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ORIGINAL ARTICLE

Flood Susceptibility Modeling of Megech River Catchment, Lake Tana Basin, North Western Ethiopia, Using Morphometric Analysis

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Abstract

The present study intended to flood susceptibility modeling by using drainage morphometric investigations of the Megech River catchment, Lake Tana Basin, North Western Ethiopia. Drainage morphometric criterion study performs a critical aspect in recognizing the factual aspects of river catchment with concern to floods. In the present study, we depicted the Megech River catchment into four sub-watersheds, followed by clipping off the drainage grid by using ALOS-PALSAR (Advanced Land Observing Satellite-Phased Array-Type L-Band Synthetic Aperture Radar) digital elevation model, toposheets, and Landsat-8 Operational Land Imager coupled with the Geographic Information System (GIS) program. The drainage morphometric parameters, such as basic, linear, areal and relief, were calculated in the current research by using the standard formula. The morphometric parameters, such as bifurcation ratio, drainage density, length of overland flow and drainage frequency, have a direct connection with flood susceptibility. Hence, rank 1 assigned to the highest values of the above-mentioned parameters followed by second-rank to second-highest value and rank third given the lowest value of the above parameters. The morphometric parameters, such as circulatory ratio, form factor, elongation ratio, drainage texture and compactness coefficient, have a reverse relation with flood proneness. Hence, rank 1 assigned to the lowest values of those parameters, followed by rank two to the second-lowest value and rank three given to the highest value of the above parameters. The compound factor is computed by aggregating the assigned ranks of the morphometric drainage parameters mentioned above and then dividing by the number of morphometric criteria used for sub-watersheds prioritization. The results of the present study displayed sub-watershed 3 scored very high prioritization (Ist), including a compound factor value of 1.89, and sub-watershed 2 got the highest compound factor value of 3.11, and it scored the lowest rank (IVth). The found sub-watershed 3 in the current research area was acquired as a high-priority grade one, and it demands urgent flood regulation remedies for competent water budget devising and administration in the Megech catchment area. The current study demonstrates the capability of sub-watershedwise drainage morphometric investigations in the flood susceptibility analysis using toposheets, optical remote sensing data and digital elevation model associated with GIS tools.

Keywords Morphometry analysis · Flood susceptibility modeling · Megech river catchment · Lake Tana basin · Ethiopia

1 Introduction

Floods are the reason for one-third risk in the biosphere (Adhikari et al. 2010) and are instigating maximum losses to the infrastructure and environment and major threat to the population in the regions in which they occur (CEOS 2003; Bajabaa et al. 2014; Elnazer et al. 2017). The long torrential rain events in the highlands of Ethiopia cause river overflow, breaching courses and submergence of the floodplains. Factors such as overgrazing, poor land management practices and lack of technological inputs are causes for river catchment's land degradation in Ethiopia (Nyssen et al. 2004). This results in more surface runoff and sediment loads in the rivers and fluctuation of water flow (Zegeye et al. 2010). Floods are very common and happening throughout the Ethiopia by varying scale and time. Flood intensity and extent of damage have become increasing time to time in Ethiopia. Further, the monsoon season is only 4 months (June to September) of the year, and most parts of Ethiopia receive more than 85% of the precipitation within these four months. It

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has noticed that flood hazards are taken place within these four months in different parts of the country (Abebe 2007; Getahun and Gebre, 2015). In the year 2006, flood occurred in almost all the regions of the Ethiopia and Lake Tana Basin is one of those regions and the impact of flood was very severe (Ayenew et al. 2007).

Flood catastrophes are initiated by rivers excess flow or spurt their banks and deluge to downstream plain area; mostly large-scale flooding in Ethiopia is very common in the low and flat area due to high concentration of precipitation from highland (Achamyeleh 2003; Chibssa 2007; Alemu 2011, 2015; Getahun and Gebre 2015). In Ethiopia, floods are very common events particularly in Gambela Plain in the Baro-Akobo Basin, Awash River plain, the downstream portions of Wabi-Shebele Basin and the lower reaches of major catchments in Lake Tana Basin (Achamyeleh 2003). The downstream reaches of Megech, Rib, Gumara and Gilgel Abay rivers in Lake Tana Basin are highly susceptible for flooding (SMEC 2007; Assefa et al. 2008). The fast-growing population, exploitation of the forest area for cultivation and settlement purposes have led to environmental deterioration. The above-mentioned causes are reason for soil erosion and flooding in the Megech River catchment (Assefa et al. 2008; Getahun and Gebre 2015).

Floods make a substantial challenge to catchment management. Flood susceptibility modeling is very significant for the management of river catchments (i.e., water resources sustainability, flood protection and drought management). Drainage morphometric characteristics considerably influence the flood proneness of the river catchment. Drainage morphometry analysis offers details of the overall landscape setup, hydrological circumstances, soil abrasion and mass displacement features of the river catchment (Baumgardner 1987; Eze and Efiong 2010). The morphometric investigation is a quantifiable measurement of landscape shape, and it is accomplished through the mathematical calculation of primary, linear, shape and relief morphometric characteristics of the river catchment (Clark 1966; Keller and Pinter 1996; Agarwal 1998; Sahu et al. 2017).

Drainage morphometric analysis is a useful method for developing the regional hydrological models at catchment level for resolving different hydrological problems of the ungauged catchment in the absence of data availability situations (Gajbhiye et al. 2014). 'Drainage morphometric analysis is an established system to know the process of the surface drainage system and characteristics of the river catchment' (Horton 1932, 1945; Smith 1950; Miller 1953; Schumn 1956; Strahler 1957, 1964). Drainage morphometric investigations are helpful for recognizing the river catchment's hydrological nature and rate the sub-watersheds based on their flood susceptibility nature (Boulton 1968; Patton and Baker 1976; Gardiner and Park 1978; Patton 1988; Khan et al. 2001; Nag and Chakraborty 2003; Al-Daghastani and Al-Maitah 2006; Roughani et al. 2007; Esper Angillieri 2008; Javed et al. 2009; Ozdemir and Bird 2009; Sreedevi et al. 2009; Akram et al. 2011; Youssef et al. 2011; Patel et al. 2012; Jasmin and Mallikarjuna 2013; Tripathi et al. 2013; Masoud 2016; Satheesh kumar and Venkateswaran 2018).

Bagyaraj and Gurugnanam (2011), Altaf et al. (2013), Kandpal et al. (2017), Meshram and Sharma (2017) and Prakash et al. (2019) employed morphometric investigation for prioritization studies in appraisal of soil erosion situation in the watershed. Jasmin and Mallikarjuna (2013) approximated the groundwater potential using morphometric analysis. Subsequent researchers employed drainage morphometric investigation for different purposes: examined plant growth expansion capacity (Kadam et al. 2017), sediment yield and flood hazard estimation (Altaf et al. 2014; Farhan and Anaba 2016; Prabhakar et al. 2019), and groundwater artificial recharge and soil conservation implementation site selections (Rekha et al. 2011; Jasmin and Mallikarjuna 2013; Wani and Javed 2013; Soni 2017; Choudhari et al. 2018).

The following authors (Horton 1945; Smith 1950; Strahler 1957) adopted traditional approaches such as topographic maps and field checks for morphometric characterization of river catchments. However, the digital elevation models (DEMs) obtained from remote-sensing instruments coupled with Geographic Information System (GIS) technology are shaped the estimation of the drainage morphometry has added high precise, speedy and practical (Bertolo 2000). Smith and Sandwell 2003; Kaliraj et al. 2015; Cunha and Bacani 2016; Girish et al. 2016; Kannan et al. 2018 have used a 90-m spatial resolution, (SRTM-DEM) Shuttle Radar Topographical Mapper-Digital Elevation Model for morphometric analysis and prioritization of the watershed. A 30-m spatial resolution (ASTER-GDEM), Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model, has been employed for the abstraction of morphometric drainage criterion by subsequent scholars (Forkuor and Maathuis 2012; Das et al. 2016; Yadav et al. 2014; 2016; Charu and Shivendra 2017; Muzamil et al 2017; Uday et al 2018; Pandian et al. 2019; Muralitharan et al 2020).

The SRTM and ASTER DEM have a rough spatial resolution such as 90 and 30 m, respectively. In the present study, Advanced Land Observing Satellite-Phased Array-Type L-Band Synthetic Aperture Radar digital elevation model (DEM), (ALOS-PALSAR) data were used, and it has a 12.5-m spatial resolution. ALOS-PALSAR is more refined DEM data, and it is highly suitable for extracting drainage networks and performing an accurate morphometric evaluation (Nitheshnirmal et al. 2020; Niipele and Chen 2019).

In this background drainage morphometric study plays a major part in the river catchment administration. But, till now in the Megech River catchment no research has been carried out on drainage morphometric investigation through remote sensing and GIS techniques. Therefore, the key purpose of this current study is to investigate the drainage morphometric parameters utilizing digital elevation model, optical satellite data, toposheets and GIS tools and prioritization of the sub-watersheds to identify the flood susceptible area in the Megech River catchment. And the current study is the leading of its kind in the present study area.

2 Materials and Methods

2.1 Study Area

The Megech River catchment is a part of Lake Tana Basin, and it is located between latitudes 12° 15′48″ to 12°45′17″ N and longitudes 37°21′31″ to 37°36′56″ E in North Western Ethiopia. Figure 1 shows the study area map. It has an area of 560 km^2, and Megech River is one of the source catchments of River Blue Nile. The Angreb River and Dimaza River are the major tributaries of the Megech River. The annual mean rainfall of the Megech catchment is 1100 mm, and the annual average maximum and minimum temperature is 28 and 15 °C, respectively (EMS 2019). The northern part of Megech River catchment is characterized by a hilly region, and having wedge-shaped sharp slopes but the southern part, near to Lake Tana, is characterized by flat low-lying land by poor drainage situations (WWDSE and Tahal Group 2008). The study area's elevation and slope maps were prepared from the ALOS-PALSAR-DEM. The study area elevation ranges from 1781 to 2896 m above mean sea level (Fig. 2). The Megech River catchment has a gentle slope to extremely steep slopes and the slope values ranging from 0° to 74° (Fig. 3).

The lithology of Ethiopia contains a mixture of a hard-basaltic rock basement, additional crystalline invasive rocks, volcanic rocks associated with the East African Rift System and sedimentary rocks of different geological ages (Smedley 2001). The major lithological units of northern part of the present study area are Termaber basalt with different weathering natures, and the age of this rock unit is Late to Middle Tertiary. The lower southern part of the catchment is covered by Quaternary lacustrine sediments (GSE 2011, 2013; Abbate et al. 2015). According to FAO (2006), the main

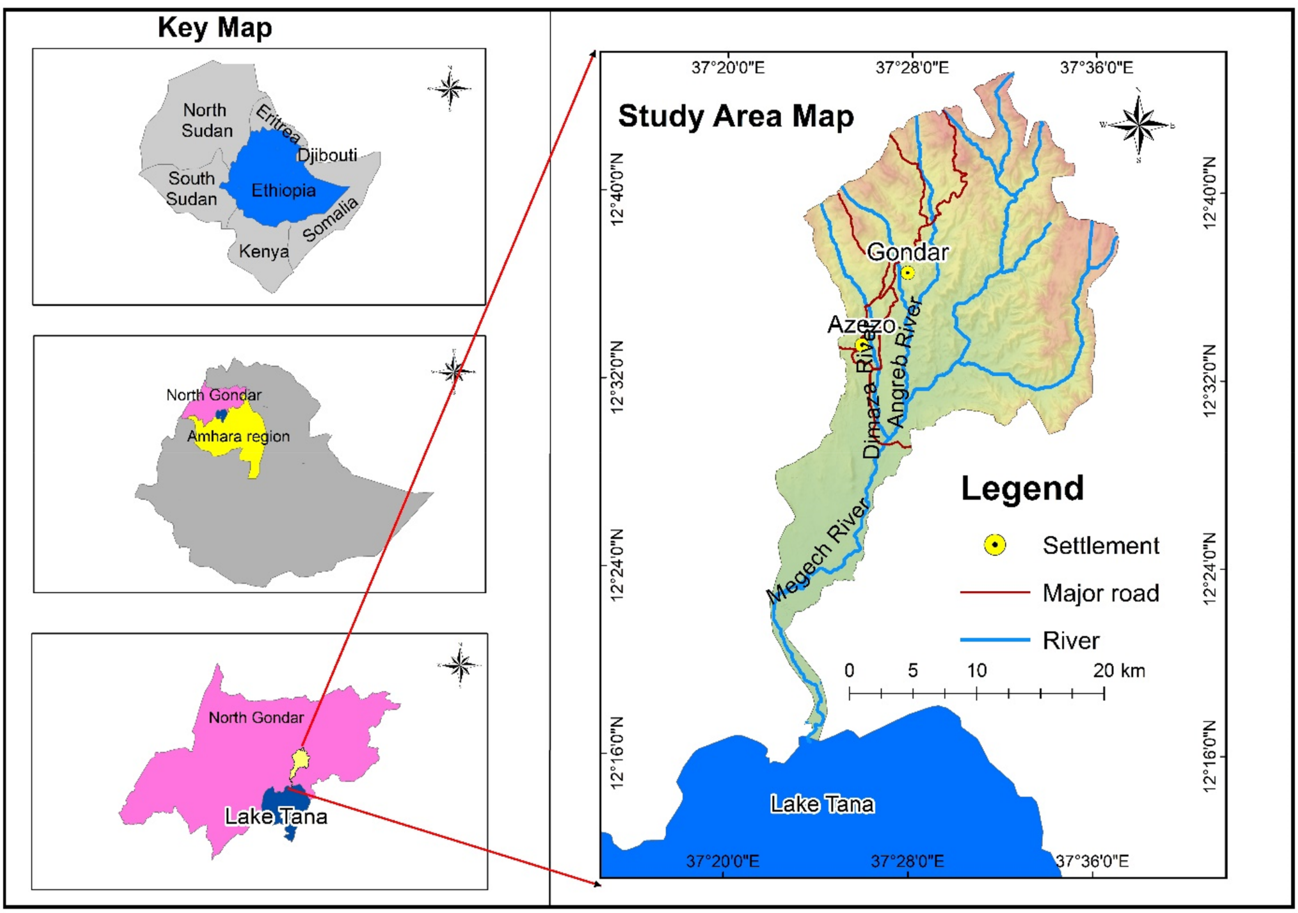

Fig. 1 Study area map

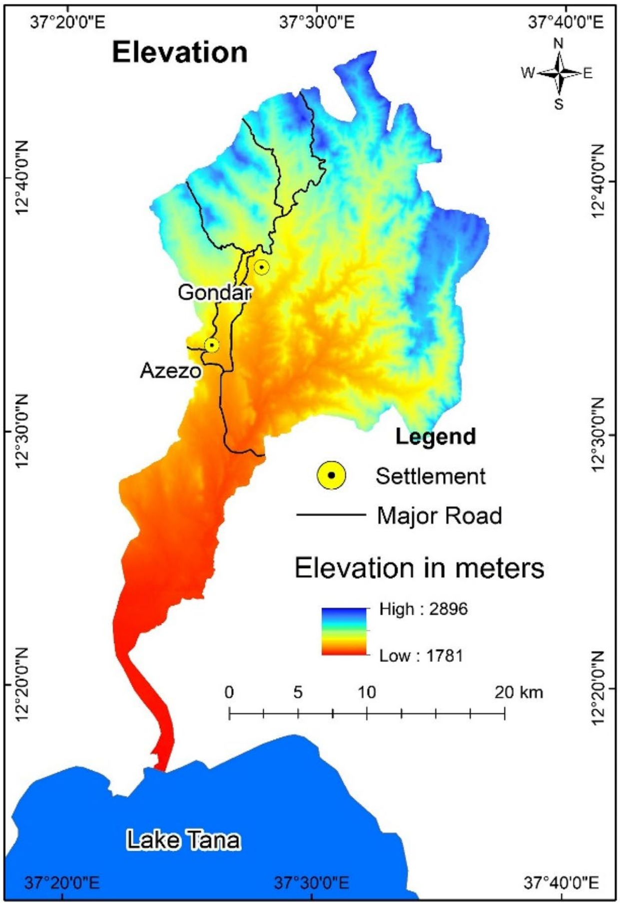

Fig. 2 Elevation map

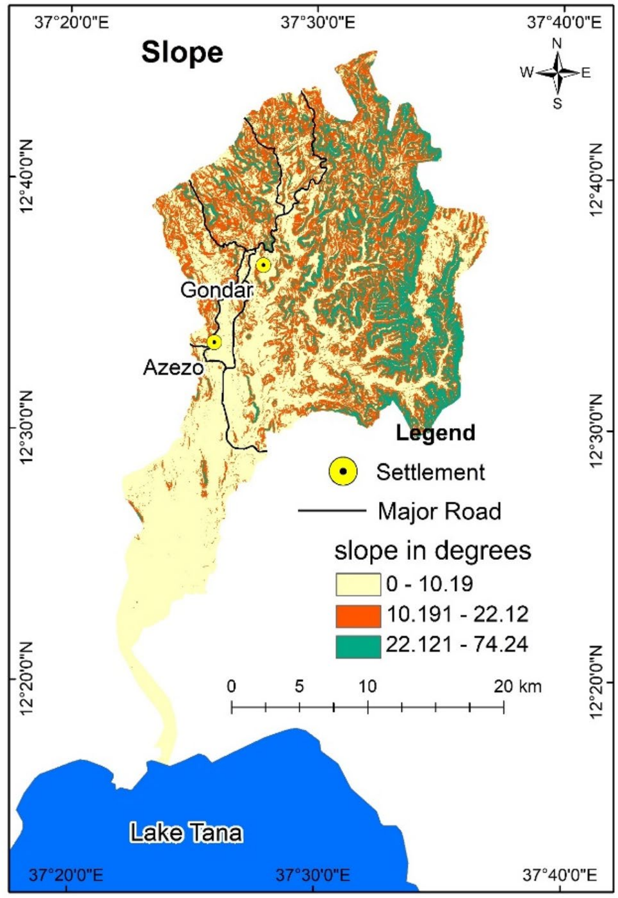

Fig. 3 Slope map

soil types in the present study area comprise Luvisols, Leptosols, Vertisols, Luvisols and Calcisols. The study area's land use/land cover map has prepared using Landsat-8 OLI data coupled with supervised image classification technique and through field studies. The Megech watershed mainly comprises the following land use/land cover types such as agricultural land, grassland, shrub land, forest, water bodies and settlements.

2.2 Materials

The following datasets were used in the present study: (1) The Ethiopian Mapping Agency's toposheets number (1237 A4, 1237 B3, 1237 C2 and 1237 D1) at the scale of 1:50,000 were used in the present study to demarcate the Megech River catchment border. (2) From the Alaska Satellite Facility site, ALOS-PALSAR RTC DEM with a spatial resolution of 12.5 m was downloaded and it was utilized to abstract the drainage system for executing drainage morphometric analysis. (3) The cloud-free optical satellite data acquired by Landsat-8 Operational Land Imager (OLI) with path-row numbers 170-051 obtained on February 22, 2018, was also inputting in the following portal (https://earthexplorer.usgs.gov/), and the same was utilized to correct and update the drainage system of the current study area.

2.3 Methods

2.3.1 Extraction of Drainage Networks and Demarcation of Sub-Watersheds Boundaries

The sub-watersheds boundary delineation and extraction of the drainage network carried out in ESRI ArcGIS v10.6.1 software coupled with ESRI Spatial Analyst and Arc Hydro tool extension. We followed the step-by-step DEM processing techniques via fill sinks, flow direction, flow accumulation, stream definition, extract the drainage networks and sub-watershed boundary demarcation. The Megech River basin is divided into four sub-watersheds based on the drainage networks, namely, SW-1, SW-2, SW-3 and SW-4. The Megech River catchment's drainage system and sub-watershed boundaries are shown in Fig. 4.

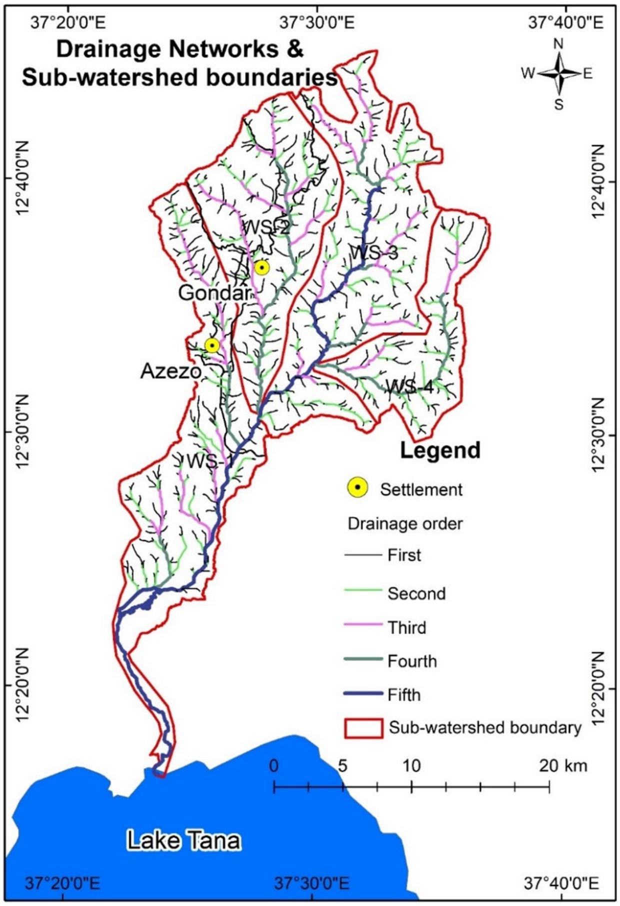

Fig. 4 Drainage network and sub-watershed boundary map

3 Results and Discussion

We calculated the following drainage morphometric parameters from using the standard formula, viz: the number of streams, stream order, area and perimeter these criteria grouped into primary drainage morphometric parameters. Stream length (*Lu*) and bifurcation ratio (R_b) were calculated and included in linear drainage morphometric criteria. Drainage frequency (F_s), drainage density (D_d), elongation ratio (R_e), form factor (F_f), circulatory ratio (R_c), length of overland flow (L_g) and compactness coefficient calculated and included in areal drainage morphometric parameters. The morphometric relief parameters calculated include catchment relief (*c*), ruggedness number (*Rn*) and relief ratio (R_r). Table 1 shows the morphometric parameters and their corresponding formulae adopted in the current study.

3.1 Linear Morphometric Parameters

The early step in the drainage morphometric characterization of a river catchment is a description of the streamline; it was measured as suggested by Strahler (1964) in the current study. Stream order always rises from the top catchment area and decreases to the lower catchment area (Horton 1945). We categorized stream orders in the Megech River catchment up to the fifth order. SW-1 and SW-3 show the fifth-order drainage patterns, SW-2 and SW-4 exhibiting fourth-order drainages. Table 2 shows the order-wise drainage numbers. A total of 5126 streamlines were analyzed in the present study area. Among these, 50% (2583) is first order, second order is 22% (1113), third order is 13% (651), 10% (529) and 5% (250) are the fourth- and fifth-order stream percentages and numbers, respectively. Further, the sub-watershedwise total drainage length is, viz SW-1 in 259 km, 204 km in SW-2, 258 km in SW-3 and 120 km in SW-4. We give the results of drainage length in (Table 2).

The proportion of the number of streams of a specific order 'u' to the sum of streams of above-order '$u+1$' termed the bifurcation ratio, and it is an indicator of the catchment shape. An elongated catchment has anticipated having a higher bifurcation ratio, while a circular catchment is anticipated to have a low bifurcation ratio (Schumn 1956). In the present study area, SW-4 displayed an elongated shape and its bifurcation ratio value (2.45), and it is approximately higher than another three sub-watersheds, whereas SW-2 is roughly circular and its bifurcation ratio value (1.56) is comparatively less than another three sub-watersheds. If mean bifurcation value is >5, then it is indicating that some sort of geological control over the drainage network (Parveen et al. 2012; Kuchay and Bhat 2013). If the mean bifurcation value is low, the catchment produces a sharp peak in discharge, and if the mean bifurcation value is high, the catchment yields low, but lengthy peak flow (Chorley 1969; Agarwal 1998). Generally, the bifurcation ratio value is between two and five where drainage network is well developed. Table 3 shows the bifurcation ratio value and mean bifurcation value of each sub-watershed, and the same varied from 1.75 in SW-1, 1.56 in SW-2, 1.88 in SW-3 and 2.45 in SW-4.

3.2 Areal Drainage Morphometric Parameters

The length of the drainage is one of the important morphometric criteria of the river basin. Sub-watersheds 2 and 3 show the maximum and minimum basin length, respectively. The basin length varied from 24, 21, 25 and 16 km in SW-1 to 4, respectively (Table 3). The calculated basin perimeter varied from 115 km in SW-1, 57 km in SW-2, 109 km in SW-3 and 58 in SW-4 (Table 3). The area of the sub-watershed is an additional significant morphometric parameter. The ArcGIS calculation geometry tool was used to calculate each sub-watershed area, and it varied in 168 km^2 in SW-1, 134 km^2 in SW-2, 177 km^2 in SW-3 and 80 km^2 in SW-4, as specified in (Table 4).

The compactness coefficient values are calculated for the study region, which varied from 2.50 in SW-1, 0.72 in SW-2,

Table 1 Morphometric parameters with formulae and references

S. no.	Morphometric parameters	Formulae with references
1	Drainage order (*u*)	Hierarchical rank, Strahler (1964)
2	Drainage number (*Nu*)	Total number of drainage segments in the order '*u*', Horton (1945)
3	Drainage length (*Lu*)	Length of the drainage, Horton (1945)
4	Bifurcation ratio (R_b)	$R_b = Nu/N(u+1)$ Nu = The total number of drainage segments of the order '*u*' and $N(u+1)$ = number of drainage segments of the next higher order, Schumn (1956)
5	Mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratios of all orders, Strahler (1957)
6	Basin length (L_b)	$1.312 \times A^{0:568}$ L = basin length (km), A = area of the basin (km^2), Nookaratnam et al. (2005)
7	Basin perimeter (*P*) (km)	GIS analysis, Schumm (1956)
8	Drainage frequency (F_s)	$F_s = \Sigma Nu/A$ Nu = total number of drainage segments, A = area of the watershed (km^2), Horton (1932)
9	Drainage density (D_d)	$D_d = \Sigma L/A$ L = drainage total length, A = area of watershed, Horton (1932)
10	Form factor (R_f)	$R_f = A/{L_b}^2$ A = basin area, L_b = basin length, Horton (1932)
11	Circulatory ratio (R_c)	$R_c = 4\pi A/P^2$ A = basin area (km^2) and P = basin perimeter (km), Miller (1953)
12	Drainage texture (D_t)	$D_t = N_1/P$ N_1 = the total number of first-order drainage; P = watershed perimeter, Horton (1945)
13	Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$ A = watershed area, $\pi = 3.14$, L_b = basin length, Schumn (1956)
14	Compact coefficient (C_c)	$C_c = P/2\sqrt{\pi}$ P = basin perimeter (km) and A = basin area (km^2), Horton (1945)
15	Length of overland flow (L_g)	$L_g = 1/2D_d$ D_d = drainage density, Horton (1945)
16	Basin relief (*H*) (m)	$H = H–h$ H = basin relief, H = maximum elevation (m), h = minimum elevation (m), Schumn (1956)
17	Relief ratio (R_r)	$R_r = H/L_b$ R_r = relief ratio, H = basin relief L_b = basin length, Schumn (1956)
18	Relative relief (R_r)	$R_r = H/L_p$ H = basin relief, L_p = basin perimeter, Schumn (1956)
19	Ruggedness number (*Rn*)	$Rn = H \times D_d$ Rn = ruggedness number, H = basin relief, D_d = drainage density, Schumn (1956)

Table 2 Sub-watershedwise morphometric analysis's results

Sub-watersheds	Streams number of each order (*Nu*)						Orderwise stream length (*Lu*) in km					
	Ist	IInd	IIIrd	IVth	Vth	Total	Ist	IInd	IIIrd	IVth	Vth	Total
WS-1	944	377	265	117	145	1848	117	49	35	14	44	259
WS-2	585	278	154	201	–	1218	107	41	32	24	–	204
WS-3	719	313	202	66	105	1405	117	57	41	16	27	258
WS-4	335	145	30	145	–	655	59	30	12	19	–	120

0.43 in SW-3 and 0.55 in SW-4 (Table 4). Flood proneness of the sub-watershed is direct propionate with a compactness coefficient value. Lower values of compactness coefficient signify less flood proneness. At the same time, higher values show considerable flood proneness in the watershed (Chopra et al. 2005; Gajbhiye et al. 2014), which represents the same demand for implementation of flood management measures.

The form factor is another important morphometric parameter in flood proneness studies. The higher the form factor value, the more the chance for the flood and vice versa (Chopra et al. 2005; Gajbhiye et al. 2014). The form factor value calculated in this study differed from 0.16 to 0.22 and suggested a flatter peak flow to a great extent. Table 4 shows the sub-watershedwise form factor value.

Table 3 Sub-watershedwise morphometric analysis's results

Bifurcation ratio						R_{bm}	L_b
Sub-watersheds	1/2	2/3	3/4	4/5	5/6		
WS-1	2.50	1.42	2.26	0.81	–	1.75	24
WS-2	2.10	1.81	0.77	–	–	1.56	21
WS-3	2.30	1.55	3.06	0.63	–	1.88	25
WS-4	2.31	4.83	0.21	–	–	2.45	16

R_{bm} = mean bifurcation ratio, R_l = stream length ratio, L_b = basin length in kms

Table 4 Sub-watershedwise morphometric analysis's results

Sub-watersheds	A	P	C_c	F_f	R_e	R_c	D_d	D_f	D_t	L_g
WS-1	168	115	2.50	0.29	0.61	0.16	1.54	11.00	8.21	0.32
WS-2	134	57	0.72	0.30	0.62	0.52	1.52	9.09	10.26	0.33
WS-3	177	109	0.43	0.28	0.60	0.19	1.46	7.94	6.60	0.34
WS-4	80	58	0.55	0.31	0.63	0.30	1.50	8.19	5.78	0.33

A = area, P = perimeter, D_f = drainage frequency, D_d = drainage density, F_f = form factor, R_c = circulatory ratio, D_t = drainage texture, R_e = elongation ratio, C_c = compact coefficient and L_g = length of overland flow

The prevailing climatic conditions and underlying geology of the watershed control the elongation ratio values (Miller 1953). The circular watershed has an elongation value of 1, whereas the elongated basin has an elongation value of < 0.5. The watershed with a higher elongation value has higher runoff potential and lower infiltration capacity (Chopra et al. 2005; Gajbhiye et al. 2014). The calculated elongation ratio values varied from 0.61, 0.62, 0.60 and 0.63 in SW-1 to 4, respectively. Horton (1945) grouped elongation values into 3 classes: (> 0.9) circular, (0.9–0.8) oval and (< 0.7) elongated. The current study region's sub-watersheds show that the elongation ratio values are < 0.7, and hence signifies the catchment shape is elongated. Table 4 shows the elongation ratio values of each sub-watershed. The circulatory ratio represents the architecture of the watersheds. The land use/land cover pattern, climatic conditions, elevation, nature of the slope, stream frequency and lithology are the controlling factors of the circulatory ratio values (Patel et al. 2013). The circular watershed has a high circulatory ratio value, whereas an elongated watershed has a low circulatory ratio value. The sub-watershedwise calculated circulatory ratio values varied from 0.16, 0.52, 0.19 and 0.30 in SW-1 to 4, respectively, as shown in Table 4. The peak circulatory ratio value of 0.52 was noticed in SW-2, meant an approximately circular aspect of the sub-watershed.

Drainage density shows the natural properties of the concealed rocks of the region. The study drainage density values differed from 1.54 km/ km^2, (SW-1), 1.52 km/ km^2, (SW-2), 1.46 km/ km^2, (SW-3), and 1.50 km/ km^2, (SW-4) (Table 4). Less drainage density results in an area where permeable subsoil material is present, solid vegetative coverage, low elevation and rough drainage texture. A higher drainage density is the result of the moderate impermeable subsurface, scant vegetative coverage, steep relief and fine drainage texture (Prabu and Baskaran 2013; Choudhari et al. 2018). Drainage network and underlying geological structures determine the drainage frequency nature of the watershed (Farhan et al. 2017). The different drainage frequency values are seen in the present study area's sub-watersheds. We observed a high drainage frequency value in SW-1 and SW-2, which shows resistant subsurface medium and high elevation. In contrast, a low drainage frequency appeared in SW-3 and SW-4 and characterized the porous sub-surface medium with low relief. In Table 4, we give the computed drainage frequency values.

The coarse drainage texture is the result of hard rock and sparse vegetation. However, fine drainage texture is the result of weathered rock and dense vegetation (Elsiad et al. 2017). According to Altaf et al. 2014, the drainage texture has direct propionate to flood proneness and vice versa. Sub-watershedwise drainage texture values were calculated and differed from 8.21, (SW-1), 10.26, (SW-2), 6.60, (SW-3), and 5.78, (SW-4) (Table 4). The watershed with a higher length of overland flow value has a gentle slope and vice versa. The watershed, which has a low length of overland flow value, has a high chance for flooding proneness and vice versa (Kumar et al. 2014). The maximum length of overland flow value (0.34) is seen in SW-3 in the current study region. Table 4 shows the sub-watershedwise length of overland flow values.

3.3 Relief Morphometric Parameters

It defines the change amid the maximum, and the minimum height points of the river catchment are defined as relief of the basin (R). Basin relief disciplined the stream gradient

Table 5 Sub-watershedwise morphometric analysis's results

Sub-watersheds number	Maximum elevation in meters	Minimum elevation in meters	Basin relief (H) (m)	Relief ratio (R_r)	Ruggedness number (Rn)	Relative relief (R_r)
WS-1	2687	1781	906	0.38	1.332	7.88
WS-2	2870	1882	988	0.47	1.383	17.33
WS-3	2896	1881	1015	0.41	1.330	9.31
WS-4	2824	1947	877	0.55	1.140	15.12

in the river catchment, and it determines the pattern of the flood and the supply of sediment transportation. Basin relief also performs an important role in the occurrence of basins, landform evolution, subsurface and surface water flow, determining the permeability of the river basin. The basin relief value for the current study area varied from 906 m in (SW-1), 988 m in (SW-2), 1015 m in (SW-3) and 877 m in (SW-4) (Table 5). The 2896 m and 1781 m are the highest and lowest elevations of the present study area, respectively (Table 5). The rock type and basin slope manage the relief ratio of the catchment. The hilly region is characterized by high relief ratio values, whereas pediplains and valleys have unique low relief values. The relief ratio value for the study area varied from 0.38 in (SW-1), 0.47 in (SW-2), 0.41 in (SW-3) and 0.55in (SW-4) (Table 5). The high values of the ruggedness number recommend structural complications and sensitive to flooding, while on the reverse, low values indicate less proneness to flooding. The ruggedness number of each sub-watershed was calculated and varied from 1.332, (SW-1), 1.383, (SW-2), 1.330, (SW-3), and 1.140, (SW-4) (Table 5).

3.4 Priority Ranking

The Megech River catchment sub-watersheds were taken in the present study for prioritizing them based on the morphometric parameter's analysis. Drainage frequency (D_f), drainage density (D_d), bifurcation ratio (R_b), elongation ratio (R_e), compactness coefficient (C_c), circulatory ratio (R_c), form factor (F_f), drainage texture (D_t) and length of overland (L_g) were considered for sub-watershedwise prioritization. The same was measured using the standard formula and ranked based on their flood susceptibility. R_b, D_d, L_g and D_f have an immediate connection with flooding susceptibility (Biswas et al. 1999; Nookaratnam et al. 2005; Javed et al. 2011; Balasubramanian et al. 2017). Hence, we assigned rank 1 to the highest values of R_b, D_d, L_g and D_f followed by second-rank to second-highest value, and rank third given the lowest value of the above parameters. 'The following drainage morphometric parameters, R_c, F_f, R_e, D_t, and C_c have a reverse relation with flood proneness' (Biswas et al. 1999; Nookaratnam et al. 2005; Javed et al. 2011). We assigned rank 1 to the lowest values of R_c, F_f, R_e, R_t and C_c, followed by rank two to the second-lowest value and rank three given to the highest value of the above parameters. Thus, the ranks allocated to each drainage morphometric parameter of the four sub-watersheds based on their flood proneness nature are shown in Table 6.

Table 6 Calculation of the compound factor values

Morphometric parameters	Sub-watersheds			
	WS-1	WS-2	WS-3	WS-4
Bifurcation ratio	3	4	2	1
Drainage frequency	1	2	3	4
Drainage density	1	2	3	4
Length of overland flow	4	3	2	1
Circulatory ratio	1	4	2	3
Form factor	2	3	1	4
Elongation ratio	2	3	1	4
Drainage texture	3	4	2	1
Compactness coefficient	4	3	1	2
Compound factor value	2.33	3.11	1.89	2.67

Table 7 Compound factor value and priority ranking of the sub-watersheds

Sub-watersheds	Compound factor	Priority ranking
WS-1	2.33	II
WS-2	3.11	IV
WS-3	1.89	I
WS-4	2.67	III

As stated, (Patel et al. 2013), the compound factor is computed by aggregating the assigned ranks of the criteria mentioned above and then dividing by the number of morphometric criteria used for sub-watersheds prioritization. In the current study, sub-watershed 3 got very highly prioritized (I) with a low compound factor value of 1.89, and sub-watershed 2 has got the lowest rank (IV) with the highest compound factor value of 3.11. The sub-watershed, which has the lowest compound factor value, has more prone to flooding. The sub-watershedwise compound factor value and its prioritization rankings are shown in Table 7 and Fig. 5.

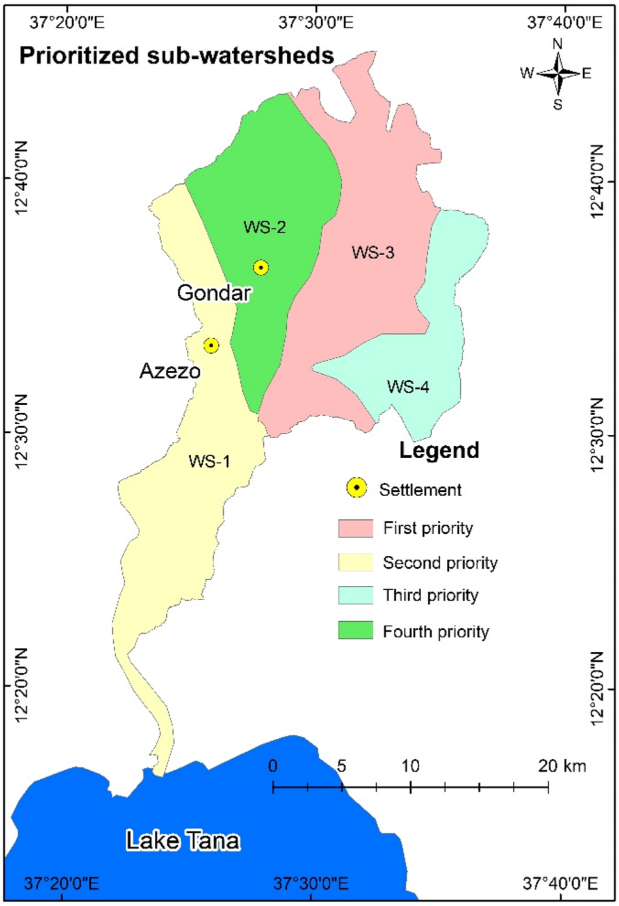

Fig. 5 Prioritization map

Through the present study, sub-watershed 3 was identified as first priority ranked watershed, and it needs immediate flood conservation measures for efficient water resource planning and management.

4 Conclusion

In the present research, quantitative morphometric analysis was completed with the help of ALOS-PALSAR (Advanced Land Observing Satellite-Phased Array-Type L-Band Synthetic Aperture Radar) digital elevation model (DEM), toposheets and Landsat-8 Operational Land Imager (OLI). The satellite remote sensing information and tools of the GIS are competent to comprehend the drainage morphometry of each sub-watershed. Linear, areal and relief morphometric aspects are useful to know the hydrologic performance of the watershed, and their features have very valuable to prioritizing the sub-watershed. In the current study, four sub-watersheds were taken for the morphometric analysis. In the present study area, SW-4 displayed an elongated shape and its bifurcation ratio value (2.45), whereas SW-2 is roughly circular and its bifurcation ratio value (1.56) is comparatively less than another three sub-watersheds. The compactness coefficient values are calculated for the study region, which varied from 0.43 (SW-3) to 2.50 (SW-1). Flood proneness of the sub-watershed is direct propionate with a compactness coefficient value. The higher the form factor value, the more the chance for the flood and vice versa. The form factor value calculated in this study differed from 0.16 to 0.22. The study drainage density values differed from 1.46 km/km^2, (SW-3), to 1.54 km/km^2, (SW-1). Less drainage density results in an area where permeable subsoil material is present, solid vegetative coverage, low elevation and rough drainage texture. The morphometric parameters such as bifurcation ratio, drainage density, length of overland flow and drainage frequency have a direct connection with flood susceptibility. Hence, rank 1 assigned to the highest values of the above-mentioned parameters followed by second-rank to second-highest value and rank third given the lowest value of the above parameters. The morphometric parameters such as circulatory ratio, form factor, elongation ratio, drainage texture and compactness coefficient have a reverse relation with flood proneness. Hence, rank 1 assigned to the lowest values of those parameters, followed by rank two to the second-lowest value, and rank three given to the highest value of the above parameters. Thus, the ranks allocated to each drainage morphometric parameter of the four sub-watersheds; then, the compound factor is computed by aggregating the assigned ranks of the criteria mentioned above and then dividing by the number of morphometric criteria used for sub-watersheds prioritization. The identified sub-watershed 3 with first priority needs to be guaranteed and immediate effective remediation for water resource conservation and watershed management planning. Henceforth, flood prevention actions would be engaged to avoid floods in the study area to protect agricultural lands and settlements in the lower part of the catchment, and there is a need for flood mitigation measures in the upper tributary drainages of the Megech catchment, for example, floodwalls, flood gates, check dams and strategic cultivation. The current study's outcomes are useful for water resources administrators, decision makers, private and government agencies who are trying to adopt water resources conserving measures or fixation of water harvesting provisions in the present study area.

Compliance with Ethical Standards

Conflict of interest No potential conflicts of interest are reported by the authors.

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