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ORIGINAL RESEARCH ARTICLE

Drainage Morphometric Characterization of Megech River Watershed, North Western Ethiopia, Using Geospatial Tools

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Abstract

Drainage morphometric characterization of a river catchment is important for appropriate preparation and administration of natural resources in sustainable growth. The main objective of this study was to extract and characterize the morphometric drainage parameters of the Megech River catchment, Northwestern Ethiopia. For this the Ethiopian mapping agency's 1:50,000 scale toposheets, ASTER (Advanced Spaceborne Thermal Emission and Reflection), and Landsat-8 Operational Land Imager (OLI) satellite data were used. Drainage morphometric parameters of the watershed were assessed by computations of linear, areal, and relief aspects using the standard formula in the Geographic Information System (GIS) environment. The Megech River catchment is spreading over an area of 560 km^2. The watershed is drained by a fifth-order river and shown a dendritic stream pattern, which is an indication of the homogeneousness in rock texture. The watershed's mean bifurcation ratio is 1.84, representing that the drainage pattern is not much affected by tectonic and structural disturbances. Lower and middle-order drainages typically control the basin with the drainage density value of 5.5 $km/km^{2,}$ which displays mild to sharp slope topography. The mean bifurcation value of the basin is 1.84, revealing drainage networks formed on regular bedrocks when the influences of geologic structures on the drainage network are insignificant. The drainage texture of the watershed is 7.4, and it falls under the category of very fine drainage texture (>8). Elongation and circularity ratios for the basin are 0.61 and 0.3, which shows that Megech watershed is elongated, having a steep to moderate slope.

Keywords: Morphometric characterization, Geospatial tools, Megech River watershed, Ethiopia.

Introduction

Drainage morphometric analysis plays a crucial role in watershed planning. It gives information about the watershed features in terms of elevation, slope, and conditions of soil erosion, runoff nature, and surface water potential. The detailed hydrological characterization is a mandate in the watershed level management scheme. Measuring a watershed's shape, size, surface and the dimensions of its landforms by adopting standard mathematical formula constitute morphometric analyses (Clarke, 1966; Agarwal, 1998). Drainage morphometric analysis is a significant part of the description of the watershed. The study of the linear, shape and morphometric relief parameters is a clue to understanding the watershed's hydrological behavior (Nag and Chakraborty, 2003). Various components are involved in quantitative morphometric analysis of the watershed area, including drainage segments, perimeter, area, elevation, and slope (Horton, 1945). Various researchers have used morphometric analyses for watershed characterization in different parts of the world (Magesh *et al.,* 2011 and 2013; Alemu and Kidane, 2014; Magesh and Chandrasekar, 2014; Kumar *et al*., 2015; Mekonnen and Fekadu, 2015; Worku and Tripathi, 2015; Bali *et al.,* 2016; Pandey and Das, 2016; Welde, 2016; Ayele *et al.,* 2017; Banerjee *et al.,* 2017; Prabhakar and Jawahar Raj, 2018; Mangan *et al.,* 2019; Gadisa *et al.,* 2020).

Drainage morphometric analyses are an excellent tool to evaluate surface and groundwater resources and address serious environmental problems, such as slope instability, soil erosion, flood, and landslides, at the catchment level. Sreedevi *et al.* (2005) delineated potential groundwater zones of the Pageru river basin, India, using morphometric drainage features. Morphometric analysis has been employed to identify suitable sub-basins to implement water harvesting techniques (Al -Daghastani and Al-Maitah, 2006; Zaidi, 2011; Jasmin, 2013; Soni, 2017; Satheeshkumar, 2018). Additionally, the approach has been used for combined land and water wealth administration purposes including groundwater assessment (Mishra *et al.,* 2011), identification of soil erosion-prone areas (Bagyaraj and Gurugnanam, 2011; Prakash, 2019; Muralitharan *et al.,* 2020a and 2020b), landslide susceptibility studies (Chen and Yu, 2011), morpho tectonic studies (Altin and Altin, 2011) and natural hazard zonation mapping (Rawat *et al.,* 2011). Drainage morphometric analysis has also been used to prioritize a watershed using geospatial technologies (Yogesh *et al.,* 2016; Farhan and Anaba, 2016; Prabhakar *et al.,* 2019). It has also been applied in the selection of groundwater recharge sites, modeling of watershed, surface runoff modeling, mapping of groundwater prospect and investigation of geotechnical aspects (Shankar *et al*., 2009; Sreedevi *et al*., 2009; Ewen *et al*., 2010; Magesh *et al*., 2011; Patel *et al*., 2012; Thomas *et al*., 2012; Magesh *et al*., 2013).

Quantitative drainage morphometric analysis can offer data about the hydrological nature of the rocks exposed inside the watershed. Further, the drainage network of watershed offers a consistent index of rocks' porousness and their association among different rock types, rock structures and their hydrological nature.

Watershed classification and administration need thorough information for elevation, stream network, surface water divide, drainage length, the geomorphologic and lithological arrangement of the area for appropriate watershed administration, and execution plan for surface and groundwater administration procedures (Sreedevi *et al*., 2013).

During the 19th century, pioneer scholars (Horton, 1945; Smith, 1950; Strahler, 1957) examined the linear, shape, and relief drainage morphometric parameters for assessing river catchment's hydrology. Data regarding the rocks' hydrological nature in a watershed area can be extracted by measurable drainage morphometric study (Sreedevi *et al*., 2005). Further, the morphometric drainage parameters are critical in understanding the processes of landform formation, soil physical properties, and erosion characteristics (Keesstra *et al*., 2016; Rodrigo-Comino *et al.,* 2016; Masselink *et al*., 2017).

Various researchers have used satellite remote sensing data and GIS tools in drainage morphometric characterization of watershed in different parts of the world (Das and Mukherjee, 2005; Hlaing *et al*., 2008; Singh and Singh, 2009; Thomas *et al*., 2012; El Bastawesy *et al*., 2013; Gajbhiye *et al*., 2014; Kaliraj *et al*., 2014; Rai *et al*., 2014). These studies have proven the satellite data and GIS tools' efficiency in extracting exact drainage data describes the morphometric parameters. Digital elevation model (DEMs), such as from the Advanced Space-borne Thermal Emission and Reflection (ASTER GDEM), have been used to abstract different morphometric parameters of the watershed, such as stream networks, watershed boundary, slope, elevation, and aspect of the slope (Mark, 1984, Tarboton, 1997). ASTER GDEM data has given exact and firm information about the drainage networks, and it is the most relevant satellite data for examining catchment area hydrological systems (Das *et al*., 2005; Ahmed *et al.,* 2010; Samy, 2015; Sayantan *et al*., 2016; Ali Hamdan, 2018). In the present study, toposheets, optical remote sensing data, ASTER DEM, and GIS tools has been utilized in combination to construct and explain the Megech River watershed's morphometric drainage parameters.

Materials and Methods

Description of the study area

In this study, morphometric characterization has been carried out for the Megech River watershed of the Lake Tana basin (Figure 1). Megech River watershed is located between latitudes 12° 15′48″ to 12°45′17″ N and longitudes 37° 21′31″ to 37° 36′56″ E, and it has an area of 560 km^2 and forms a part of Lake Tana basin, establishing one of the source basins of Blue Nile river in northwestern Ethiopia. Megech River originates from the Semen Mountains and flows towards the southern course and confluence into Lake Tana. It is one of the chief rivers flowing into Lake Tana from the northern part of Ethiopia. A hilly region characterizes the northern part of Megech watershed with sharp wedge-shaped slopes. However, the southern part, about Lake Tana, is characterized by flat, low-lying land with low drainage situations (WWDSE and TAHAL GROUP, 2008).

The study area's elevation and slope maps were prepared from the ASTER-DEM. The study area elevation ranges from 1781 to 2896 m above mean sea level. The Megech watershed has higher elevation at the northern part and lower elevation at the southern part neighboring Lake Tana. The Megech watershed has a gentle slope to exceptionally steep slopes with values in the range of 0^0 to 74^0 (Figure 2).

Ethiopia's lithology contains a mixture of a hard-basaltic rock basement, other crystalline invasive rocks, volcanic rocks associated with East African Rift System, and sedimentary rocks of different geological ages (Smedley, 2001; Kawo and Karuppannan, 2018; Shankar and Kawo, 2019). The present study area's major lithological units is Termaber basalt with different weathering natures. The age of this rock is Late to Middle Tertiary. The lower southern part of the catchment is covered by Quaternary lacustrine sediments (GSE, 2011, 2013 and Abbate *et al.,* 2015). According to FAO (2006), the main soil types in the present study area comprises Luvisols, Leptosols, Vertisols, Luvisols, and Calcisols.

The area's land use/land cover map has been prepared using Landsat-8 OLI data coupled with supervised image classification techniques and field studies. The Megech watershed mainly comprises land use/land cover types such as agricultural land, grassland, shrubland, forest, water bodies, and settlements.

Materials

The Ethiopian Mapping Agency's toposheet (number 1237 A4, 1237 B3, 1237 C2 & 1237 D1) at the scale of 1:50,000 was used to find the Megech River catchment border. Satellite -borne ASTER (Advanced Space-borne Thermal Emission and Reflection), 30 m resolution and tile number N12°E37° was downloaded from the website (https://search.earthdata.nasa.gov/search/) to extract the drainage network initially. The cloud-free optical satellite data obtained from Landsat-8 Operational Land Imager (OLI) with path-row numbers 170-051 dated on 22-February-2018 has been downloaded from the United States Geological Survey (USGS) Global Visualization Viewer (GLOVIS) portal (http://earthexplorer.usgs.gov/) and used to update the drainage network of the present area.

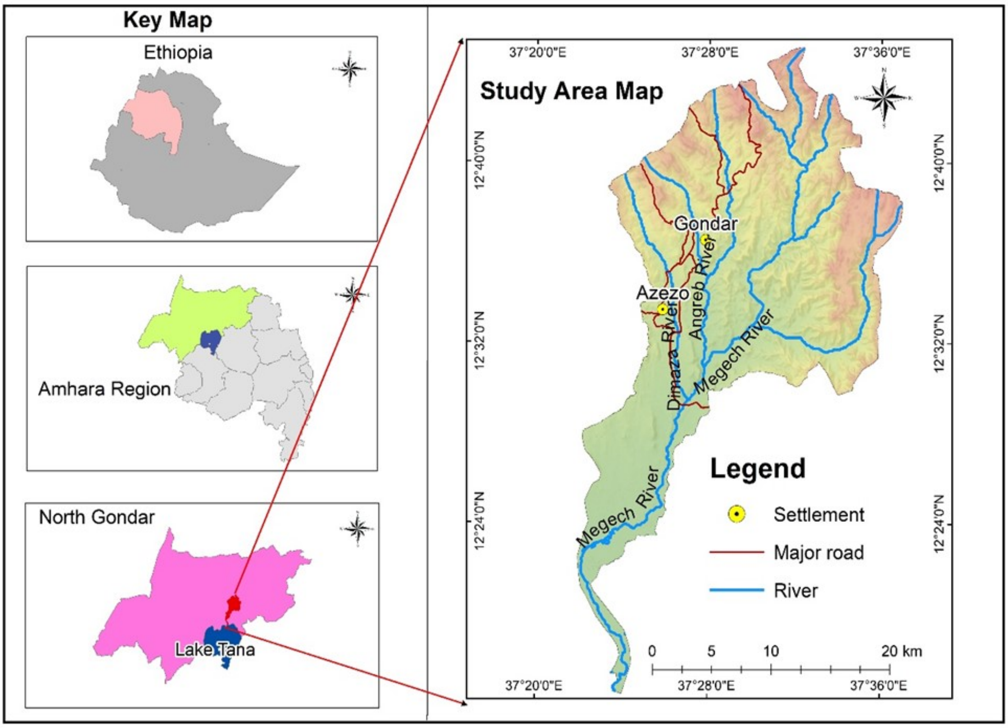

Figure 1. Map of the study area

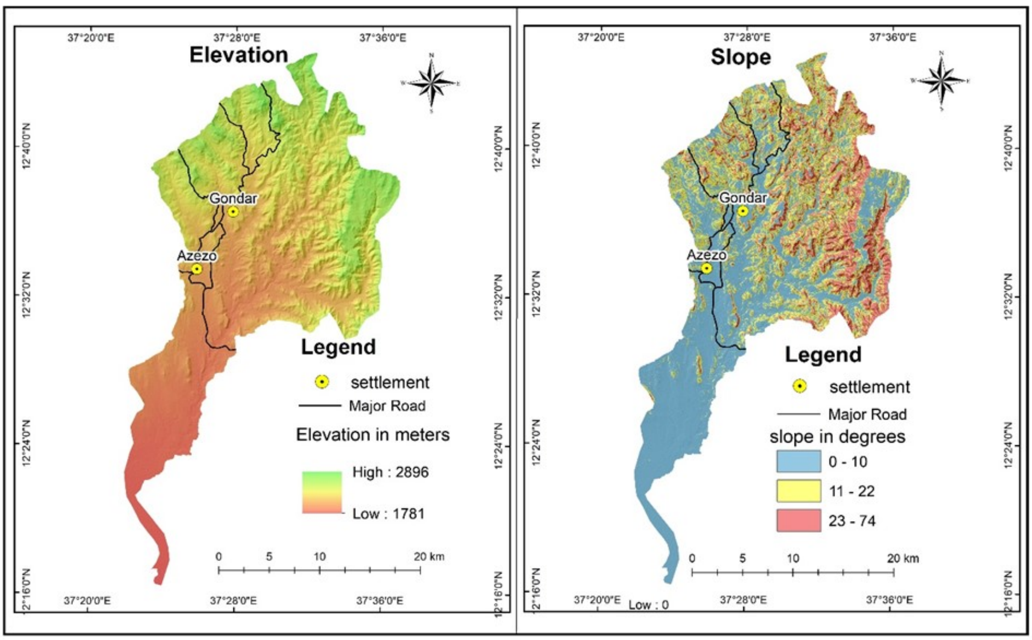

Figure 2. Elevation and slope map of the study area

Extraction of drainage networks

The watershed boundary and initial drainage network were extracted from the Ethiopian Mapping Agency's toposheets. The DEM processing methods, including fill sinks, flow direction, flow accumulation, stream definition, stream segmentation, watershed grid delineation and watershed polygon, were applied on the ASTER-DEM to extract drainage networks and calculation of various drainage morphometric parameters. Finally, OLI image was used to update the drainage network. ArcGIS10.6.1. Software and arc hydro tools were used to demarcate the watershed boundary and extract the drainage networks. The flow chart in Fig.3 shows the methodology used in the study. The Megech River watershed's drainage networks are also shown in Fig.4.

Results and discussion

Morphometric characterization

The following drainage morphometric parameters were calculated using standard formula, namely area, stream order, number of streams and perimeter. These parameters were grouped into basic drainage morphometric parameters. Linear drainage morphometric parameters calculated include stream order (u), stream number (Nu), stream length (Lu), bifurcation ratio (Rb), mean stream length (Lsm), and stream length ratio (Rl). Areal drainage morphometric parameters calculated include drainage density (Dd), drainage frequency (Fs), circulatory ratio (Rc), form factor (Ff), elongation ratio (Re), length of overland flow (Lg), and constant of channel maintenance (C). The morphometric relief parameters calculated include catchment relief (h), relief ratio (Rr), and ruggedness number (Rn). The formulae utilized in calculating the above-mentioned drainage morphometric parameters are shown in Tables 1, 2 &3.

Linear morphometric parameters

The first step in the drainage morphometric characterization of a watershed is the description of stream order; stream order, as suggested by Strahler (1964), was used for this study area. The Megech watershed showed a 5^{th} order drainage pattern. The watershed is drained by a 5^{th} order river and showed a dendritic stream pattern. Hydrologically dendritic drainage pattern is a symbol of homogeneousness in rock texture and absence of structural control. Stream order is always increasing from upstream to downstream (Horton, 1932). The order-wise drainage numbers are shown in Table 4. A total of 5076 streamlines is recognized in the whole Megech River watershed. Out of which 49.37% (2506) is first- order, 21.45% (21.45), second-order, 14.58% (740), third-order, 9.93% (504) fourth-order, and 4.67% (237) contains fifth-order stream.

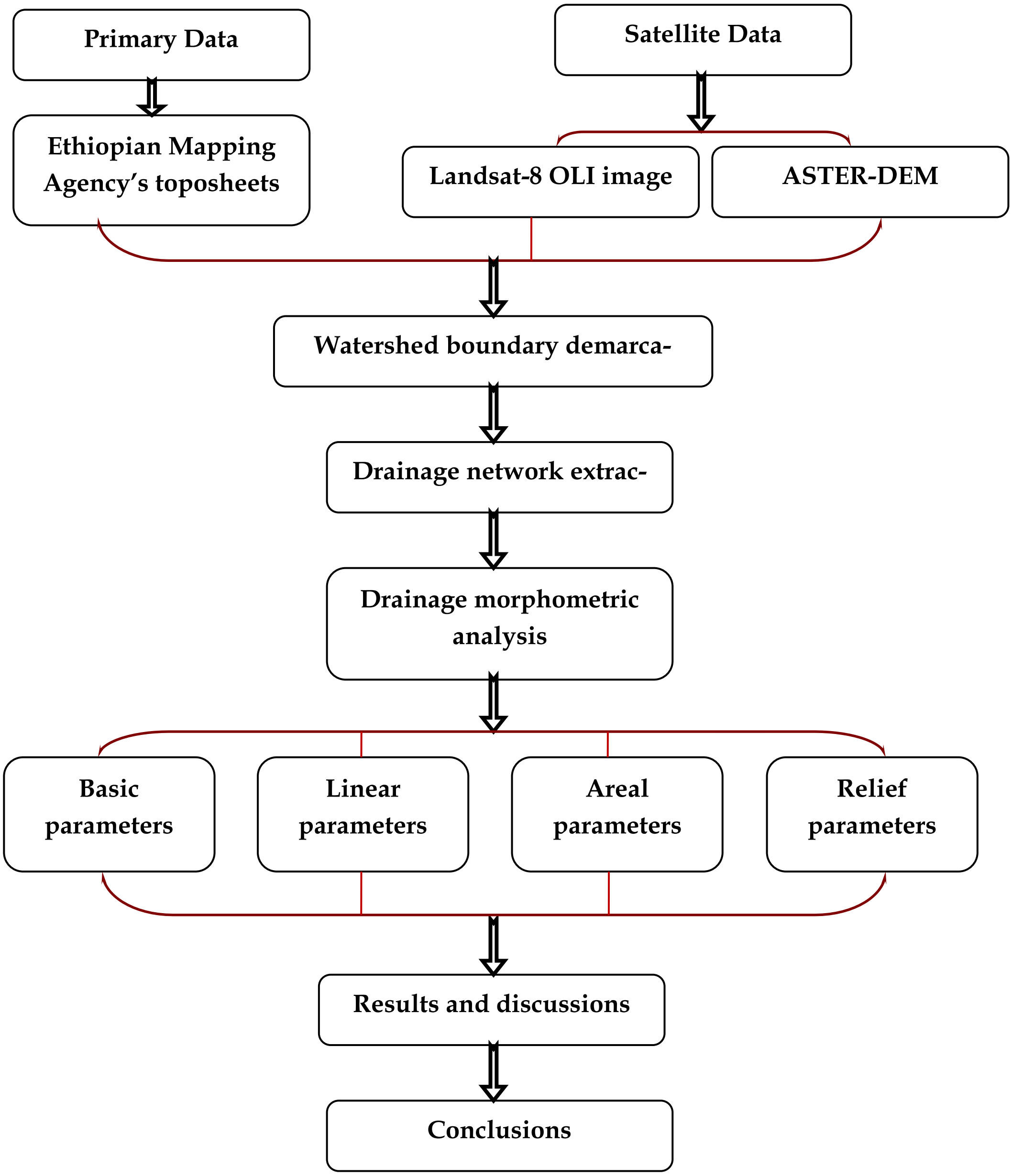

Figure 3. Flow chart showing the Methodology used in the study

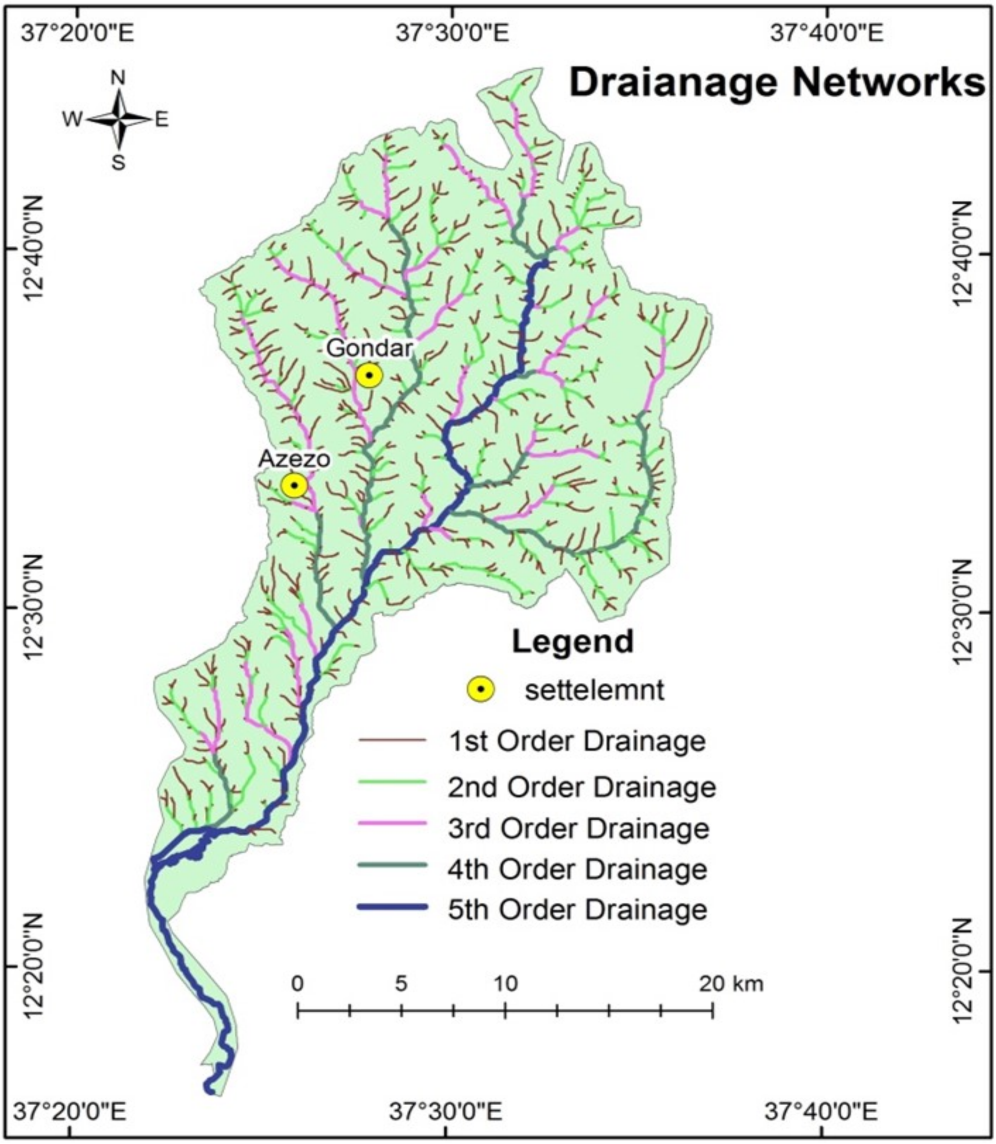

Figure 4. Drainage networks map of the study area

Table 1. Linear morphometric parameters with formulae and references

Morphometric parameter	Formula/definition	Reference
Stream order (*u*)	Hierarchical rank	Strahler (1964)
Stream number (*Nu*)	Total number of stream segments of the order '*u*'	Horton (1945)
Stream length (L*u*)	The total length of the stream segments of that particular order	Horton (1945)
Bifurcation ratio (*Rb*)	*R*b = *N*u/*N*(*u*+1) where *Nu* = total number of stream segments of the order '*u*' and N(u+1) = number of stream segments of the next higher order	Schum (1956)
Mean bifurcation ratio (*Rbm*)	Rbm=average of bifurcation ratios of all orders	Strahler (1957)
Mean stream length (L*sm*)	Lsm = ΣLu/Nu where Lu = total length of the stream segments of the particular order Nu = total number of stream segments of the same order 'u'	Horton (1932)
Stream length ratio (R*l*)	Rl = Lu/L(u−1) where Lu = the mean length of all stream segments of a given order (u) and L(u−1) = the mean length of all stream segments of one order less to given order (u)	Horton (1945)
Basin length (L*b*)	$1.312*A^{0:568}$ where, L= basin length (km), A=area of the catchment (km^2)	Nooka *et al*., (2005)

Table 2. Areal morphometric parameters with formulae and references

Morphometric parameter	Formula/definition	Reference
Basin Perimeter (P) (km)	GIS analysis	Schumn (1956)
Drainage frequency (*Fs*)	F*s* = ΣNu/A where Nu = total number of stream segments of the order 'u' and A = area of the basin (km^2)	Horton (1932)
Drainage density (D*d*)	D*d* = ΣL/A where L = the total length of streams; A = area of the watershed	Horton (1932)
Form factor (R*f*)	R*f* = A/Lb^2, where A = area of the basin and Lb = (maximum) basin length	Horton (1932)
Circulatory ratio (R*c*)	R*c* = $4\pi A/P^2$ where A = area of the basin(km^2) and P = perimeter of basin (km)	Miller (1953)
Drainage texture (D*t*)	D*t* = N1/P where N1 = the total number of first-order streams; P = perimeter of watershed	Horton (1945)
Elongation ratio (R*e*)	R*e* = 2√(A/π)/Lb where A = the area of watershed, π = 3.14, Lb = basin length	Schumn (1956)
Length of overland flow (L*g*)	Lg = 1/2Dd where Dd = drainage density of the basin or Lg = (1/Dd)/2	Horton (1945)
Constant of channel maintenance (*C*)	*C*=1/*D*d where, *C*=constant of channel maintenance, *D*d=drainage density	Schumn (1956)

Table 3. Relief morphometric parameters with formulae and references

Morphometric parameter	Formula/definition	Reference
Basin relief (R) (m)	R = *H*-*h* where, *R* = basin relief, *H* = maximum elevation in meter, *h* = minimum elevation in meter	Schumn (1956)
Relief ratio (*Rr*)	*Rr* = R/L*b* where, Rr=relief ratio, R= basin relief L*b* = basin length,	Schumn (1956)
Ruggedness number (*Rn*)	Rn = R×Dd where, R*n*=ruggedness number, R=basin relief, D*d*=drainage density	Schumn (1956)

Table 4. Linear drainage morphometric results of the Megech River catchment

Stream Order	No. of streams	Length of drainage (kms)	Bifurcation ratio	Mean Bifur-cation ratio	Length ratio	Mean length ratio
1st	2506	383	2.30	1.84	0.42	0.55
2nd	1089	160	1.47		0.64	
3rd	740	102	1.47		0.59	
4th	504	60	2.13		1.08	
5th	237	65	0		0	

The total drainage length of each order is measured using the GIS tool and tabulated in Table 4. Drainages with comparatively lesser lengths show that the watershed area is with great slopes. Longer drainage lengths are revealing of a gentle slope gradient. According to Strahler (1964), mean stream length describes the stream network's components' characteristic size. The stream length of the individual stream order of the present study area is shown in Table 4.

The value of the total length of drainages, mean length of streams, and stream length ratio of the watershed stream orders are shown in Table 4. The watershed's mean bifurcation ratio is 1.84, representing that the drainage pattern is not much affected by tectonic and structural disturbances. Stream frequency (Fs) or drainage frequency is the total number of stream segments of all stream orders per unit area, and results indicate an affirmative association with the drainage density of the Megech catchment, suggesting an increase in drainage frequency concerning the surge in drainage density (Horton, 1932). The observed drainage frequency (Fs) is 0.36 for the present study area.

Areal morphometric parameters

Horton (1932) has presented the drainage density as an expression to specify the arrangement of drainages' chumminess. Drainage density benefits us to analyze a numerical dimension of landscape partition and run-of probable (Reddy *et al.,* 2004; Yadav *et al*., 2014). If drainage density value is near zero, this designates a permeable river catchment with very high intrusion rates and high groundwater. High drainage density specifies impervious rocks below thin vegetation and undulating relief area (Horton 1945; Kumar *et al.,* 2011). The drainage density of the Megech catchment is 5.5

The form factor of a river catchment is well-defined as a ratio among the catchment (A) area and the squared value of the catchment length (Horton 1945). If the form factor value is higher it displays a high-peak low in the briefer period. In comparison, the form factor's lesser value shows a lower peak low of a more extended river catchment (Chopra *et al.,* 2005). Lesser form factor value indicates the elongated shape of the river catchment. The form factor of the Megech catchment is 0.3. The circularity ratio values vary from 0 (for a line) to 1 (for a sphere). The circularity ratio is prejudiced by drainage length, drainage frequency, geological structures, land use/ land cover, weather, elevation, and river catchment slope. It is a vital factor, which specifies the phase of the river catchment. Circularity ratio low value shows the youth phase, and intermediate value displays developed phase and high values specify the grownup phase of the tributaries in the river catchment (Sreedevi *et al*., 2005). The circularity ratio of the Megech catchment is 0.3.

The shape factor of the river catchment aids to examine form indiscretion of the drainage basin (Yadav *et al*., 2014). The shape factor value of the present study area is 13.4. Drainage texture is one of the significant geomorphology impressions, which means the close spacing of streamlines. According to Horton (1945), drainage texture is the total amount of stream sections of all orders per perimeter of the basin area. The observed drainage texture of the Megech River basin is 30. The values of elongation ratio vary from 0 (highly elongated shape) to 1 (circular shape) (Bali *et al*., 2012); higher values of the elongation ratio of the river catchment specifies vigorous denudational procedure with high infiltration volume and low runoff in the river catchment. At the same time, lower elongation ratio values show higher relief of the river catchment and highly susceptible to headward erosion (Reddy *et al.,* 2004; Yadav *et al.,* 2014). According to Strahler (1964), elongation ratio values close to 1.0 are characteristic of shallow relief areas, while elongation ratio values between 0.6–0.8 are connected with higher relief and sharp ground slope. The value of the elongation ratio of the Megech River catchment is 0.61.

The length of overland flow is defined as half of the reciprocal of drainage density (Horton, 1945). It is the length of the flow of surface water over the ground earlier. It becomes focused on definite watercourse channels; it is relatively equal to the sheet flow length to a great degree. It is one of the most significant self-determining variables, affecting equally the physiographical developments and hydrology of the river catchment (Horton 1945). The length of the overland flow value of the Megech River catchment is 0.69. Constant channel maintenance depends on the River catchment slope, nature of bedrocks, vegetative cover, and the duration of erosion. Generally, the River catchment's channel maintenance values' higher constant indicates the higher permeability of rocks and vice versa (Rao, 2009; Kumar *et al.,* 2011). The constant of channel maintenance value of the present study area is 0.7.

Relief morphometric parameters

Basin relief is the variance in elevation between the highest and the lowest points of the River catchment. It is a very significant parameter useful for understanding the denudational features of the River catchment, which controls the drainage slope and, consequently, affects the surface runoff, quantity of sediment, and the flood outline in the catchment (Hadley and Schumm, 1961). The highest elevation point of the present study area is 2896 m, and the lowest elevation point is 1781 m. Hence basin relief is 1115 m.

Relief ratio is defined as the ratio between the basin relief and the basin length. The nature of the bedrocks influences the slope of the basin. If the relief ratio value is high, it specifies that a hilly area and low-value relief ratio signify the peneplain and valley region (Kumar *et al.,* 2011; Yadav *et al.,* 2014).

The relief ratio value of the present specifies that a hilly area and low-value relief ratio signify the peneplain and valley region (Kumar *et al.,* 2011; Yadav *et al.,* 2014). The relief ratio value of the present study area is 0.03. Ruggedness number is the product of basin relief and stream density, and it typically combines gradient sharpness with its length. Very high values of ruggedness number ensue when slopes of the basin are not only sharper but prolonged as well. For the present basin, the ruggedness number obtained is 0.61.

Conclusion

In the present study, GIS-based morphometric analysis using remote sensing data and toposheets has been proved as an efficient tool for hydrological evaluation and drainage network analysis of the Megech River catchment. The various morphometric parameters representing one-dimensional view via linear, two-dimensional view via aerial, and three-dimensional view via relief aspect of the watershed (stream order, stream length, bifurcation ratio, stream frequency, stream length ratio, form factor, drainage density, drainage texture, elongation ratio, circulatory ratio, infiltration number, relief ratio, relative relief, etc.) has been calculated in the present study. The morphometric analysis of the drainage network of the Megech watershed exhibits a dendritic pattern and signifies the homogeneity in texture and absence of structural control. Based on the drainage orders, the Megech watershed has been classified as a fifth-order watershed. The study area's drainage density is 5.5 Km^{-1}, which specifies impermeable rock materials. The drainage texture of the watershed is 7.4, and it falls under the category of very fine drainage texture (>8). Elongation and circularity ratios for the basin are 0.61 and 0.3, which shows that Megech Watershed is elongated, having a steep to moderate slope. The computation of linear, areal, and relief parameters of the Megech River watershed confirms that there is a constructive association among hydrological comportment of the river catchment and their related landforms, which is probable for natural resources administration actions. The watershed drainage pattern is chiefly dendritic category representing rock textural homogeneity and absence of geological structural control, which could help understand the different terrain parameters viz. nature of the bedrock, surface water infiltration capacity,

surface runoff, drainage density, etc. Hydrologically dendritic drainage pattern is a representative of homogeneousness in rock texture and absence of structural control. Thus, concluding toposheets, optical remote sensing information, digital elevation model, and GIS techniques together an effective, actual, and effectual technique to study the hydrologic and characteristics of the drainage morphometry of a watershed. The present study's results provide relevant information for improved insight into the hydro-geological and erosion features of the Megech watershed. The morphometric drainage parameters selected for this study give an improved understanding of watershed features. It can aid as a base for better development, supervision, and decision-making to confirm the sustainable use of watershed's natural resources.

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