).

In the existing literature in Turkiye, flash floods have been investigated using hydroclimatic and morphometric analyses within the frame of river basins (Özdemir, 2011; Özşahin, 2008). These methods, which are used directly in some studies and as complementary analyses in others, have generally been supported by GIS techniques in the last few decades (Elbaşı & Özdemir, 2018). Thus, much faster and easier results are obtained compared to traditional methods (Yıldırım, 2021), and ease of use is provided in terms of the spatial distribution of the analysis and evaluations in the basin (Dursun & Babalık, 2023).

As a result of the torrential rains in the Black Sea catchment area of the Strandja Region between September 4 and 6, 2023, flash floods occurred in the Değirmen River basin on September 5, 2023. This event, which turned into a natural hazard in a short time, caused flash floods in Igneada town of Demirkoy district, and the Demirkoy-Igneada highway was closed to traffic for a while. Moreover, it caused the death of 6 out of 16 people who were trapped in the Sisli Valley in Igneada town of Demirkoy district (Governorship of Kırklareli, 2023). However, official institutions have shared no detailed scientific explanation or information about the causes of natural hazards. Publishing scientific studies immediately after natural hazards is a necessary action. In this way, the root causes of the problem can be understood and managed, and the effects of similar natural hazards can be reduced.

This study aims to investigate the effects and consequences of the main factors leading to flash floods in the Degirmen River basin in the Black Sea catchment area of the Strandja Region. Therefore, it is aimed to reveal in detail what needs to be done to prevent similar events from turning into natural hazards or to reduce their impacts. The natural hazard that is the subject of the study is defined as a flash flooding, which is different from a river flood, as it is caused by short-term heavy or excessive rainfall and occurs in less than six hours (Xia et al., 2011). This study can provide a scientific reference for flash floods prevention and mitigation in similar areas. Furthermore, the study data can be used to adapt mitigation strategies and prepare Natural Hazard Risk Reduction Plans.

Method

Study area

The study area is the Degirmen River basin, where the flash floods occurred on 5.9.2023, which resulted in serious loss of life and property. The basin area, with a surface area of 107.78 km², which is located on the Black Sea catchment area of the Strandja Region of the Thracian Peninsula, is one of the two peninsulas that make up Türkiye (Figure 1). The main river tributary in the study area is 27 km long and terminates at Lake Mert within the borders of Igneada Floodplain Forest National Park (Figure 1).

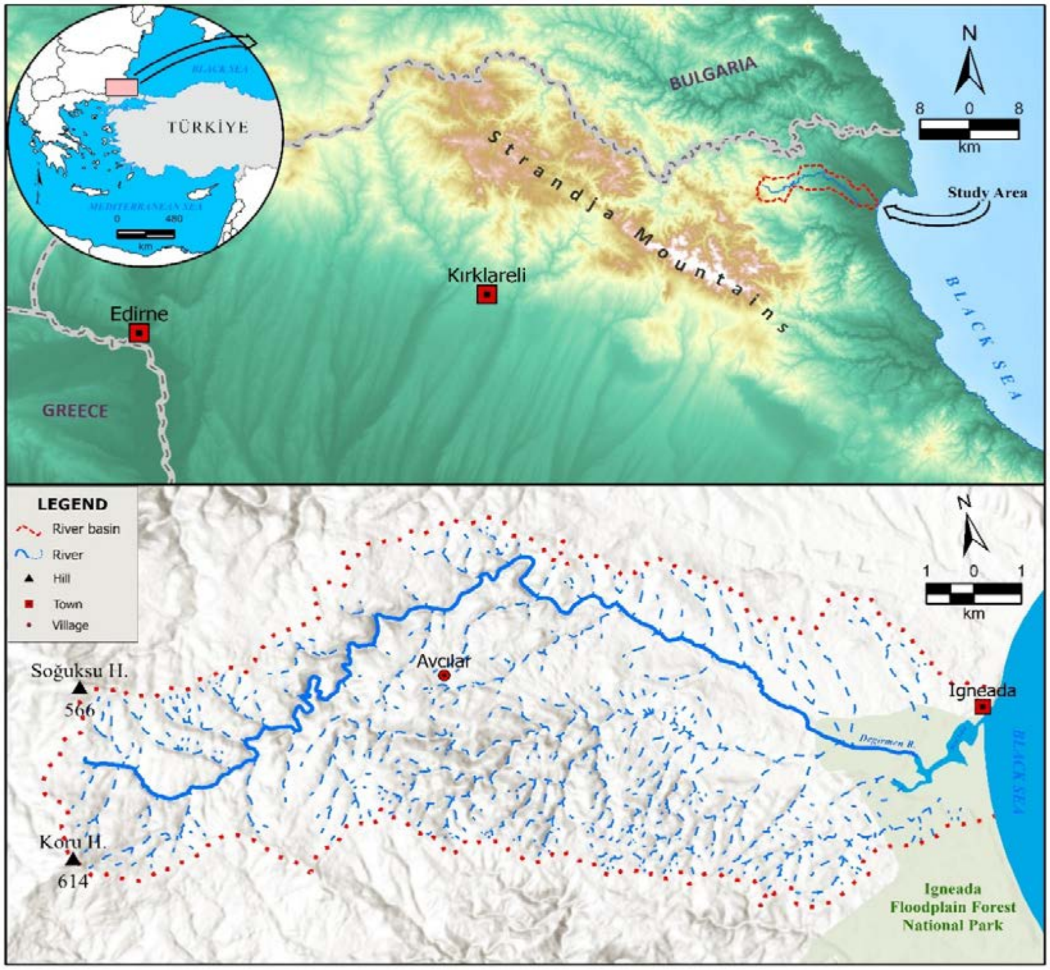

Figure 1.
Location Map of the Study Area.

The study area has lithologic features where the transition from old to young units is observed from land to sea on a geologic time scale. In the study area, where the basal terrain consists of Paleozoic schist and gneiss rocks of the Strandja massif and Mesozoic flysch, the lower river basin is covered with Neogene sediments. Quaternary alluvium is spread in the valley floor and coastal areas of the main river (MTA, 2002).

There are major landforms with different features in the study area. Strandja Mountains, which correspond to the Miocene erosion surface, constitute the most important major landform in the study area (Kurter, 1978; 1982). This mountainous area is surrounded by a plateau developed as an Upper Pliocene-aged erosion surface.

The deposition areas in the seaward parts of the plateau show a plain character (Turoğlu, 1997). Apart from this mostly terrestrial plain, a coastal plain is developed as a delta in the section where the main river branch in the study area reaches the coast.

The Black Sea climate is dominant in the study area. Although it varies according to the aspect and elevation, it is generally rainy in summer and cool and rainy in winter (Turoğlu, 1997). When the annual average temperature and total precipitation values of the meteorological stations in the study area are compared, it is seen that although the temperature and precipitation vary monthly, they decrease from the coast to the interior (Table 1).

Table 1.
Temperature and Precipitation Values of Meteorological Stations in the Study Area (Edited from TSMS, 2022 data)

Months	Station	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Temperature (˚C)	İgneada	3.7	4.2	6.6	10.9	15.4	20.0	22.0	22.0	18.8	14.9	10.0	6.2	12.9
	Demirkoy	2.1	4.1	5.9	11.1	15.6	19.1	21.1	20.4	17.0	12.7	9.2	4.8	11.9
Precipitation (mm)	İgneada	91.1	65.5	60.8	57.1	49.2	42.5	45.1	35.1	40.1	91.4	118.1	106.9	802.9
	Demirkoy	120.3	77.0	65.8	51.9	43.1	37.8	22.5	40.1	44.9	87.7	95.4	105.3	791.8

The study area is very rich in terms of hydrographic features. In this area dominated by fluvial processes, there are groundwater, rivers, lakes, and the sea. The main river and its tributaries, which originate from the mountainous area, flow towards the Black Sea in a parallel or subparallel manner, even if they show a dendritic drainage network regarding their general structure (Turoğlu, 1997). The level of the rivers in the study area increases in winter and decreases in summer. On the other hand, the level rise in the rivers reaches its maximum value in February and its minimum value in August and September (Table 2). Therefore, the river flows in the study area bear the main features of the Rainy-Mediterranean regime type. For this reason, there are also slope springs in the areas where groundwater comes to the surface in the sections of the study area towards the Strandja Mountains and Lake Mert, which developed as a lagoon in the coastal region.

Table 2.
Average Monthly Flows of the Current Observation Stations in the Study Area (Edited from GDSHW, 2015 data)

Streamflow gauging station	Mean monthly discharge (m^3/sec)												
	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Degirmen R.	0.4	0.6	0.5	0.3	0.1	0.1	0.01	0.005	0.1	0.1	0.3	0.5	0.25

In the study area, there are two types of developed soil orders. In the mountain and plateau areas in the drainage basin of the river, inceptisols, which were formed as a result of the decomposition of the main material and are not fully matured, are spread. On the other hand, there are entisols in the plain in the study area, whose horizons are not fully developed and have young characteristics.

In the study area, the natural vegetation formations are represented by moist forests, pseudomaquis, and coastal plants (Dönmez, 1990). While almost the entire river basin is dominated by trees, land use in the form of crops, rangeland, and built-up areas is common in some areas close to the coast and in some areas with pseudomaquis and coastal plants (ESRI, 2022). There are also floodplain forests with national park status in the sections where the main river branch reaches the coast (Turoğlu, 1997).

Method

The Root Cause Analysis (RCA) method was used in this study. This technique, developed for structured risk identification and management following adverse events, is used to determine how and why an event occurred and how to prevent the event and similar problems from happening again (Peerally et al., 2017). The aim of RCA, which is a problem-solving method widely used in science to identify the main causes of mistakes or problems, is to identify the root cause of the problem (Turhan & Ünalan, 2022). RCA is usually performed in five steps (Figure 2). In the first step, the problem is clearly defined. This step also gives an idea about the scope of the study. The second step is data collection. In this step, all available data about the incident should be collected. The third step is to identify the possible causal factors of the problem. In this step, the events that led to the problem and the conditions that caused the problem are tried to be identified. The fourth step is to identify the root cause(s). In this step, the real reason behind the problem is tried to be identified. Maps are used to represent the relationship between the event that occurred in the third and fourth steps and the data collected. The fifth and final step is to propose and implement solutions. At this stage, recommendations should be developed to solve the root cause and prevent the recurrence of the same event (Rooney and Heuvel, 2004).

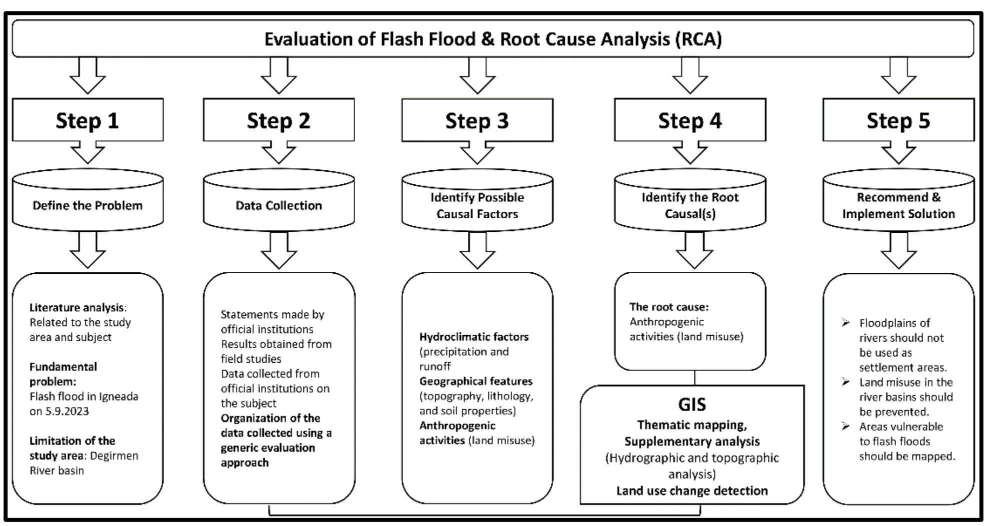

Figure 2.
Methodology Flowchart.

In the first step of the application phase of the method, the flash floods that occurred on 5.9.2023 were defined as the main problem. In the same step, it was understood that the problem should be handled at the river basin scale since it is a natural hazard of hydro-meteorological origin. For this purpose, the river basin and drainage network in the area where the problem is effective were determined using topography maps. In the second step, all available data related to the study problem were collected. For this purpose, the findings obtained from office and field studies and the data received from official institutions were organized using a general evaluation approach. In the third step, the events leading to the problem and the conditions that led to the emergence of the problem were considered separately. For this purpose, hydroclimatic and morphometric complementary analyses were utilized. The amount of daily precipitation falling in the river basin was determined using the precipitation maps method due to the scarcity and irregularity of precipitation observation stations (Eriş & Ağıralioğlu, 2017). The flow on the day of the natural hazard in the basin was taken from the report prepared by GDSHW (2023). For the topographic analysis, the most preferred morphometric indices in flash flood studies were used (Table 3). In the fourth step, the real cause behind the flash floods was tried to be identified. In this step, the results supported by complementary analyses were reinterpreted and discussed with the observations made through field studies. Land use change detection (LUCD) was also performed to better understand the land misuse caused by anthropogenic activities. Thus, data were obtained to better understand the relationship between humans and natural phenomena (Liu et al., 2023). Furthermore, the third and fourth steps of the method were supported by GIS techniques. In the last step, a conclusion was reached with the data obtained, and some recommendations were presented.

Table 3.
Morphometric Indices Applied for the River Basin in the Study Area

Morphometric indices		Formula/Definition	References
Areal	Basin length (L)	Length of basin	The present study
	Basin perimeter (P)	Perimeter of basin	
	Basin area (A)	Area of basin	
	Form factor (Rf)	$R_f = A / L^2$	Horton, 1932, 1945
	Stream frequency (Fs)	$F_s = N_u / A$	Strahler, 1964
	Drainage density (Dd)	$D_d = \Sigma L_u / A$	Horton, 1932, 1945
Linear	Stream Length (Lu)	Length of the stream	The present study
	Bifurcation Ratio (Rb)	$R_b = Nu / Nu + 1$	Schumm, 1956; Strahler, 1964
	Length of overland flow (L_o)	$L_o = (1/D_d) \times 0.5$	Horton, 1945
	Elongation ratio (Re)	$R_e = (2/L_b) \times (A/\pi)^{0.5}$	Horton, 1945; Strahler, 1964
	Texture Ratio (T)	$T = N_{u1} / P$	Kirpich, 1940
Relief	Basin relief (Bh)	$B_h = H_{max} - H_{min}$	Schumm, 1956
	Relief Ratio (Rh)	$R_h = H / L$	Schumm, 1956
	Ruggedness Number (Rn)	$R_n = B_h \times D_d$	Strahler, 1954; Melton, 1957
	Hypsometric Integral (H_i)	$H_i = (H_{ort} - H_{min}) / (H_{mak} - H_{min})$	Strahler, 1952
	Time of concentration (T_c)	$T_c = 0.0195 * L^{0.77} / S^{0.385}$	Kirpich, 1940

Results

Step 1: Definition of the Problem

The main problem of this study is the flash floods that occurred on 5.9.2023. This natural hazard was effective in the Degirmen River basin, which is located in the Black Sea catchment area of the Strandja Region. Hence, it was found worthy to analyzed the problem within the scope of the river basin. Moreover, to better diagnose the study problem, it is necessary to name it correctly. In this respect, this natural hazard, which can be classified as flash flooding according to its duration, can be included in the group of river and river floods according to the place of occurrence (Kadıoğlu, 2019).

Step 2: Data Collection

The data required to investigate the main factors that cause flash floods to turn into natural hazards are generally not clearly stated in the literature (Subraelu et al., 2023). However, it was emphasized that the studies to be conducted in this regard should be determined in the light of available data and according to the geographical location and characteristics of the basin where the natural hazard occurred (Kelly et al., 2023). Therefore, the data of this study were determined according to the available data and the geographical location and characteristics of the study area. These data were utilized to determine the possible causal factors and identify the root cause(s), which constitute the main problem of the study.

The general climatic features of the study area were described using the data of Igneada (25 m) and Demirkoy (330 m) meteorological stations covering a period of 29 (1964-1993) and 55 (1966-2021) years, respectively, as they have longer-term observation records (TSMS, 2022). Precipitation values during the effective dates of the natural hazard in the study area were determined according to the data of Demirkoy (18102), Demirkoy/Begendik village (18795), and Pınarhisar/Mahya Hill (18797) meteorological stations to characterize the river basin as a whole (TSMS, 2023a). The flow characteristics of the main tributary were determined using the streamflow yearbook of the Degirmen River (D02A151) streamflow observation station (GDSHW, 2015). Base mapping was performed using the relevant sheets of the 1:25,000 scale topographic maps of Türkiye (GDM, 2023). At the same time, topographic conditions were determined using the data obtained by digitizing these maps (GDM, 2023). Lithological features (GDMRE, 2002) and soil properties were compiled from maps published by GDRS (1991). Land use was determined using the Land Use/Land Cover (LULC) data provided by ESRI (2022) (Table 4).

Table 4.
Data and Data Sources Used in This Study

No	Data	Derivation	Source
1	Related sheets of topographic maps of Türkiye (Scale: 1:25.000)	Basemap Determination of the basin area Production of river network Thematic mapping	GDM, 2023
2	Meteorological observations data of temperature and precipitation	Mean monthly temperature and precipitation values	TSMS, 2022
3	Meteorological observations data of rainfall	Daily rainfall	TSMS, 2023a
4	Streamflow observation data of streamflow-gauging stations (2009-2015)	Mean monthly discharge (m^3/sec)	GDSHW, 2023
5	Runoff and discharge data of Degirmen River (September 04-06, 2023)	Runoff and discharge (m^3/sec)	GDSHW, 2023
6	Geological map (Scale: 1:100.000)	Lithological features	GDMRE, 2002
7	Soil maps (Scale: 1:100.000)	Soil features	GDRS, 1991
8	Land use maps (2017&2022) (Resolution: 10 m)	Land use changes (2017&2022)	ESRI, 2022

Step 3: Identification of Possible Causal Factors

Flash floods, which are considered a major threat to the sustainability of natural and human systems, are controlled by hydroclimatic factors (precipitation and runoff), geographical features (topography, lithology, and soil properties), and anthropogenic activities (land misuse) in river basins (van Vliet et al., 2023). Therefore, the flash floods in the study area, which constitute the main problem of this study, were similarly caused by possible causal factors.

Hydroclimatic Factors

The hydroclimatic factors in the river basin primarily affect the formation of flash floods in the study area. In this context, the primary meteorological cause of flash floods is the weather movements that direct seasonal weather events (Karabulut et al., 2007). At the time of the natural hazard, the study area and its immediate surroundings were under the influence of the storm called "Daniel". This storm developed from the meteorological phenomenon called the Omega block when the jet streams in the upper troposphere formed a pattern similar to the Greek letter omega (Ω) as the high-pressure system was squeezed between two low-pressure systems (Figure 3). The low-pressure system over Greece was joined by air currents over the Aegean Sea and the Black Sea carrying large amounts of moisture, leading Daniel to become a "Medicane" (Mediterranean hurricane) a week after it was named (JBA Risk Management, 2023). Abnormal seawater temperatures contributed significantly to this atmospheric activity. Thus, severe winds and flash floods occurred between September 4 and 7, 2023, in regions such as Türkiye, Greece, Sicily Island, Italy, and Malta (Korosec, 2023). It is estimated that the effects of human-induced climate change were also involved in the occurrence of this event (World Weather Attribution, 2023).

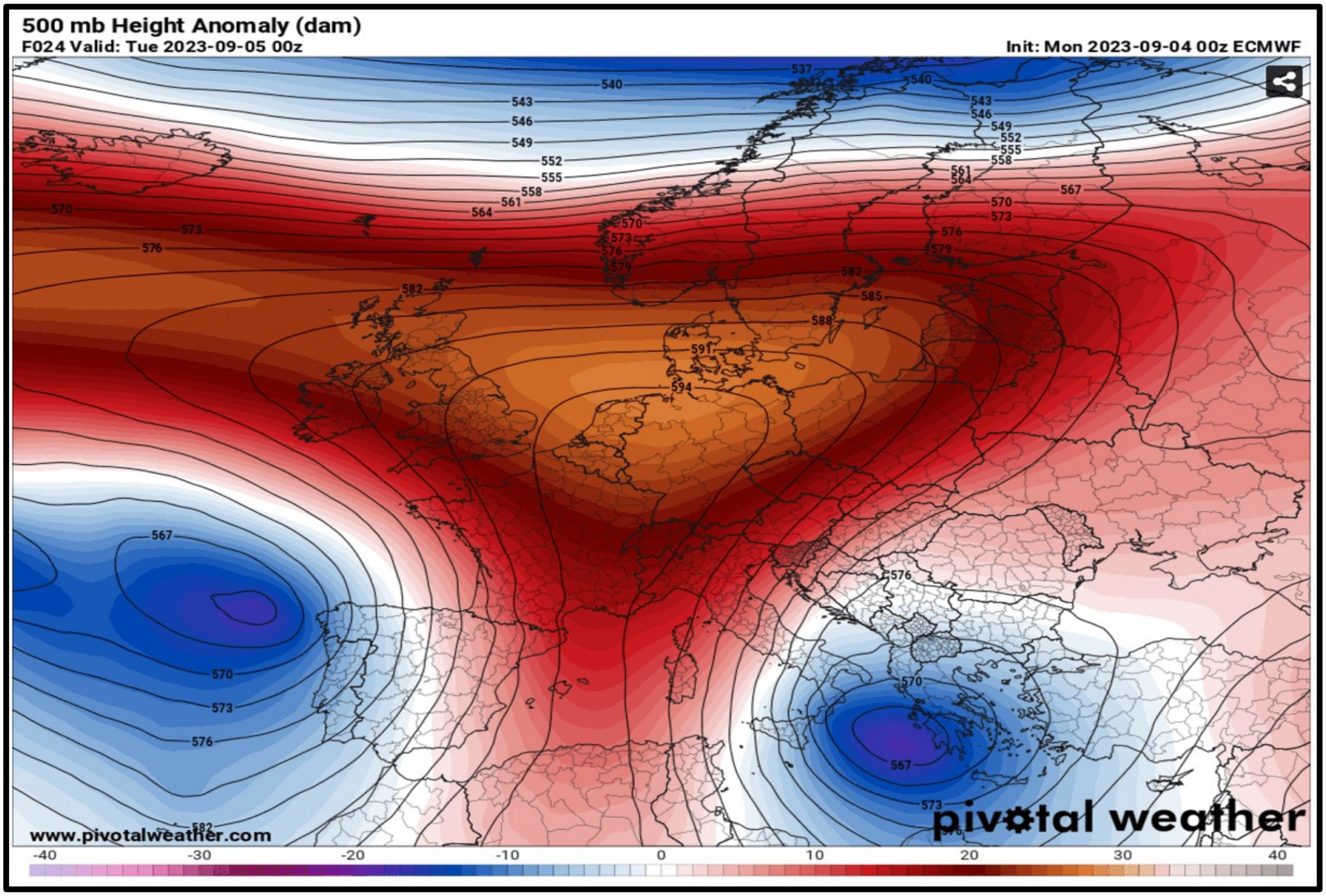

Figure 3.
The Omega Blog, Caused by A High-Pressure System Being Squeezed Between Two Low-Pressure Systems, Causing Storm Daniel (Korosec, 2023).

The occurrence and development of the natural hazard in the study area occurred in three days (4-6.9.2023) in terms of hydroclimatic factors. It had the greatest impact on the second day (5.9.2023). Short-term and high-intensity downpours occurred on the relevant dates depending on the atmospheric activity effective in the study area (Figure 4). According to the rainfall intensity classification, heavy rainfall (21-50 mm), extreme rainfall (over 100 mm), and very heavy rainfall (51-75 mm) occurred in the study area on the relevant dates, respectively (TSMS, 2023b). Due to the heavy rainfall, the flow of the rivers in the study area also increased. Therefore, it is understood that the precipitation that fell on the natural hazard dates was much higher than the total annual precipitation amount and the annual average flow of the rivers in the study area (Table 5). In particular, the day of the flash flooding also corresponds to the time when the rainfall and flow were the highest (Table 5).

A flash flooding detection and calculation report was prepared by GDSHW (2023) to explain the occurrence of natural hazards in the study area. In this report, some hydrological-hydraulic calculations were made using n (cross-section) sections taken from the water traces in the area where the natural hazard occurred. According to these calculations, it was determined that the amount of water passing through the river at the time of the flash flood event was 320.4 m^3/sec. This flow was higher than the 10000-year recurring flow magnitude (GDSHW, 2023; Table 6). Therefore, it is understood that extreme hydroclimatic factors were effective in the natural hazard in the study area. Xiong et al. (2019) stated that due to the impact of climate change, short-term and high-intensity precipitation and subsequent high river flows, especially in river basins, cause flash floods that have the risk of turning into natural hazards.

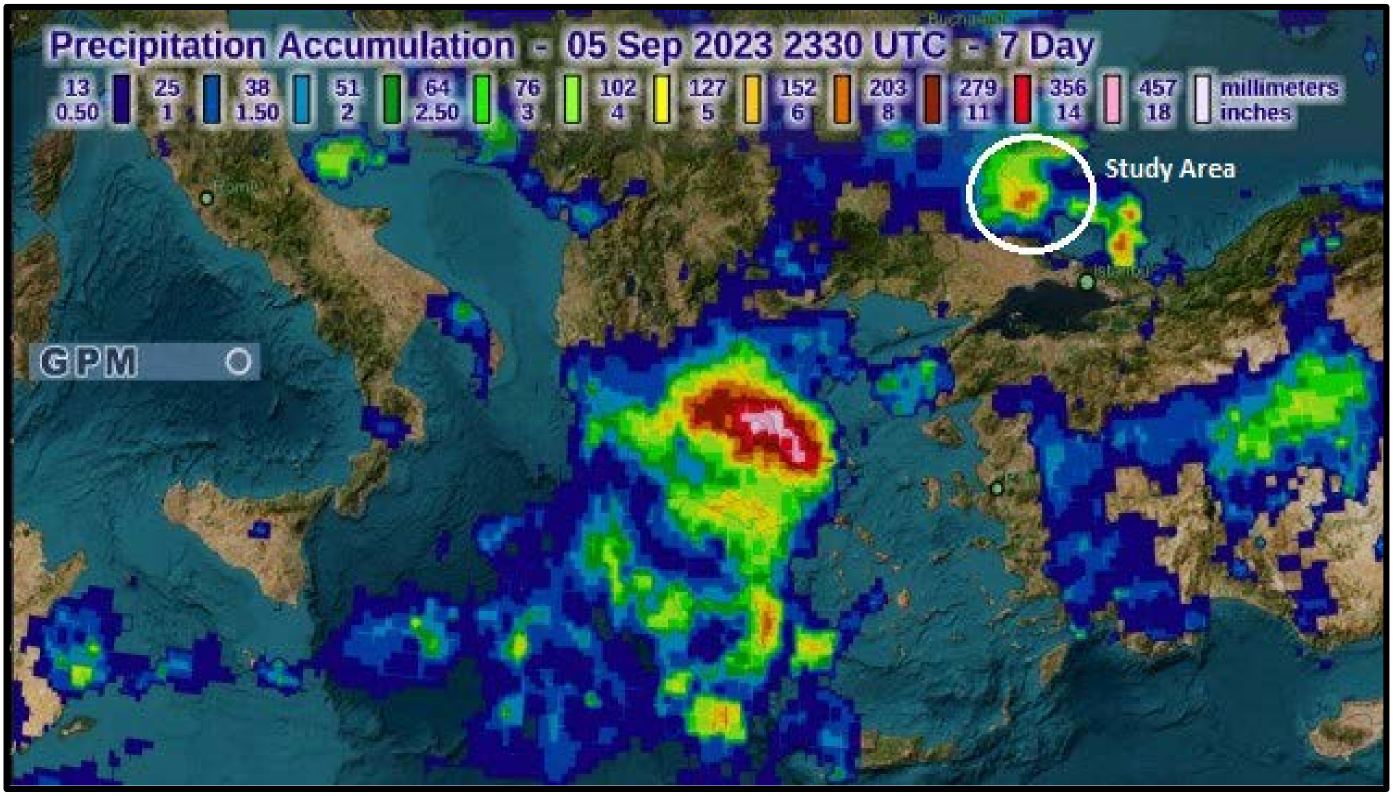

Figure 4.
NASA's Global Precipitation Measurement Product, the Amount of Precipitation in The Study Area on the Date of the Natural Hazard (5.9.2023) (Glenny, 2023).

Table 5.
Daily Precipitation and Flow Values for the Dates of Flash Floods in the Study Area (Edited from TSMS, 2023a; b and GDSHW, 2023)

Hydroclimatic factors	Rainfall	Runoff
Date	**P (mm)**	**Q (mm)**
September 4, 2023/Monday	25.50	17.37
September 5, 2023/Tuesday	140.22	130.26
September 6, 2023/Wednesday	51.89	42.70
Total	**217.62**	**190.33**
Annual	**812.4**	**802.01**

Table 6.
Repetition Periods Discharges of Degirmen River (Edited from GDSHW, 2023 data)

Repeated periods (Year)	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
Discharge (m^3/sec)	8.73	23.15	35.56	54.06	69.53	86.32	121.45	136.57

Geographical Features

The geographical features of the river basin have a guiding effect on the occurrence of flash floods in the study area. In this respect, topography conditions were the primary determinant. In the study area with a high and rugged topography, elevation level changes were observed within short distances (Figure 5). Thus, in the study area where sudden elevation differences were observed, the topography's slope and the flow rate of the water increased. It was reported that the flash flooding risk increases in mountainous areas dominated by topographic conditions where water flows suddenly through valleys and slopes (Subraelu et al., 2023).

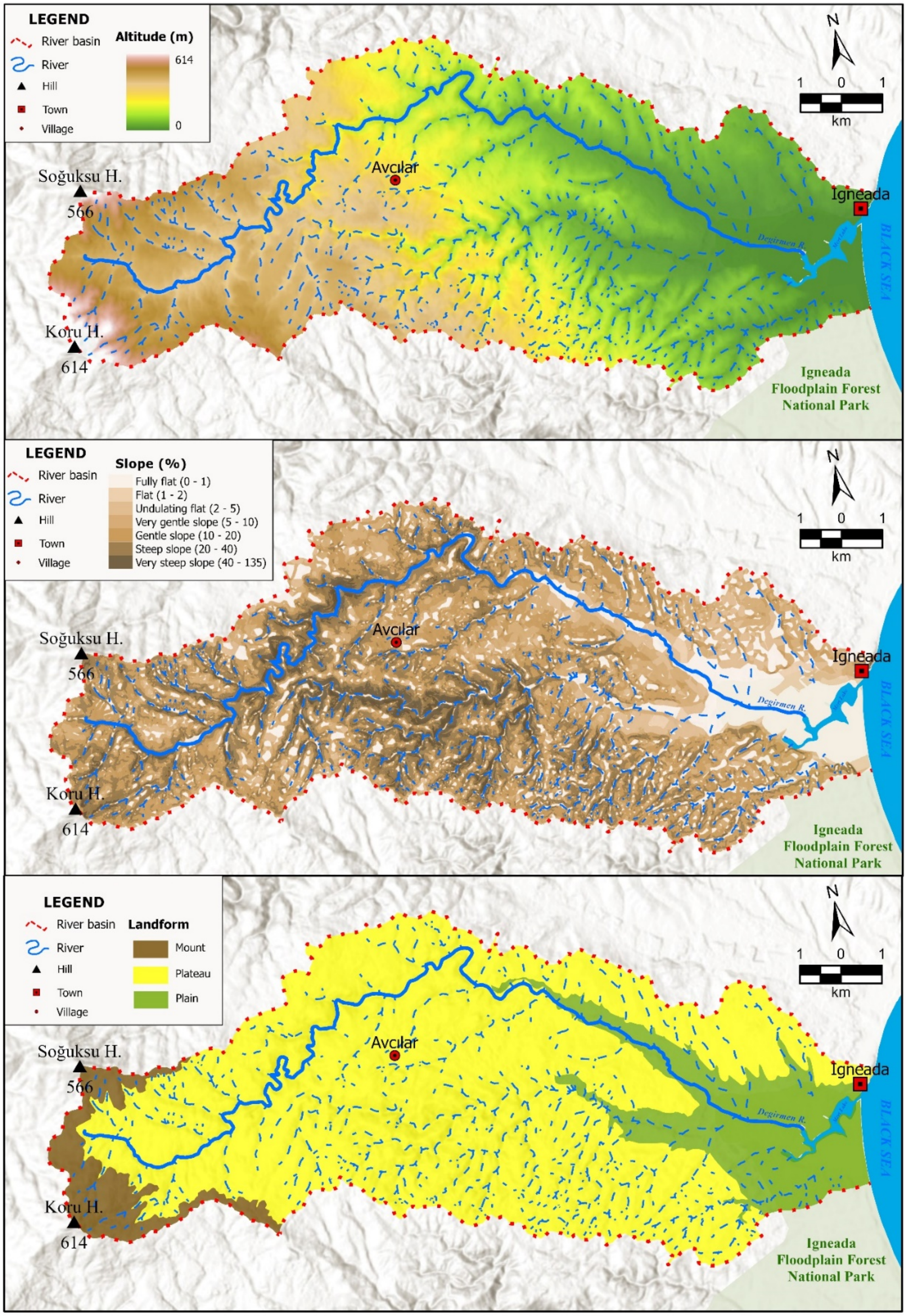

Figure 5.
Elevation, Slope, and Landform Maps of the Study Area.

In the study area, especially in the mountain and plateau areas that characterize the upper and middle part of the river basin, the topography conditions increase the flow rate of the water with torrential rainfall, leading to the danger of flash floods (Figure 2). On the other hand, the rapid runoff due to high flow rates also erodes the soil and causes sediment and debris to be added to the water (Yin et al., 2023). This situation triggers the blockage or dysfunction of the river channel in areas where elevation and slope values decrease in the river valley. Sediment and debris coming with flash floods in the plain in the lower parts of the river basin in the study area caused floods (Figure 2).

The effect of topographic features on the occurrence of flash floods in the study area is better understood through morphometric indices. The river basin in the study area has areal morphometric parameters that show a relatively less circular shape, with a considerable capacity for surface runoff and water transport, and where the main river reaches higher flows in a short time with the flow from its tributaries. However, the river basin in the study area shows a linear morphometry with a distinct long axis with less water lingering and flash floods characterized flows due to the large number of parallel or sub-parallel tributaries contributing to the main river flow. Moreover, the river basin in the study area has a relief morphometry closer to the old age stage with flash flood character, where the flow collection time is less due to the steep slopes and high river gradients due to the high incision in the river basin (Table 7).

Table 7.
The Results of Morphometric Indices Applied for the River Basin in the Study Area

Morphometric indices		Unit	Study area
Areal	Basin length (L)	km	20.26
	Basin perimeter (P)	km	68.30
	Basin area (A)	km^2	107.78
	Form factor (Rf)	km^2	0.26
	Stream frequency (Fs)	km/km^2	5.02
	Drainage density (Dd)	km/km^2	2.29
Linear	Stream Length (Lu)	km	27.02
	Bifurcation Ratio (Rb)	-	1.96
	Length of overland flow (L_o)	km	1.145
	Elongation ratio (Re)	-	0.58
	Texture Ratio (T)	km/km	4.02
Relief	Basin relief (Bh)	m	612.5
	Relief Ratio (Rh)	m	0.03
	Ruggedness Number (Rn)	-	1.40
	Hypsometric Integral (H_i)	m	0.28
	Time of concentration (T_c)	hour/minute	44.69

Other factors affecting the occurrence of flash floods in the study area are lithology and soil properties. Lithologically, the upper and middle parts of the river basin in the study area are dominated by Paleozoic-Mesozoic aged bedrocks with low metamorphism and low permeability (Ergün & Ülker, 1970; Figure 6). Pedologically, the soils belonging to the Inceptisols, where the effect of the bedrock factor on soil formation is strongly felt, are very shallow (Figure 6). Thus, in the study area, especially in the upper parts of the river valley, both the impermeability of the bedrock and the weak soil cover due to the high slope and the dry character of the soil cover due to climatic conditions played an effective role in terms of facilitating the flow of rainwater.

Karaaslan (2018) mentioned that the Paleozoic-Mesozoic aged basement rocks of the Strandja massif are mostly impermeable, which prevents the infiltration of meteoric waters into the subsurface to a great extent. Özdemir and Kaymak (2022) reported that shallow soils in lands where slope values increase reduce infiltration and support surface runoff. Yin et al. (2023) stated that more destructive flash floods may occur because the drying of soils due to climatic conditions prevent water infiltration. Therefore, lithology and soil properties also supported the flash flooding character of the water mass fed by sudden downpours in the study area.

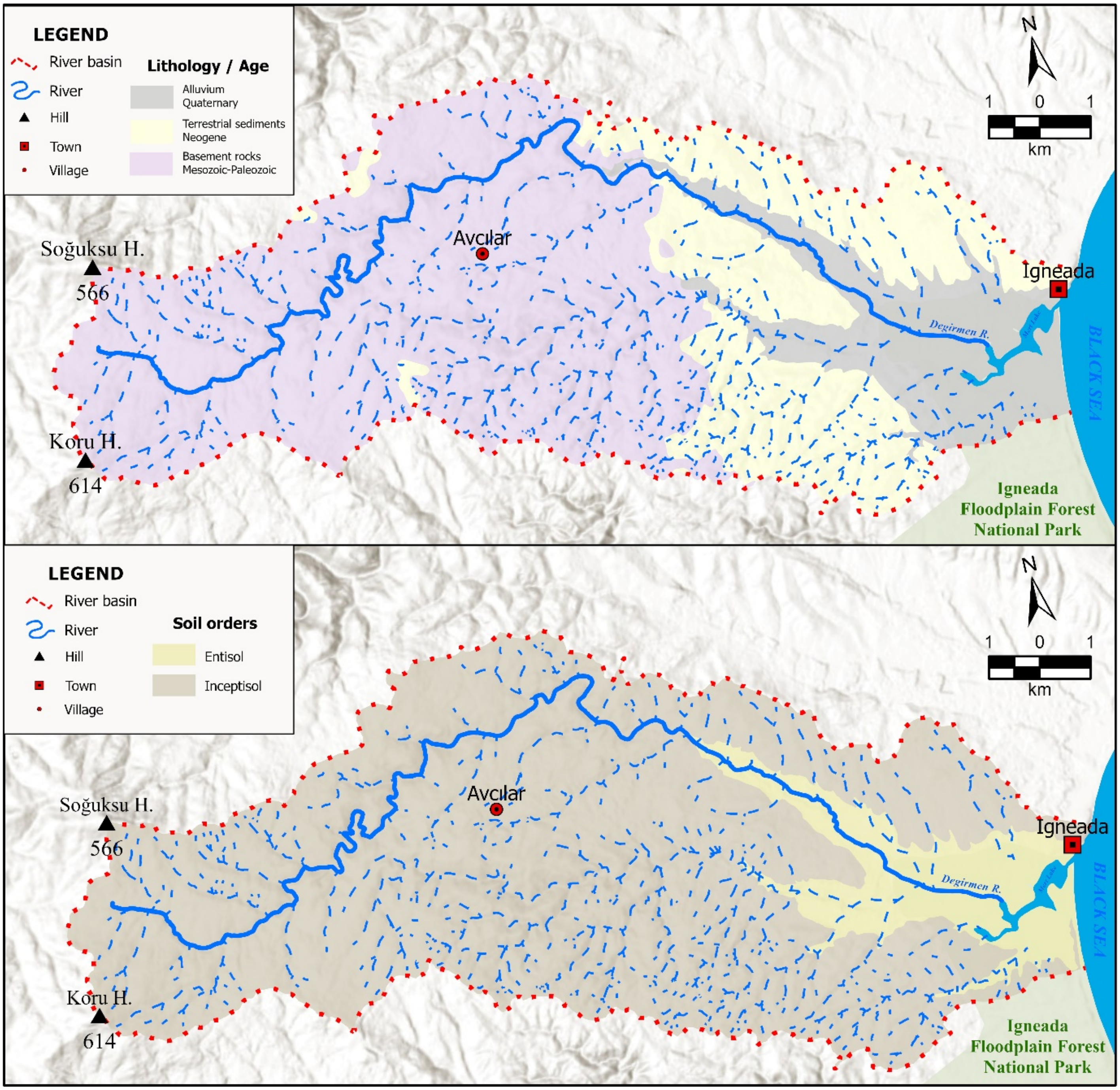

Figure 6.
Lithology and Soil Maps of the Study Area.

Anthropogenic factors

Although hydroclimatic factors and geographical features play an important role in flash floods, anthropogenic factors such as improper land use have a more critical effect (Taherizadeh et al., 2023). The main factor in transforming the naturally occurring flash floods in the study area into a natural hazard is the anthropogenic factors and land misuse associated with them. No natural hazards happened in the neighboring basins, which have almost similar hydroclimatic and geographical features during the flash floods. This situation proves that the primary root cause of the study area's flash floods is anthropogenic rather than natural factors.

Step 4: Identification of the Root Cause(s)

According to the possible factors that caused the problem in the study area, the event's root cause is anthropogenic factors. The wrong land use that led to the flash flood event in the study area has emerged with intensive and faulty land use changes in the river floodplain. In this context, the most prominent change was experienced in and around Sisli Valley, where both life and property loses occured. As a result of these changes, which were observed between 2017 and 2022, pastures were transformed into agricultural and residential areas (Figure 7). Moreover, the conversion to settlements took place in the river's floodplain and some areas violating the coastal law (Figure 8). According to the information shared by authorities, it is understood that the unlicensed campsite and the bungalow houses built in violation of the zoning in Sisli Valley, where the loss of life occurred, are located in the floodplain of the river (Karaloğlu, 2023). On the other hand, it is scientifically understood that the construction that has developed in the study area, especially after 2017, is in violation of the coastal law in force as the river is located within the coastal edge line. Hence, when the river overflowed its bed, it directly damaged the bungalow houses and the people in them (Figure 9). Therefore, a natural phenomenon in the study area has been transformed into a natural hazard due to anthropogenic factors in violation of both natural and coastal laws.

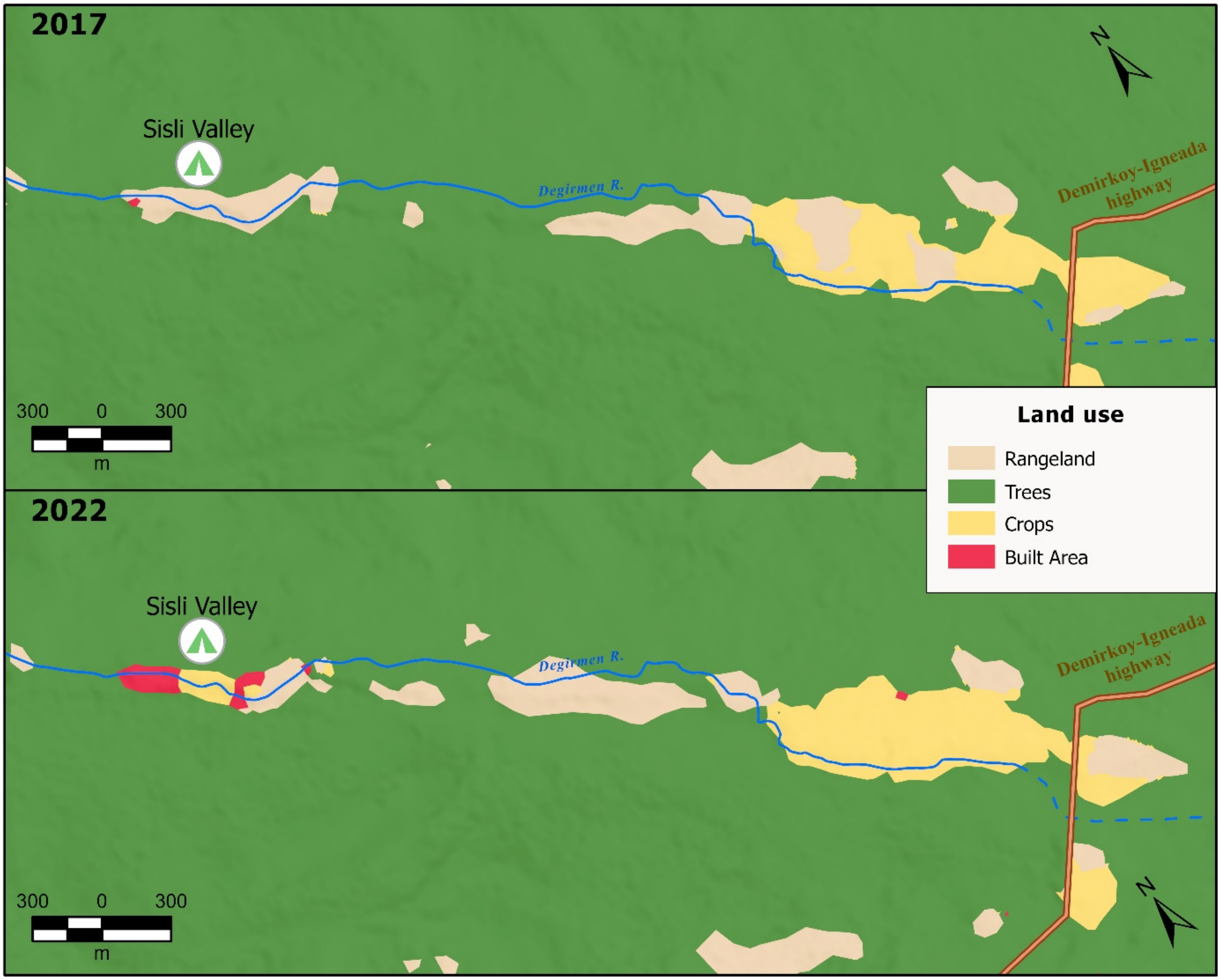

Figure 7.
Land Use Maps of Sisli Valley and its Immediate Surroundings in the Study Area for the Years 2017-2022.

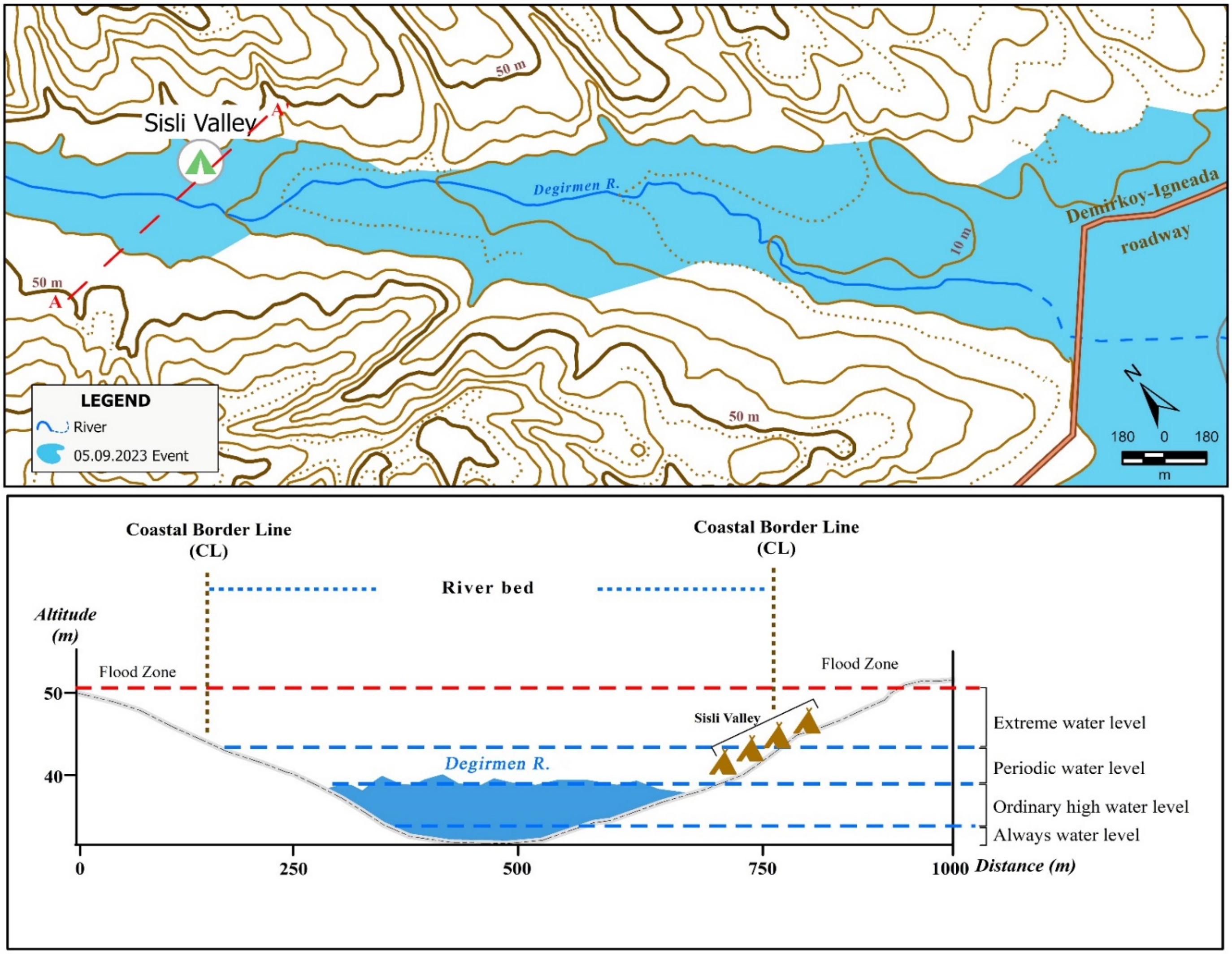

Figure 8.

(a) Map of the Areas Affected by Inundation in and Around Sisli Valley in the Study Area, (B) Scientific Coastal Elements and Coastal Sections of the River in the Study Area (Modified and Adapted from Turoğlu, 2023).

Step 5: Solution Recommendation and Implementation

Recently, the incidence and severity of flash floods have been increasing worldwide (Archer & Fowler, 2021) due to changes in the quantitative, temporal, and spatial patterns of seasonal precipitation associated with global climate change (Feng et al., 2013) and anthropogenic-induced land use changes, resulting in increased runoff generation and decreased groundwater infiltration (Nosetto et al., 2012). Flash flooding is one of the most frequent and dramatic natural hazards in drainage basins originating from mountainous areas (Víg et al., 2023). This natural hazard causes significant destruction in the regions where it strikes, resulting in loss of life and property as well as damage to infrastructure and disruption of public services (Ekmekcioğlu, 2023).

In the study area located on the Black Sea catchment area of the Strandja Mountains, the flash flood event on 5.9.2023 gained a catastrophic natural hazard dimension. In addition to hydroclimatic factors and geographical features, causal factors consisting of anthropogenic factors controlled the flash flooding at the basin scale. Some measures should be taken to prevent such natural hazards in the study area. The most important of these is the scientific evaluation of the causes and consequences of the flash floods. Thus, the impact of flash floods can be mitigated, and social resilience can be developed (Asare-Kyei et al., 2015). Furthermore, a good assessment and understanding of flash floods help to strengthen infrastructure against them and to plan the future development of less risky areas (Kadıoğlu, 2019). Other mitigation measures include controlling the misuse of rivers and floodplains and implementing flash flood control projects. All these recommendations can help reduce the resources needed to restore flood-affected areas (Kabenge et al., 2017).

Figure 9.
Significant Loss of Life and Property Was Experienced in the Sisli Valley in the Study Area. Besides, in the River Basin Where Forestry Activities Are Widespread, Some Rows of Logs and Uprooted Trees Were Dragged Along with the Flash Floods.

Conclusion

The results of the study show that the flash flood problem, which turned into a natural hazard on 5.9.2023 in the study area, occurred at the basin scale under the control of causal factors consisting of hydroclimatic factors, geographical features, and anthropogenic factors. Accordingly, it is understood that extreme hydroclimatic factors were dominant when the natural hazard was effective. These factors triggered the flash floods due to the geographical characteristics of the river basin. However, it is surprising that this natural event turned into a natural hazard only in the Degirmen River basin and not in all the river basins in the Black Sea catchment area of the Strandja Region. This was due to anthropogenic factors associated with improper land use in the lower part of the river basin. Therefore, an ordinary event in the natural environment was transformed into a natural hazard by anthropogenic factors, leading to the emergence of an extraordinary natural hazard. In other words, the event's root cause was determined to be anthropogenic factors. The following measures should be taken as soon as possible to prevent such natural hazards.

1. Flash flood management plans should be prepared at the scale of large river basins in and around the study area.

2. It is essential that the river floodplain in the study area is not used for settlement purposes.

3. Inspections should be tightened to prevent wrong land uses in the form of informal settlements in the river floodplain in the study area.

4. It is also essential to map areas susceptible to flash floods in the study area and nearby river basins.

All these measures are critical for developing mitigation strategies in flood-prone areas.

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