Artvin Çoruh Üniversitesi
Doğal Afetler Uygulama ve Araştırma Merkezi
Doğal Afetler ve Çevre Dergisi

Artvin Çoruh University
Natural Hazards Application and Research Center
Journal of Natural Hazards and Environment

Araştırma Makalesi / Research Article, Doğ Afet Çev Derg, 2023; 9(2): 216-239, DOI: 10.21324/dacd.1210797

A Morphometric Approach to Bozkurt (Kastamonu-Türkiye) Flood

Vedat Avci[1,*], Ömer Ünsal[2]

[1]Bingöl University, Faculty of Arts and Sciences, Department of Geography, 12000, Bingöl, Türkiye.
[2]İstanbul University, Institute of Social Sciences, 34093, İstanbul, Türkiye.

Abstract

*This study aims to analyze the flood disaster that occurred in Kastamonu-Bozkurt in 2021 through the morphometric parameters of the basin. In the study, the Basin of Ezine Stream, which is the flood experienced most effectively, was analyzed together with the neighboring basins. Bozkurt flood is one of the most destructive floods in the history of Türkiye. As a result of the floods that occurred in Kastamonu and neighboring provinces on 10th - 12th August 2021, 82 people lost their lives. The Digital Elevation Model (DEM) of the study area was created with a cell size of 10*10 m using topography maps, and the boundaries of the basins to be analyzed with the ArcGIS-Archydro Module were determined. 30 indices were applied to these basins within the scope of shape (geometric), areal and relief morphometric features of the basins. The relationship between morphometric parameters was determined with the Pearson correlation coefficient. When the analysis results are evaluated for the Basin of Ezine Stream, it is the basin with the largest area, and the largest value of basin relief, relative relief and ruggedness. As a result, erosional activities and the risk of flood are high. When all basins are evaluated in general, it has been revealed that the shape of basins are more elongated, and the features of relief morphometry facilitate the formation of floods. Basin relief, relative relief, dissection degree, slope values, and average slope values are high for all basins; and both the amount of water added to the overland flow and the speed of the overland flow increased. This situation also increased the amount of material carried during the flood. Constructions built close to the stream bed increased the effect of the flood. Depending on the global climate change, the study area corresponds to the area where the change in daily maximum precipitation varies between 5-10%. Therefore, floods are likely to continue. For this reason, it is recommended to consider geometric, areal and relief morphometric features of the basins along with the climatic features of the basins while taking the necessary precautions. According to CORINE land cover data, urban areas in the Ezine Stream Basin increased by over 100% between 1990 and 2018, which is also affected by disastrous floods and overflows. Conservation and strengthening of natural vegetation in the study area will reduce the damage level of floods and overflows.*

Keywords
Basin of Ezine Stream, Bozkurt, Kastamonu, Flood, Morphometry

Bozkurt (Kastamonu-Türkiye) Taşkınına Morfometrik Yaklaşım

Özet

*Bu çalışmada 2021 yılında Kastamonu-Bozkurt'ta meydana gelen taşkın afetinin havza morfometrik parametreleriyle değerlendirilmesi amaçlanmıştır. Çalışmada taşkın etkilerinin en fazla olduğu Ezine Çayı Havzası, komşu havzalarla birlikte değerlendirilmiştir. Bozkurt taşkını, Türkiye tarihinde en fazla yıkıma neden olan taşkınlardan biridir. 10-12 Ağustos 2021 tarihlerinde Kastamonu ve komşu illerde meydana gelen taşkınlar sonucu 82 kişi hayatını kaybetmiştir. Çalışma alanına ait Sayısal Yükseklik Modeli (SYM) topoğrafya haritaları kullanılarak 10*10 m hücre boyutunda oluşturulmuş, ArcGIS-Archydro Modülü ile analize tabi tutulacak havzaların sınırları belirlenmiştir. Bu havzaların; şekil (geometrik), alan ve rölyef morfometrik özellikleri (30 indices) hesaplanmıştır. Morfometrik parametreler arasındaki ilişki, Pearson korelasyon katsayısı ile bulunmuştur. Analiz sonuçları Ezine Çayı Havzası için değerlendirildiğinde; alanı en büyük, havza rölyefi, rölatif rölyef, engebelilik değeri en büyük olan havzadır. Buna bağlı olarak erozyonel faaliyetler fazla ve taşkın tehlikesi yüksektir. Tüm havzalar genel olarak değerlendirildiğinde; havzaların daha çok uzunlamasına bir şekle sahip olduğu, rölyef morfometrisi özelliklerinin taşkın oluşumunu kolaylaştırdığı ortaya çıkmıştır. Tüm havzalar için havza rölyefi, rölatif rölyef, yarılma derecesi, eğim ve ortalama eğim değerleri yüksek olup, hem yüzeysel akışa geçen su miktarı artmış hem de yüzeysel akışın hızı artmıştır. Bu durum taşkın sırasında taşınan malzeme miktarını da artırmıştır. Dere yatağına yakın yapılaşmalar taşkının etki derecesini büyütmüştür. Küresel iklim değişikliğine bağlı olarak çalışma alanı günlük maksimum yağışlardaki değişimin % 5-10 arasında olduğu alana tekabül etmektedir. Bu nedenle taşkınların yaşanmaya devam etmesi olasıdır. Bu nedenle gerekli tedbirler alınırken havzaların iklim özellikleri ile birlikte geometrik (şekil), alansal ve rölyef morfometrik özelliklerinin dikkate alınması önerilmektedir. CORINE arazi örtüsü verisine göre Ezine Çayı Havzası'nda 1990-2018 yılları arasında kentsel alanlar %100'ün üzerinde artmıştır. Sel ve taşkınların afet boyutuna dönüşmesinde bu durumun da etkisi bulunmaktadır. Çalışma alanında doğal bitki örtüsünün korunması ve güçlendirilmesi sel ve taşkınların zarar derecesini azaltacaktır.*

Anahtar Sözcükler
Ezine Çayı Havzası, Bozkurt, Kastamonu, Taşkın, Morfometri

* Sorumlu Yazar: Tel: +90 (426) 2160031 Faks: +90 (426) 2150877
E-posta: vavci@bingol.edu.tr (Avci V), oomer.unsal@gmail.com (Ünsal Ö)

Gönderim Tarihi / Received : 27/11/2022
Kabul Tarihi / Accepted : 30/05/2023

1. Introduction

Flood, is a natural event that turns into a disaster, where the water cannot fit into its bed for various reasons and damages the surrounding settlements, agricultural lands, and infrastructure facilities. Flood rank second among all disasters in the world and Türkiye in terms of loss of life and property and rank first among meteorological disasters (Demir and Ülke Keskin 2022a). According to the available data, in Türkiye, the economic losses caused by the floods are approximately 300 million Turkish Lira (TL) every year (GDWM 2014; Demir and Ülke Keskin 2022b). The importance of flood management is increasing day by day, both because it causes material and moral losses in the region, and because it is a disaster that adversely affects the development of the region (Ertürk and Kaya 2019; Çanta et al. 2022). Flood management refers to all the studies and works conducted to address the core reasons that trigger the flood in order to control and minimize the impacts of the flood (Sunkar and Tonbul 2010; Yılmaz et al. 2017; Çanta et al. 2022). With the effect of climate change, the number of natural disasters with meteorological character is increasing every year around the world. In Türkiye, a great increase has been observed in disaster-sized flood due to heavy rains in recent years (Çanta et al. 2022). In order to be protected from flood and flood damages, the flood susceptibility of the basins should be determined through various approaches, such as hydraulic modeling, analytic hierarchy, statistical methods and basin morphometry studies.

Ertürk and Kaya (2019), created flood hazard maps for Kirazlı Stream located in the Trabzon-Vakfıkebir district. According to these maps, the Kirazlı stream bed could not carry the Q_{500} flood flow and the flooding waters affects some settlements downstream. Gülbaz (2019), created flood spread and water depth maps of the Türkköse Stream located in Sazlıdere Basin in İstanbul via WMS, HEC-HMS, and HEC-RAS software. In these maps, a 6 m deep water elevation and a 260 m wide flood spread occurred in the main stream passing through the settlement areas. Oğraş and Önen (2019), carried out a flood analysis with HEC-RAS software in the section of the Tigris River between the Diyarbakır-Silvan highway and the historical Ten Eyed Bridge. In this study, it was evaluated that many public facilities and historical places could be submerged. Çanta et al. (2022), produced flood inundation maps of the Pona and Örtülü Stream Basins in Artvin-Ardanuç with FLO-2D and HEC-RAS software. According to the models, it was evaluated that the flood waters in Örtülü Stream exceeded the stream bed limit in most places and that the floods could cause loss of life and property.

Demir and Ülke Keskin (2022a), used 50, 100, 500, and 1000 year recurrent flow rates (Q_{50}, Q_{100}, Q_{500}, and Q_{1000}) calculated in the downstream region where Mert River Basin intersects with the city boundaries in Samsun and produced HEC-RAS, FLO-2D flood hazard maps in ArcGIS environment by using the Department for Environment Food and Rural Affairs (DEFRA) method and the model results obtained using the software. According to the findings, it was determined that the region was affected by recurrent floods in both models and 42%-70% of the flood areas are at very high danger levels. Demir and Ülke Keskin (2022c), reported that 40%-80% of the study area could be submerged in their modeling for Mert River using the FLO-2D program.

Sözer et al. (2019) created a flood susceptibility map for Ankara by using modified AHP method. It is stated that especially urban planning and the efficiency and effectiveness of disaster management studies will increase with the creation of susceptibility maps for natural dangers and their utilization as base.

Sarkar and Mondal (2020), determined the flood susceptibility of Kulik Basin in Bangladesh with the frequency ratio method. This study reveals the importance of susceptibility maps for planners and decision makers in taking possible precautions with regards to minimizing flood vulnerability.

Yılmaz (2022), created susceptibility maps for Bozkurt flood-overflow by using GIS-based AHP and FR methods. In this study, the map classified by AHP-FR has areas in high and very high susceptible classes that were calculated as 128,72 km^2 and 6.89 km^2, these areas constitute %0,99 and %0,05 of the entire region, respectively.

Addis (2023), using frequency ratio and information value methods in his work which determined the flood susceptibility in Abay Basin, Bangladesh, proposes that this kind of studies contribute a great deal to decision processes regarding future planning and plans to reducing floods.

Morphometric analysis of river basins is widely used in hydrological and geomorphological studies (Beg 2015). Morphometry plays a key role in basin management and flood control planning (Mahala 2020). Because, the hydrological and morphological characteristics of the basins can be understood by the drainage morphometric parameters (Mani et al. 2022).

The basin morphometry and flood relationship has been discussed in the literature. There are many studies analyzing the relationship between basin morphometry and flood-overflow (Turoğlu 1997; Bendjoudi and Hubert 2002; Nooka Ratnam et al. 2005; Şener 2011; Withanage et al. 2014; Beg 2015; Kaliraj et al. 2015; Erdede and Öztürk 2016; Thapliyal et al. 2017; Choudhari et al. 2018; Alqahtani and Qaddah 2019; Baduna Koçyiğit and Akay 2019; Jose et al. 2019; Islam and Deb Barman 2020; Mahala 2020; Makhamreh et al. 2020; Pathare and Pathare 2020; Sharma and Mahajan 2020; Abdelouhed et al. 2021; Bogale 2021; Ahad et al. 2022; Al-Neama et al. 2022; Chauhan et al. 2022; Dongare et al. 2022; Jothimani et al. 2022; Khalifa et al. 2022; Shankar et al. 2022; Shekar and Mathew 2022;Singh and Singh 2022; Oyedotun 2022; Şener and Arslanoğlu 2023). In these studies, the relationship between morphometric parameters and floods was evaluated on the basis of basins. Some studies are detailed below.

Alqahtani and Qaddah (2019), evaluated the flood hazard of the Jeddah-Mecca region with morphometric analysis. In this study, it was reported that the hydrological hazard in the research area is mostly caused by the basin area, relief ratio, relative relief, and ruggedness number.

Jose et al. (2019), reported that in the Ithikkara Basin in India, the basin shape is elongated and the flood susceptibility is low, with indices reflecting the basin shape such as form factor, elongation ratio, circularity ratio, lemniscate ratio among morphometric parameters.

Charizopoulos et al. (2019), in their study of the morphometric analysis of the drainage network of Samos Island in the North Aegean, revealed that the flood susceptibility is high. In the study, it was reported that a high relief ratio also indicates the risk of erosion.

Mahala (2020), evaluated the morphometric features of the Kosi and Kangsabasti basins in India. In this study, it was revealed that the areal morphometric characteristics of the Kosi basin show a large amount of water discharge and peak flow in a shorter time, while the areal morphometric characteristics of the Kangsabati Basin plateau show low surface flow and low peak point.

Makhamreh et al. (2020), conducted a morphometric analysis of the Wadi Al-Shumar drainage basin in Jordan and reported that the elongation ratio values of the sub-basins indicate the circular shape of the basins, and they are susceptible to the risk of flood in case of frequent precipitation.

In the morphometric analysis of the Darna Basin in India, Pathare and Pathare (2020), correlated high drainage density and high stream frequency with low permeability and high surface flow. Bogale (2021), evaluated the basin morphometric features with Geographic Information Systems (GIS) in the Gilgey Abay drainage area in Ethiopia. In the study, it was revealed that the flood susceptibility is high in the upper parts of the basin. In a study conducted through morphometric parameters in the Betwa Basin located in central India, Singh and Singh (2022), revealed that it is necessary to take protective measures in the upstream parts of the basin due to the high ruggedness, high degree of cleavage and high surface flow. In the study, it was reported that high river frequency is the evidence of high flood risk, low average bifurcation ratio values indicate elongated drainage basins with well-split topography, high surface flow, and high infiltration ratio (Strahler 1957; Thomas et al. 2010; Singh and Singh 2022).

This study aims to analyze Bozkurt flood by using basin morphometric features. Bozkurt flood is one of the biggest flood disasters in Turkey. In 2021, 82 people lost their lives (URL-1 2021) in the floods occurred in Kastamonu, Sinop and Karabük provinces, and great financial losses were experienced. In the study, the Basin of Ezine Stream, which is the flood experienced most effectively, was analyzed in terms of its morphometric features together with the neighboring basins.

2. Material and Method

2.1. Area, Location, Boundaries and Major Geographical Features of the Study

The Basin of Ezine Stream is located within the borders of Kastamonu province in the Western Black Sea Region. The stream, which takes its source from the mountains behind the Black Sea, empties into the sea from the north of Bozkurt. The basin and its surroundings attract attention with the high relative elevation difference. Kastamonu province, where the study area is located, is very sensitive to natural disasters. The most common naturally occurring event within the provincial borders is landslides (Figure 1). It can be stated that the danger is high in the province also in terms of flood. Also in 2022, as a result of excessive rainfall in the Basin of Ezine Stream, Ezine Stream overflowed and the overflowing water spread to the district center (Bozkurt). As a result of the flood, the culvert-bridges were destroyed (URL-2 2022). The units formed from the Triassic-Jurassic to the Quaternary period constitute the lithology in and around the Basin of Ezine Stream. The Triassic-Jurassic period is represented by carbonate and continental clasts and these units have the largest outcrop area in the study area. Lithology from this period outcrops between Kutluca and Çörekçi. Carbonate and continental clasts dated back to the Jurassic period outcrop at Kertme hill and in the south of Çörekçi; the unit, consisting of marble dated back to the Middle Triassic-Jurassic, outcrops in the form of islands in the south and west of Çörekçi; Dogger granitoid outcrops in and around Kirazsökü; Middle Jurassic-Cretaceous neritic limestone outcrops around Özpınar hill and SW of Harmankaya hill Cretaceous continental clasts and carbonate rocks outcrop around Kutluca, and in south and southeast of Özpınar hill; Mesozoic undifferentiated basic and ultrabasic rocks outcrop in the southwest of Kuştepe; upper Senonian pelagic limestone units outcrop in the southwest of the Basin of Ezine Stream; volcanic and sedimentary rocks outcrop in the north and northwest of Esentepe; continental clasts and carbonates outcrop in and around Bozkurt, and in the Manastır Stream, Adıyaman Stream and Evrenye Stream basins (Uğuz et al. 2002).

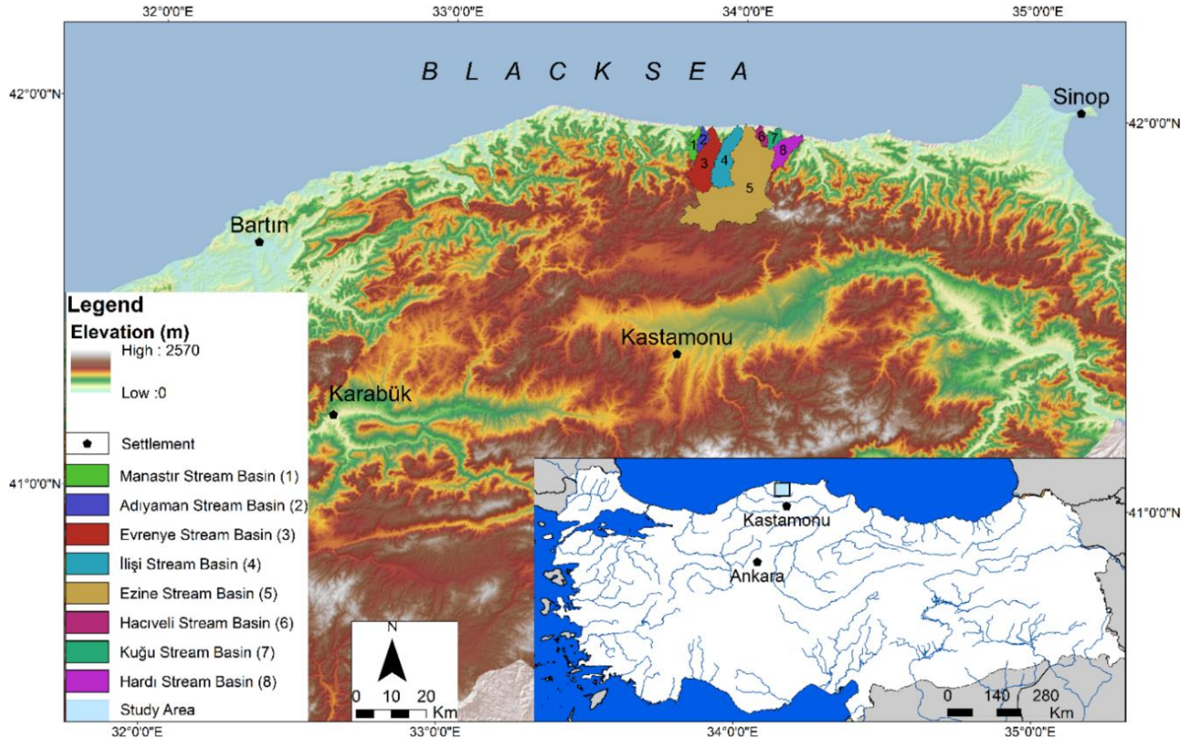

Figure 1: Location map of the Basin of Ezine Stream and neighboring basins (Kastamonu)

Upper Cretaceous-Eocene continental clasts and carbonates are observed at the mouths of Hacıveli, Kuğu and Hardı streams; Eocene continental clasts and carbonates are observed limitedly in Yukarıkuğuköy and in the east of Esentepe; and undifferentiated Quaternary units are observed in the Basin of Ezine Stream and in the southeast of Özpınar hill (Uğuz et al. 2002; Figure 2)

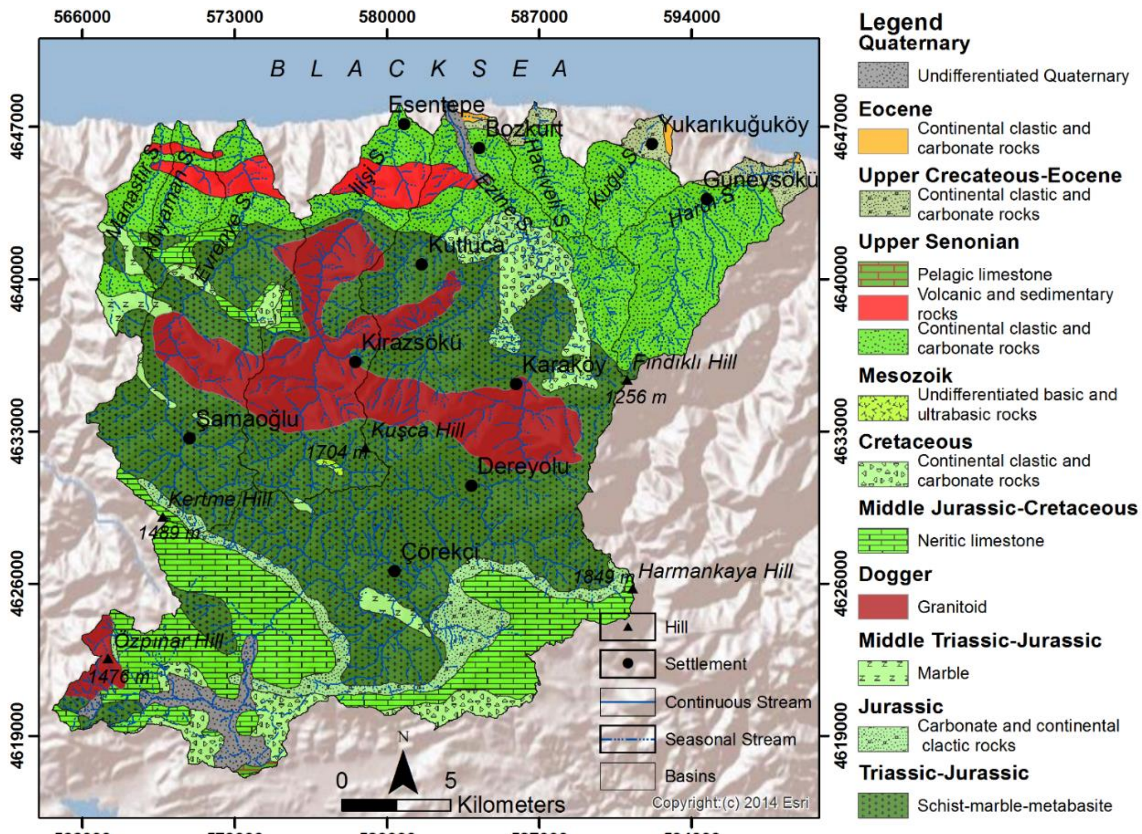

Figure 2: Lithology map of the Basin of Ezine Stream and neighboring stream basins (Kastamonu) (Uğuz et al. 2002)

A significant difference in elevation between the south and north of the study area. The fact that this height difference is reached in short distances shows that the slope is high in the field. The minimum elevation in the study area is 0 m on the shore and the maximum elevation is 2015 m in the Basin of Ezine Stream. The basin with the highest relative elevation difference is the Basin of Ezine Stream. The elevation difference in this basin is 2015 m. Elevation difference in Hacıveli Stream Basin and Kuğu Stream Basin is less than other basins and is 794 m and 796 m (Figure 3).

Aspect and slope characteristics were analyzed within the scope of the geomorphology-flood relationship of the study area. The aspect factor is very important for the amount of precipitation. Slopes facing west in Western Europe, north in the Black Sea, and south in the Taurus Mountains receive more precipitation (Atalay 2018). For this reason, flood susceptibility is quite high on the north-facing slopes of the Black Sea. The dominant aspect of the basins in the study area is north. The rate of northern directions is 48.2%, 51.4%, 43.4%, 41.4%, 40.5%, 47.3%, 54.2, and 55.9% in respectively from 1st to 8th basin. As the elevation in the study area increases over short distances, the slope increases, and thus the surface flow becomes faster and the amount of infıltration decreases (Atalay 2018). Flood inundation occurs mostly in areas where the slope is less. In this respect, the ratio of the areas with 0-2º slope group with high flood susceptibility in all basins to the total area is very low, and these areas are limited to the coast. The proportion of areas with 0-2º slope is 0.2%, 0.28%, 0.35%, 0.28%, 3.14%, 0.55%, 0.65%, 0.48% in respectively from 1st to 8th basin. This situation has caused large volumes of water masses originating from very sloping areas to gather in narrow areas and cause flood. The average slope values in all basins are also high, above 15º. This is another proof that the runoff is excessive and fast.

According to the data of Bozkurt meteorological station located in Bozkurt town center (41°57'34.9"N 34°00'13.3"E) (1985-2021), the annual average temperature is 13.4 ºC, and the mean total precipitation (2006-2021) is 1006 mm. In Kastamonu, on the other hand, the annual average temperature is 10.1 ºC, and the mean total precipitation is 523 mm (1991-2020).

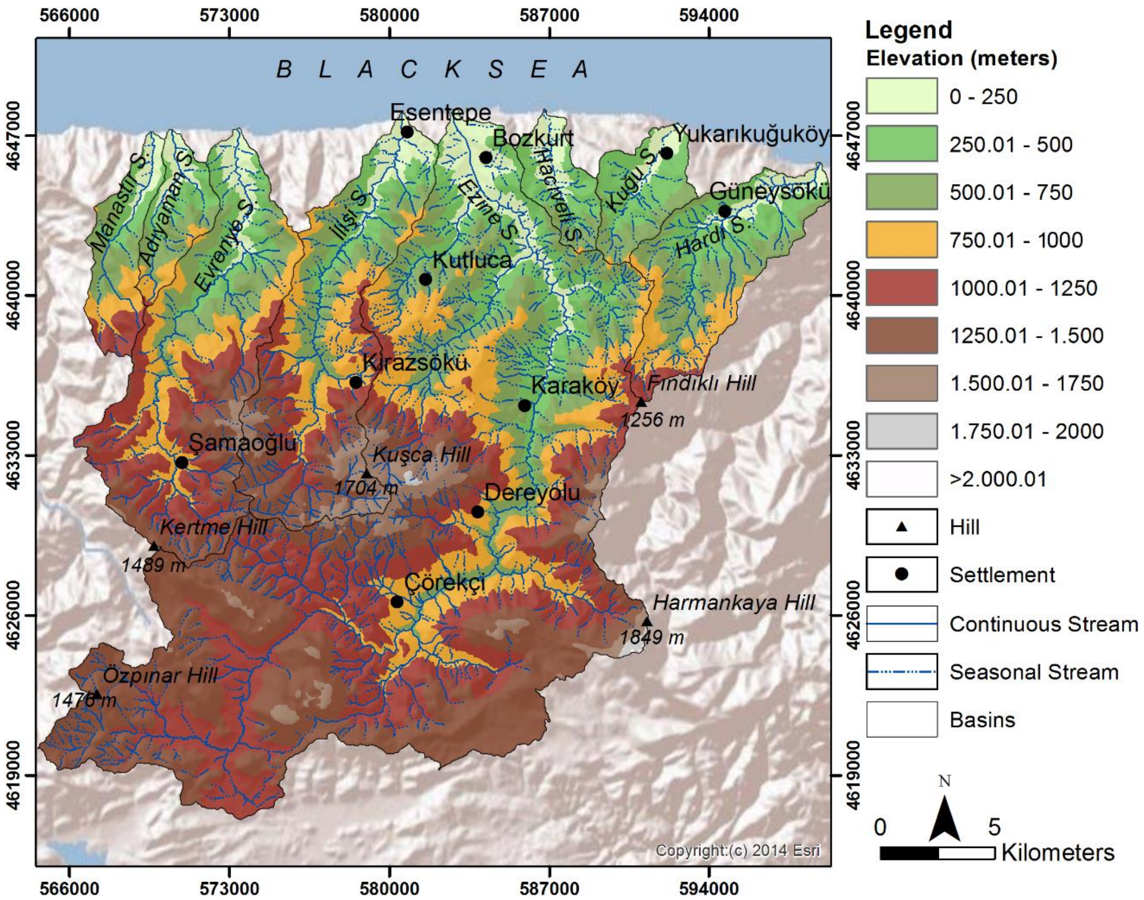

Figure 3: Elevation range map of the Basin of Ezine Stream and neighboring basins (Kastamonu)

While the climate features of the Black Sea region are dominant in Bozkurt, continental conditions are effective in Kastamonu. This situation is mainly caused by the fact that Küre Mountains prevent the marine air masses (Coşkun 2021). In Bozkurt, the average temperature has never fallen below 0 ºC in any month due to the marine effects. However, the average temperatures in Kastamonu in January are below 0 ºC (Table 1; Figure 4).

Table 1: Monthly temperature averages and precipitation of Bozkurt and Kastamonu stations for years (TSMS 2022)

Parameter	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Bozkurt Mean Temperature (°C)	5.8	5.6	7.4	11.1	15.3	19.6	22.2	22.4	18.7	14.7	10.8	7.5	13.4
Bozkurt Precipitation (mm)	98.6	95.29	84.01	53.34	51.9	54.57	45.03	47.9	105.54	131	97.6	141.97	1006
Kastamonu Mean Temperature (°C)	-0.6	1.1	4.8	9.5	14.2	17.7	20.5	20.5	16.2	11.2	4.9	0.7	10.5
Kastamonu Precipitation (mm)	29.4	28.1	38.5	50.5	77.9	89.6	36	38.2	38.7	34.8	27.5	36.1	523.3

According to the distribution of precipitation throughout the year, while the rainiest period in Bozkurt is autumn (33.2%), the rainiest season in Kastamonu is spring (31.7%). The least rainy season is summer in Bozkurt (9.8%) and winter in Kastamonu (17.8%) (Figure 4).

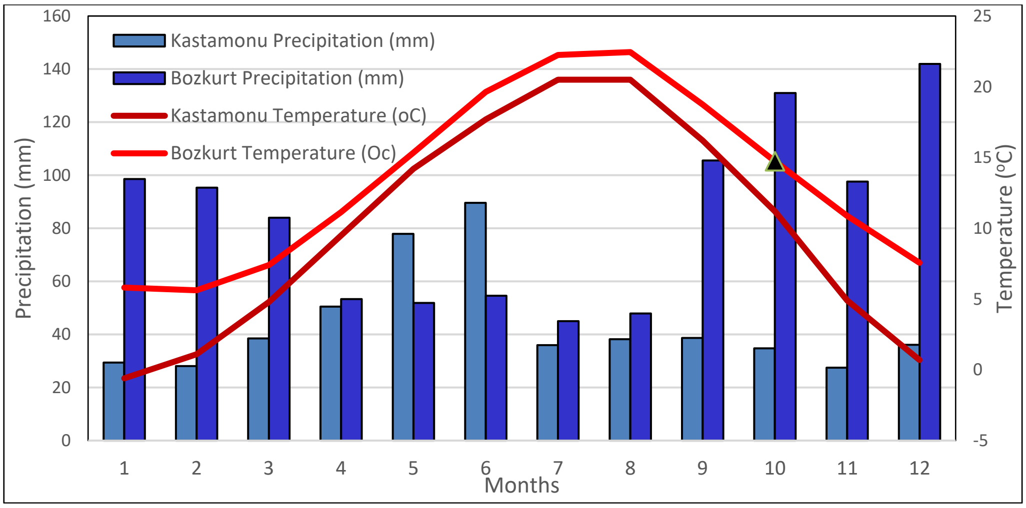

Figure 4: Distribution of temperature and precipitation by months at Kastamonu and Bozkurt stations (TSMS 2022)

2.2. Method

One of the main data sources in basin morphometry studies is Digital Elevation Model (DEM). The DEM used in this study was created from topography maps scaled at the rate of 1/25.000 (GDM 2010), by using ArcMap Spatial Analysis-Topo to Raster Module. Eight drainage basins, analyzed from DEM with 10*10 m resolution, were determined (with ArcMap-ArcHydro add-on). DEM was used to determine the geometric, areal and relief morphometric features of the basins (Figure 1). The hillshade data used as a base was taken from ESRI (ESRI 2022). The area and perimeter features of the basins were found through ArcGIS-calculate geometry while the widths and maximum lengths were found through the ArcMap plugin ETGeoWizards-polygon charecteristic. Indices were applied to the specified basins using the following formulas in the literature. These indices include geometric (shape) features, and areal and relief morphometric features of the basin (Table 2). While determining the indices, studies investigating the relationship between flood susceptibility and morphometric characteristics and those conducted on basin morphometry in the introduction section of the study were taken as reference points. Form factor and elongation ratio values from the geometric (shape) properties of the basin are among the indices that provide information about the basin shape properties and, accordingly, the overflow type and duration (Soni 2017; Bogale 2021; Shankar et al. 2022). Drainage density was defined as the most important morphometric parameter when evaluating the areal morphometric features. This index is found by dividing the sum of the valley length by the basin area (Horton 1932, Horton 1945). As drainage density (Dd) values increase, the basin gets more susceptible to flood (Jackson 2012; Charizopoulos et al. 2019). The hypsometric integral, which is used to evaluate the basin relief features, is an index that gives information about the morphological stage of the basins and the degree of erosive activities accordingly (Keller and Pinter 2002). High values in Hi index correspond to basins that are morphologically young and have high erosion and therefore flood susceptibility.

Table 2: The indices used in the determination of the morphometric features of the Basin of Ezine Stream and the Neighboring Basins (Kastamonu)

	Morphometric Parameter	Formula	Source
Geometric Features	Basin Length (Lb)	Determined by GIS	
	Basin Width (W)	Determined by GIS	
	Basin Perimeter (P)	Determined by GIS	
	Form Factor (Ff)	$Ff = A/L$	(Horton, 1932)
	Shape Factor (Sf)	$Sf = Lb^2/A$	(Horton, 1945)
	Elongation Ratio (Re)	$Re = (2/Lm) * [A/p]^{0.5}$	(Schumm, 1956)
	Circularity Ratio (Rc)	$Rc = 4pA/P^2$	(Miller 1953; Strahler 1964)
	Gravelius Index (Kg)	$K_g = P/2\sqrt{pA}$	(Gravelius, 1914)
	Amount of Circularity (Rcn)	$Rcn = A/P$	(Strahler, 1964)
	Lemniscate Ratio (K)	$K = Lb^2/4A$	(Chorley et al. 1957)
Areal Morphometry	Basin Area (A)	Determined by GIS	
	Drainage Density (Dd)	$Dd = \sum L/A$	(Horton 1932, Horton 1945)
	Constant of channel maintenance (CCM)	$C = 1/Dd$	(Schumm 1956)
	Infiltration Number (If)	$If = Fs * Dd$	(Faniran 1968)
	Drainage Intensity (Di)	$Di = Fs/Dd$	(Faniran 1968)
	Stream Frequency (Fs)	$F_s = N/A$	(Horton 1945; Strahler 1964; Reddy et al. 2004)
	Length of Overland Flow (Lg)	$Lg = 1/2Dd$	(Horton 1945)
Relief Morphometry	High Relief (m)	Determined by GIS	
	Low Relief (m)	Determined by GIS	
	Relief Ratio (Rh)	$R_h = H/L$	(Schumm1956)
	Basin Relief (Bh)	$B_h = H_{max} - H_{min}$	(Schumm 1956)
	Hypsometric Integral (Hi)	$Hi = (H_{mean} - H_{min})/(H_{max} - H_{min})$	(Strahler 1952)
	Hypsometric Curve (Hc)	$y = h/H, x = a/A$	(Strahler 1952)
	Dissection Index (Dis)	$Dis = H/Ra$	(Singh and Dubey 1994)
	Gradient Ratio (Rg)	$Rg = (Z - z)/Lb$	(Sreedevi et al. 2005)
	Melton Ruggedness Number (Mrn)	$Mrn = H/A^{0.5}$	(Melton 1965)
	Slope (o)	Determined by GIS	
	Average Slope (o)	Determined by GIS	
	Relative Relief	Determined by GIS	(Smith 1935)
	Ruggedness Number	$R_n = B_h * D_d$	(Melton 1957)

3. Results

In this section, the Bozkurt Flood was evaluated with meteorological conditions and anthropogenic effects, and the morphometric characteristics of the basin were analyzed. The relationship between morphometric parameters was evaluated with Pearson correlation coefficient.

3.1. Bozkurt Flood

When the distribution of natural hazard sources in the study area is analyzed, landslides come first. According to Disaster and Emergency Management Presidency (DEMP 2022) data, a total of 126 landslides, floods, rockfalls and avalanches occurred between 1950 and 2022. Landslides constitute 115 of these natural events. Floods are following landslides as a source of natural hazard (the number of incidents is 9). It is observed that flood events mostly occur in the Basin of Ezine Stream. In the study area, avalanche events occur due to high slope and snowfall, and rockfall events also occur due to high slope and temperature differences (Figure 5).

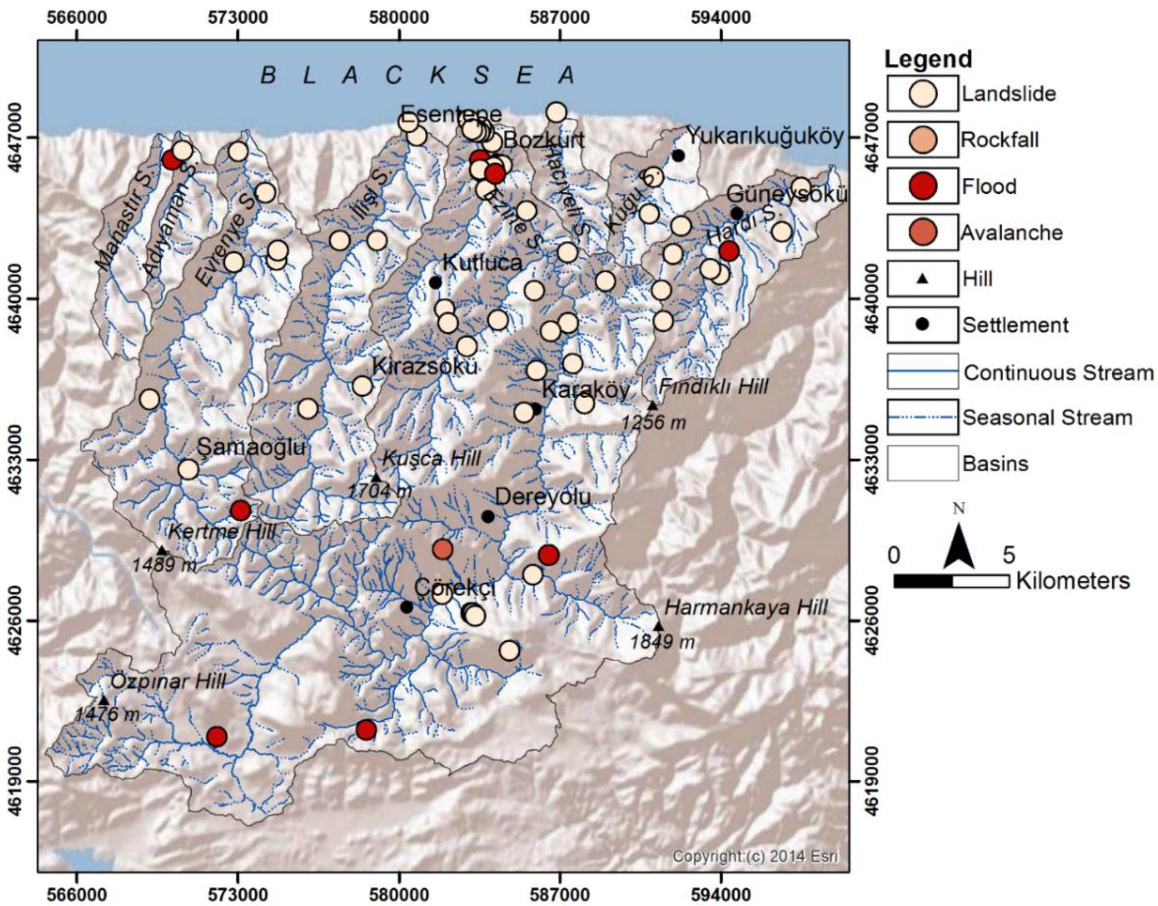

Figure 5: Distribution of landslide, flood, rockfall and avalanche events in the Basin of Ezine Stream and neighboring basins (Kastamonu) (DEMP 2022)

The most damage occurred in Bozkurt district center during the flood on 10-12 August. Bozkurt settlement was established on the edge of Ezine Stream. The houses located in the district center, which were situated on the edge of Ezine Stream at low elevations, were demolished (Figure 6). It has been reported that 168 buildings, including 135 residences, 27 shops and 6 public buildings, were damaged in the flood-affected districts and villages of Kastamonu (URL-3 2022). The flood causing the disaster was related to the severe erosion in the Basin of Ezine Stream and the material carried to the stream bed (Figure 7). Gaps of the bridge crossing in the flood channel were clogged with tree branches and logs carried by the flood, so the channel could not carry the water flow. The settlement area of Bozkurt was covered with large amounts of mud, sand, flood debris, tree branches and logs (Bilgen et al. 2022).

Figure 6: Many buildings located on the edge of the Ezine Stream were destroyed in Bozkurt flood (Photos: Vedat Avci)

Other reasons of the disaster are the discharge of the excavation material from the tunnel, dam and road construction works into the river beds, the plants growing in the river beds and not being cleared, the material carried by the landslides blocking the bridges and culverts (URL-4 2021).

Figure 7: Severe erosion and the stream with increasing flow caused flood in the Basin of Ezine Stream (Photos: Vedat Avci)

While the stream bed of Ezine Stream is 30 m, the floodplain is 240 m (URL-4 2021). When the satellite images of Bozkurt district for the years of 2002 and 2021 are analyzed, it is observed that the settlements on the stream bed have increased. While the areas far from the stream bed were settled in 2002, it is clear that the settlements in the stream bed intensified in the right part of the valley in 2021 (Figure 8).

Figure 8: When the satellite images of Bozkurt district from different years (Google Earth Pro images a) 2002, b) 2021) are analyzed, it is observed that settlements on the stream bed have increased

The elevation difference between the floor of Ezine Stream valley and the buildings located on the left and right sections is quite small. These buildings were built just behind the flood reclamation barrier, the elevation difference between the buildings and the valley floor varies between 5-10 m. For this reason, especially the 1st row buildings located on the right were under water. On the left side, the building density is relatively low (Figure 9). Curved reclamation sets also facilitated the overflow of water.

Figure 9: Some of the buildings in Bozkurt town center are very close to the floor of Ezine Stream valley (ESRI 2022)

Corine land cover data was used to determine the change in city structure and forest areas. According to this analysis, the increase in urban areas between 1990 and 2018 is over 100%. While there was a 37.2% decrease in broad-leaved forest areas in the same period, there was an increase of 77.5% in the ratio of mixed forests (Table 3). Excessive rainfall causing floods caused mass movements (Figure 10). It has been reported that “a total of 170 events such as landslide/landfall, flood, and rockfall occurred on 10-12 August 2021” (URL-3 2022).

Table 3: Change in urban and forest areas in Ezine Stream basin according to corine land cover data (URL-5 2023)

Land Cover	1990 Area (Km^2)	2018 Area (Km^2)	Change (%)
Urban Area	0.40	0.88	118.5
Broad-leaved forest	134.76	84.56	-37.2
Coniferous forest	63.65	67.33	0.9
Mixed forest	43.37	77.02	77.5

Figure 10: The rain that led to the flood caused landslides on the valley slopes (Photos: Vedat Avci)

On 10-12 August 2021 (48 hours), 158.2 mm precipitation was measured at Bozkurt station (TSMS 2022). The average precipitation for many years is 1006 mm in Bozkurt, and the total precipitation in August 2021 is 249 mm. More than half of the August 2021 precipitation at Bozkurt station fell on 10-12 August. More precipitation was measured at Bozkurt/Mamatlar and Devrekani/Kuz Village stations located in the upper part of the basin. Between these dates, 358 mm of precipitation fell in Devrekani-Kuz village, 424.1 mm in Bozkurt-Mamatlar village and 264.5 mm in Abana. The precipitation in Bozkurt-Mamatlar village was close to half of the annual precipitation in Bozkurt station in 2021 (TSMS 2022). This precipitation is close to twice the precipitation in August (Figure 11). The fact that most of this precipitation passed into the overland flow caused the flood.

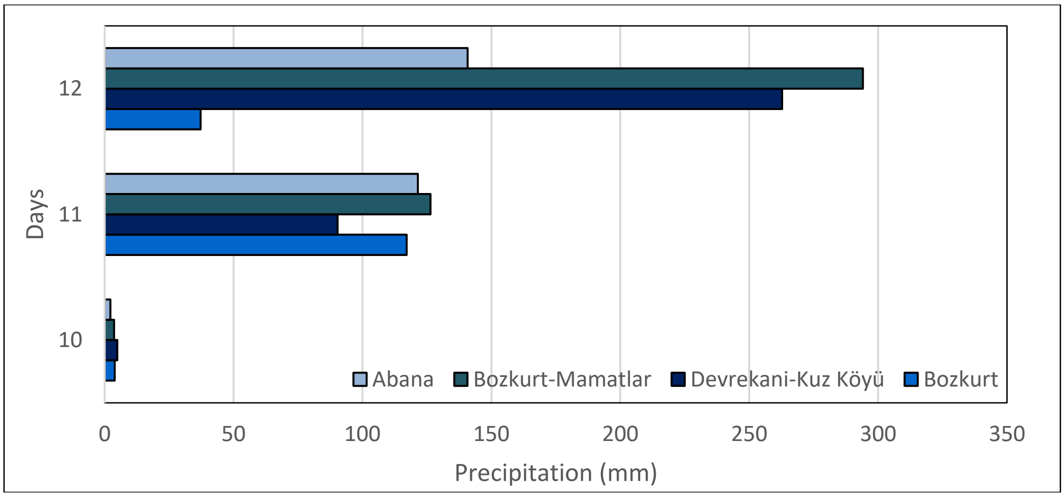

Figure 11: Distribution of precipitation falling on Abana, Mamatlar, Kuz and Bozkurt on 10-12 August (TSMS 2022)

It can be stated that the effect of this precipitation, which fell between 10-12 August, on the flood event was high. It is stated that the flood peak passed through Bozkurt district center at noon, and there was at least 2-3 hours between the precipitation causing the flood and the peak flood flow rate (URL-4 2021). The positive anomaly of the sea surface temperature over the Black Sea (Baltacı 2017; Doğan et al. 2019) has brought along excessive precipitation, the effect of which gradually increases in the summer season on the Black Sea coasts of Türkiye (Halis et al. 2022). In the Black Sea, which is one of the regions that attract attention in terms of precipitation amount, duration, and severity, many flood disasters have occurred in the summer months (Kapochkina et al. 2015, Alexeevsky et al. 2016; Korshenko et al. 2020, Baltacı 2017; Halis et al. 2022). When various projections related to climate change are analyzed, it has been emphasized that there shall be an increase in the amount of precipitation in the northern coast of Türkiye in summer (Demircan et al. 2017), and that the possibility of excessive precipitation and flood may increase (TECCWRP 2016; Demircan et al. 2017). The Basin of Ezine Stream corresponds to areas where the maximum precipitation shall vary between 5-10% in a day (with 3 degrees of global warming) in IPCC Europe Fact Sheet 2022 documents (URL-6 2022). This change in precipitation will be in the form of an increase and the flood risk will increase depending on short-term precipitation.

3.2. Morphometric Analysis

In this section, the geometric, areal and relief morphometric features of the Basin of Ezine Stream and the neighboring basins were analyzed relatively, and the basins were compared in terms of flood hazard.

3.2.1. Geometric Features of the Basins

The geometric features of the basin provide information about the duration and type of floods. In this section, the morphological features of the basins were analyzed using 10 indices (Table 4).

Table 4: Geometric features of Ezine Stream and neighboring basins (Kastamonu)

	Morphometric Indices	Basins							
		1	2	3	4	5	6	7	8
Geometric Features	***Basin Length (Lb)***	10.01	7.80	19.42	18.93	34.30	6.59	6.89	13.08
	Basin Width (W)	3.35	3.33	9.10	7.44	20.43	3.30	4.61	5.71
	Basin Perimeter (P)	31.42	24.21	67.56	68.62	163.85	22.81	24.64	44.35
	Form Factor (Ff)	0.18	0.23	0.23	0.21	0.32	0.30	0.36	0.25
	Shape Factor (Sf)	5.46	4.24	4.22	4.57	3.12	3.32	2.76	3.96
	Elongation Ratio (Re)	0.48	0.54	0.54	0.52	0.63	0.61	0.67	0.56
	Circularity Ratio (Rc)	0.23	0.30	0.24	0.20	0.17	0.31	0.35	0.27
	Gravelius Index (Kg)	2.07	1.79	2.01	2.18	2.38	1.78	1.67	1.90
	Amount of Circularity (Rcn)	0.58	0.59	1.32	1.14	2.29	0.58	0.69	0.97
	Lemniscate Ratio *(K)*	1.36	1.05	1.05	1.14	0.78	0.83	0.69	0.99

Length of the Basin (Lb): The maximum basin length measured parallel to the main stream varies between 6.59 and 34.30 km in the lower basins. The minimum value was measured in the 6th basin, and the maximum value was measured in the Basin of Ezine Stream (5th basin), where the effects of the flood were greatest (Table 4).

Width of the Basin (W): This value varies between 3.30 and 20.43 km. In parallel with the length of the basin, the minimum value was measured in the 6th basin and the maximum value was measured in the 5th basin in the parameter of the width of the basin (Table 4).

Perimeter of the Basin (P): Perimeter of the basin is considered one of the main morphometric variables because it is related to many morphometric features (Doornkamp and King 1971, Malik et al. 2016). The basin perimeter in the study area varies between 22.81 and 163.85 km. In this parameter, the minimum value was measured in the 6th basin and the maximum value was measured in the 5th basin. In terms of basin perimeter, the Basin of Ezine Stream ranks the first compared to other basins (Table 4).

Form Factor (Ff): The flow characteristic of the drainage basin can be explained by the form factor. When the form factor value decreases, the basin becomes more elongated. In longitudinal basins with a small form factor degree, low flow but long flow time occurs. Whereas, round shaped basin with high form factor value is exposed to high flow with short concentration time and is highly sensitive to flood (Waikar and Nilawar 2014; Bogale 2021). The form factor values of the basins vary between 0.18 and 0.36. 1st Basin has the lowest form factor value and 7th Basin has the maximum form factor value. The form factor was found to be 0.32 in the Basin of Ezine Stream. The form values of all basins are quite low. The form factor indicates that the basins have a longitudinal shape (Table 4, Figure 12).

Shape Factor (Sf): Shape factor corresponds to form factor (Horton 1932, Shekar and Mathew 2022). Higher shape index value indicates basin elongation and weak flood discharge period (Soni 2017). The shape factor values calculated for the basins vary between 2.76 and 5.46. In this parameter, the minimum value was measured in the 7th basin and the maximum value was measured in the 1st basin. The shape factor value in the Basin of Ezine Stream was found to be 3.12 (Table 4, Figure 12).

Elongation Ratio (Re): Schumm (1956) suggested a classification in terms of the relationship between the elongation rate and the shape of the basin as follows: circular basin (>0.9), oval basin (0.9 to 0.8), less long basin (0.7 to 0.8), 0.8), long basin (0.5 to 0.7), and longer basin (<0.5) (Shankar et al, 2022). Re values vary between 0.48-0.67 in the study area. The minimum Re value was measured in the 1st basin and the maximum Re value was measured in the 7th basin in the study area. The Re value for the Basin of Ezine Stream was found to be 0.63. According to the proposed classification, among the basins in the study area, the first basin is longer and the others are long basins (Table 4, Figure 12).

Circularity Ratio (Rc): The Rc value indicates the shape of the basin; when the Rc value increases, the basin becomes more rounded in shape and the flood potential is high at the short flow time outlet point (Bogale 2021). The Rc value varies between 0.17 and 0.35 in the Basin of Ezine Stream and the neighboring basins. The minimum Rc value was measured in the 5th basin, and the maximum Rc value was measured in the 7th basin.

Rc was found to be 0.17 for the Basin of Ezine Stream (Table 4, Figure 12). In terms of this parameter, it can be stated that the flood potential is high in the Basin of Ezine Stream.

Gravelius Index (Kg): Kg value is close to 1 for a circular basin and this value shall be higher than 1 at the rate of basin elongation (Faye and Ndiaye 2021). While Kg values in the basins varied between 1.67 and 2.38, the minimum value was measured in the 7th basin and the maximum value was measured in the 5th basin. Kg was measured as 2.38 for the Basin of Ezine Stream (Table 4, Figure 12). In terms of this parameter, it can be stated that the basins are far from circular form and have a longitudinal form.

Amount of Circularity (Rcn): The Rcn value varies between 0.58 and 2.29 in the basins. The minimum Rcn value was measured in 1st and 6th basins, and the maximum Rcn value was measured in 5th basin (Table 4, Figure 12). Shape parameters such as elongation rate, form factor and compactness coefficient are inversely proportional to soil erosion force. Indeed, a low value of the shape parameter is an indicator of erosion risk (Brahim et al. 2016; Faye and Ndiaye 2021). In general, low values were observed in the basins in terms of shape parameters. This indicates a high risk of erosion. In parallel with the erosion risk, the flood hazard is also high.

Lemniscate Ratio (K): High values of this index indicate increased elongation of the basin (Malik et al. 2016). Lemniscate ratio also indicates basin slope (Chorley et al. 1957). The K value indicates values between 0.69 and 1.36 in the lower basins. The minimum K value was measured in the 7th basin, and the maximum K value was measured in the 1st basin. The value found for the lemniscate ratio in the Basin of Ezine Stream is 0.78 (Table 4, Figure 12).

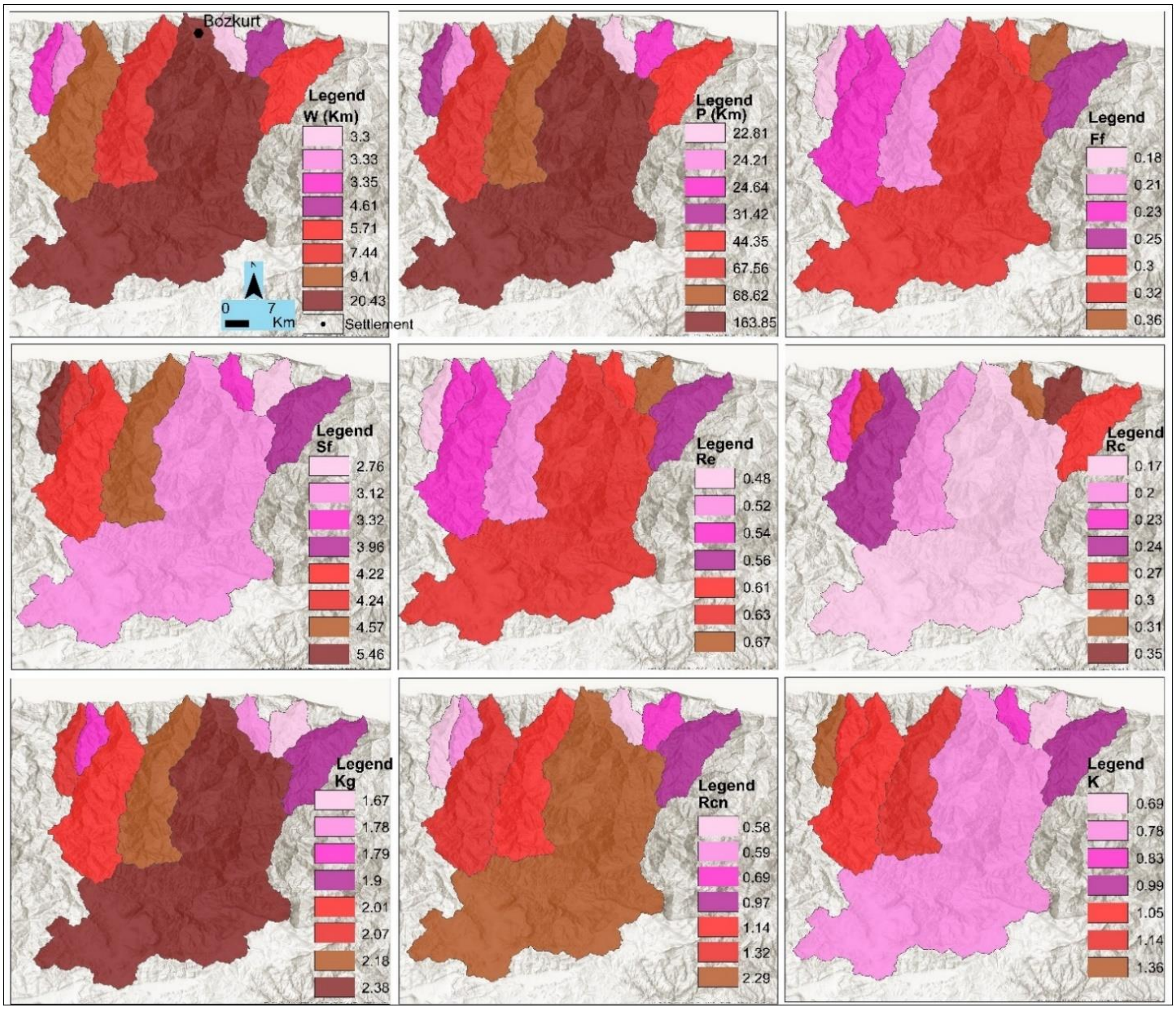

Figure 12: Distribution of basin geometric features of Ezine Stream and neighboring basins (Kastamonu)

3.2.2. Areal Morphometric Features

While analyzing the areal morphometric features of Ezine Stream and neighboring basins, the basin area, drainage density, channel maintenance constant, infiltration number, drainage density, stream frequency and overland flow length were used (Table 5).

Table 5: Areal morphometric features of Ezine Stream and neighboring basins (Kastamonu)

	Morphometric Indices	Basins							
		1	2	3	4	5	6	7	8
Areal Morphometry	***Basin Area (A)***	18.33	14.43	89.28	78.26	376.58	13.06	17.19	43.10
	Drainage Density (Dd)	1.26	1.57	1.71	2.18	1.91	2.38	1.60	2.16
	Constant of channel maintenance (CCM)	0.79	0.63	0.75	0.49	0.52	0.42	0.62	0.46
	Infiltration Number (If)	0.88	1.83	2.25	4.44	3.62	3.8	1.85	4.55
	Drainage İntensity (Di)	0.55	0.74	0.77	0.93	0.99	0.67	0.72	0.97
	Stream Frequency (Fs)	0.70	1.17	1.32	2.04	1.90	1.60	1.16	2.11
	Length of Overland Flow (Lg)	0.39	0.31	0.29	0.22	0.26	0.21	0.31	0.23

Area of the Basin (A): Area of the basin is a parameter that directly reflects the total water volume (Shekar and Mathew 2022). Areas of the basins vary between 13.06 and 376.58 km^2. The basin with the minimum area is the 6th basin while the basin with the maximum area is the 5th (the Basin of Ezine Stream). When evaluated in terms of this parameter, while the accumulation of water coming from the side branches takes place in a shorter time in the 6th basin, this period is longer for the Basin of Ezine Stream (Table 5).

Drainage Density (Dd): "A drainage density value close to zero indicates a permeable basin with high infiltration rates and high groundwater potential. Low drainage density is associated with dense vegetation and highly resistant permeable material under low relief (Nautiyal 1994). High Dd value indicates impermeable rocks and sparse vegetation and hilly areas" (Choudhari et al. 2018). Dd values of the basins vary between 1.26 and 2.38. The minimum Dd value was measured in the 1st basin, and the maximum Dd value was measured in the 6th basin. The Dd value in the Basin of Ezine Stream, where the flood disaster occurred, is 1.91 (Table 5, Figure 13). Depending on the morphology, low Dd values were measured in the southeast and southwest of the Basin of Ezine Stream. In general, Dd value is high in 4th, 5th, 6th, and 8th basins.

Constant of Channel Maintenance (CCM): The constant of channel maintenance represents the drainage area required to maintain one unit channel length; therefore, it is a measure of erosion in the basin (Sakthivel et al. 2019; Sinha et al. 2023). With this parameter, which is the opposite of the drainage density, low values indicate low permeability, steep and very steep slopes, and high overland flow (Ali and Khan 2013). In the study area, this value varies between 0.42 (6th basin) and 0.79 (1st basin) (Table 5, Figure 13). The constant of channel maintenance in the Basin of Ezine Stream is 0.52. In terms of this parameter, it can be stated that the flood hazard is high in the 6th basin.

Infiltration Number (If): The infiltration number gives information about the infiltration capacity of the basin. High infiltration is low flow, low infiltration is high flow (Rai et al. 2017a). The number of infiltrations varies between 0.88 (1st basin) and 4.55 (8th basin) in the basins. The "If" value in the Basin of Ezine Stream was found to be 3.62 (Table 5, Figure 13). In terms of If, infiltration is low and overland flow is high in the 8th basin. The opposite conditions exist for the 1st basin. It can be stated that this parameter increases the risk of flood in the Basin of Ezine Stream, and that infiltration is low and overland flow is high.

Drainage Intensity (Di): Di is the ratio of stream frequency to drainage density (Faniran 1968). With low values of stream frequency and drainage density, overland flow is not quickly removed from the basin, making it highly sensitive to flood, gully erosion, and landslides (Pareta and Pareta 2012). Di varies between 0.55 (1st basin) and 0.99 (the Basin of Ezine Stream) in the lower basins. In terms of this index, it can be stated that the flood hazard is high in the 1st basin (Table 5, Figure 13).

Stream Frequency (Fs): Fs is found by dividing the number of stream segments in a basin by the basin area (Horton 1945; Sinha et al. 2023). High slope and more precipitation increase the stream frequency in mountainous regions while high permeability and less surface water reduce the stream frequency in the plateau environment (Bali et al. 2012; Sinha et al. 2023). Stream frequency varies between 0.70 and 2.11 for lower basins. Fs was found to be minimum in the 1st basin and maximum in the 8th basin. The Fs value in the Basin of Ezine Stream is 1.90 (Table 5, Figure 13). Due to low drainage density values in the southeast and southwest of the Basin of Ezine Stream, stream frequency values are low. The abundance of seasonal rivers in the studied lower basins has an effect on the flood hazard. Stream frequency is high in 4th, 5th, 6th, and 8th basins.

Length of Overland Flow (Lg): A low overland flow length indicates high relief, short flow paths, high overland flow and low infiltration. A high value of Lg indicates more infiltration and less overland flow with a low slope and long flow paths (Vinutha and Janardhana 2014; Rai et al. 2017a; Sukristiyanti et al., 2018). The Lg value varies between 0.21 (6th basin) and 0.39 (1st basin) in the study area. Lg was found to be 0.26 in the Basin of Ezine Stream. The Lg value is generally low in the basins. This shows that the danger is high in terms of flood (Table 5, Figure 13).

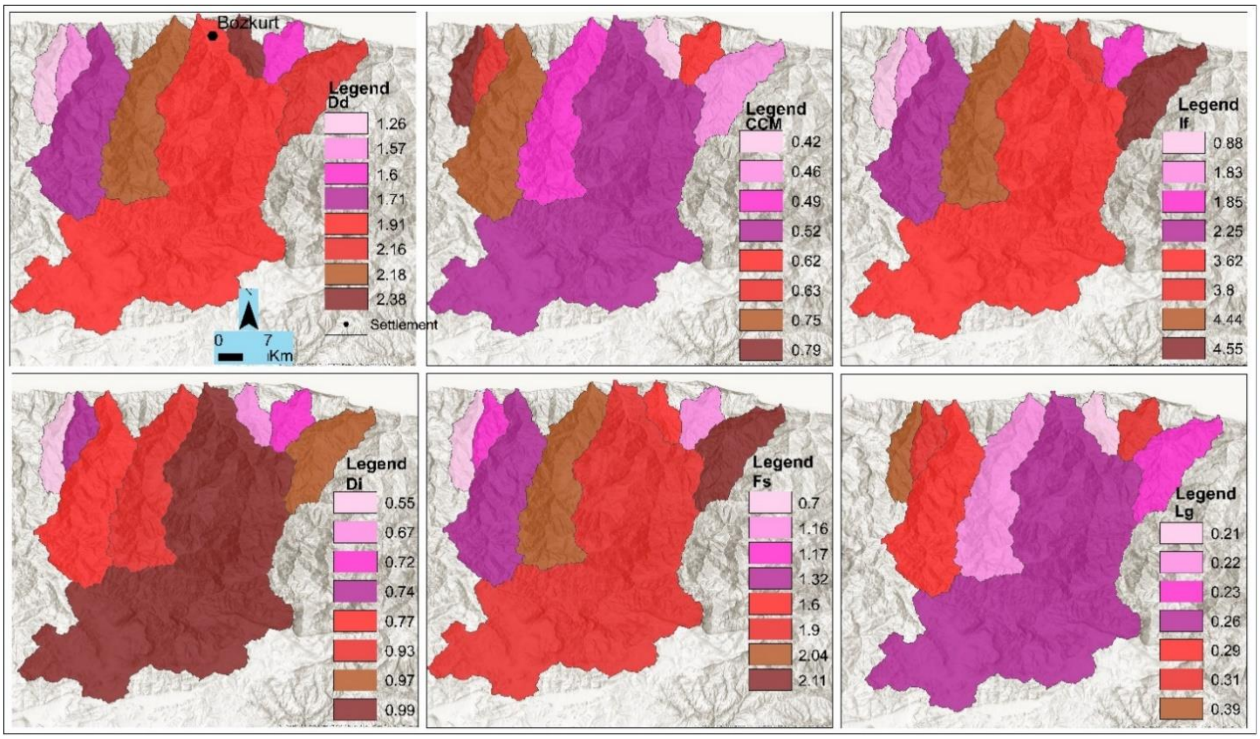

Figure 13: Distribution of areal morphometric features of Ezine Stream and neighboring basins (Kastamonu)

3.2.3. Relief Morphometry Features

Erosion in the basins is closely related to the relief morphometry features. In this section, the basins are compared in terms of their relief morphometric features (Table 6).

Table 6: Relief Morphometric Features of Ezine Stream and Neighboring Basins (Kastamonu)

	Morphometric Indices	Basins							
		1	2	3	4	5	6	7	8
Relief Morphometry	***High Relief***	1269	1031	1655	1721	2015	794	796	1251
	Low Relief	0	0	0	0	0	0	0	0
	Relief Ratio (Rh)	0.12	0.13	0.08	0.09	0.05	0.12	0.11	0.09
	Basin Relief (Bh)	1269	1031	1655	1721	2015	794	796	1251
	Hypsometric Integral (Hi)	0.49	0.46	0.54	0.53	0.51	0.43	0.51	0.45
	Dissection Index (Dis)	1	1	1	1	1	1	1	1
	Gradient Ratio (Rg)	0.12	0.13	0.08	0.09	0.05	0.12	0.11	0.09
	Melton Ruggedness Number (Mrn)	0.29	0.27	0.17	0.19	0.10	0.21	0.19	0.19
	Slope (S)	0-49	0-54.5	0-65.3	0-53.7	0-61.26	0-61.26	0-50.77	0-56.42
	Maximum Slope	49	54.5	65.3	53.7	61.26	61.26	50.77	56.42
	Average Slope (o)	23.1	25.11	23.75	24.46	19.64	19.62	17.21	19.74
	Relative Relief (RR)	1269	1031	1655	1721	2015	794	796	1251
	Ruggedness Number (Rn)	1.59	1.61	2.83	3.75	3.84	1.88	1.27	2.70

Relief Ratio (Rh): For Rh, which is the ratio of basin relief to basin length, high values characterize hilly regions while low values characterize plains and valleys (Kumar and Chaudhary 2016). Relief ratio values were measured as 0.05 in the Basin of Ezine Stream, which is the minimum value, and 0.13 in the 2nd basin, which is the maximum value. In general, the relief ratio values for the lower basins are high (Table 6, Figure 14).

Basin Relief (Bh): Bh was found from the maximum and minimum elevation values of the basins using the histogram of the DEM. Bh, one of the morphometric parameters controlling the denudation features of the basins, also affects the flow gradient, overland flow and sediment transport (Choudhari et al. 2018). It is a very important parameter that can be used to detect the erosion of the basin (Shaikh et al. 2021; Kılıç et al. 2022). While the minimum elevation value in the basins was 0 m, the maximum elevation value was measured as 2015 m in the Basin of Ezine Stream, where the effects of flood were the most (Table 6, Figure 14). The high Bh values in the lower basins increased the slope and erosional activities, which increased the flood hazard.

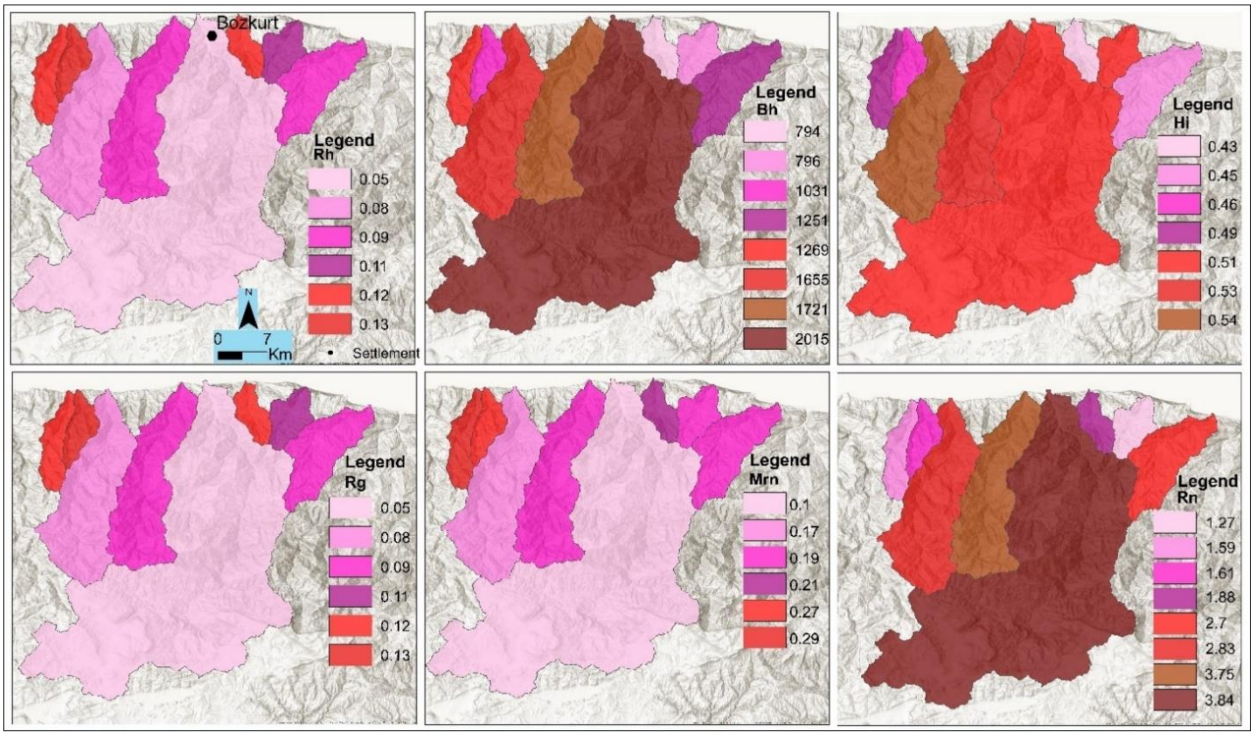

Figure 14: Distribution of relief morphometric features of Ezine Stream and neighboring basins (Kastamonu)

Hypsometric Curve (Hc) and Integral (Hi): Hc enables inferences about the geomorphological stage of basins. Convex Hc indicates young basins in geomorphological terms (Strahler 1952). Over time, due to high erosion and weathering, Hc can take a concave form (Strahler 1952; Chai et al. 2022). The fact that the basins are young indicates that the erosion is severe and accordingly the sediment transport is high. Concave curves, on the other hand, are associated with old and low erosion basins (Strahler 1952). While the curves of 3rd, 4th, 5th, and 7th basins are convex, the curves of the other basins are concave. According to this, 3rd, 4th, 5th and 7th basins are the ones where the erosion intensity is high and floods may occur. Other basins show the characteristics of mature drainage areas (Table 6, Figure 15).

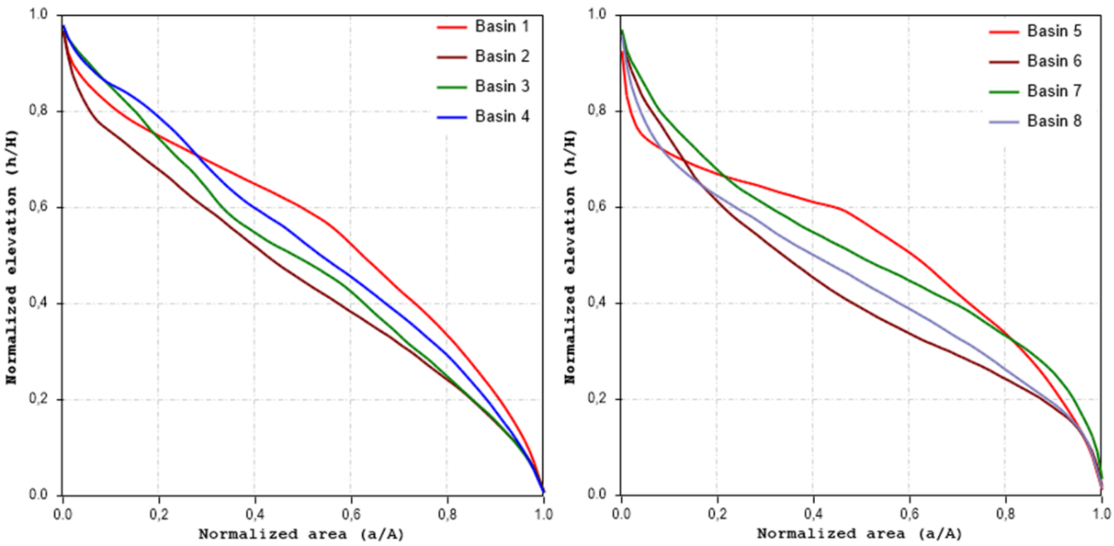

Figure 15: Hypsometric curves of the Basin of Ezine Stream and neighboring basins (Kastamonu) (Drawn with the CalHypso extension developed by Perez-Pena et al. 2009)

The HI value quantitatively refers to the three stages (young, mature and old) of Davis's (1899) geomorphic erosion cycle (Chai et al. 2022). In the comparison made in terms of Hi values, Hi values of 3rd, 5th, 6th and 7th basins are higher than 0.5, and Hi values of the other basins are less than 0.5 (Table 6, Figure 14). When Hc and Hi are evaluated together, it can be stated that 3rd, 5th, 6th and 7th basins are in their youth phase, therefore the flood hazard is high, and that the other basins are less dangerous in this respect.

Dissection Index (Di): Di is the parameter that expresses the degree of cleavage or erosion that occurs in a basin (Nir 1957; Thomas et al. 2012; Roy et al. 2022). Di values in all basins are the maximum value, which is 1 (Table 6). These values prove that cleavage and ruggedness are high. These values, which indicate that erosion is also high in the basins, indicate that the flood hazard is high.

Gradient Ratio (Rg): The gradient ratio, which is an indicator of the channel slope, is a parameter allowing the evaluation of the flow volume (Sreedevi et al. 2005; Thomas et al. 2010). Low Rg indicates a flat stream bed and slowly moving water that can only carry small amounts of very fine sediments (Kumar and Chaudhary 2016). Rg values calculated in the basins vary between 0.05 and 0.13. The minimum Rg value was detected in the Basin of Ezine Stream, and the maximum Rg value was detected in the 2nd basin (Table 6).

Melton Ruggedness Number (Mrn): Another index that takes the general relief conditions of the drainage basin into account is Mrn. Mrn is basically a slope index and a topographic indicator (Marchi and Dalla Fontana 2005). Mrn is an index of overland flow accumulation, which is calculated by dividing the difference between the maximum and minimum elevation in the basin area by the square root of the basin area size (URL-7 2022). Mrn value varies between 0.10 (5th basin) and 0.29 (1st basin) in the studied basins (Table 6, Figure 14).

Slope (S): There is a positive relationship between slope and erosion because the flow force of water increases with increasing slope (Roy et al. 2022). The maximum slope values of the lower drainage areas in the study area vary between 49.8º (1st basin) and 65.3º (3rd basin). The maximum slope value in the Basin of Ezine Stream is 61.26º (Table 6, Figure 16). It can be stated that slope values are high in all basins, and it increases the flood hazard.

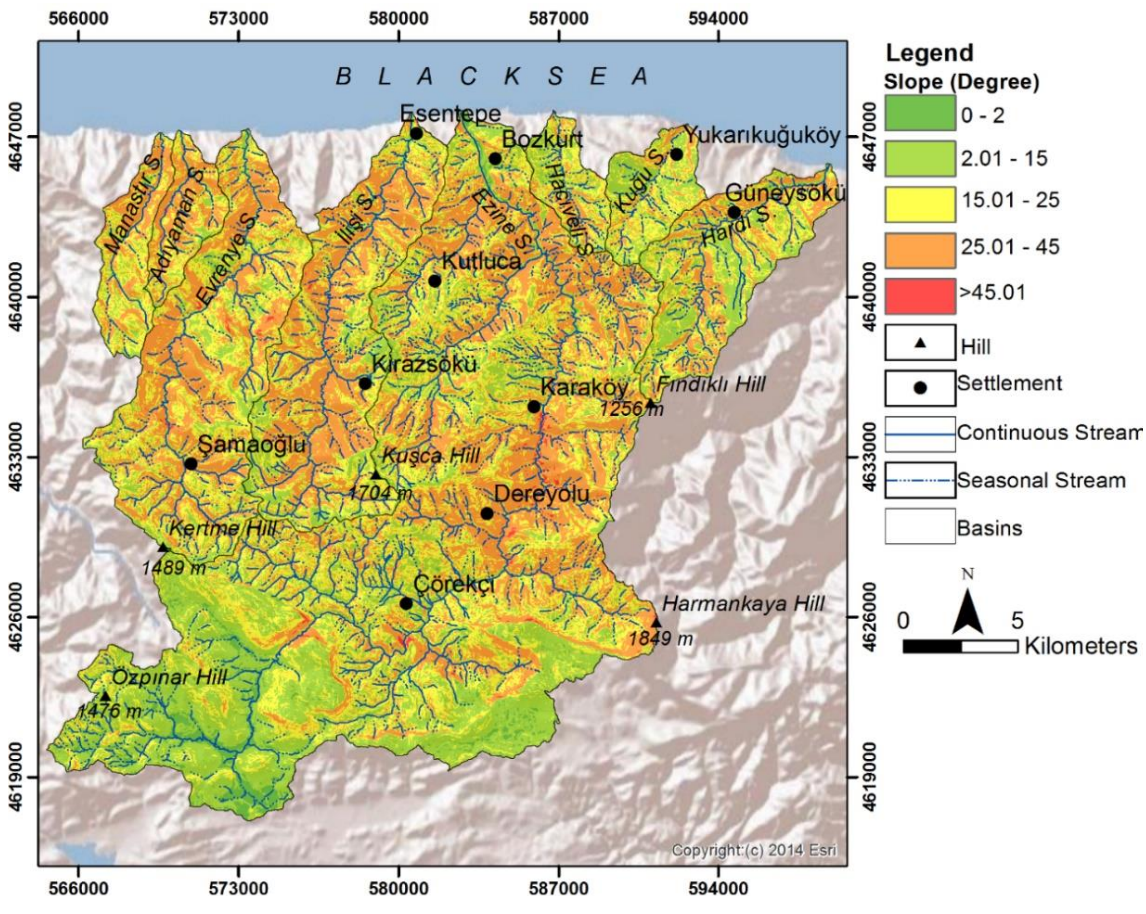

Figure 16: Slope map of Ezine Stream and neighboring basins (Kastamonu)

Average Slope (º): The average slope of a basin has a direct effect on erosion in the basin. It has been proven by researchers that if other factors remain unchanged, the greater the percentage of slope, the greater the erosion (Meshram and Sharma 2017). Average slope values in the basins vary between 17.21º and 25.11º. The average slope value in the Basin of Ezine Stream is 19.64º (Table 6, Figure 14). It can be stated that the average slope values in all basins are higher than 15º and the flood hazard is high.

Relative relief (RR): It is defined as the difference in elevation between the highest and lowest points in a basin. Relative relief provides an indication of the intensity of erosion processes operating in a field, as well as an idea of the morphological units in a field (Smith 1935; Kühni and Pfiffner 2001; Rai et al. 2017b; Roy et al. 2022). Relative relief values in the study area vary between 794 and 2015 m (Table 6). In this respect, the lowest value was measured in the 6th basin, and the highest value was measured in the 5th basin. As the relative relief values increase, the severity of erosion increases. Accordingly, the 5th basin, where the flood event occurred, is also a basin where erosion is severe due to the high relative relief. This situation can be considered as an important factor in the occurrence of the disaster. All basins were divided into 1000*1000 m grids and the distribution of relative relief within the basin was determined. Accordingly, it was found that relative relief values are 3.94-454 m in the 1st basin, 24.8-492.7 m in the 2nd basin, 13.1-572 m in the 3rd basin, 1.47-569.4 m in the 4th basin, 0.7-701.64 m in the 5th basin, 25.5-380.9 m in the 6th basin, 51.5-341.9 m in the 7th basin and 15.9-530.6 m in the 8th basin. Ezine Stream Basin has the highest value in the sub-basins where the elevation change in an area of 1 km^2 is quite high (Figure 17).

Ruggedness Number (Rn): High Rn value indicates high relative relief and high drainage density (Roy et al. 2022). It can be stated that the Basin of Ezine Stream is in a risky position in terms of the ruggedness numbers varying between 1.27 (7th basin) and 3.84 (the Basin of Ezine Stream) (Table 6).

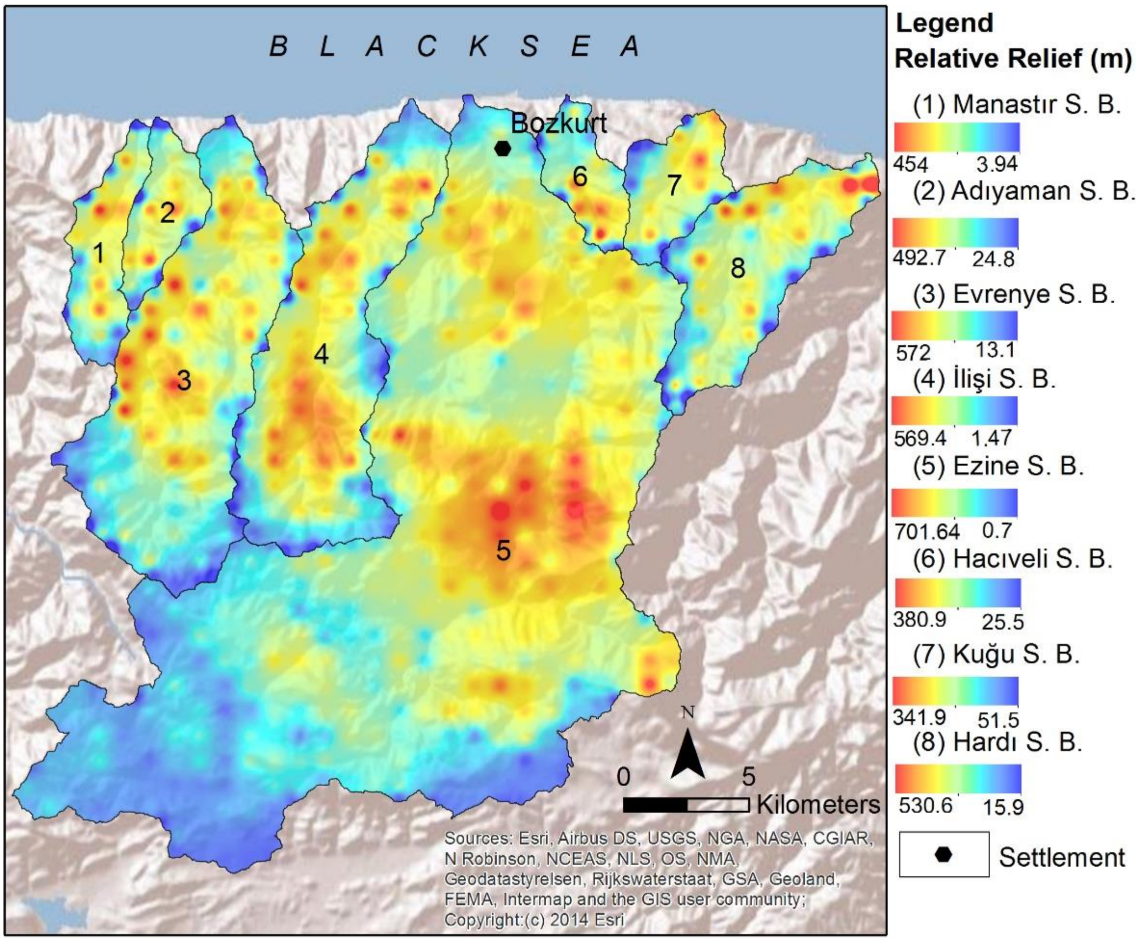

Figure 17: Relative relief map of Ezine Stream and neighboring basins (Kastamonu)

3.2.4. Correlation Analysis

Correlation analysis between morphometric parameters can be identified with the help statistical analyses used for specifying basin features that help prepare a comprehensive plan for mapping hydraulic potential and sustainability (Hamdan 2020). Pearson corelation analysis was used for the correlation between the parameters used in the study. Analysis results reveal a significant positive correlation between form factor and elongation ratio, and drainage density and stream frequency. A significant positive correlation was found between drainage density and infiltration number, drainage intensity and stream frequency, relief ratio and Mrn, and Rg and Mrn. There is a strong negative correlation between shape factor, form factor, elongation ratio, lemniscate ratio, and slope. There is a strong negative correlation between Rc and Kg; Rcn and Rh, and Rg; K and Ff; Dd and CCm, and Lg; If and Ccm, and Lg (Figure 18).

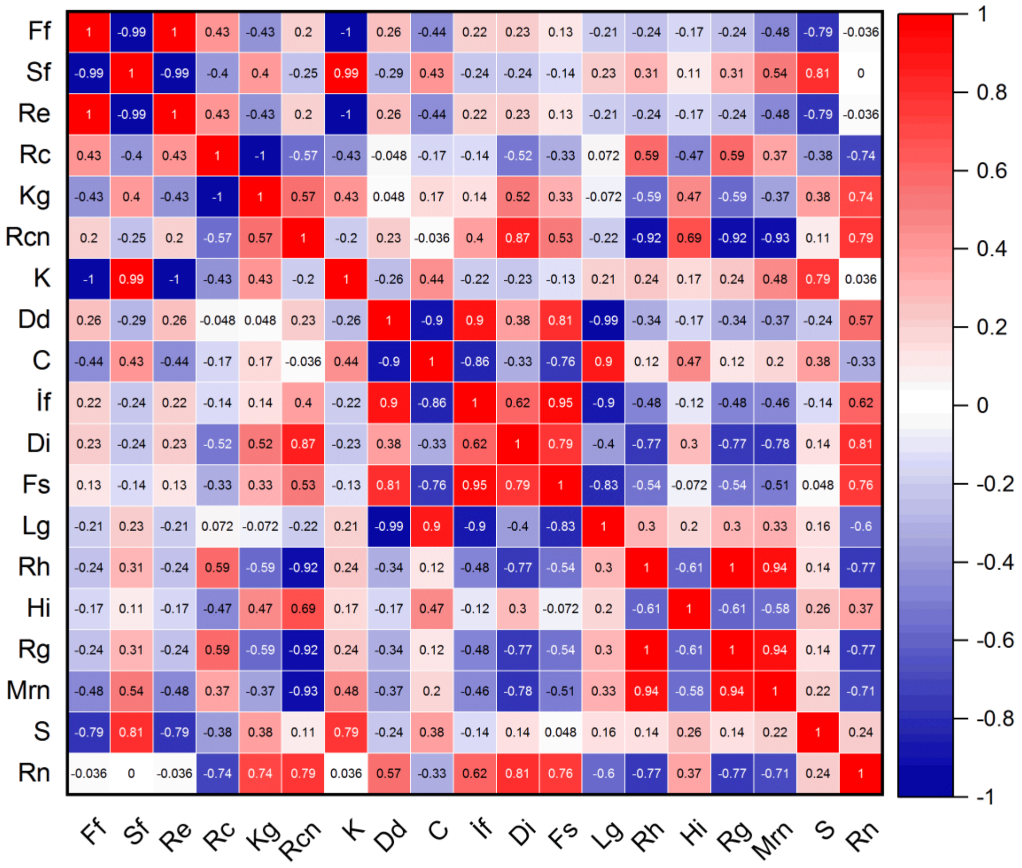

Figure 18: Pearson correlation analysis results of geometric, areal and relief morphometric parameters of the basin of Ezine Stream and neighboring basins

4. Discussion

Indices such as form factor, shape coefficient, and elongation ratio, which determine the shape of the basin, provide information about the flood type and duration. The results showing the elongated basins according to these indices reveal that the erosion risk is high and the floods are long but the overflow peak is flat. In terms of these indices, the basins show a elongated shape rather than a square, circular shape. For this reason, the erosion risk is high in the drainage basins and the flood hydrograph of the elongated basins can be seen (Javed et al. 2009; Ameri et al. 2018; López-Ramos et al. 2022). Drainage density and stream frequency are indices that provide information about the flood risk from the areal features of the basin. High drainage density and high stream frequency mean that the flood risk is high. When the distribution of these indices according to the basins is evaluated, the flood risk is high due to the high Dd and Fs values in the 4th, 5th, 6th, 7th, and 8th basins. The relief features of the basins enable us to make inferences about the speed and amount of the runoff and the period of the geomorphological development of the basins. Basin relief, relative relief, dissection index, hypsometric integral, hypsometric curve, slope and average slope, and ruggedness number analyzes and when basins are evaluated in this respect, it can be seen that relief features enable high runoff ratio and amount, and increase flood risk. In short distances from the coast, the elevation change exceeds 2000 m. This result can be accepted as another indicator that the flood risk is high in the basins. In all basins, the dissection index is the highest value of 1. The ruggedness number, basin relief, and relative relief values were measured the highest in the Ezine Stream Basin. Hypsometric integral (HI), a geomorphological parameter, shows the stage of basin development (Said et al. 2018). The shape shown by Hc gives information about erosion and sediment transport (López-Ramos et al. 2022). The hypsometric integral value and the convex curve of the Ezine Stream Basin are evidence of high flood risk.

5. Conclusion

This study has attempted to reveal the relationship between the basin morphometric parameters of Bozkurt disaster, which is one of the biggest flood disasters in our country. In the study, the Basin of Ezine Stream, where the effects of flood was most intense, has been relatively analyzed in terms of geometric (shape), areal and relief morphometric features together with its neighboring basins.

In the analyzed basins, Ff value ranges between 0.18-0.36, Sf 2.76-5.46, Re, 0.48-0.67, Rc, 0.17-0.35, Kg, 1.67-2.38, Rcn, 0.58-2.29, K, 0.69-1.36, Dd, 1.26- 2.38, If, 0.88-4.55, Fs, 0.70-2.11, and Lg, 0.21-0.39. Basin relief values are high and range between 794-2015. The dissection index values are 1, which is the maximum value for this index in all basins. Hi, varies between 0.43-0.54, and Rn between 1.27 and 3.84. Pearson correlation coefficient was used for the correlation between morphometric parameters. According to the results, there are strong and very strong relationships between some indices. There is a strong positive correlation between drainage density and infiltration number, drainage density and stream frequency, relief ratio and Mrn, and Rg and Mrn.

According to the results, the Basin of Ezine Stream is the basin with the highest value of basin relief, relative relief and ruggedness. It can be stated that these features of the basin increase denudation and facilitate flooding. When all basins are evaluated, it indicates that the basins have a more elongated shape. This result is an indication that the flood hydrograph shall be more flat, that is to say, flows shall be low and of long duration. Basin relief, relative relief, average slope and maximum slope values are quite high in basins. Average slope values are higher than 15^{o} for all basins. Hi values are higher than 0.5 in 3rd, 5th, 6th and 7th basins and hypsometric curves are convex. It can be suggested that the precipitation in the area close to the source part of the basin on 10-12 August increased the degree of impact of the event. Between these dates, 424.1 mm of precipitation fell in the village of Bozkurt-Mamatlar. This precipitation rate is close to half of the total annual precipitation rate of Bozkurt station. According to projections related to global climate change, the site shall be one of the areas where the change in maximum daily precipitation is high. It is predicted that this change may be between 5-10% (URL-6 2022). This change in daily precipitation amounts will be in the form of an increase. In addition, the increase in temperatures will increase the probability of seeing heavy rains due to strong convective movements. For this reason, it can be anticipated that flood events shall continue. In order to prevent such events from turning into disasters, it is recommended to consider the geomorphological, climatic and morphometric features of the basins in the studies to be carried out. Constructions located close to the stream bed also played most important role in the flood event causing the disaster. For this reason, the areas close to the stream bed should not be zoned for construction. Public institutions such as residences, schools and hospitals should not be allowed to be built in the floodplain area of Ezine Stream. Stream beds should not be narrowed, debris should not be thrown into stream beds, and stream beds should be cleaned at regular intervals.

In the Ezine Stream Basin, where the flood effects are the most, urban areas have increased over 100% between 1990 and 2018. Preventing the destruction of natural vegetation in the study area and starting reinforcement works are other important studies to reduce flood damages.

References

Abdelouhed F., Ahmed A., Abdellah A., Yassine B., Mohammed I., (2021), *Using GIS and remote sensing for the mapping of potential groundwater zones in fractured environments in the Chaouıa-Morocco area*, Remote Sensing Applications: Society and Environment, 23, 100571-100516.

Addis A., (2023), *GIS – based flood susceptibility mapping using frequency ratio and information value models in upper Abay river basin, Ethiopia,* Natural Hazards Research, 3(2), 247-256.

Ahad U., Shah A.R., Ali U., (2022), *Quantitative estimation of drainage characteristics of the Pohru Catchment, Kashmir valley, India: a remote sensing and GIS based approach*, Geocarto International, 37(26), 13839-13859.

Alexeevsky N., Magritsky D.V., Koltermann K.P., Krylenko I., Toropov P., (2016), *Causes and systematics of inundations of the Krasnodar territory on the Russian Black Sea coast*, Natural Hazards Earth System Sciences, 16(6), 1289-1308.

Ali S.A., Khan N., (2013), *Evaluation of morphometric parameters-A remote sensing and GIS based approach*, Open Journal of Modern Hydrology, 3(1), 27229, 20-27.

Alqahtani F., Qaddah A.A., (2019), *GIS digital mapping of flood hazard in Jeddah–Makkah region from morphometric analysis*, Arabian Journal Geosciences, 12, 199, doi: 10.1007/s12517-019-4338-8.

Al-Neama S.N., Yang S., Yayha B.M., (2022), *Evaluation of surface run-off potential of basins in Nineveh governorate, Iraq based on morphometric analysis, using RS and GIS*, Materials Today: Proceedings, 60(3), 1753-1768.

Ameri A.A., Pourghasemi H.R., Cerda A., (2018), *Erodibility prioritization of sub-watersheds using morphometric parameters analysis and ıts mapping: A comparison among TOPSIS, VIKOR, SAW, and CF multi-criteria decision making models*, Science of The Total Environment, 613-614, 1385-1400.

Atalay İ., (2018), *Uygulamalı hidroğrafya*, Meta Basım Matbaacılık Hizmetleri, İzmir, Türkiye, 350ss.

Baduna Koçyiğit M., Akay H., (2019), *Estimation of flash flood potential of gökırmak basin using morphometric parameters*, Proceedings International Science and Engineering Applications Symposium on Hazards 2019, Karabuk, Turkey, ss.150-158.

Bali R., Agarwal K.K., Nawaz Ali S., Rastogi S.K., Krishna K., (2012), *Drainage morphometry of Himalayan Glacio-fluvial basin, India: hydrologic and neotectonic implications*, Environmental Earth Science, 66, 1163-1174.

Baltacı H., (2017), *Meteorological analysis of flash floods in Artvin (NE Turkey) on 24 August 2015*, Natural Hazards Earth System Sciences, 17(7), 1221-1230.

Beg A.A.F., (2015), *Morphometric toolbox: a new technique in basin morphometric analysis using ArcGIS*, Global Journal of Earth Science Engineering, 2(2), 21-30.

Bendjoudi H., Hubert P., (2002), *The Gravelius compactness coefficient: critical analysis of a shape index for drainage basins*, Hydrological Sciences Journal, 47(6), 921-930.

Bilgen G., Balcı E., Kalça M.Y., (2022), *Kastamonu Bozkurt ilçesinde 11.08.2021 tarihinde meydana gelen sel felaketinin yerinde incelenmesi*, Fenerbahçe ÜniversitesiTasarım Mimarlık ve Mühendislik Dergisi, 2(1), 20-35.

Bogale A., (2021), *Morphometric analysis of a drainage basin using geographical information system in Gilgel Abay watershed, Lake Tana Basin, upper Blue Nile Basin, Ethiopia*, Applied Water Science, 11, 122, doi: 10.1007/s13201-021-01447-9.

Brahim B., Larbi B., Abdallah D., Driss S., (2016), *Utilisation du sig dans l'analyse morphometrique et la prioritisation des sous-bassins versants de oued ınaouene (Nord-Est du maroc)*, European Scientific Journal, 12(6), 283-306.

Chai L., Zhong C.D., Guo F.S., Huang X.S., Wang D.Y., Shao C.J., Chen L.Q., (2022), *Evolution stage, spatial and temporal variabilities of granite landforms in the Mount Wugongshan in Jiangxi Province of South China*, Journal of Mountain Science, 19, 2743-2757.

Charizopoulos N., Mourtzios P., Psilovikos T., Psilovikos A., Karamoutsou L., (2019), *Morphometric analysis of the drainage network of Samos Island (northern Aegean Sea): Insights into tectonic control and flood hazards*, Comptes Rendus Geoscience, 351(5), 375-383.

Choudhari P.P., Nigam G.K., Singh S.K., Thakur S., (2018), *Morphometric based prioritization of watershed for groundwater potential of Mula river basin, Maharashtra, India,* Geology, Ecology, and Landscapes, 2(4), 256-267.

Chauhan N., Paliwal R., Kumar V., Kumar S., Kumar R., (2022), *Watershed prioritization in Lower Shivaliks Region of India using ıntegrated principal component and hierarchical cluster analysis techniques: A case of Upper Ghaggar Watershed*, Journal of the Indian Society of Remote Sensing, 50(6), 1051-1070.

Chorley R.J., Malm D.E.G., Pogorzelski H.A., (1957), *A new standard for estimating drainage basin shape*, American Journal of Science, 255(2), 138-141.

Çanta E.E., Temuçin Kılıçer S., Akıncı H., (2022), *FLO-2D ve HEC-RAS Yazılımları ile Ardanuç (Artvin) İlçesindeki Pona Deresi ve Örtülü Deresi'nin Taşkın Yayılım Haritalarının Karşılaştırmalı Üretilmesi*, Turkish Journal of Remote Sensing and GIS, 3(1), 50-64.

Coşkun S., (2021), *Küre Dağlarının Kastamonu iklimi üzerindeki etkileri*, Türk Coğrafya Dergisi, 77, 37-52.

Davis W.M., (1899), *The geographical cycle*, The Geographical Journal, 14(5), 481-504.

Demircan M., Gürkan H., Eskioğlu O., Arabacı H., Coşkun M., (2017), *Climate change projections for Turkey: Three models and two scenarios*, Turkish Journal of Water Science and Management, 1(1), 22-43.

Demir V., Ülke Keskin A., (2022a), *Taşkın tehlike haritalarının oluşturulması (Samsun, Mert Irmağı örneği)*, Türkiye Coğrafi Bilgi Sistemleri Dergisi, 4(1), 47-54.

Demir V., Ülke Keskin A., (2022b), T*aşkınların ekonomik zararlarının değerlendirilmesi (Samsun-Mert Irmağı Havzası)*, Uluslararası Mühendislik Araştırma ve Geliştirme Dergisi, 14(2), 663-678.

Demir V., Ülke Keskin A., (2022c), *Yeterince akım ölçümü olmayan nehirlerde taşkın debisinin hesaplanması ve taşkın modellemesi (Samsun, Mert Irmağı örneği)*, Geomatik , 7(2), 149-162.

DEMP, (2022), *Disaster Statistics*, Disaster and Emergency Management Presidency, Ankara.

Doğan O.H., Önol B., Turunçoğlu U.U., Kahraman A., (2019), *Heavy Precipitation sensitivity of sea surface temperature over the Eastern Blacksea Region: Ensemble simulations of Hopa/Artvin case*, Proceedings 9th International Symposium on Atmospheric Sciences (ATMOS 2019), ITU, Istanbul, ss.614-618.

Dongare C.U., Deota B.S., Deshpande R.D., (2022), *High resolution morphometric studies with special reference to hydrological setup of Khapri watershed, Dangs district, Gujarat, Western India*, Geocarto International, 37(13), 3697-3720.

Doornkamp J.C., King C.A., (1971), *Numerical Analysis in Geomorphology-Introduction*, Edward Arnold, London, UK, 372ss.

Erdede B., Öztürk D., (2016), *Kızılırmak havzasının taşkın potansiyelinin çizgisel, alansal ve rölyef morfometrik indisler kullanılarak değerlendirilmesi*, 6. Uzaktan Algılama-CBS Sempozyumu (UZAL-CBS 2016), Adana, Türkiye, pp.392-399.

Ertürk E., Kaya N., (2019), *Taşkın tehlike alanlarının oluşturulması: Trabzon ili Vakfıkebir ilçesi Kirazlı Deresi örneği*, Fırat Üniversitesi Mühendislik Bilimleri Dergisi, 31(2), 337-344.

ESRI, (2022), *ArcGIS Earth desktop apps*, Environmental Systems Research Institute, https://www.esri.com/en-us/arcgis/products/arcgis-earth/downloads, [Accessed 09 November 2021].

Faniran A., (1968), *The index of drainage Intensity-a provisional new drainage factor*, Australian Journal of Science, 31(9), 328-330.

Faye C., Ndiaye M., (2021), *Use of geospatial tools in morphometric analysis and prioritisation of sub-catchments of the Soungrougrou (Casamance Basın)*, Quaestıones Geographicae, Sciendo, 40(3), 65-84.

GDM, (2010), *1/25.000 scale standart topographic maps, (Map sheets: E31c1,c2, E32 d1, E32 a1, a2, a4, E32 b1, b2, b3, b4)*, General Directorate of Mapping, Ankara, Türkiye.

GDWM, (2014), *Guidelines for the preparation of flood risk management plans*, General Directorate of Water Management, http://taskinyonetimi.suyonetimi.gov.tr/taskin/Files/Outputs/TRYP_Kilavuzlar.pdf, [Accessed 11 May 2019].

Gravelius H., (1914), *Grundrifi der Gesamten Gewcisserkunde, Band I: Flufikunde (Compendium of Hydrology, vol. I. Rivers)*, Goschen, Berlin, German.

Gülbaz S., (2019), *Sayısal modeller ile taşkın yayılım haritasının oluşturulması ve risk altında olan alanların belirlenmesi: Türkköse Deresi örneği*, Doğal Afetler ve Çevre Dergisi, 5(2), 335-349.

Hamdan A.M., (2020), *Hydro-Morphometric analysis using geospatial technology: A case study of Wadi Gabgaba and Wadi Allaqi Watersheds, Southern Egypt-Northern Sudan*, Journal of Asian Scientific Research, 10(3), 190-212.

Halis O., Gönençgil B., Acar Z., (2022*), An atmospheric approach to the flood disaster in the Western Black Sea region (Turkey) on 10-12 August 2021*, Natural Hazards and Earth System Sciences, doi: 10.5194/nhess-2022-185.

Horton R.E., (1932), *Drainage-basin characteristics Eos*, transactions american geophysical union, 13(1), 350-361.

Horton R.E., (1945), *Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology*, Geological society of America bulletin, 56(3), 275-370.

Islam A., Deb Barman S., (2020), *Drainage basin morphometry and evaluating its role on flood-inducing capacity of tributary basins of Mayurakshi River, India*, SN Applied Science, 2, 1087, doi: 10.1007/s42452-020-2979-6.

Jackson A., (2012), *Discharge & hydrographs*, Geography AS Notes, https:// geographyas.info/rivers/discharge-and-hydrographs/, (Accessed 10 December 2022).

Javed A., Khanday M.Y., Rizwan A., (2009), *Prioritization of sub-watersheds based on morphometric and land use analysis using remote sensing and gıs techniques*, Journal of the Indian Society of Remote Sensing, 37, 261-274.

Jose C., Thomas J., Prasannakumar V., Reghunath R., (2019), *BaDAM toolbox: A GIS-Based approach for automated drainage basin morphometry*, Journal of the Indian Society of Remote Sensing, 47, 46-478.
Jothimani M., Abebe A., Berhanu G., (2022), *Application of remote sensing, GIS, and drainage morphometric analysis in groundwater potential assessment for sustainable development in Iyenda River Catchment, Konso Zone, Rift Valley, Southern Ethiopia*, IOP Conf. Series: Earth and Environmental Science, 982, 012032, doi: 10.1088/1755-1315/982/1/012032.
Kaliraj S., Chandrasekar N., Magesh N.S., (2015), *Morphometric analysis of the River Thamirabarani sub-basin in Kanyakumari District, South west coast of Tamil Nadu, India, using remote sensing and GIS*, Environmental Earth Sciences, 73, 7375-7401.
Kapochkina A., Kapochkin B., Kucherenko N., Uchytel I., (2015), *Floods and droughts as a result of deformability of the geological environment*, Meteorology Hydrology and Water Managegement, 3(2), 3-7.
Keller E.A., Pinter N., (2002), *Active tectonics: Earthquakes, uplift, and landscape*, Prentice-Hall, New Jersey, NY, USA, 362ss.
Khalifa A., Bashir B., Alsalman A., Bachir H., (2022), *Morphometric-Hydro Characterization of the Coastal Line between El-Qussier and Marsa-Alam, Egypt: Preliminary Flood Risk Signatures*, Applied Sciences, 12(12), 6264, doi: 10.3390/app12126264.
Kılıç B., Gülgen F., Çelen M., Öncel M.S., Oruç H.N., Vural S., (2022), *Morphometric analysis of Saz-Çayırova Drainage Basin using geographic ınformation systems and different digital elevation models*, International Journal of Environment and Geoinformatics (IJEGEO), 9(2), 177-186.
Korshenko E., Zhurbas V., Osadchiev A., Belyakova P., (2020), *Fate of river-borne floating litter during the flooding event in the northeastern part of the Black Sea in October 2018*, Marine Pollution Bulletin 160, 111678, doi: 10.1016/j.marpolbul.2020.111678.
Kühni A., Pfiffner O.A., (2001), *The relief of the Swiss Alps and adjacent areas and its relation to lithology and structure: Topographic analysis from a 250-m DEM*, Geomorphology, 41(4), 285-307.
Kumar S., Chaudhary B.S., (2016), *GIS applications in morphometric analysis of Koshalya-Jhajhara Watershed in northwestern India*, Journal of the Geological Society of India, 88, 585-592.
López-Ramos A., Medrano-Barboza J.P., Martínez-Acosta L., Acuña G.J., Remolina López J.F., López-Lambraño A.A., (2022), *Assessment of morphometric parameters as the basis for hydrological ınferences in water resource management: A case study from the Sinú River Basin in Colombia*, ISPRS International Journal of Geo-Information, 11(9), 459, doi:10.3390/ijgi11090459.
Mahala A., (2020), *The significance of morphometric analysis to understand the hydrological and morphological characteristics in two different morpho-climatic settings*, Applied Water Science, 10, 33, doi: 10.1007/s13201-019-1118-2.
Makhamreh Z., Al-Hawary M., Odeh S., (2020), *Assessment of morphometric characteristics of Wadi Al-Shumar catchment in Jordan*, Open Journal of Geology, 10(2), 155-170.
Malik M.I., AL-Shammary S.H., AL-Hamzawy H.M., (2016), *Morphometric analysis of Al-Chabab River Basin East of Iraq using remote sensing and gis techniques*, International Journal of Scientific Engineering and Research (IJSER), 4(3), 53-58.
Mani A., Kumari M., Badola R., (2022), *Morphometric Analysis of Suswa River Basin Using Geospatial Techniques*, Engineering Proceedings, 27(1), 65, doi: 10.3390/ecsa-9-13225.
Marchi L., Dalla Fontana G., (2005), *GIS morphometric indicators for the analysis of sediment dynamics in mountain basins*, Environmental Geology, 48, 218-228.
Melton M.A., (1957), *An analysis of the relations among elements of climate, surface properties, and geomorphology*, Columbia University, Department of Geology, Technical Report No: ONR-11, New York, NY, USA, 118ss.
Melton M.A., (1965), *The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona*, The Journal of geology, 73(1), 1-38.
Meshram S.G., Sharma S.K., (2017), *Prioritization of watershed through morphometric parameters: a PCA-based approach*, Applied Water Science, 7, 1505-1519.
Miller V.C., (1953), *A quantitative geomorphologic study of drainage basin characteristics in the clinch mountain area, Virginia and Tennessee*, The Journal of Geology, 65(1), 271-300.
Nautiyal, M. D., (1994), *Morphometric analysis of a drainage basin using aerial photographs: A case study of Khairkuli basin, district Dehradun*, U.P. Journal of the Indian Society of Remote Sensing, 22, 251-261.
Nir D., (1957), *The ratio of relative and absolute altitudes of Mt. Carmel: A contribution to the problem of relief analysis and relief classification*, Geographical Review, 47(4), 564-569.
Nooka Ratnam K., Srivastava Y.K., Venkateswara Rao V., Amminedu E., Murthy K.S.R., (2005), *Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis-Remote sensing and GIS perspective*, Journal of the Indian Society of Remote Sensing, 33, 25-38.
Oğraş S., Önen F., (2019), *Dicle Nehri'nin taşkın analizinin HEC-RAS programı ile yapılması*, Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi, 10(3), 1087-1098.
Oyedotun T.D.T., (2022), *Quantitative assessment of the drainage morphometric characteristics of Chaohu Lake Basin from SRTM DEM Data: a GIS-based approach*, Geology Ecology Landscape, 6(3), 174-187.
Pareta K., Pareta U., (2012), *Quantitative geomorphological analysis of a Watershed of Ravi River Basin, H.P. India*, International Journal of Remote Sensing and GIS, 1(1), 47-62.
Pathare J.A., Pathare A.R., (2020), Prioritization of micro-watershed based on morphometric analysis and runoff studies in upper Darna basin, Maharashtra, India, Modeling Earth Systems and Environment, 6, 1123-1130.
Perez-Pena J.V., Azanon J.M., Azor A., (2009), *CalHypso: An ArcGIS extension to calculate hypsometric curves and their statistical moments, Applications to drainage basin analysis in SE Spain*, Computers & Geosciences, 35(6), 1214-1223.
Rai P.K., Mishra V.N., Mohan K., (2017a), *A study of morphometric evaluation of the Son basin, India using geospatial approach*, Remote Sensing Applications: Society and Environment, 7, 9-20.
Rai P.K., Mohan K., Mishra S., Ahmad A., Mishra V.N., (2017b), *A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India*, Applied Water Science, 7, 217-232.

Reddy G.P.O., Maji A.K., Gajbhiye K.S., (2004), *Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India–a remote sensing and GISf approach*, International Journal of Applied Earth Observation and Geoinformation, 6(1), 1-16.

Roy S., Das S., Sengupta S., (2022), *Predicting terrain erosion susceptibility from drainage basin morphometry using ALOS-PALSAR DEM: analysis from PCA-weighted AHP approach in a river system of Eastern India*, Environment, Development and Sustainability, doi: 10.1007/s10668-022-02450-z.

Said S., Siddique R., Shakeel M., (2018), *Morphometric analysis and sub-watersheds prioritization of Nagmati River watershed, Kutch District, Gujarat using GIS based approach*, Journal of Water and Land Development, 39(1), 131-139.

Sakthivel R., Raj N.J., Sivasankar V., Akhila P., Omine K., (2019), *Geo-spatial technique-based approach on drainage morphometric analysis at Kalrayan Hills, Tamil Nadu, India*, Applied Water Science, 9, 1-18, doi: 10.1007/s13201-019-0899-7.

Sarkar D., Mondal P., (2020), *Flood vulnerability mapping using frequency ratio (FR) model: a case study on Kulik river basin, Indo-Bangladesh Barind region*, Applied Water Science, 10(1), 1-13, doi: 10.1007/s13201-019-1102-x.

Schumm S.A., (1956), *Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey*, Geological Society of America Bulletin, 67(5), 597-646.

Shaikh M., Yadav S., Manekar V., (2021), *Accuracy assessment of different open-source digital elevation model through morphometric analysis for a semi-arid river basin in the western part of India*, Journal of Geovisualization and Spatial Analysis, 5, 1-21.

Shankar V.S., Purti N., Ganta N., Mandal K. K., Singh R.P., Kaviarasan T., Satyakeerthy T.R., Jacob S., (2022), *Assessment of the hydrological and erosive status of South Andaman's watersheds using drainage morphometric studies and climatic water balance model*, Geocarto International, 37(26), 13391-13418.

Sharma S., Mahajan A.K., (2020), *GIS-based sub-watershed prioritization through morphometric analysis in the outer Himalayan region of India*, Applied Water Science, 10, 1-11, doi: 10.1007/s13201-020-01243-x.

Shekar P.R., Mathew A., (2022), *Morphometric analysis for prioritizing sub-watersheds of Murredu River basin, Telangana State, India, using a geographical information system*, Journal of Engineering and Applied Science, 69, 1-30, doi: 10.1186/s44147-022-00094-4.

Smith G.H., (1935), *The Relative Relief of Ohio*, Geographical Review, 25(2), 272-284.

Singh S., Dubey A., (1994), *Geoenvironmental planning of watersheds in India*, Chugh Publications, Allahabad, India, 199ss.

Singh V.G., Singh S.K., (2022), *Analysis of geo-morphometric and topo-hydrological indices using COP-DEM: a case study of Betwa River Basin, Central India*, Geology, Ecology, and Landscapes, doi: 10.1080/24749508.2022.2097376.

Sinha J., Harshavardhana B.G., Sinha A.K., Das Mahapathra S., (2023), *A review on remote sensing and GIS technique-based morphometric analysis*, Flexible Electronics for Electric Vehicles'in İçinde, (Dwivedi S., Singh S., Tiwari M., Shrivastava A., Ed.), Springer, Singapore, ss. 333- 342.

Soni S., (2017), *Assessment of morphometric characteristics of Chakrar watershed in Madhya Pradesh India using geospatial technique*, Applied Water Science, 7, 2089-2102.

Sözer B., Kocaman S., Nefeslioğlu H.A., Fırat O., Gökçeoğlu C., (2019), *Değiştirilmiş AHP (M-AHP) yöntemi kullanılarak Ankara için taşkın duyarlılık haritası üretimi*, Harita Dergisi, 162, 12-24.

Sreedevi P.D., Subrahmanyam K., Ahmed S., (2005), *The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain*, Environmental Geology, 47, 412-420.

Strahler A.N., (1952), *Hypsometric (area-altitude) analysis of erosional topography*, Geological society of America bulletin, 63(11), 1117-1142.

Strahler A.N., (1957), *Quantitative analysis of watershed geomorphology*, Eos, Transactions American Geophysical Union, 38(6), 913-920.

Strahler A.N., (1964), *Quantitative geomorphology of drainage basins and channel net work*, Handbook of Applied Hydrology'nin İçinde, (Chow V., Ed.), McGraw Hill, New York, USA, ss.39-76.

Sukristiyanti S., Maria R., Lestiana H., (2018), *Watershed-based Morphometric Analysis: A Review*, IOP Conference Series: Earth and Environmental Science, 118, 012028, doi:10.1088/1755-1315/118/1/012028.

Sunkar M., Tonbul S., (2010), *Batman'da 31 Ekim-1 Kasım 2006 tarihinde yaşanan taşkının nedenleri*, II. Ulusal Taşkın Sempozyumu, 22-24 Mart, Afyonkarahisar, ss. 349-361.

Şener M., (2011), *Determination of basin characteristics by using geographical ınformation Systems (GIS)*, Journal of Environmental Protection and Ecology, 12(4), 1941-1947.

Şener M., Arslanoğlu M.C., (2023), *Morphometric analysis in Google Earth Engine: An online interactive web-based application for global-scale analysis*, Environmental Modelling & Software, 162, 105640, doi: 10.1016/j.envsoft.2023.105640.

TECCWRP, (2016), *The Effect of Climate Change on Water Resources Project Report (TECCWRP)*, The Ministry of Forestry and Water Affairs, General Directorate of Water Management (GDWM), June 2016, Ankara, Türkiye.

Thapliyal A., Panwar A., Kimothi S., (2017), *Prioritization based on morphometric analysis in Alaknanda Basin*, Global Journal of Science Frontier Research H Environment and Earth Science, 17(13), 29-34.

Thomas J., Joseph S., Thrivikramaji K.P., (2010), *Morphometric aspects of a small tropical mountain river system, the southern Western Ghats, India*, International Journal of Digital Earth, 3(2), 135-156.

Thomas J., Joseph S., Thrivikramji K.P., Abe G., Kannan N., (2012), *Morphometrical analysis of two tropical mountain river basins of contrasting environmental settings, the southern Western Ghats, India*, Environmental Earth Sciences, 66, 2353-2366.

TSMS, (2022), *Temperature and Precipitation Data of Kastamonu, Bozkurt and Abana meteorological stations*, Turkish State Meteorological Service (TSMS), Ankara, Türkiye.

Turoğlu H., (1997), *İyidere havzasının hidrografik özelliklerine sayısal yaklaşım*, Türk Coğrafya Dergisi, 32, 355-364.

Uğuz M.F., Sevin M., Duru M., (2002), *1/500.000 ölçekli Türkiye jeoloji haritası Sinop paftası*, Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

URL-1, (2021), *Sel felaketi yaşayan Bozkurt'un sokakları yeniden sular altında*, https://www.ntv.com.tr/galeri/turkiye/sel-felaketi-yasayan-bozkurtun-sokaklari-yeniden-sular-altinda,EHD39e_cKk2ZZHgd4wmVvA/A-i0HvP6r0GwZSPc7cgbwA, [Accessed 1 September 2021].

URL-2, (2022), *Kastamonu hava durumu: İnebolu ve Bozkurt'ta sağanak*, https://www.ntv.com.tr/turkiye/kastamonu-hava-durumu-inebolu-ve-bozkurtta-saganak-nedeniyle-sel-taskinlari-yasaniyor,N3mUyex0h0WNz4iAPwYqrg, [Accessed 1 August 2022].

URL-3, (2022), *Bakan Kurum Kastamonu basın açıklaması*, T.C. Çevre, Şehircilik ve İlklim Değişikliği Bakanlığı, https://www.csb.gov.tr/bakan-kurum-kastamonu-basin-aciklamasi-bakanlik-faaliyetleri-34155, [Accessed 08 November 2022].

URL-4, (2021), *11 Ağustos 2021 Bozkurt taşkın felaketi değerlendirme raporu*, İnşaat Mühendisleri Odası Ankara Şubesi, https://imop.imo.org.tr/resimler/dosya_ekler/40a47e39410932f_ek.pdf, [Accessed 09 November 2021].

URL-5, (2023), *CORINE land cover*, https://land.copernicus.eu/pan-european/corine-land-cover, [Accessed 23 February 2023].

URL-6, (2022), *Climate change ımpacts and risks*, Sixth assessment report IPCC, https://www.ipcc.ch/report/ar6/wg2/downloads/outreach/IPCC_AR6_WGII_FactSheet_Europe.pdf, [Accessed 1 December 2022].

URL-7, (2022), SAGA-GIS module library documentation (version 2.3.0), https://saga-gis.sourceforge.io/saga_tool_doc/2.3.0/ta_hydrology_23.html, [Accessed 1 September 2022].

Vinutha D.N., Janardhana M.R., (2014), *Morphometry of the Payaswini Watershed, Coorg District, Karnataka, India, using remote sensing and GIS techniques*, International Journal of Innovative Research in Science, Engineering and Technology, 3(5), 516-524.

Yılmaz İ., Öztürk D., Kırbaş U., (2017), *Çorum ili taşkın tehlikesinin analitik hiyerarşi yöntemi kullanılarak incelenmesi*, In TMMOB Harita ve Kadastro Mühendisleri Odası 16. Türkiye Harita Bilimsel ve Teknik Kurultayı, 3-6 Mayıs 2017, Ankara.

Yılmaz O.S., (2022), *Flood hazard susceptibility areas mapping using Analytical Hierarchical Process (AHP), Frequency Ratio (FR) and AHP-FR ensemble based on Geographic Information Systems (GIS): A case study for Kastamonu, Türkiye*, Acta Geophysica, 70, 2747-2769.

Waikar M.L., Nilawar A.P., (2014), *Morphometric Analysis of a Drainage Basin Using Geographical Information System: A Case study*, International Journal of Multidisciplinary and Current Research, 2, 179-184.

Withanage N.S., Dayawansa N.D.K., De Silva R.P., (2014), *Morphometric analysis of the Gal Oya river basin using spatial data derived from GIS*, Tropical Agricultural Research, 26(1), 175-188.