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Evaluation of Relief Morphometry of Kılıçözü and Acıöz Drainage Sub-Basins (Kırşehir, Turkey) in Relation to Flood Events

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Abstract

Morphometric analysis of drainage basins and their channel networks plays an important role in understanding the causes of flood occurrence in basins. In the present study, morphometric analysis was carried out using Geomorphological Information System (GIS) to assess the relief morphometry of Kılıçözü and Acıöz drainage basins which are sub-basins of the Kızılırmak River, the longest river in Turkey. These basins have been subjected to flooding several times. The obtained values of slope and morphometric parameters (basin relief, relief ratio, time of concentration, hypsometric curve and hypsometric integral) indicate that the two basins do not differ from each other with respect to flood occurrence; however the Acıöz subbasin is more prone to flash floods. This result will help in producing a sustainable management plan for the basins to overcome the risk of flooding.

Keywords: Flash flood, Relief morphometry, Basin management, Kırşehir

INTRODUCTION

Large volumes of water falling and accumulating in a short time are among the most important reasons for flash flood events. Sudden and unusual increases in rainfall and temperature are the principal causes of flooding (Özcan, 2006). Variations from the norm in climate and temperature also bring about increased flood and drought risk (IPCC, 2007). This leads to irregular rainfall throughout the year and an increase in sudden rainfall. As a result, floods are deeper and more likely to occur in the catchment basins. For example, flooding has become more frequent and more damaging as a direct result of floodplain loss, especially when combined with the loss of vegetation cover in the drainage basin (Wetland, 2016). A river and its basin, together with the channel networks within the basin, is a shaped area of land resulting from rainfall and the topographic properties (slope, aspect, elevation) of that basin. Morphometric analysis of the drainage basin and channel network play a vital role in understanding the geo-hydrological behavior of the drainage basin and determines the prevailing climate, geology and geomorphology of the catchment (Hajam *et al*., 2013).

Basin morphometry is also effective in understanding and solving the likelihood of floods in the basin; the reason being that outside factors (e.g. land use, rainfall, vegetation) may change considerably and suddenly over a short period, while the basic basin morphometry changes more slowly, if at all (Özdemir, 2011). Most researchers have used morphometric parameters and emphasized their importance in studies on flood events in Turkey (Özdemir and Bayrakdar, 2009; Özdemir and Bird, 2009; Günek *et al*., 2013; Uzun, 2014; Bayer Altın, 2014; Erdede and Öztürk, 2016). The Kızılırmak Basin has, in general, morphometric features that reduce the danger of floods (Erdede and Öztürk, 2016). However, flooding did occur on the Kılıçözü River in the years 1965, 2014 and 2015. The largest and most catastrophic event occurred in 1965. During this flood, many people lost their homes and harvests were ruined (Gökçe *et al*., 2008). The purpose of this study is to determine the relationship in the Kılıçözü and Acıöz sub-basins between relief morphometric parameters including slope and elevation values of the basins and flood occurrence.

GEOGRAPHIC SETTING and CLIMATE

The study area is located in the Middle Kızılırmak sub-region of the Central Anatolia Region. The Kızılırmak is the main river in the study area. Kılıçözü Stream originates from the northern slopes of Mt. Baranlı. Running not far from the city of Kırşehir and village of Güzler, the Kılıçözü stream enters the main river at the border of Kocabey village (Figure 1). Predominantly flowing from north to south, the stream is about 65 km long and is used to support agriculture. The Kılıçözü sub-basin covers an area of about 791 km^2, and the basin elevation varies from 845 to 1802 m above sea level (asl) (Figure 1). Irrigation regulators were constructed on the stream at Iğdeliöz, Kılıçözü and Güzler to provide irrigation for crops and to prevent flooding. In the summer its flow rate decreases due to irregular rainfall; however, sudden overflows have occurred in winter and spring due to excessive rainfall and melting snow from time to time. Thus, the rapid onset of floods occurred.

The Acıöz sub-basin covers an area of about 595 km^2, and basin elevation varies from 855 to 1123 m (asl). The Acıöz stream originates on the western slopes of highlands to the east of the town of Hacıbektaş and the southwestern slopes of Mt. Ayrı. The stream is about 40 km long and enters the main river near the village of Kesikköprü. There are ponds for irrigation on its tributaries.

A continental and semi-arid climate is dominant over the study area with annual rainfall of 379 mm, received mostly during the winter and spring. The hottest month is July, with a mean temperature of 23.1°C. January is the coldest month with a mean temperature of -0.1°C (Figure 2). This month is followed by February, with a mean temperature of 1.3°C. According to the Erinç Aridity Index (1965) and Thornthwaite's climate classifications (1948), Kırşehir is semi-arid and semi-arid/less humid, respectively (Karabulut *et al*., 2016).

Kırşehir province, which is located within the steppe belt of the Central Anatolia Region, is generally devoid of forest cover and is dominated by steppe vegetation. The area, which was covered with forests in ancient times, has lost forestland as a result of human activity and an irregular rainfall regime. The forestland previously covered 2% of the total area of the province. This has increased to 3.7% due to planting programs in recent years.

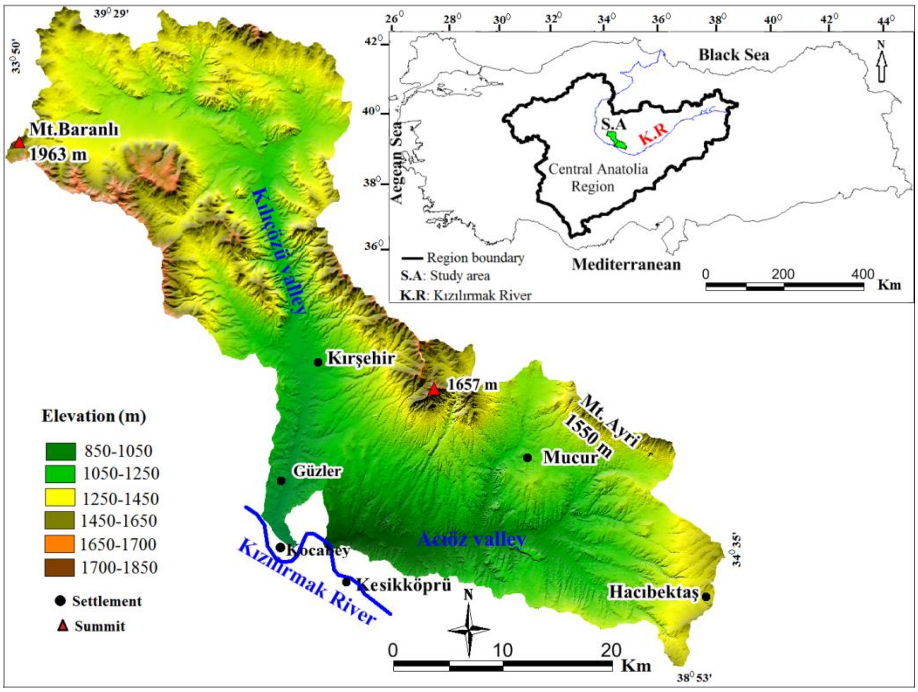

Figure 1. Location and DEM map of study area

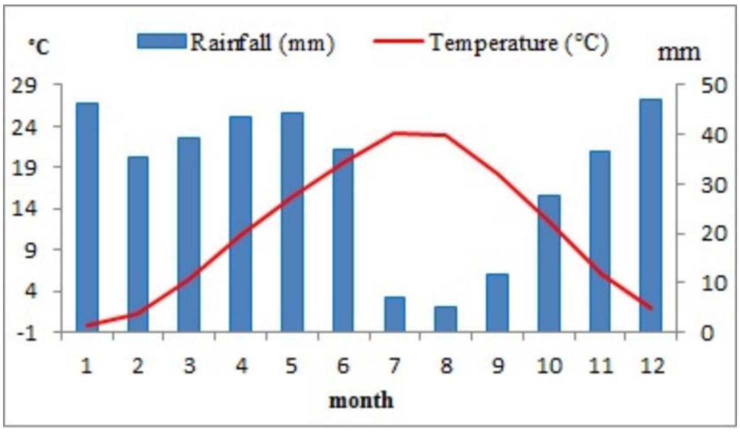

Figure 2. Mean temperatures and total rainfall by month for years 1950-2015 in Kırşehir province.

MATERIALS and METHOD

The drainage network was extracted from a 10-m resolution DEM (Digital Elevation Model) using GIS (Geographic Information System). The DEM was derived from 1:25,000 scale topographic maps including the sheets for Kırşehir (J31-32) and Aksaray (K32-33). The relief parameters such as Basin relief (Bh), Relief ratio (Rh), Time of concentration (Tc), Hypsometric integral (Hi) and curve for the delineated basin area were calculated based on the formulas seen in Table 1.

Table 1. Relief parameters of drainage network and their mathematical expressions

Relief parameters	Formula	Description	References
Basin relief (Bh)	Bh=Hmax/Hmin	Hmin: lowest point,	Strahler, 1957
		Hmax: highest point in the basin	
Relief ratio (Rh)	Rh=Bh (m)/Lb (m)	Lb: maximum basin length	Schumm, 1956
Time of concentration (Tc)	$Tc= 0.0078*L^{0.77}/S^{0.385}$	L: stream length (m),	Kirpich, 1940
		S: gradient slope of the basin (m/m)	
Hypsometric integral (Hi)	Hm-Hmin/Hmax-Hmin	see description of Bh for	Strahler, 1952
		Hmax and Hmin	
		Hm: mean elevation of the basin.	
Hypsometric curve	h/H/a/A	h and a: height and	Strahler, 1952
		area between contours;	
		H and A: total height and	
		area of the basin	
		a/A: relative area; h/H: relative height.	

RESULTS and DISCUSSION

The high value of basin relief shows that higher relief with steeper slopes implies higher runoff rates (Patton, 1988). The Bh value (957) of the Kılıçözü sub-basin is higher than the Bh value (810) of the Acıöz sub-basin (Table 2). As shown in Table 3, the majority of the Kılıçözü sub-basin is comprised of very gentle (0-5%) and gentle slopes (5-10%) that cover about 423 km² and occupy about 26.6% and 26.8% of the total area, respectively. Moderate (10-15%) and moderately steep (15-20%) slopes occupy about 15.6% and 10% of the total area. 21% of the total area corresponds to steep (20-30%) and very steep (+30) slopes.

Table 2. Relief parameters of drainage network derived from DEM.

Sub-basin	Area (km²)	Stream Length (km)	Bh	Rh	Hi	Tc (hours)
Kılıçözü	791	65	957	0.01	0.39	01:49
Acıöz	595	40	810	0.02	0.33	01:34

Very gentle (0-5%) and gentle (5-10%) slopes cover about 509 km² and occupy 41.5% and 44% of the Acıöz sub-basin, respectively. Moderate (10-15%) and moderately steep (15-20%) slopes occupy about 10.1% and 2.75% of the total area. 1.5% of the total area corresponds to steep (20-30%) and very steep (+30) slopes (Figure 3). As a result, it can be said that the Kılıçözü sub-basin, having steep valleys, is more prone to flash flood risk than Acıöz sub-basin with its lower relief.

Table 3. Slope values of sub-basins.

Sub-basin		Slope (%)				
	0-5	5-10	10-15	15-20	20-30	+30
		Area (km²)				
Kılıçözü	211	212	124	80	98	66
Acıöz	247	262	60	17	5	4

Rh values of the Kılıçözü and Acıöz sub-basins are 0.01 and 0.02 (Table 2), respectively. This shows that the area of higher relief with steeper slopes in Kılıçözü sub-basin exceeds the area of higher relief in Aciöz sub-basin. It has been suggested that Rh value is a measure of the overall steepness of a river basin and is an indicator of the intensity of erosion on the slope of the basin (Schumm, 1956). It is also reveals that the Kılıçözü sub-basin is morphometrically less susceptible than Acıöz sub-basin.

Hi values have a strong relationship with basin hydrology, especially flood response (Perez-Pena *et al*., 2009). Moreover, Hi value is used as a rapid reconnaissance technique to evaluate hydrology characteristics and to quantify the effects of lithology and structural deformation on low stream flow (Kowall, 1976). Basins have been classified (Strahler, 1952) according to their stages of geomorphic evolution as: young stage (convex curve, Hi≥0.6), where the watershed is highly prone to flooding; equilibrium or mature stage (S-Shaped hypsometric curve; concave curve at high elevations and convex curve at low elevations, 0.30≤Hi≤0.6); and peneplain or monadnock stage (concave curve, Hi≤0.30), where the watershed is less prone to floods. The Hi value of the Kılıçözü and Acıöz sub-basins is 0.39 and 0.33, respectively (see Table 2). In other words, both sub-basins are at the mature stage represented by the S-Shaped curve.

The convex form shows that the flow of the streams and the sediments transported by the streams are decreasing, while aggregation is more dominant and more flood discharge is widespread (Özdemir, 2011). This form is more evident in the low-lying land of the sub-basins (Figure 4). The hypsometric curve shows that the upper course of both sub-basins and their tributaries has a convex form. Namely, the western and eastern parts of the Kılıçözü sub-basin and the northern part of the Acıöz sub-basin both have steeper topography, which typically generate more runoff (see Figure 3).

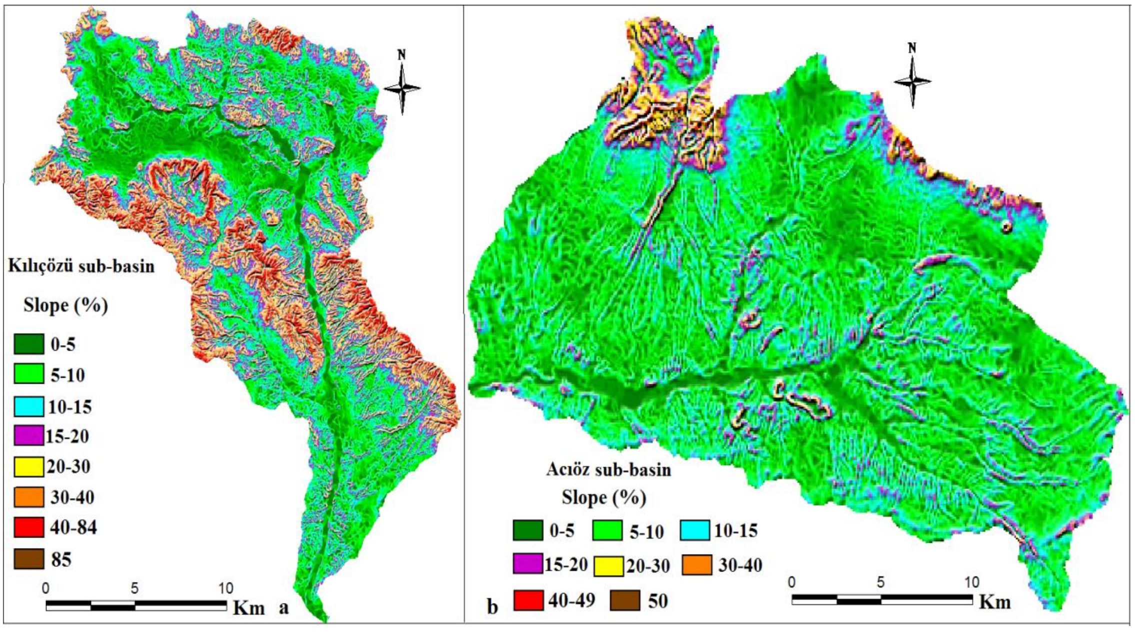

Figure 3. Slope map and values of Kılıçözü sub-basin (a) and Acıöz sub-basin (b).

This is because it is more difficult for water to infiltrate the ground on the steeper slopes and more precipitation finds its way into stream channels (Kanarek, 2012). As shown in Figure 5, elevations of 1170 m and 1080 m have more area than other elevations in the Kılıçözü and Acıöz sub-basins, respectively. These elevations correspond to the slopes of valleys and hills. This condition is noted as a flash flood triggering factor.

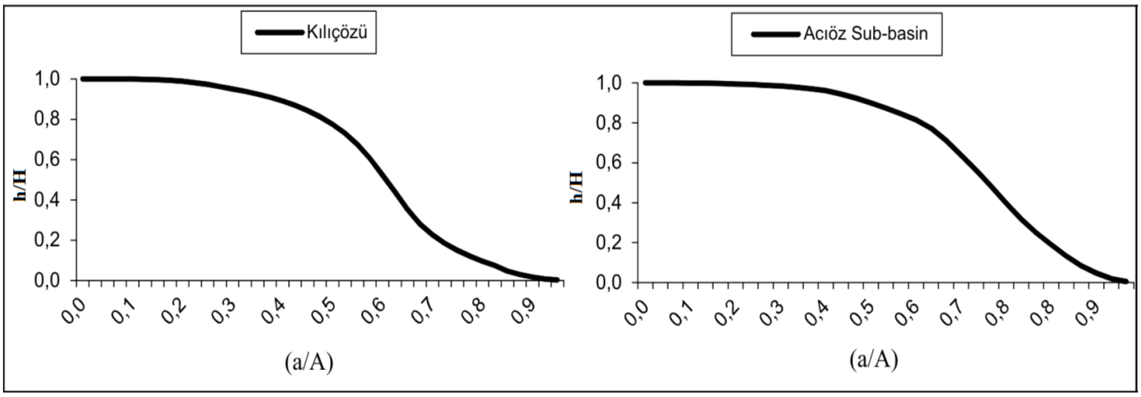

Figure 4. Hypsometric curve of sub-basins

Time of concentration (Tc) is defined as the time taken by water to travel hydraulically from the most distant point of a watershed to its downstream (Verstappen, 1983). Slope conditions affect the concentration time of water in a basin and are inversely proportional to the Tc. The Tc value may decrease as a result of an increase in slope values. The concentration time of water in the Kılıçözü sub-basin is one hour and forty-nine minutes. It is one hour and thirty-four minutes in the Acıöz sub-basin (see Table 2). This shows that there is no significant difference between the Kılıçözü and Acıöz sub-basins in terms of Tc value; however, flow time in the Acıöz sub-basin is shorter than that of the Kılıçözü sub-basin. Although the high slope values cover more area in the Kılıçözü sub-basin, the Tc value is high. This can be explained by its stream length being longer than the Acıöz stream.

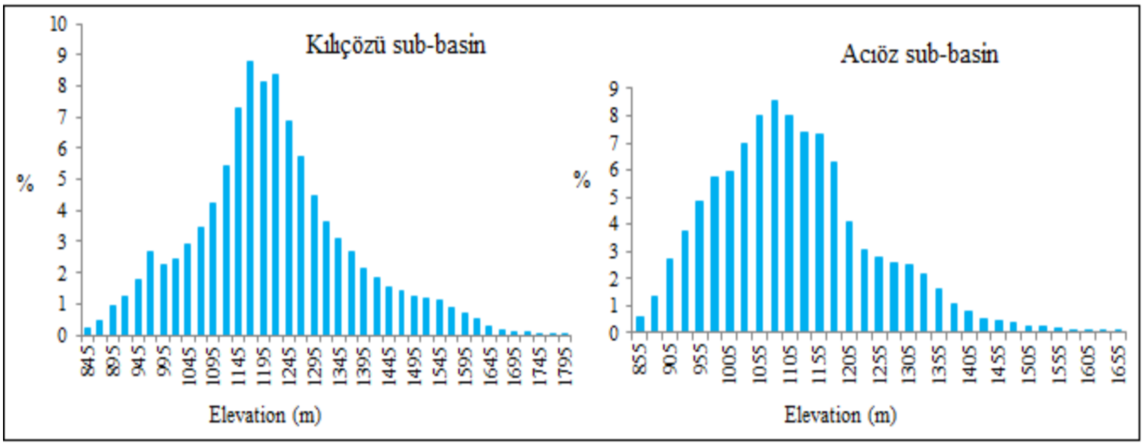

Figure 5. Elevation frequency of sub-basins

CONCLUSIONS

As a result of the Rh, Tc and Hi analyses, it appears that the sub-basins have a lower peak of direct runoff for a longer duration, which reduces the risk of flooding within the sub-basin. However, according to the hypsometric curve and slope values, a convex curve on the upper part of both sub-basins reveals they are highly prone to flooding. Thus, settlements such as villages and rural settings near or around the upper course of the sub-basins are under flash flood risk. Stream length extends runoff travel from the hydraulically most distant point in the Kılıçözü sub-basin. This reduces flood risk, especially in the lower course of the sub-basin. Since the length of the Acıöz stream is shorter, the water formed by sudden rainfall is collected in a short time and the flash flood risk is greater. This risk is more evident on the upward part of the sub-basin. In other words, the Acıöz sub-basin is more prone to floods than the Kılıçözü sub-basin.

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