**Jeomorfolojik Araştırmalar Dergisi**
Journal of Geomorphological Researches
© Jeomorfoloji Derneği www.dergipark.gov.tr/jader E - ISSN: 2667 - 4238

**Araştırma Makalesi / Research Article**

# Flood Prioritization Watersheds of the Aras River, Based on Geomorphometric Properties: Case Study Iğdır Province

**Mustafa UTLU[a], Redvan GHASEMLOUNIA[b]**

[a] Bingöl University Faculty of Science and Letter, Department of Geography, Bingöl
utlumus@gmail.com https://orcid.org/0000-0002-7508-4478
[b] İstanbul Gedik University, Engineering Faculty, Department of Civil Engineering, Istanbul
redvanghasemlounia@gedik.edu.tr https://orcid.org/0000-0003-1796-4562

Makale Tarihçesi
Geliş 16 Ağustos 2020
Düzenleme 15 Ekim 2020
Kabul 18 Kasım 2020

Article History
Received August 16, 2020
Received in revised form 15 October, 2020
Accepted November 18, 2020

Anahtar Kelimeler
Taşkın Önceliği, Morfometrik Parametre, Coğrafi Bilgi Sistemleri, Temel Bileşenler Analizi (TBA)

Keywords
Flood Prioritization, Morphometric parameter, Geographic Information Systems (GIS), Principal Component Analysis (PCA)

Atıf Bilgisi / Citation Info
Utlu, M. & Ghasemlounia, R. (2021) Flood Prioritization Watersheds of the Aras River, Based on Geomorphometric Properties: Case Study Iğdır Province, *Jeomorfolojik Araştırmalar Dergisi / Journal of Geomorphological Researches*, 2021 (6): 21-40
doi: 10.46453/jader.781152

ABSTRACT

Drainage watershed morphometry plays a major role in terms of understanding flood dynamics. Flood potentials are explained considering the linear, areal, and relief morphometry features of the watersheds. In general, there are number of geomorphometric indices in the description of these features. The formal geometries, geomorphology, geology, and general climate characteristics, etc., which play a decisive role in the flood potential in the watershed, can be determined relatively with morphometric indices. In this study, 35 different river watersheds draining their waters to the Aras, located in the center of Iğdır Province, were examined. Geographic information systems (GIS) and statistical software were chosen to analyze and calculate indices for this research. Flood events occur in these 35 different river watersheds and this study evaluates river watersheds in terms of their flood potential using 14 different indices. In the evaluation of the results obtained, the values that have a high impact on the floods are ranked according to their priorities. These results were evaluated in terms of flood priorities using morphometric analysis and principal component analysis methods. Flood priorities of watersheds, obtained through two different methods, are classified as high, medium, or low priorities. The number of common watersheds, determined based on two different methods, is 8 in river watersheds with "high" priority, 11 in river watersheds with "medium" priority, and 7 in river watersheds with "low" priority. According to these results, it is seen that river watersheds with high priority flood potential correspond to the areas where flood events occurred.



## INTRODUCTION

Floods are one of the most disasters that occurs in almost every country around the world resulting in losses of life and property, and structural damages (Mukherjee & Singh, 2019). Floods and their frequency are controlled by several factors including climate, geomorphology, geology, improper engineering practices on river beds, destruction of the flood plain, agricultural land and forest area due to urbanization and population growth, etc. (Brown et al., 2007; Ergünay 2007; Mason et al., 2007; Nied et al., 2014; Mukherjee & Singh, 2019; Skilodimou et al., 2019; Komolafe et al., 2020). Floods are also one of the most common and devastating natural hazards in Turkey (Ergünay, 2007). According to the Emergency Events Database (EM-DAT) data, the flood events that occurred between 1960 and 2014 caused 876 people to lose their lives and inflicted an approximate damage of 800 million dollars on economy. (Koç & Thieken, 2018; Koç et al., 2020).

Drainage watershed morphometry is one of the most actively used methods (Kumar Rai et al., 2017). Drainage morphometry is used to determine landform developments, flood dynamics, and erosional processes, etc. (Cürebal & Erginal, 2007; Memon et al., 2020). Morphometric analysis is a quantitative method which is used to understand the earth's surface processes based on mathematical measurement of the earth's topography (Clarke, 1966; Sakthivel et al., 2019). The morphometric analysis reveals important information mainly about topographical, climatic, hydrologic evolution, and processes in river drainage watershed through using quantitative measurements (Strahler, 1957; Morisawa, 1962; Nag & Chakraborty, 2003; Kim et al., 2011; Krishnan et al., 2017). So, scientific interest in drainage watershed morphometry has increased in recent years, with the use of geomorphic indices in studies on watersheds (Fural & Poyraz, 2015; El Tahan & Elhanafy, 2016; Amiri et al., 2019; Karabulut & Özdemir, 2019; Rahmati et al., 2019; Sakthivel et al., 2019; Eludoyin & Adewole, 2020; Siddiqui et al., 2020). For example, El Tahan and Elhanafy (2016) performed a morphometric and hydrologic analysis to evaluate the flood parameters. Özdemir and Bird (2009) tested different drainage networks which are extracted from DEM data of 10 m resolution and topographical maps with 1/25000 scale in Havran River watershed, Turkey. Utlu & Özdemir (2018) explained the flood generation potential of the sub-basins of the Biga stream with basin morphometry. There are various studies conducted through the employment of drainage watershed morphometry based on DEM, orthophotos, different scale topographic maps, satellite images, and field measurement data using GIS to understand of the hydrological situation of the watershed concerning flood (Özdemir & Bird, 2009; Youssef et al., 2011; Poyraz et al. 2011; Bhat et al., 2018; Hamdan & Khozyem, 2018; Bhat et al., 2019; Elsadek et al., 2019a; 2019b; Shadmehri Toosi et al., 2019). Morphometric studies measure various river drainage watershed properties using several indices concerning linear, areal, and relief parameters that mainly involve many indices such as stream order-rank, watershed geometry, watershed relief properties, ruggedness number, form factor, drainage network, density, and texture, etc. (Youssef et al., 2011; Patel et al., 2012; Kumar, 2016). These indices facilitate understanding hydrologic properties and drainage watershed properties concerning flood potential (Bhat et al., 2019). Because drainage networks reflect the general characteristics of the watersheds, which are geomorphology, lithology, and hydrologic situation, etc.

The main purpose of this study is to prioritize watersheds in terms of their flood potential using geomorphometric indices. For this purpose, 35 different watersheds in Iğdır Province, Turkey, were selected as study areas. Linear, areal, and relief morphometric parameters were used to assess the flood potential and rank based on morphometric and principal component analyses (PCA).

## 2. STUDY AREA

35 different watersheds were selected for the drainage morphometry studies. These watersheds are located in the East Anatolian Region of Turkey in Iğdır Province (Figure 1a-b) and they drain into Aras River. Iğdır is located in an alluvial plain, which is created by the Aras River and its sub-watersheds. These watersheds drain from south to north direction and have a drainage area of approximately 1105.9 $km^2$, and the elevation ranges from 838m to 3627.5m (Figure 1c). The lithology of the study area varies including Mesozoic, Miocene, and Quaternary lithological units based on the 1/500000 scale geology map (Figure 2a). Basalt, andesite, and pyroclastic substances originating from Ağrı Stratovolcano

occupy large areas in high mountainous areas. There is an undifferentiated Quaternary deposit formed by Aras River and its tributaries in Iğdır Plain and its immediate surroundings. Tectonic and volcanic movements that started in the Middle Miocene and Pliocene were highly influential in the structural and geomorphological development of the region (Şaroğlu & Güner, 1979; Ketin, 1983; Yulu; 2019).

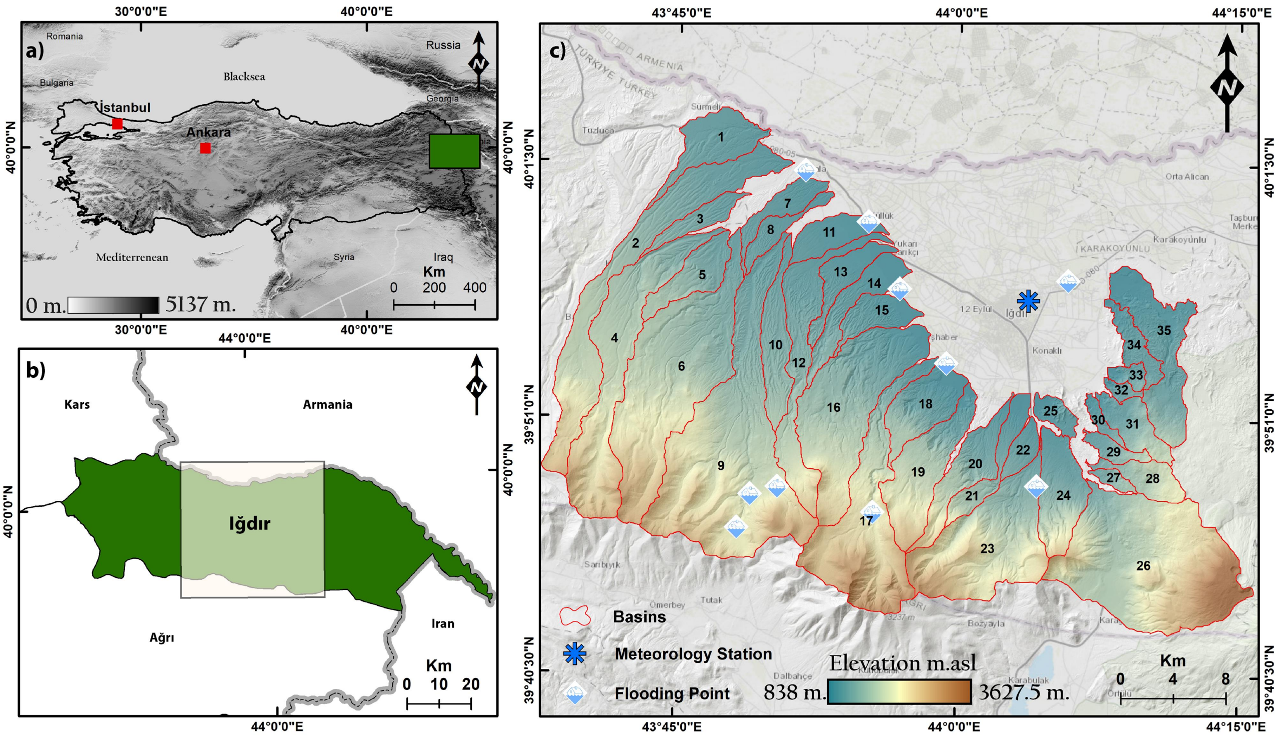


**Figure 1:** a-b) The location of the watersheds c) the elevation of the watersheds

The study area and its surroundings include Ağrı Mts. (in English: Ararat Mts. 5137 m), an extension of the tectonically active collision zone of the Alp-Himalayan mountain belt (Nicoll, 2010; Azzoni et al., 2017; 2019). While narrow and deep valleys with flood character developed within these N-S oriented watersheds, valleys with a meandering flow developed in E-W directional watersheds (Karaoğlu & Çelim, 2018). Ağrı Mts. is the source of many watersheds in the study area and one of the most explicit examples of glacial morphology and skullcap glacier (Çiner, 2003; de Silva & Lindsay, 2015; Azzoni et al., 2017). The study area consists of different landforms that include basalt plateau, alluvial fans, badlands topography, and floodplain. Slope degree ranges from 0 to 65.4° which indicates that the study area is a mountainous and badlands topography based on the geomorphology of the study area (Figure 2b). Areas with high slopes correspond to mountainous areas. The swath profile south to the east that is extracted from the study area represents steep and mountainous topography (Figure 2c-A-B-C).

The study area has hot summers and warm winters, which classified as semi-arid climate (BSk) according to Koppen climate classification (Öztürk et al., 2017). Moreover, the average annual temperature is 12.9°C whereas total precipitation is 268 mm according to the 50-year data of Iğdır Meteorology Station (857 m.) located at the center of the Iğdır Province. The highest precipitation is observed in May (106.9 mm) and in June (92 mm). Watershed's stream show seasonal flows leading to sudden floods. Most of the settlements or towns that were built at the intersection of sub-watersheds has suffered more damage than expected during flood events. (Figure 3).

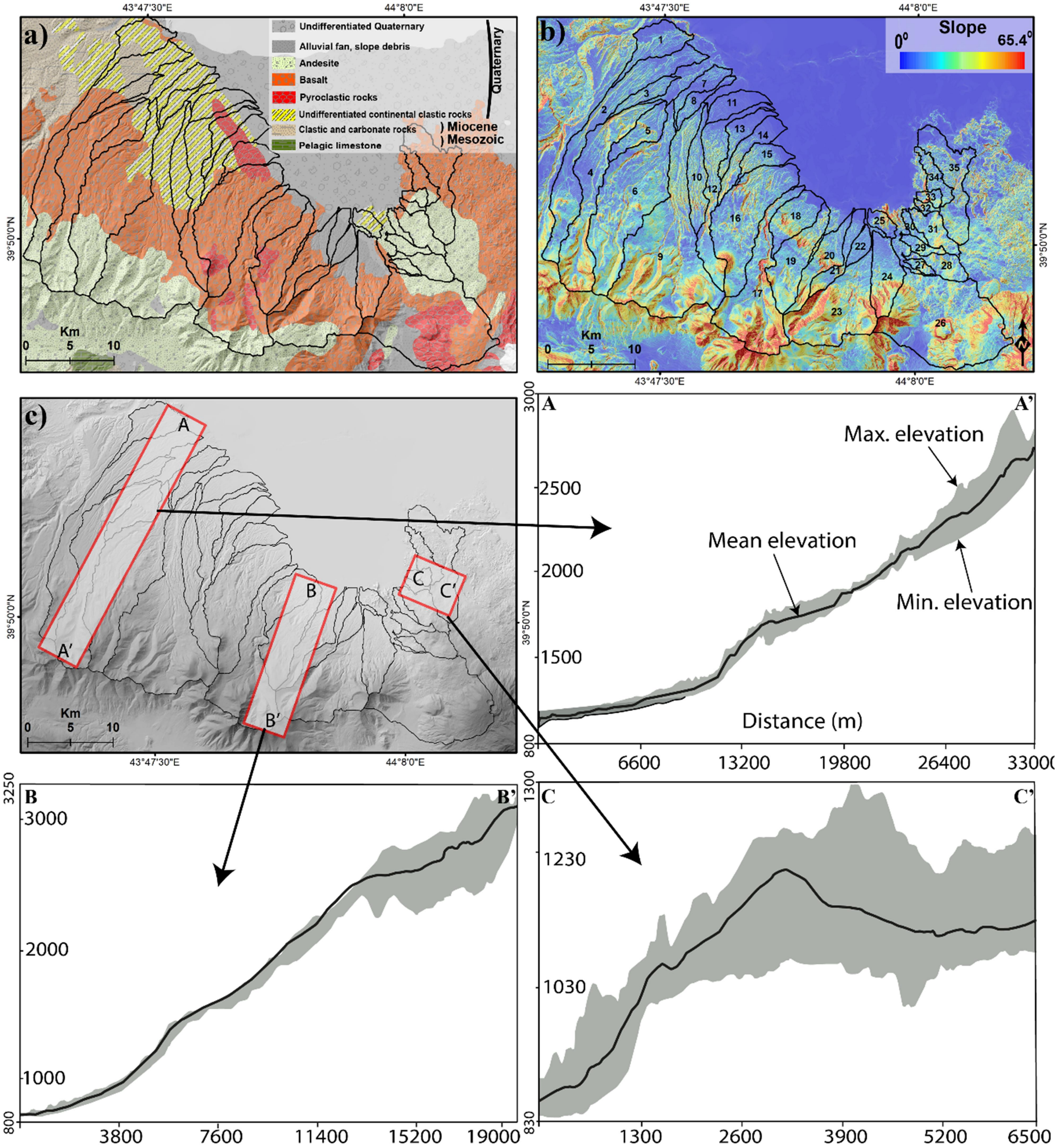


**Figure 2: a)** The geology map of the study area 1/500000 scale **b)** slope map **c)** three swath profiles with red boxes showing the trend of the max. min. and mean topography of watershed south to the east (A-B-C)

## 3. MATERIAL and METHOD

10m spatial resolution Topo-DEM derived from topographic maps was used in this study. The topographic maps with the working scale of 1:25000 were also used to determine the drainage watersheds using visual interpretation methods. For drainage morphometry analysis (*i*) linear, (*ii*) areal, and (*iii*) relief aspects that are widely used drainage morphometric parameters (Table 1) were applied to 35 different watersheds. These datasets were geo-referenced using the UTM projection Zone38, WGS84 horizontal datum coordinate system. ArcGIS 10.5 was used for the analysis of drainage morphometry and Microsoft Office Excel and SPSS were used to analyze the drainage morphometry and computation results.

**Figure 3:** Flood event that led to harm on settlements and structures in villages (URL-1-2-3-4)

Moreover, SPSS software was used to determine flood priority rank using principal component analysis (PCA). In this study, in which Topo-DEM data were employed, the ArcGIS Hydrology tool was used to determine the watersheds. Within this scope, methods, which may be listed as (I) fill (to remove fill-sink error), (II) flow direction (D8), (III) flow accumulation processes (threshold 500), and (IV) pour point, were employed to ascertain the watersheds. The computed morphometric parameters for all 35 sub-watersheds are given in Table 2. The general flow chart of the study is presented in Figure 4.

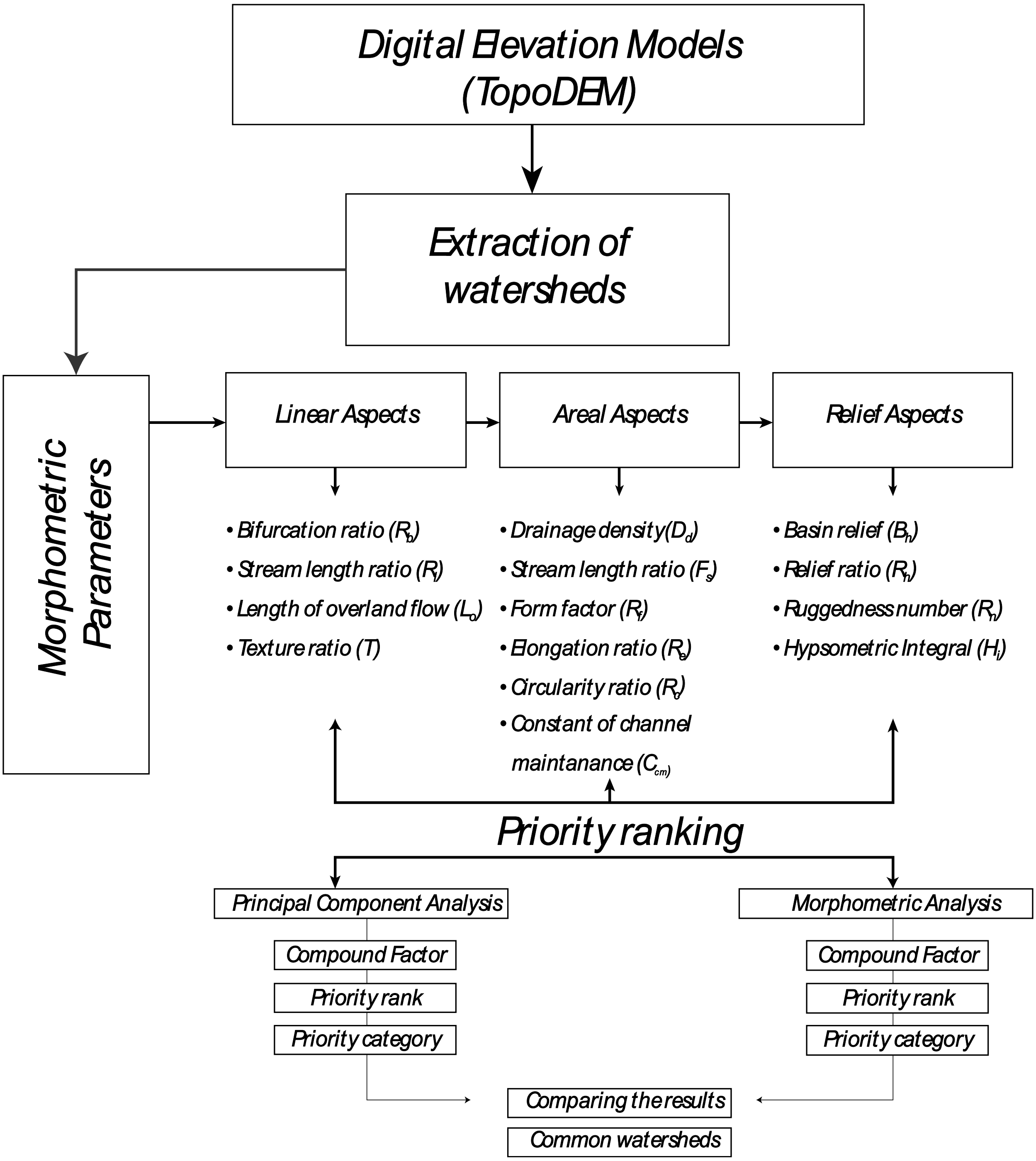


**Figure 4**: General flowchart of the study

## 4. RESULT and DISCUSSION

The morphometric parameters were evaluated in terms of linear, areal, and relief aspects that are widely used in drainage morphometry based on the flood outputs. Totally 14 different morphometric parameters were used in 35 different watersheds. Linear aspect results of the study area include stream orders and stream number, total stream length, average bifurcation ratio ($R_b$), length ratio ($R_l$), length of overland flow ($L_o$), and texture ratio (T). Areal aspect results include drainage density ($D_d$), stream frequency ($F_s$), form factor ($R_f$), elongation ratio ($R_e$), circulatory ratio ($R_c$), and constant of channel maintenance ($C_{cm}$). Relief aspect results include basin relief ($B_h$), relief ratio ($R_h$), ruggedness number ($R_n$), and hypsometric integral ($H_i$).

**Table 1:** Morphometric parameters and formula and explanation

| No. | Parameters | Unit | Mathhematical expression | Reference |
|---|---|---|---|---|
| **Basic parameters** | | | | |
| 1 | A | $km^2$ | Area of river basin | Horton (1945) |
| 2 | u | dimensionless | Strahler stream order. Hierarchical rank | Strahler (1964) |
| 3 | N | dimensionless | Total number of streams in basin | Strahler (1958) |
| 4 | $Nu_{(1,2,3...)}$ | dimensionless | Total number of streams of each order | Horton (1945) |
| 5 | L | km | Total length of stream | Horton (1945) |
| 6 | $Lu_{1,2,3...)}$ | km | Total lenght of stream of each order | |
| 7 | $H_{max}$ | m | Maximum elevation of basin | |
| 8 | $H_{min}$ | m | Minimum elevation of basin | |
| 9 | $H_{mean}$ | m | Mean elevation of basin | |
| **Linear parameters** | | | | |
| 10 | $R_b$ | dimensionless | Bifurcation ratio, $R_b$= Nu/(Nu+1)<br>Nu= total number of stream segments of order "u"<br>Nu+1=number of stream segments of next high order | Horton (1945) |
| 11 | $R_l$ | dimensionless | Stream length ratio, $R_l$= Lu/(Lu+1)<br>Lu= total length of stream segments of order "u"<br>Lu+1=length of stream segments of next high order | Strahler (1964) |
| 12 | $L_g$ | km | Length of overland flow, Lg= 1/2*$D_d$ | Horton (1945) |
| 13 | $T$ | $km^2$ | Texture ratio, T= $N_{u1}$*(1/P)<br>$N_{u1}$=Total number of 1st order<br>P= Perimeter of the basin | Smith (1950) |
| **Aeral parameters** | | | | |
| 14 | $D_d$ | $km/km^2$ | Drainage density $D_d$ = L/A<br>L= total length of streams in basin<br>A= area of the basin ($km^2$) | Horton (1945) |
| 15 | $F_s$ | $km^2$ | Stream frequency Fs = N/A<br>N= total number of streams in basin<br>A= area of the basin ($km^2$) | Horton (1945) |
| 16 | $R_f$ | dimensionless | Form factor $R_f$= A/$L_b^2$<br>$L_b$= basin length (km)<br>A= area of the basin ($km^2$) | Horton (1932) |
| 17 | $R_c$ | dimensionless | Circularity ratio $R_c$ = 4πA/$P^2$<br>P= perimeter of the basin ($km^2$)<br>A= area of the basin ($km^2$) | Miller (1953) |
| 18 | $R_e$ | dimensionless | Elongation ratio $R_c$ = (2/$L_b$)*$(A/\pi)^{0.5}$<br>$L_b$= basin length (km)<br>P= perimeter of the basin ($km^2$) | Schumm (1956) |
| 19 | $C_{cm}$ | dimensionless | Constant of channel maintenance<br>C= 1/$D_d$(Drainage density) | Schumm (1956) |
| **Relief parameters** | | | | |
| 20 | $B_h(R)$ | m | Basin relief, $B_h$(R) = Hmax -Hmin | Schumm (1956) |
| 21 | $R_h$ | m | Relief ratio, $R_h$ = H/L<br>H= Basin relief ($B_h$)<br>$L$=Maksimum length of the basin | Schumm (1956) |
| 22 | $H_i$ | m | Hypsometric Integral= (Hmean-Hmin)/(Hmax-Hmin) | Pike and Wilson (1971)<br>Mayer (1990) |
| 23 | $R_n$ | dimensionless | Ruggedness number, Rn =Bh(R) x Dd $B_h$ | Melton (1957) |

Table 2: Linear, areal, and relief parameters results

| | Basic parameters | | | | | Linear parameters | | | | Areal parameters | | | | | | Relief parameters | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Basin no. | A ($km^2$) | P (km) | Nu | $L_b$ (km) | $L_u$ (km) | $R_b$ | $R_l$ | $L_o$ | T | $D_d$ | $F_s$ | $R_f$ | $R_c$ | $R_e$ | $C_{cm}$ | $B_h$ | $R_h$ | $H_i$ | $R_n$ |
| 1 | 22.4 | 38.3 | 266 | 11.2 | 111.8 | 3.85 | 2.11 | 0.10 | 5.39 | 4.98 | 11.86 | 0.18 | 0.19 | 0.48 | 0.20 | 434.0 | 0.04 | 0.35 | 2.16 |
| 2 | 68.0 | 98.1 | 838 | 33.3 | 333.2 | 5.08 | 1.78 | 0.10 | 6.61 | 4.90 | 12.32 | 0.06 | 0.09 | 0.28 | 0.20 | 1895.7 | 0.06 | 0.34 | 9.29 |
| 3 | 10.1 | 28.3 | 33 | 9.9 | 42.1 | 3 | 3.46 | 0.11 | 0.84 | 4.18 | 3.27 | 0.10 | 0.16 | 0.36 | 0.24 | 457.6 | 0.05 | 0.39 | 1.91 |
| 4 | 67.3 | 79.4 | 903 | 23.8 | 286.6 | 5.37 | 1.69 | 0.11 | 9.07 | 4.26 | 13.42 | 0.12 | 0.13 | 0.39 | 0.23 | 1810.5 | 0.08 | 0.46 | 7.71 |
| 5 | 17.8 | 30.0 | 214 | 9.6 | 73.4 | 5.75 | 1.57 | 0.12 | 5.70 | 4.13 | 12.04 | 0.19 | 0.25 | 0.50 | 0.24 | 610.0 | 0.06 | 0.43 | 2.52 |
| 6 | 97.3 | 74.7 | 1365 | 24.1 | 445.8 | 4.09 | 1.98 | 0.10 | 14.27 | 4.58 | 14.03 | 0.17 | 0.22 | 0.46 | 0.22 | 1822.0 | 0.08 | 0.42 | 8.35 |
| 7 | 11.9 | 25.1 | 103 | 9.2 | 60.5 | 4.57 | 4.35 | 0.09 | 3.38 | 5.08 | 8.66 | 0.14 | 0.24 | 0.42 | 0.20 | 251.2 | 0.03 | 0.32 | 1.28 |
| 8 | 8.9 | 28.2 | 97 | 9.1 | 47.5 | 4.38 | 1.78 | 0.09 | 2.72 | 5.31 | 10.85 | 0.11 | 0.14 | 0.37 | 0.19 | 240.2 | 0.03 | 0.45 | 1.28 |
| 9 | 131 | 91.6 | 1884 | 25.3 | 620.6 | 3.53 | 2.62 | 0.10 | 16.14 | 4.74 | 14.38 | 0.20 | 0.20 | 0.51 | 0.21 | 1836.6 | 0.07 | 0.51 | 8.70 |
| 10 | 21.5 | 40.7 | 166 | 15.1 | 103.2 | 5.11 | 1.52 | 0.10 | 3.29 | 4.80 | 7.73 | 0.09 | 0.16 | 0.35 | 0.21 | 692.4 | 0.05 | 0.44 | 3.33 |
| 11 | 14.5 | 23.1 | 195 | 7.6 | 87.5 | 5.58 | 2.03 | 0.08 | 6.62 | 6.04 | 13.45 | 0.25 | 0.34 | 0.56 | 0.17 | 156.3 | 0.02 | 0.37 | 0.94 |
| 12 | 39.0 | 75.2 | 464 | 21.8 | 199.8 | 4.52 | 1.97 | 0.09 | 4.89 | 5.13 | 11.90 | 0.08 | 0.09 | 0.32 | 0.20 | 1776.4 | 0.08 | 0.30 | 9.10 |
| 13 | 13.9 | 32.2 | 170 | 10.2 | 80.4 | 3.73 | 2.84 | 0.08 | 4.22 | 5.78 | 12.21 | 0.13 | 0.17 | 0.41 | 0.17 | 392.8 | 0.04 | 0.28 | 2.27 |
| 14 | 18.4 | 38.4 | 236 | 12.3 | 119.8 | 4.26 | 4.72 | 0.07 | 4.96 | 6.50 | 12.81 | 0.12 | 0.16 | 0.39 | 0.15 | 594.5 | 0.05 | 0.28 | 3.87 |
| 15 | 13.5 | 25.0 | 150 | 7.7 | 74.5 | 3.87 | 2.44 | 0.09 | 4.59 | 5.52 | 11.12 | 0.23 | 0.27 | 0.54 | 0.18 | 434.0 | 0.06 | 0.25 | 2.40 |
| 16 | 71.4 | 45.6 | 992 | 17.1 | 362.3 | 3.80 | 1.85 | 0.09 | 16.73 | 5.08 | 13.90 | 0.24 | 0.43 | 0.56 | 0.20 | 1788.1 | 0.10 | 0.35 | 9.08 |
| 17 | 67.6 | 72.1 | 1132 | 20.0 | 329.6 | 4.09 | 1.93 | 0.10 | 12.17 | 4.88 | 16.75 | 0.17 | 0.16 | 0.46 | 0.21 | 2361.4 | 0.12 | 0.59 | 11.52 |
| 18 | 23.8 | 30.6 | 335 | 9.0 | 137.7 | 4.07 | 2.14 | 0.08 | 8.44 | 5.78 | 14.06 | 0.30 | 0.32 | 0.62 | 0.17 | 944.4 | 0.11 | 0.31 | 5.46 |
| 19 | 35.5 | 43.2 | 560 | 13.7 | 190.5 | 3.45 | 2.22 | 0.09 | 9.67 | 5.36 | 15.77 | 0.19 | 0.24 | 0.49 | 0.19 | 1978.0 | 0.14 | 0.44 | 10.61 |
| 20 | 22.5 | 42.7 | 305 | 14.7 | 117.3 | 3.90 | 1.98 | 0.09 | 5.40 | 5.22 | 13.59 | 0.10 | 0.15 | 0.36 | 0.19 | 1972.8 | 0.13 | 0.32 | 10.31 |
| 21 | 14.1 | 35.2 | 177 | 12.2 | 77.0 | 3.54 | 4.15 | 0.09 | 3.80 | 5.45 | 12.53 | 0.10 | 0.14 | 0.35 | 0.18 | 1986.9 | 0.16 | 0.21 | 10.83 |
| 22 | 7.1 | 16.1 | 70 | 5.4 | 40.5 | 3.79 | 3.32 | 0.08 | 3.22 | 5.68 | 9.83 | 0.25 | 0.34 | 0.56 | 0.18 | 416.6 | 0.08 | 0.42 | 2.37 |
| 23 | 66.7 | 53.5 | 998 | 15.5 | 338.6 | 3.84 | 2.14 | 0.09 | 14.62 | 5.08 | 14.97 | 0.28 | 0.29 | 0.59 | 0.20 | 2223.4 | 0.14 | 0.48 | 11.29 |
| 24 | 26.5 | 31.1 | 342 | 10.0 | 145.2 | 4.01 | 2.05 | 0.09 | 8.32 | 5.47 | 12.90 | 0.27 | 0.34 | 0.58 | 0.18 | 1741.2 | 0.17 | 0.28 | 9.53 |
| 25 | 6.5 | 13.2 | 116 | 4.4 | 31.2 | 3.19 | 2.13 | 0.10 | 6.44 | 4.82 | 17.90 | 0.33 | 0.47 | 0.65 | 0.21 | 252.1 | 0.06 | 0.32 | 1.22 |
| 26 | 113 | 61.0 | 1814 | 14.8 | 660.5 | 3.79 | 1.88 | 0.08 | 23.01 | 5.85 | 16.06 | 0.52 | 0.38 | 0.81 | 0.17 | 2455.8 | 0.17 | 0.43 | 14.36 |
| 27 | 3.4 | 12.5 | 60 | 4.1 | 20.5 | 4.07 | 1.97 | 0.08 | 3.93 | 6.00 | 17.60 | 0.20 | 0.28 | 0.50 | 0.17 | 519.2 | 0.13 | 0.47 | 3.11 |
| 28 | 12.2 | 25.7 | 232 | 8.0 | 65.6 | 3.70 | 1.86 | 0.09 | 6.96 | 5.39 | 19.06 | 0.19 | 0.23 | 0.49 | 0.19 | 1118.2 | 0.14 | 0.58 | 6.03 |
| 29 | 6.0 | 19.4 | 111 | 5.7 | 36.8 | 4.46 | 1.63 | 0.08 | 4.21 | 6.15 | 18.56 | 0.19 | 0.20 | 0.49 | 0.16 | 326.8 | 0.06 | 0.93 | 2.01 |
| 30 | 3.7 | 16.6 | 66 | 5.4 | 20.7 | 8.5 | 1.62 | 0.09 | 3.13 | 5.54 | 17.69 | 0.13 | 0.17 | 0.40 | 0.18 | 428.8 | 0.08 | 0.39 | 2.37 |
| 31 | 14.9 | 27.5 | 282 | 8.0 | 81.1 | 3.79 | 2.09 | 0.09 | 7.50 | 5.46 | 18.98 | 0.23 | 0.25 | 0.54 | 0.18 | 1037.0 | 0.13 | 0.43 | 5.66 |
| 32 | 2.8 | 12.3 | 55 | 3.3 | 12.7 | 3.41 | 1.67 | 0.11 | 3.16 | 4.49 | 19.50 | 0.26 | 0.23 | 0.58 | 0.22 | 434.4 | 0.13 | 0.46 | 1.95 |
| 33 | 4.2 | 12.2 | 74 | 3.2 | 20.3 | 3.80 | 1.66 | 0.10 | 4.49 | 4.86 | 17.75 | 0.42 | 0.35 | 0.73 | 0.21 | 420.3 | 0.13 | 0.42 | 2.04 |
| 34 | 10.4 | 30.5 | 179 | 7.5 | 50.6 | 3.56 | 1.72 | 0.10 | 4.42 | 4.88 | 17.26 | 0.18 | 0.14 | 0.48 | 0.21 | 424.5 | 0.06 | 0.37 | 2.07 |
| 35 | 38.2 | 56.6 | 614 | 14.3 | 194.6 | 4.92 | 1.87 | 0.09 | 8.40 | 5.10 | 16.08 | 0.19 | 0.15 | 0.49 | 0.20 | 929.5 | 0.07 | 0.22 | 4.74 |

## 4.1. Linear Parameters

***Bifurcation ratio ($R_b$)*** is play major roles runoff potential and hydrograph curve of the watershed (Rakesh et al. 2000). $R_b$ values ranging from 3 to 8.5 indicate that some of the watersheds are structurally controlled whereas some of are not controlled. While the highest $R_b$ value result of the watershed is 30 ($R_b$ = 8.5), the lowest value result of the watershed was 3 ($R_b$ =3). There were also relatively higher (>5) values of the watershed that are 2, 4, 5, 10, and 11. The well-developed drainage network showed that $R_b$ values ranged from 2 to 5 (Horton, 1945). Higher $R_b$ values indicate more structural control in terms of geologically.

***Stream length ratio ($R_l$)*** was defined by Patton in 1988 and $R_l$ is affected by many factors such as topographic conditions of drainage watershed, surface runoff (Dhanusree and Bhaskaran, 2019; Sreedevi et al., 2005). The $R_l$ allows us to have an idea about the rate of retention of water in the stream branches depending on the length. The $R_l$ values obtained from 35 watershed values ranged from 1.52 (watershed 10) to 4.72 (watershed 14). While some of the watersheds showed higher $R_l$ (> 2) including 1, 3, 7, 9, 11, 13, 14, 15, 18, 19, 21, 22, 23, 24, 25, 31, the rest of them showed lower $R_l$ (<2). While high $R_l$ values showed lower-order source for the next order streams, low values of $R_l$ indicated a limited length of lower-order streams to the next order.

***Length of overland flow ($L_o$)*** was defined by Horton in 1945, depending on the drainage density of the watersheds; it is effective in revealing the relationship between the factors controlling superficial erosions. In the watersheds where the circular and drainage density is high, the $L_o$ value is quite small since it has more distraction depending on the density of the water. On the other hand, this value is relatively higher in the longitudinal watersheds where water distraction is less. In the watersheds, located in the selected study area, the values of $L_o$) varied from 0.08 (watershed 11, 13, 18, 22, 26, 27, 29) to 0.12 (watershed 5). This means that the rainwater has to run over between 0.08 km and 0.12 km for watershed 11, 13, 18, 22, 26, 27, 29, and watershed 5, respectively before it gets concentrated in stream channels.

***Texture ratio (T)*** values depend on the geological and geomorphological properties, and infiltration capacity of the drainage watershed (Thomas & Prasannakumar, 2015; Vijith & Satheesh, 2006). Watersheds with high T with values show that there are more first-order streams whereas watersheds with low T values show the opposite. T value is higher in circular watersheds, while elongation watershed shows lower values. The results given in Table 2 showed that values ranged from 0.84 to 23.01 for watershed 2 and 26.

### 4.2. Areal Parameters

***Drainage density ($D_d$)*** was defined by Horton in 1932 and it plays a crucial role in geomorphological evolution, permeability, and capability of the drainage watershed (Horton, 1945). The results of $D_d$ showed that most of the watersheds had moderate to high $D_d$ values of drainage density indicating high surface runoff, gullied landform, and low permeability. While the watershed 11, 14, 27, 29 showed the highest values (6 to 6.50), the rest of the watersheds had moderate values ranging from 4.13 to 6.50. Watershed 14 showed a very high value with 6.5 resulting from high surface runoff rate, high flood peak, and low permeability characteristics.

***Stream frequency ($F_s$)*** *was* defined by Horton in 1932 and 1945 and it represents the total number of streams. A $F_s$ of higher values represent low permeability and more surface runoff (Melton, 1957). Each watershed's $F_s$ values ranged from 3.27 to 19.5. Most of the watershed $F_s$ values were greater than 10 except watershed 3, 10, 22. $F_s$ values showed that surface run-off other watersheds would be more than that of watershed 3, 10, 22.

***Form factor ($R_f$)*** was defined by Horton in 1932 and it expresses the shape of the watershed quantitively and ranges from 0 to 1. A $R_f$ value of “0” represents an elongated watershed, whereas “1” a circular watershed (Sakthivel et al. 2019). The results $R_f$ values ranged from 0.06 to 0.52. Most of the $R_f$ values indicates that watersheds have an elongated geometry that likely to have low flood peak values. Watershed 26 and 33 had 0.41 and 0.51 as $R_f$ values and this represents slightly circular geometries compared to other watersheds which mean short duration and the highest peak flow.

***Circulatory ratio ($R_c$)*** was defined by Melton in 1957 and it depends on many factors such as climate, land use/land cover, structural, lithological, and geomorphological characteristics of landforms (Kim et al., 2011; Sreedevi et al., 2009). High values represents circular watershed which indicates higher vulnerability to sharp peak discharge and shorter lag time (Ajibade et al., 2010) The results shows that $R_c$ values range from 0.09 to 0.47, watershed 16 and 25, when compared to other watersheds, had $R_c$ values of 0.43, 0.47, which indicates that they having circular shape results in shorter lag time and high flood potential.

***The elongation ratio ($R_e$)*** was defined by Schumm in 1956 and it is used to determine the shape of the drainage watershed. $R_e$ generally ranges from 0.6 to 1.0. Watershed shape characteristics are divided into 3 categories based on elongation ratio ($R_e$) values: (1) circular (0.9), (2) oval (0.9–0.8), and (3) less elongated (0.7), (Sharma et al., 2015). $R_e$ values range from 0.28 (Watershed 2) to 0.81 (Watershed 26). The watershed 2 shows elongated geometries that indicate a high infiltration rate and low runoff potential. Watershed 26 has an oval shape which indicates high surface runoff, high sediment transportation rate; while 22, 23, 25, 32 are less circular. The rest of the watersheds are more elongated.

***Constant of channel maintenance ($C_{cm}$)*** is controlled by drainage watershed relief, climate, and lithology properties. This parameter was defined by Schumm in 1956. The results ranged from 0.15 to 0.24 $km^2/km$ indicating a relatively low erodible surface. While high $C_{cm}$ values lead to low surface runoff and high permeability, Low $C_{cm}$ values correspond to high surface runoff and low permeability.

### 4.3. Relief Parameters

***Basin relief ($B_h$)***, was defined by Schumm in 1956 and it determines the shape and sediment transport suggested by Hadley and Schumm (1961). The $B_h$ values ranged from 156.3 m to 2455.8 m. The watershed 11 showed the lowest values that corresponded to low transportation and spread of water through the watershed and low runoff. Watershed 26 showed the highest $B_h$ values meaning increased relief values, steeper slopes, and high stream bed slopes, where current accumulation decreases the time and consequently increases the peak of the flood to increase.

***Relief ratio ($R_h$)*** was defined by Schumm in 1956 means the differences of minimum and a maximum elevation of the watershed. In the study area, the $R_h$ value ranged from 0.02 to 0.17, and for watershed 7, 8, 11. $R_h$ values in that area exhibited low, moderate, and high relief characteristics. The low value of $R_h$ mostly depends on the properties of the resistance lithology of the drainage watershed and the low degree of the gradient (Kumar Rai et al., 2017).

***Hypsometric integral ($H_i$)*** was defined by Strahler in 1952 and it means the distribution of the ground surface area concerning elevation (Strahler, 1952). $H_i$, values play crucial roles in understanding the hydrological situation of the drainage watershed area (Ritter et al. 2002). $H_i$, values are divided into three categories: (1) $H_i \leqslant 3$ old stage (2) $0.3 \leqslant H_i \leqslant 0.6$ mature stage and (3) $H_i \geqslant 0.6$ young stage (Strahler, 1952; Sarangi et al., 2001). $H_i$ is related to the geomorphological evolution of the watershed area which is linked with erosional landform and tectonic processes in the watershed area (Strahler, 1952; Schumm, 1956) The $H_i$ values ranged from 0.21 to 0.93 and this indicate a relatively old and mature stage except watershed 29 in the area. High values correspond to high erosion processes, high sediment transportation, whereas low values show the maturity stage, which indicates high permeability, low drainage density, and low denudation, processes. Watershed 29 showed high $H_i$ values that are mostly related to the lithology and geomorphology of the drainage watershed area.

***Ruggedness number ($R_n$)*** was defined by Schumm (1956) and Strahler (1958), respectively, indicates the interaction of relief and dissection; due to the high dissection watersheds show low relief properties, however, watersheds with less dissection exhibit high relief properties (Melton, 1957) The results show low, moderate, and high $R_n$ values that ranged from 0.94 to 14.36. This result indicated that the hilly and steep slope of drainage areas had a high potential of surface erosion.

### 4.4. Potential Flood Prioritization of Watersheds

Prioritization of river watersheds based on geomorphometric analysis to understand the flood dynamics of the river is of great importance in taking the necessary precautions and measures against floods. (Mundetia et al., 2018). Examining the geohydrological characteristics using parameters such as linear, areal, and relief aspects reveals the importance of morphometric indices (Kumar & Joshi, 2019). Because these indices are hydrologically related to factors such as surface runoff, peak discharge, and lag time, directly. (Nooka Ratnam et al., 2005; Javed et al., 2009; Meshram & Sharma, 2017; Singh & Singh, 2017; Abdeta et al., 2020). In this study, flood prioritization was made based on two different methods by using 14 different indices on 35 basins. The first of these is the morphometric priority and the other is obtained through the PCA method. (Malik et al., 2019; Martins and Nunes, 2020; Siddiqui et al., 2020; Waiyasusri and Chotpantarat, 2020).

### 4.4.1. Flood priority rank based on morphometric results

Morphometric analysis is one of the methods used to estimate the prioritization to understand the flood outputs in the drainage watershed scale (Memon et al. 2020). Each basin was evaluated in terms of flood priority depending on the indices used. The compound value was calculated by taking the average of the total values in each basin. (Choudhari et al., 2018; Mundetia et al., 2018). The calculated compound value of watersheds was evaluated based on each score. Finally, flood prioritization was determined based on compound values. While the low values represented high flood priority, the high compound values show low flood priority ranks (Waiyasusri & Chotpantarat 2020). The obtained compound values were between 6.93 - 28.57. According to these results, priority was classified as (i) High priority (H: 6.93 - 15), (ii) Moderate priority (M: 15.1 - 20), (iii) Low priority (L: 20.1 - 28.57). Flood prioritization of basins is given in Figure 5. The results revealed that 8 river basins had high priority (watershed no. 18, 19, 23, 24, 26, 27, 28, and 31). Basins with high flood priority had a flood characteristic with sudden flood peaks in a short time and showed a high degree of erosional processes and sediment transportation. 16 river basins were found to have moderate flood priority. These basins were 6, 8, 9, 11, 14, 15, 16, 17, 20, 21, 22, 25, 29, 30, 33, 35, which had different geology, geomorphology, and moderate flood peak. 11 different river basins of the selected area had low priority including basins 1, 2, 3, 4, 5, 7, 10, 12, 13, 32 and 34, which is clear in Table 3.

### 4.4.2. Flood priority rank based on principal component analysis results

In the PCA method, the input information is assumed to be an n*p matrix. “n” is the number of observation, which is the number of sub-basins in this research. “p” represents the variables to be analyzed, which are the criteria or the morphometric characteristics of the sub-watersheds. PCA is used to determine the priority of watershed based on the flood scale (Farhan et al. 2017). Table 4a shows the correlation matrix results of 14 morphometric indices. Results show that the correlation between elongation ratio ($R_e$), and form factor ($R_f$), ruggedness number ($R_n$), and basin relief ($B_h$), length of overland flow ($L_o$), and constant of channel maintenance ($C_{cm}$) is strong (> 0.9). It is obvious; there is a good correlation (> 0.75) between the circularity ratio ($R_c$), and form factor ($R_f$), form factor ($R_f$), and length of overland flow ($L_o$). There is a moderate correlation (> 0.6) between relief ratio ($R_h$) and basin relief ($B_h$), texture ratio ($T_,$) and basin relief ($B_h$), relief ratio ($R_h$), and ruggedness number ($R_n$). The principal component loading matrix result was also evaluated (4b) based on eigenvalues, which were greater than 1 and corresponds to 81.17 % of the total variance in morphometric indices values (4c).

This prioritization was tested in watersheds and the obtained value was called a compound parameter value, which was used for priority assessment. Moreover, component 1: form factor ($R_f$), elongation ratio ($R_e$), circularity ratio ($R_c$), 2: basin relief ($B_h$), ruggedness number ($R_n$), 3: length of overland flow ($L_o$), channel constant maintenance ($C_{cm}$) and drainage density were strongly correlated according to the inter-correlation matrix results (4a). Accordingly, Table 4b, showed that the first component was most highly correlated with elongation ratio ($R_e$), form factor ($R_f$), and circularity ratio ($R_c$). But, the elongation ratio ($R_e$) was a better representative. It was also obvious that the second component was most highly correlated with ruggedness number ($R_n$) and basin relief ($B_h$). The third component was most highly correlated with constant of channel maintenance ($C_{cm}$), drainage density ($D_d$), and length of overland flow ($L_o$).

**Table 3:** Calculation of compound parameters and priority ranks according to morphometric analysis results

| Basin No | $R_b$ | $D_d$ | $F_s$ | $R_l$ | $L_o$ | $B_h$ | $R_n$ | $R_h$ | $H_i$ | $T$ | $R_f$ | $R_e$ | $R_c$ | $C_{CM}$ | Compound Values | Priority |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 20 | 23 | 29 | 13 | 23 | 25 | 26 | 31 | 22 | 19 | 21 | 21 | 21 | 23 | 22.64 | L |
| 2 | 6 | 24 | 25 | 27 | 24 | 7 | 8 | 25 | 24 | 15 | 35 | 35 | 34 | 24 | 22.36 | L |
| 3 | 35 | 34 | 35 | 4 | 34 | 22 | 31 | 29 | 19 | 35 | 31 | 31 | 26 | 34 | 28.57 | L |
| 4 | 4 | 33 | 21 | 29 | 33 | 10 | 13 | 18 | 8 | 8 | 28 | 28 | 33 | 33 | 21.36 | L |
| 5 | 2 | 35 | 27 | 34 | 35 | 19 | 21 | 22 | 13 | 17 | 15 | 15 | 12 | 35 | 21.57 | L |
| 6 | 13 | 31 | 17 | 18 | 31 | 9 | 12 | 19 | 17 | 5 | 23 | 23 | 18 | 31 | 19.07 | M |
| 7 | 8 | 20 | 33 | 2 | 20 | 33 | 32 | 33 | 27 | 29 | 24 | 24 | 15 | 20 | 22.86 | L |
| 8 | 11 | 16 | 31 | 26 | 16 | 34 | 33 | 34 | 9 | 34 | 29 | 29 | 31 | 16 | 24.93 | M |
| 9 | 31 | 30 | 15 | 7 | 30 | 8 | 11 | 20 | 4 | 3 | 13 | 13 | 20 | 30 | 16.79 | M |
| 10 | 5 | 29 | 34 | 35 | 29 | 18 | 19 | 30 | 10 | 30 | 33 | 33 | 25 | 29 | 25.64 | L |
| 11 | 3 | 3 | 20 | 16 | 3 | 35 | 35 | 35 | 21 | 14 | 9 | 9 | 7 | 3 | 15.21 | M |
| 12 | 9 | 18 | 28 | 20 | 18 | 12 | 9 | 15 | 29 | 21 | 34 | 34 | 35 | 18 | 21.43 | L |
| 13 | 27 | 7 | 26 | 6 | 7 | 30 | 25 | 32 | 30 | 25 | 25 | 25 | 23 | 7 | 21.07 | L |
| 14 | 12 | 1 | 23 | 1 | 1 | 20 | 18 | 28 | 32 | 20 | 27 | 27 | 27 | 1 | 17.00 | M |
| 15 | 19 | 10 | 30 | 8 | 10 | 24 | 22 | 27 | 33 | 22 | 12 | 12 | 11 | 10 | 17.86 | M |
| 16 | 22 | 22 | 18 | 25 | 22 | 11 | 10 | 14 | 23 | 2 | 10 | 10 | 2 | 22 | 15.21 | M |
| 17 | 13 | 25 | 10 | 21 | 25 | 2 | 2 | 12 | 2 | 6 | 22 | 22 | 24 | 25 | 15.07 | M |
| 18 | 15 | 6 | 16 | 10 | 6 | 16 | 16 | 13 | 28 | 9 | 4 | 4 | 8 | 6 | 11.21 | H |
| 19 | 32 | 15 | 13 | 9 | 15 | 5 | 5 | 4 | 11 | 7 | 17 | 17 | 14 | 15 | 12.79 | H |
| 20 | 18 | 17 | 19 | 17 | 17 | 6 | 6 | 7 | 26 | 18 | 30 | 30 | 28 | 17 | 18.29 | M |
| 21 | 30 | 13 | 24 | 3 | 13 | 4 | 4 | 3 | 35 | 28 | 32 | 32 | 30 | 13 | 18.86 | M |
| 22 | 24 | 8 | 32 | 5 | 8 | 29 | 24 | 17 | 15 | 31 | 8 | 8 | 5 | 8 | 15.86 | M |
| 23 | 21 | 21 | 14 | 11 | 21 | 3 | 3 | 5 | 5 | 4 | 5 | 5 | 9 | 21 | 10.57 | H |
| 24 | 17 | 11 | 22 | 15 | 11 | 13 | 7 | 1 | 31 | 11 | 6 | 6 | 6 | 11 | 12.00 | H |
| 25 | 34 | 28 | 5 | 12 | 28 | 32 | 34 | 24 | 25 | 16 | 3 | 3 | 1 | 28 | 19.50 | M |
| 26 | 24 | 5 | 12 | 22 | 5 | 1 | 1 | 2 | 14 | 1 | 1 | 1 | 3 | 5 | 6.93 | H |
| 27 | 15 | 4 | 8 | 19 | 4 | 21 | 20 | 11 | 6 | 27 | 14 | 14 | 10 | 4 | 12.64 | H |
| 28 | 28 | 14 | 2 | 24 | 14 | 14 | 14 | 6 | 3 | 13 | 16 | 16 | 17 | 14 | 13.93 | H |
| 29 | 10 | 2 | 4 | 32 | 2 | 31 | 29 | 23 | 1 | 26 | 19 | 19 | 19 | 2 | 15.64 | M |
| 30 | 1 | 9 | 7 | 33 | 9 | 26 | 23 | 16 | 18 | 33 | 26 | 26 | 22 | 9 | 18.43 | M |
| 31 | 24 | 12 | 3 | 14 | 12 | 15 | 15 | 10 | 12 | 12 | 11 | 11 | 13 | 12 | 12.57 | H |
| 32 | 33 | 32 | 1 | 30 | 32 | 23 | 30 | 9 | 7 | 32 | 7 | 7 | 16 | 32 | 20.79 | L |
| 33 | 22 | 27 | 6 | 31 | 27 | 28 | 28 | 8 | 16 | 23 | 2 | 2 | 4 | 27 | 17.93 | M |
| 34 | 29 | 26 | 9 | 28 | 26 | 27 | 27 | 26 | 20 | 24 | 20 | 20 | 32 | 26 | 24.29 | L |
| 35 | 7 | 19 | 11 | 23 | 19 | 17 | 17 | 21 | 34 | 10 | 18 | 18 | 29 | 19 | 18.71 | M |

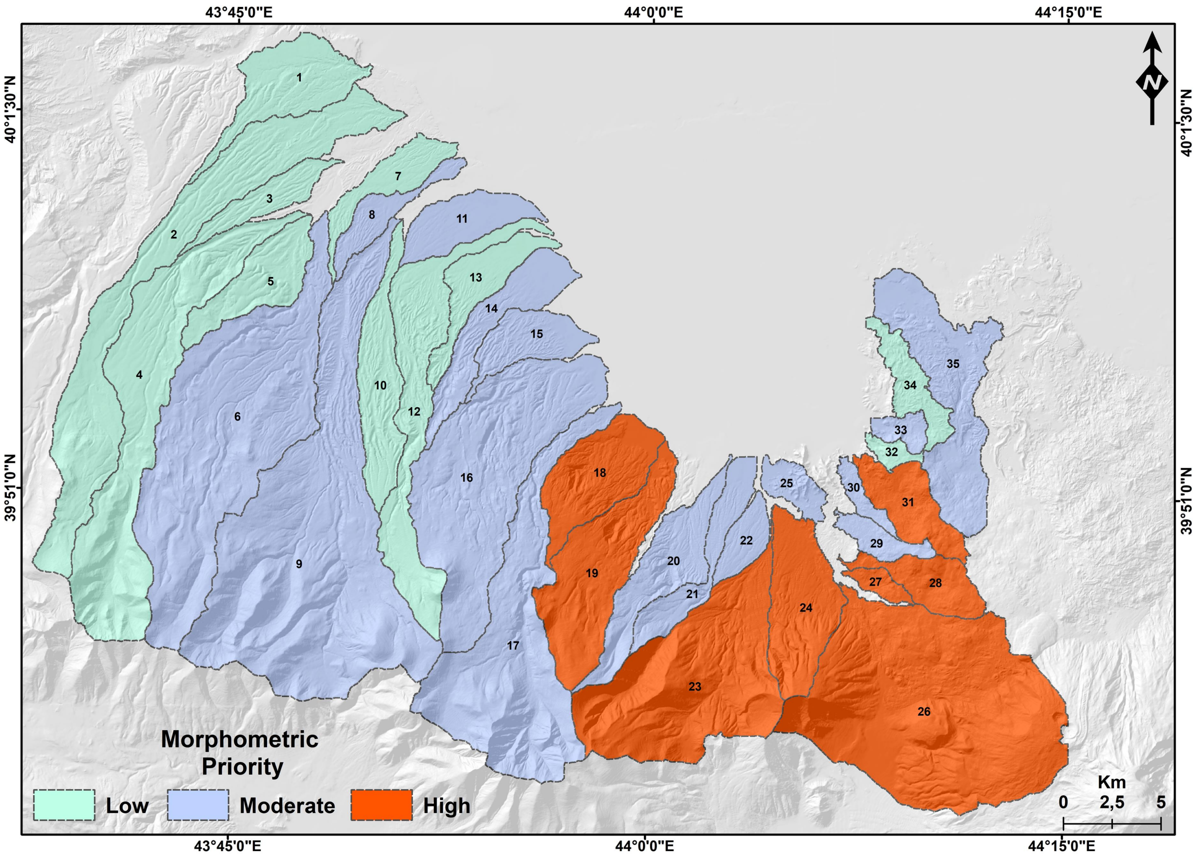


**Figure 5:** Flood priority of the 35 watersheds based on the morphometric analysis.

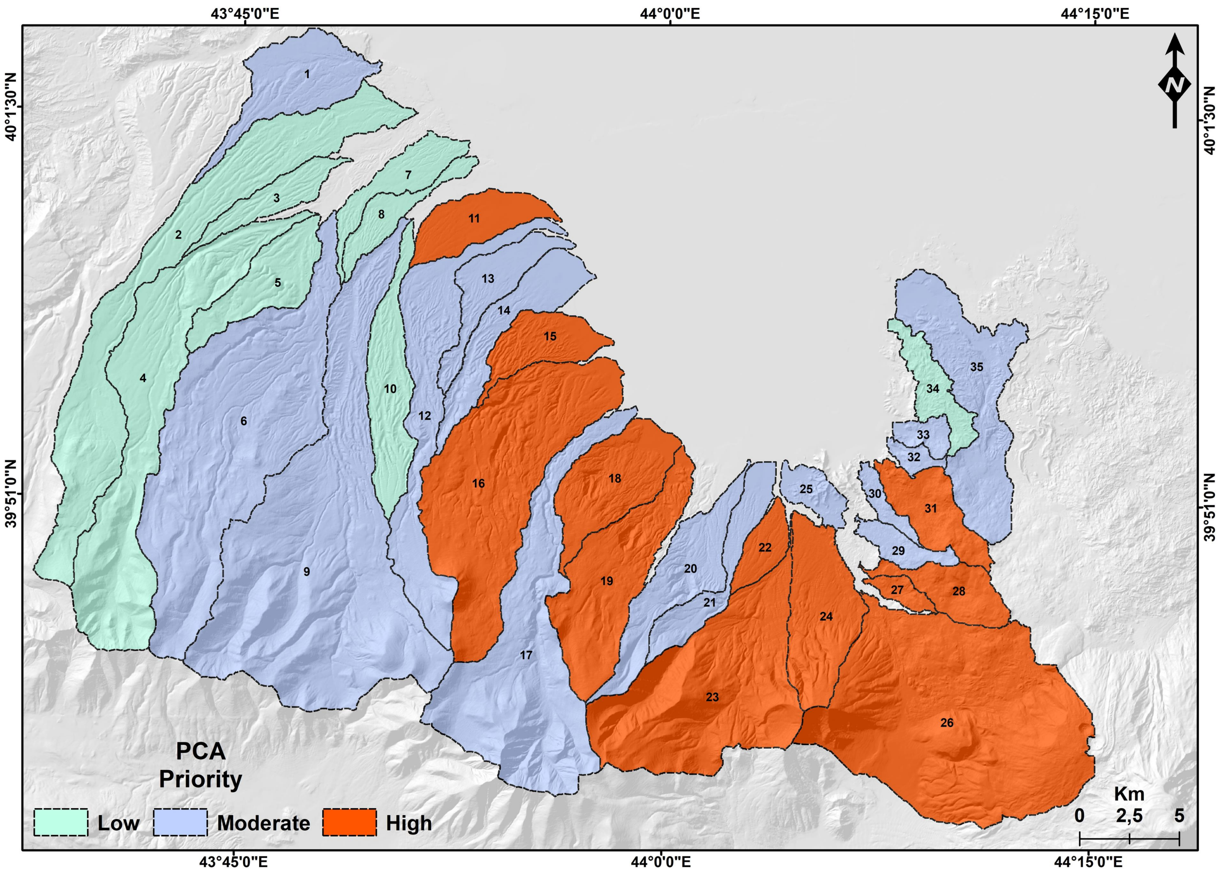


**Figure 6.** Flood priority of 35 watersheds based on PCA analysis.

**Table 4:** (a) Inter- Correlation matrix, (b) Principal component loading matrix, (c) total variance explained of the morphometric indices

(a)

| Morph. Param. | $R_b$ | $D_d$ | $F_s$ | $R_l$ | $L_o$ | $B_h$ | $R_n$ | $R_h$ | $H_i$ | $T$ | $R_f$ | $R_e$ | | $C_{cm}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_b$ | 1 | | | | | | | | | | | | | |
| $D_d$ | 0.05 | 1 | | | | | | | | | | | | |
| $F_s$ | 0.02 | 0.21 | 1 | | | | | | | | | | | |
| $R_l$ | -0.26 | 0.27 | -0.46 | 1 | | | | | | | | | | |
| $L_o$ | 0.03 | -0.99 | -0.23 | -0.24 | 1 | | | | | | | | | |
| $B_h$ | -0.15 | -0.15 | 0.10 | -0.11 | 0.11 | 1 | | | | | | | | |
| $R_n$ | -0.17 | -0.03 | 0.13 | -0.07 | -0.01 | 0.99 | 1 | | | | | | | |
| $R_h$ | -0.29 | -0.08 | 0.46 | -0.15 | -0.12 | 0.62 | 0.67 | 1 | | | | | | |
| $H_i$ | 0.01 | 0.02 | 0.36 | -0.37 | 0.01 | 0.00 | -0.02 | 0.06 | 1 | | | | | |
| $T$ | -0.16 | -0.03 | 0.26 | -0.21 | 0.01 | 0.72 | 0.75 | 0.40 | 0.12 | 1 | | | | |
| $R_f$ | -0.28 | 0.15 | 0.42 | -0.22 | -0.16 | 0.04 | 0.09 | 0.43 | 0.09 | 0.5 | 1 | | | |
| $R_e$ | -0.29 | 0.16 | 0.46 | -0.22 | -0.16 | -0.01 | 0.04 | 0.41 | 0.11 | 0.48 | 0.99 | 1 | | |
| $R_c$ | -0.24 | 0.18 | 0.23 | -0.09 | -0.18 | 0.0 | -0.04 | 0.28 | -0.02 | 0.37 | 0.82 | 0.84 | 1 | |
| $C_{cm}$ | -0.03 | -0.99 | -0.23 | -0.24 | 1 | 0.11 | -0.01 | -0.12 | 0.01 | 0.01 | -0.16 | -0.16 | -0.18 | 1 |

(b)

| Morph. Param. | Component | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| $R_b$ | -0.423 | -0.231 | -0.082 | 0.437 |
| $D_d$ | 0.080 | -0.025 | -0.985 | -0.032 |
| $F_s$ | 0.327 | 0.211 | -0.258 | 0.692 |
| $R_l$ | -0.114 | -0.085 | -0.266 | -0.818 |
| $L_o$ | -0.087 | 0.068 | 0.970 | -0.055 |
| $B_h$ | -0.106 | 0.979 | 0.119 | -0.006 |
| $R_n$ | -0.059 | 0.991 | 0.005 | -0.031 |
| $R_h$ | 0.329 | 0.722 | -0.142 | 0.135 |
| $H_i$ | 0.011 | 0.011 | -0.013 | 0.679 |
| $T$ | 0.386 | 0.744 | 0.083 | 0.123 |
| $R_f$ | 0.940 | 0.149 | -0.090 | 0.158 |
| $R_e$ | 0.961 | 0.099 | -0.077 | 0.178 |
| $R_c$ | 0.906 | -0.013 | -0.105 | -0.017 |
| $C_{cm}$ | -0.057 | -0.024 | 0.986 | 0.040 |

(c)

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings |
|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total |
| 1 | 4.202 | 30.013 | 30.013 | 4.202 | 30.013 | 30.013 | 3.504 |
| 2 | 3.230 | 23.070 | 53.084 | 3.230 | 23.070 | 53.084 | 3.172 |
| 3 | 2.248 | 16.057 | 69.141 | 2.248 | 16.057 | 69.141 | 3.368 |
| 4 | 1.685 | 12.037 | 81.179 | 1.685 | 12.037 | 81.179 | 1.967 |
| 5 | 0.920 | 6.575 | 87.754 | | | | |
| 6 | 0.705 | 5.037 | 92.791 | | | | |
| 7 | 0.376 | 2.683 | 95.474 | | | | |
| 8 | 0.350 | 2.501 | 97.975 | | | | |
| 9 | 0.187 | 1.335 | 99.310 | | | | |
| 10 | 0.045 | 0.325 | 99.635 | | | | |
| 11 | 0.034 | 0.243 | 99.878 | | | | |
| 12 | 0.009 | 0.062 | 99.941 | | | | |
| 13 | 0.007 | 0.048 | 99.989 | | | | |
| 14 | 0.002 | 0.011 | 100.00 | | | | |

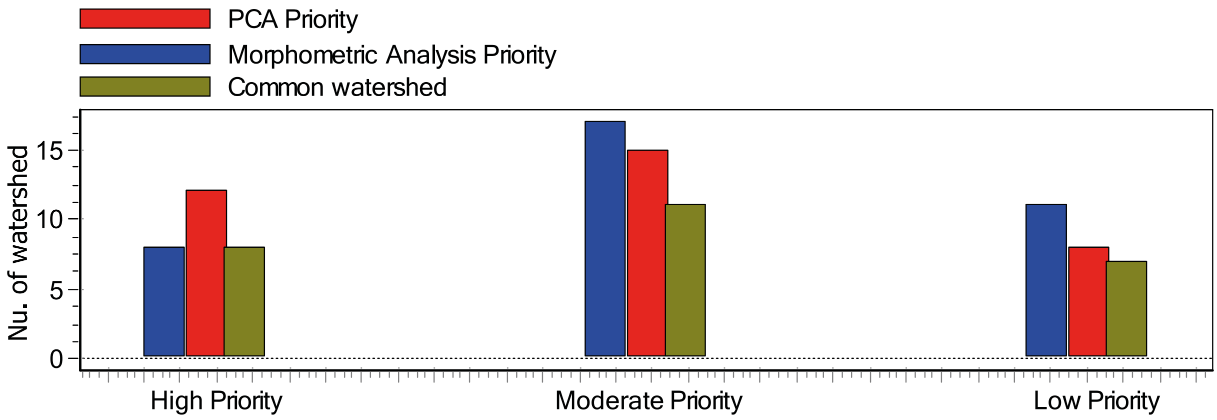


**Figure 7:** Priority and common watersheds properties based on morphometry and PCA analysis

As mentioned, according to rotated component matrix results, 8 different indices showed a high correlation. Thus, 8 indices were evaluated using PCA compound parameters for watershed flood priority (Table 5). PCA map showed that 12 watersheds had a high priority, 15 watersheds had moderate priority, and 8 watersheds had low priority (Figure 6). According to the morphometric analysis results, 8 watersheds had high priorities, while 12 watersheds had high priorities based on PCA analysis. 8 watersheds were found to have common high priorities (Figure 7). 11 watersheds were found to have moderate priorities and 7 watersheds to have common priorities. These results revealed that different prioritization methods gave the almost similar results.

**Table 5:** Calculation of compound parameters and prioritized ranks according to PCA analysis results

| Basin No | $D_d$ | $L_o$ | $B_h$ | $R_n$ | $R_f$ | $R_e$ | $R_c$ | $C_{CM}$ | Compound Values | Priority |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 23 | 23 | 25 | 26 | 21 | 21 | 21 | 23 | 22.88 | M |
| 2 | 24 | 24 | 7 | 8 | 35 | 35 | 34 | 24 | 23.88 | L |
| 3 | 34 | 34 | 22 | 31 | 31 | 31 | 26 | 34 | 30.38 | L |
| 4 | 33 | 33 | 10 | 13 | 28 | 28 | 33 | 33 | 26.38 | L |
| 5 | 35 | 35 | 19 | 21 | 15 | 15 | 12 | 35 | 23.38 | L |
| 6 | 31 | 31 | 9 | 12 | 23 | 23 | 18 | 31 | 22.25 | M |
| 7 | 20 | 20 | 33 | 32 | 24 | 24 | 15 | 20 | 23.50 | L |
| 8 | 16 | 16 | 34 | 33 | 29 | 29 | 31 | 16 | 25.50 | L |
| 9 | 30 | 30 | 8 | 11 | 13 | 13 | 20 | 30 | 19.38 | M |
| 10 | 29 | 29 | 18 | 19 | 33 | 33 | 25 | 29 | 26.88 | L |
| 11 | 3 | 3 | 35 | 35 | 9 | 9 | 7 | 3 | 13 | H |
| 12 | 18 | 18 | 12 | 9 | 34 | 34 | 35 | 18 | 22.25 | M |
| 13 | 7 | 7 | 30 | 25 | 25 | 25 | 23 | 7 | 18.63 | M |
| 14 | 1 | 1 | 20 | 18 | 27 | 27 | 27 | 1 | 15.25 | M |
| 15 | 10 | 10 | 24 | 22 | 12 | 12 | 11 | 10 | 13.88 | H |
| 16 | 22 | 22 | 11 | 10 | 10 | 10 | 2 | 22 | 13.63 | H |
| 17 | 25 | 25 | 2 | 2 | 22 | 22 | 24 | 25 | 18.38 | M |
| 18 | 6 | 6 | 16 | 16 | 4 | 4 | 8 | 6 | 8.25 | H |
| 19 | 15 | 15 | 5 | 5 | 17 | 17 | 14 | 15 | 12.88 | H |
| 20 | 17 | 17 | 6 | 6 | 30 | 30 | 28 | 17 | 18.88 | M |
| 21 | 13 | 13 | 4 | 4 | 32 | 32 | 30 | 13 | 17.63 | M |
| 22 | 8 | 8 | 29 | 24 | 8 | 8 | 5 | 8 | 12.25 | H |
| 23 | 21 | 21 | 3 | 3 | 5 | 5 | 9 | 21 | 11 | H |
| 24 | 11 | 11 | 13 | 7 | 6 | 6 | 6 | 11 | 8.88 | H |
| 25 | 28 | 28 | 32 | 34 | 3 | 3 | 1 | 28 | 19.63 | M |
| 26 | 5 | 5 | 1 | 1 | 1 | 1 | 3 | 5 | 2.75 | H |
| 27 | 4 | 4 | 21 | 20 | 14 | 14 | 10 | 4 | 11.38 | H |
| 28 | 14 | 14 | 14 | 14 | 16 | 16 | 17 | 14 | 14.88 | H |
| 29 | 2 | 2 | 31 | 29 | 19 | 19 | 19 | 2 | 15.38 | M |
| 30 | 9 | 9 | 26 | 23 | 26 | 26 | 22 | 9 | 18.75 | M |
| 31 | 12 | 12 | 15 | 15 | 11 | 11 | 13 | 12 | 12.63 | H |
| 32 | 32 | 32 | 23 | 30 | 7 | 7 | 16 | 32 | 22.38 | M |
| 33 | 27 | 27 | 28 | 28 | 2 | 2 | 4 | 27 | 18.13 | M |
| 34 | 26 | 26 | 27 | 27 | 20 | 20 | 32 | 26 | 25.50 | L |
| 35 | 19 | 19 | 17 | 17 | 18 | 18 | 29 | 19 | 19.50 | M |

## 5. CONCLUSION

The flood properties of 35 different watersheds were evaluated in terms of morphometric parameters. 14 different morphometric indices including parameters such as linear, areal, and relief aspects, were used to determine flood priority in this study. Surface runoff, permeability, drainage density, geologic and relief properties, infiltration capacity are factors affecting the flood potential. For this reason, morphometric analysis has a crucial role in determining the flood characteristics of a watershed quantitatively at a different scale using GIS. Also, it helps to prioritize watersheds for flood potential based on compound values. According to morphometric results, watersheds were evaluated in terms of flood prioritization based on two different methods. Morphometric analysis and principal component analysis methods were used in this study. As a consequence of the morphometry analysis, 8 watersheds were found to have high priorities, 17 watersheds to have moderate priorities, and 11 watersheds to have low priorities. The watersheds with high priority correspond to a circular shape that represents shorter lag time and high peak flood hydrography. Besides, principal component analysis (PCA) results showed that 12 watersheds had high priorities, 15 watersheds had moderate priorities and 8 watersheds had low priorities. As the consequence of morphometric analyses and the principal component analysis made, this study revealed that 8 watersheds had high priority; 11 watersheds had medium priority, and 7 watersheds had a low priority in terms of the flood. Basins with high flood risk were the basins where river erosion factors and processes continued actively. In these basins, elevation difference, drainage density, stream frequency, surface runoff and first stream order texture ratio values were quite high. There have been floods in various watersheds in different periods. Therefore, basin morphometry is of great importance in understanding floods. The priority classification showed that necessary measures should be taken in areas with high flood potential.

## REFERENCES

Abdeta, G. C., Tesemma, A. B., Tura, A. L., Atlabachew, G.H. (2020) Morphometric analysis for prioritizing sub-watersheds and management planning and practices in Gidabo Basin, Southern Rift Valley of Ethiopia. Appl Water Sci. 10(7):1–15.

Ajibade, L., Ifabiyi, L., Iroye, K., Ogunteru, S. (2010) Morphometric Analysis of Ogunpa and Ogbere Drainage Basins, Ibadan, Nigeria. Ethiop. J. Environ. Stud. Manag. 3. https://doi.org/10.4314/ejesm.v3i1.54392

Amiri, M., Pourghasemi., H. R., Arabameri, A., Vazirzadeh, A., Yousefi, H., Kafaei, S. (2019) Prioritization of Flood Inundation of Maharloo Watershed in Iran Using Morphometric Parameters Analysis and TOPSIS MCDM Model. Elsevier Inc. http://dx.doi.org/10.1016/B978-0-12-815226-3.00016-8

Azzoni, R.S., Fugazza, D., Garzonio, C. A., Nicoll, K., Diolaiuti, G. A., Pelfini, M., Zerboni, A. (2019) Geomorphological effects of the 1840 Ahora Gorge catastrophe on Mount Ararat (Eastern Turkey). Geomorphology 332, 10–21. https://doi.org/10.1016/j.geomorph.2019.02.001

Azzoni, R. S., Zerboni, A., Pelfini, M., Garzonio, C. A., Cioni, R., Meraldi, E., Smiraglia, C., Diolaiuti, G. A. (2017) Geomorphology of mount Ararat/Ağri daği (Ağri daği milli parki, Eastern Anatolia, Turkey). J. Maps 13, 182–190. https://doi.org/10.1080/17445647.2017.1279084

Bhat, M. S., Alam, A., Ahmad, B., Kotlia, B. S., Farooq, H., Taloor, A. K., Ahmad, S. (2018) Flood frequency analysis of river Jhelum in Kashmir basin. Quat. Int. 0–1. https://doi.org/10.1016/j.quaint.2018.09.039.

Bhat, M. S., Alam, A., Ahmad, S., Farooq, H., Ahmad, B. (2019) Flood hazard assessment of upper Jhelum basin using morphometric parameters. Environ. Earth Sci. 78, 1–17. https://doi.org/10.1007/s12665-019-8046-1

Brown, J. D., Spencer, T., Moeller, I. (2007) Modeling storm surge flooding of an urban area with particular reference to modeling uncertainties : A case study of Canvey Island, United Kingdom. Water Resour Res. 43(6):1–22.

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. Geol Ecol Landscapes. 2(4):256–267. http://doi.org/10.1080/24749508.2018.1452482

Clarke, J. I. (1966) Morphometry from Maps. In: Dury, G.H., Ed., Essays in Geomorphology, Elsevier Publ. Co., New York, 235-274.

Cürebal, İ., Erginal, A. E. (2007) Mıhlı çayı havzası'nın jeomorfolojik özelliklerinin jeomorfik indislerle analizi. Elektron. Sos. Bilim. Derg. 19, 126–135.

Çiner, A. (2003) Recent Glaciers and Late Quaternary Glacial Deposits of Turkey. Geol. Bull. Turkey 46.

De Silva, S., Lindsay, J. M. (2015) Chapter 15 – Primary volcanic landforms. In H. Sigurdsson (Ed.), The encyclopedia of volcanoes (2nd ed., pp. 273–297). Amsterdam: Academic.

Dhanusree, M., Bhaskaran, G. (2019) GIS-Based Approach in Drainage Morphometric Analysis of Bharathapuzha River Basin, India. J. Geogr. Environ. Earth Sci. Int. 20, 1–12. https://doi.org/10.9734/jgeesi/2019/v20i130097

El Tahan, A. H. M. H., Elhanafy, H. E. M. (2016) Statistical analysis of morphometric and hydrologic parameters in arid regions, case study of Wadi Hadramaut. Arab. J. Geosci. 9, 1–10. https://doi.org/10.1007/s12517-015-2195-7

Eludoyin, A. O., Adewole, A. O. (2020) A remote sensing-based evaluation of an ungauged drainage basin in Southwestern Nigeria. Int J River Basin Manag. 18(3):307–319. https://doi.org/10.1080/15715124.2019.1640226

Elsadek, W. M., Ibrahim, M. G., Mahmod, W. E. (2019a) Runoff hazard analysis of Wadi Qena Watershed, Egypt based on GIS and remote sensing approach. Alexandria Eng. J. 58, 377–385. https://doi.org/10.1016/j.aej.2019.02.001

Elsadek, W. M., Ibrahim, M. G., Mahmod, W. E., Kanae, S. (2019b) Developing an overall assessment map for flood hazard on large area watershed using multi-method approach: case study of Wadi Qena watershed, Egypt. Nat. Hazards 95, 739–767. https://doi.org/10.1007/s11069-018-3517-3

Ergünay, O. (2007) Türkiyenin Afet Profili. In: TMMOB Afet Sempozyumu. Ankara; p. 1–14.

Farhan, Y., Anbar, A., Al-Shaikh, N., Mousa, R. (2017) Prioritization of Semi-Arid Agricultural Watershed Using Morphometric and Principal Component Analysis, Remote Sensing, and GIS Techniques, the Zerqa River Watershed, Northern Jordan. *Agricultural Sciences*, *08*(01), 113–

Fural, Ş., Poyraz, M. (2015) Değirmendere Havzası'nın (EDREMİT) Jeomorfolojik ve Hidrografik Özelliklerine Morfometrik Yaklaşım, New approaches in Geography, Dokuz Eylül Üniversitesi Yayinları, p. 495-508

Hadley, R. F., Schumm, S. A. (1961) Sediment Sources and Drainage Basin Characteristics in Upper Cheyenne River Basin. US Geological Survey Water-Supply Paper 1531-B, 198.

Hamdan, A., Khozyem, H. (2018) Morphometric, statistical, and hazard analyses using ASTER data and GIS technique of WADI El-Mathula watershed, Qena, Egypt. Arab. J. Geosci. 11. https://doi.org/10.1007/s12517-018-4068-3

Horton, R. E. (1932) Drainage-basin characteristics. Eos. Transactions American Geophysical Union 13 (1), 350e361.

Horton, R. E. (1945) Erosional development of streams and their drainage basins: hydro physical approach to quantitative morphology. Bull Geol Soc Am 56:275–370, 275e370.

Javed, A., Khanday, M. Y., Ahmed, R. (2009) Prioritization of sub-watersheds based on morphometric and land use analysis using Remote Sensing and GIS techniques. J Indian Soc Remote Sens. 37(2):261–274.

Karabulut, M. S., Özdemir, H. (2019) Comparison of basin morphometry analyses derived from different DEMs on two drainage basins in Turkey. Environ. Earth Sci. 78, 1–14. https://doi.org/10.1007/s12665-019-8585-5

Karaoğlu, M., Çelim, Ş. (2018) Doğu Anadolu Blgesi ve Iğdır'ın Jeolojisi ve Toprak Özellikleri. J. Agric. 1, 14–26. https://doi.org/10.3977/j.issn.1005-8478.2018.07.13

Ketin, İ. (1982) Türkiye Jeolojisine Genel Bir Bakış. İ.T.Ü Vakfı Yayınları, İstanbul.

Kim, J., Kuwahara, Y., Kumar, M. (2011) A DEM-based evaluation of potential flood risk to enhance decision support system for safe evacuation. Nat. Hazards 59, 1561–1572. https://doi.org/10.1007/s11069-011-9852-2

Koç, G., Petrow, T., Thieken, A. H. (2020) Analysis of the most severe flood events in Turkey (1960-2014): Which triggering mechanisms and aggravating pathways can be identified? Water (Switzerland). 12(6):1–32.

Koç, G., Thieken, A. H. (2018) The relevance of flood hazards and impacts in Turkey: What can be learned from different disaster loss databases? Nat Hazards. 91(1):375–408.

Komolafe, A. A., Awe B.S., Olorunfemi, I. E., Oguntunde, P.G. (2020) Modelling flood-prone area and vulnerability using integration of multi-criteria analysis and HAND model in the Ogun River Basin, Nigeria. Hydrol Sci J. 65(10):1766–1783. https://doi.org/10.1080/02626667.2020.1764960

Kumar, R. P., Narayan, M. V., Mohan, K. (2017) A study of morphometric evaluation of the Son basin, India using geospatial approach. Remote Sens. Appl. Soc. Environ. 7, 9–20. https://doi.org/10.1016/j.rsase.2017.05.001

Kumar, P., Joshi, V. (2019) A Geospatial- Statistical Approach To Alienate Priority Area of Upper Watershed of River Subarnarekha Using Morphometric Assessment Framework. Malaysian J Geosci. 3(1):21–31.

Kumar, R. (2016) Flood hazard assessment of 2014 floods in Sonawari sub-district of Bandipore district (Jammu & Kashmir): An application of geoinformatics. Remote Sens Appl Soc Environ. 4(November):188–203.

Krishnan, M. V. N., Prasanna, M. V., Vijith, H. (2017) Optimisation of morphometric parameters of Limbang river basin, Borneo in the equatorial tropics for terrain characterization. Model Earth Syst Environ. 3(4):1477–1490. http://dx.doi.org/10.1007/s40808-017-0394-9

Malik, A., Kumar, A., Kushwaha, D. P., Kisi, O., Salih, S. Q., Al-Ansari, N., Yaseen, Z. M. (2019) The implementation of a hybrid model for hilly sub-watershed prioritization using morphometric variables: Case study in India. Water. 11(6), 1138.

Martins, B., Nunes, A. (2020) Exploring flash flood risk perception using PCA analysis: The case of Mindelo, S. Vicente (Cape Verde). Geogr J.(July):1–15.

Mason, D. C., Horritt, M. S., Hunter., N. M., Bates, P. D. (2007) Use of fused airborne scanning laser altimetry and digital map data for urban flood modelling 1447, 1436–1447. https://doi.org/10.1002/hyp

Mayer, L. (1990) Introduction to quantitative geomorphology: an exercise manual. Prentice Hall, Englewood Cliffs

Melton, M. A. (1957). An analysis of the relations among elements of climate, surface properties and geomorphology (Project NR 389042, Tech. Rep. 11). New York, NY: Columbia University

Memon, N., Patel, D. P., Bhatt, N., Patel, S. B. (2020) Integrated framework for flood relief package (FRP) allocation in semiarid region: a case of Rel River flood, Gujarat, India. [place unknown]: Springer Netherlands. https://doi.org/10.1007/s11069-019-03812-z

Meshram, S. G., Sharma, S. K. (2017) Prioritization of watershed through morphometric parameters: a PCA-based approach. Appl Water Sci. 7(3):1505–1519.

Miller, V. C. (1953) A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area Virginia And Tennessee, , DTIC Document.

Morisawa, M. E. (1962) Quantitative geomorphology of some watersheds in the Appalachian Plateau. Geol Soc Am Bull 73(9):1025–1046

Mukherjee, F., Singh, D. (2019) Detecting flood prone areas in Harris County: a GIS based analysis. GeoJournal. 85(3):647–663. https://doi.org/10.1007/s10708-019-09984-2

Mundetia, N., Sharma, D., Dubey, S. K. (2018) Morphometric assessment and sub-watershed prioritization of Khari River basin in semi-arid region of Rajasthan, India. Arab J Geosci. 11(18).

Nag, S. K., Chakraborty, S. (2003) Influence of rock types and structures in the development of drainage network in hard rock area. J. Indian Soc. Remote Sens. 31, 25–35. https://doi.org/10.1007/bf03030749

Nicoll, K. (2010) Landscape development within a young collision zone: Implications for post-Tethyan evolution of the upper Tigris River system in southeastern Turkey. Int. Geol. Rev. 52, 404–422. https://doi.org/10.1080/00206810902951072

Nied, M., Pardowitz, T., Nissen, K., Ulbrich, U., Hundecha, Y., Merz, B. (2014) On the relationship between hydro-meteorological patterns and flood types. J Hydrol. 519:3249–3262. http://dx.doi.org/10.1016/j.jhydrol.2014.09.089

Nooka, R. K., Srivastava, Y. K., Venkateswara, R. V., Amminedu, E., Murthy, K. S. R. (2005) Check Dam positioning by prioritization micro-watersheds using SYI model and morphometric analysis - remote sensing and GIS perspective. J Indian Soc Remote Sens. 33(1):25–38.

Özdemir, H., Bird, D. (2009) Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point of floods. Environ. Geol. 56, 1405–1415. https://doi.org/10.1007/s00254-008-1235-y

Öztürk, M. Z., Çetinkaya, G., Aydın, S. (2017) Köppen-Geiger İklim Sınıflandırmasına Göre Türkiye'nin İklim Tipleri. Coğrafya Derg. 17–27.

Patel, D. P., Dholakia, M. B., Naresh, N., Srivastava, P. K. (2012) Water Harvesting Structure Positioning by Using Geo-Visualization Concept

and Prioritization of Mini-Watersheds Through Morphometric Analysis in the Lower Tapi Basin. J. Indian Soc. Remote Sens. 40, 299–312.
https://doi.org/10.1007/s12524-011-0147-6

Patton, P. C. (1988) Drainage basin morphometry and floods. In: Baker VR, Kochel, RC, Patton, PC, editors. Flood geomorphology. New York: Wiley, p. 51-65.

Pike, R. J., Wilson S. E. (1971) Elevation-relief ratio, hypsometric integral and geomorphic area-altitude analysis. Bull Geol Soc Am 82(4):1079–1083

Poyraz, M, Taşkın, S., Keleş, K. (2011) Morphometric approach to geomorphologic characteristics of Zeytinli Stream basin. Elsevier, Procedia - Social and Behavioral Sciences 19, 2011, Pages 322-330.
https://doi.org/10.1016/j.sbspro.2011.05.138

Rahmati, O., Samadi, M., Shahabi, H., Azareh, A., Rafiei-Sardooi, E., Alilou, H., Melesse, A. M., Pradhan, B., Chapi, K., Shirzadi, A. (2019) SWPT: An automated GIS-based tool for prioritization of sub-watersheds based on morphometric and topo-hydrological factors. Geosci Front. 10(6):2167–2175.

Rakesh, K., Lohani, A. K., Sanjay, C. C., Nema, R. K. (2000) GIS based morphometric analysis of Ajay river basin up to Sararath gauging site of south Bihar. J Appl Hydrol 14(4):45–54

Ritter, D. F., Kochel, R. C., Miller, J. R. (2002) Process geomorphology. McGraw Hill, Boston.

Sakthivel, R., Jawahar, R. N., Sivasankar, V., Akhila, P., Omine, K. (2019) Geo-spatial technique-based approach on drainage morphometric analysis at Kalrayan Hills, Tamil Nadu, India. Appl Water Sci. 9(1):1–18.
https://doi.org/10.1007/s13201-019-0899-7

Sarangi, A., Bhattacharya, A.K., Singh A., Singh, A.K. (2001) Use of geographic information system (GIS) in assessing the erosion status of watersheds. Indian J Soil Conserv 29, 190-195.

Schumm, S.A. (1956) Evolution of drainage systems and slopes in Badlands at Perth Amboy New Jersey. Geological Society of America Bulletin, 67, 597–64.

Shadmehri Toosi, A., Calbimonte, G.H., Nouri, H., Alaghmand, S. (2019) River basin-scale flood hazard assessment using a modified multi-criteria decision analysis approach: A case study. J. Hydrol. 574, 660–671.
https://doi.org/10.1016/j.jhydrol.2019.04.072

Sharma, S.., Gajbhiye, S., Nema, R.., Tignath, S. (2015) Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS Assessing the vulnerability to soil erosion sensing and GIS. Int. J. Sci. Innov. Eng. Technol. 1.
https://doi.org/10.1080/02626660209492905.

Siddiqui, R., Said, S., Shakeel, M. (2020) Nagmati River Sub-watershed Prioritization Using PCA, Integrated PCWS, and AHP: A Case Study. Nat Resour Res. 29(4):2411–2430.
https://doi.org/10.1007/s11053-020-09622-6

Singh, N., Singh, K. K. (2017) Geomorphological analysis and prioritization of sub-watersheds using Snyder's synthetic unit hydrograph method. Appl Water Sci. 7(1):275–283.

Skilodimou, H. D., Bathrellos, G. D., Chousianitis, K., Youssef, A. M., Pradhan, B. (2019) Multi-hazard assessment modeling via multi-criteria analysis and GIS: a case study. Environ Earth Sci. 78(2):78–47. http://dx.doi.org/10.1007/s12665-018-8003-4

Smith, K. G. (1950) Standards for grading texture of erosional topography. American Jour. Science, v.248, pp.655-668.

Sreedevi, P. D., Owais, S., Khan, H. H., Ahmed, S. (2009) Morphometric analysis of a watershed of South India using SRTM data and GIS. J. Geol. Soc. India 73, 543–552.
https://doi.org/10.1007/s12594-009-0038-4.

Sreedevi, P. D., Subrahmanyam, K., Ahmed, S. (2005) The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environ. Geol. 47, 412–420.
https://doi.org/10.1007/s00254-004-1166-1

Strahler, A. N. (1952). Dynamic basis of geomorphology. Geological Society of America Bulletin, 63, 923_938.

Strahler, A. N. (1957) Watershed geomorphology. Am Geophys Union Trans 38(6):913–920.

Strahler, A. N (1958) Dimensional analysis applied to fluvially eroded landforms. Geol Soc Am Bull 69:279–300.

Strahler, A. N. (1964) Quantitative geomorphology of drainage basin and channel network. Handbook of Applied Hydrology. pp. 39–76.

Şaroğlu, F., Y. Güner, (1979) The active Tutak fault, its characteristics and relations to the Çaldıran fault, Yeryuvarı ve İnsan 4, 11-14.

Thomas, J., Prasannakumar, V. (2015) Comparison of basin morphometry derived from topographic maps, ASTER and SRTM DEMs: an example from Kerala, India. Geocarto Int. 30, 346–364.
https://doi.org/10.1080/10106049.2014.955063

Utlu, M., Özdemir, H. (2018) The Role of Basin Morphometric Features in Flood Output: A Case Study of the Biga River Basin. J. Geog. 36, 49–62. https://doi.org/10.26650/JGEOG408101

Vijith, H., Satheesh, R., (2006) GIS based morphometric analysis of two major upland sub-watersheds of Meenachil river in Kerala. J. Indian Soc. Remote Sens. 34, 181–185. https://doi.org/10.1007/BF02991823

Yulu, A. (2019) Friedrich Parrot'un Ağrı Dağı Araştırma Keşif Gezisi, Coğrafya Dergisi, 38:49-58. https://doi.org/10.26650/JGEOG2019-0003

Waiyasusri, K., Chotpantarat, S. (2020) Watershed prioritization of kaeng lawa sub-watershed, khon kaen Province using the morphometric and land-use analysis: A case study of heavy flooding caused by tropical storm podul. Water (Switzerland). 12(6).

Youssef, A. M., Pradhan, B., Hassan, A. M. (2011) Flash flood risk estimation along the St. Katherine road, southern Sinai, Egypt using GIS based morphometry and satellite imagery. Environ. Earth Sci. 62, 611–623.

https://doi.org/10.1007/s12665-010-0551-1

URL-1 https://igdirhaberleri.wordpress.com/2012/07/15/sel-igdir-ve-agrida-hasara-yol-acti/

URL-2 https://www.haberler.com/igdir-da-koyu-sel-sulari-basti-4687557-haberi/

URL-3 http://haberciniz.biz/igdirda-koyu-sel-sulari-basti-2072184h.htm

URL-4https://www.yenisafak.com/foto-galeri/gundem/igdir-da-sel-manzaralari-2011609?page=1