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Research Paper

Morphometric Analysis and Prioritization of Sub-watersheds for Soil Erosion using Geomatics Technologies in Megech River Catchment, Lake Tana Basin, North Western Ethiopia

Muralitharan Jothimani[1,*], Francis Lawrence[2], Zerihun Dawit[3]

[1]*Department of Geology, College of Natural Sciences, Arba Minch University, Arba Minch, Ethiopia*
[2]*Department of Applied Geology, Adama Science & Technology University, Adama, Ethiopia*
[3]*Department of Geology, College of Natural and Computational Sciences, University of Gondar, Gondar, Ethiopia*

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Abstract

Soil erosion is one of the most critical environmental problems in the sustainable development of agriculture and natural resources. Ethiopia is facing severe soil erosion problems. The present study was carried out in the Megech River catchment, Lake Tana Basin, North Western Ethiopia. The present study aims to identify the sensitive soil erosion-prone sub-watersheds in the Megech River catchment. ASTER-DEM (Advanced Space-borne Thermal Emission and Reflection), a 30 m spatial resolution digital elevation model (DEM), was used to delineate the sub-watersheds and drainage networks through spatial Analyst and ArcHydro extension of ESRI ArcGIS v10.6.1 software. The cloud-free optical satellite data got from Landsat-8 Operational Land Imager (OLI) has been used to update the drainage network of the present study area. The study area was divided into four sub-watersheds: WS-1, WS-2, WS-3, and WS-4. The primary, linear, and areal drainage morphometric parameters were calculated by applying the standard formula. Furthermore, the ranks were allocated to each drainage morphometric parameter of the four sub-watersheds based on their soil erosion proneness. The compound factor value was calculated for the sub-watersheds. The lower value of the compound factor has a high possibility of soil erosion and vice versa. The compound factor of the present study area's sub-watersheds is 2.33 (WS-1), 2.88 (WS-2), 2.11(WS-3), and 2.67 (WS-4). Based on the compound factor value, the present study area's sub-watersheds 3,1,4 and 4 were classified into very high, high, medium, and low priority sub-watersheds, respectively. Through morphometric drainage analysis, the sub-watershed-3 has been identified as a very high-priority ranked watershed in the present study. It needs immediate soil conservation measures for efficient watershed planning and management. Further, the present study shows the effectiveness of the drainage morphometric analysis using the satellite image and GIS techniques in prioritizing the sub-watersheds for soil resource conservation and management in the Megech River catchment, Lake Tana Basin, North Western Ethiopia.

1. Introduction

In Ethiopia, agricultural productivity and food security are facing problems due to land degradation resulting from soil erosion (Hurni 1993; Hengsdijk et al., 2005; Erkossa et al., 2015; Taguas et al., 2015; Fazzini et al., 2015; Keesstra et al., 2016; Nigussie et al., 2017; Mekuriaw et al., 2018). At present, the northwestern part of Ethiopia faces the highest soil erosion problems (Hurni et al., 2015). According to (Woldeamlak and

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[*] *Corresponding author, e-mail: muralitharangeo@gmail.com*

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Stroosnijder, 2003; Belay et al., 2014; Halefom and Teshome, 2019), soil erosion in Ethiopia is caused by deforestation and the growth of the urban area and rangeland. This continued soil erosion has led to soil loss, exposure of rock outcrops, soil nutrient depletion, agricultural productivity, and environmental degradation. By organizing the community for agricultural production, food security, population livelihood improvement, and alleviating environmental damage, the Ethiopian government facilitates soil conservation techniques and methods. (Tesfaye et al., 2014a, 2014b; Haregeweyn et al., 2015; Kebede, 2014; Teshome et al., 2016; Kawo and Shankar, 2018; Athick and Shankar, 2019; Shankar and Kawo, 2019). According to Amare et al. (2014) and Teshome et al. (2016), the following soil conservation structures, such as stone bunds, soil bunds, and percolation ditches, have been constructed in different parts of Ethiopia through community mobilization. Poitras et al. (2011) stated that deprived and inadequate data on soil erosion and stream flow lead to unreliable planning and inadequate project operation of soil conservation measures. There is a need for a scientific study to identify the soil erosion-prone area and further identify suitable soil erosion conservation structures. Hence, detailed hydrological and soil erosion proneness information is needed for sustainable development in soil conservation management practices of the region of interest.

Watershed prioritization is a well-known scientific method for identifying soil erosion-prone areas, flood-prone areas, and suitable areas for groundwater exploration (Vittala et al., 2008; Magesh et al., 2011; Thomas et al., 2012). It is essential for comprehensive watershed development and improved soil management in arid and semi-arid regions to know the local drainage morphometry and their environmental implications (Sreedevi et al., 2009; Shankar et al. 2009; Gulavani et al., 2017; Everard et al., 2018).

A drainage basin is an essential landscape of geomorphic and hydrologic structure. It is an elementary unit concerned with collecting the supply of water and sediments. It requires a drainage morphometric analysis for the watershed prioritization process and covers the mathematical quantification of the basin's diverse aspects (Clarke, 1966). Linear, shape, and relief features comprise numerous parameters like stream number, stream length, drainage density, circularity ratio, form factor, and relief ratio (Magesh and Chandrasekar, 2014). Horton (1945) introduced morphometric quantification first and explained the fundamental relation of drainage arrangements with the basin's hydrology. Later, several researchers have contributed to the development of methods of drainage morphometric analysis (Strahler 1957; Shreve 1966; Gregory and Walling, 1968; Ziemer, 1973; Breyer and Scott Snow, 1992; Al-sulaimi et al., 1997; Agarwal, 1998; Nag and Chakraborty, 2003; Reddy et al., 2004; Das and Mukherjee, 2005).

In the past, watershed management studies needed the data associated elevation, slope, geology, soil data through topographic maps, and collection of the datasets mentioned above wanted extensive and tedious field surveys (Sreedevi et al., 2013). Nowadays, advanced remote sensing and GIS (geomatics) technologies made watershed management studies relatively easy with high precision. Geomatics technologies became a vital component in watershed management research (Subyani et al., 2010; Sangle and Yannawar, 2014; Kumar et al., 2018). Remote sensing provides high accurate terrain information and GIS technologies contributing advanced tools for analyzing the satellite data for the drainage morphometric investigations. Remote sensing and GIS method-based morphometric studies have been conducted in different parts of the world by the following researchers (Al-sulaimi et al., 1997; Subyani et al., 2010; Sehgal and Babar, 2013; Aouragh and Essahlaoui, 2014; Biswas et al., 2014; Pophare and Balpande, 2014; Martins and Gadiga, 2015; Osano, 2015; Kumar and Kshitij, 2017; Rawat et al., 2017; Yanina et al., 2017; Kumar et al., 2018; Jothimani et al., 2019 & 2020).

Drainage morphometric studies are critical in hydrological investigations of the watersheds (Sreedevi et al., 2009), and it is also essential for the subsequent studies at the watershed level such as estimation of soil erosion proneness and flood susceptibility mapping (Bagyaraj and Gurugnanam, 2011; Altaf et al., 2014; Farhan and Anaba, 2016; Gopinath et al., 2016; Masoud 2016; Yogesh et al., 2016; Kandpal et al., 2017; Meshram and Sharma, 2017; Satheesh kumar and Venkateswaran 2018 Prabhakar et al., 2019; Prakash, 2019), estimation of groundwater potentialities (Jasmin and Mallikarjuna, 2013), estimation of surface water potential (Suresh and

Sudhakar 2004), to determine plant growth potential (Kadam et al., 2017), sediment yield (Altaf and Meraj, 2014), and site selection for groundwater recharge structure and soil protection in the basin (Rekha et al., 2011; Wani and Javed, 2013; Choudhari et al., 2018). With this background, the present study was conducted with the following specific objectives:

(i) ASTER DEM coupled with GIS techniques were used to extract the drainage network, and the cloud-free optical satellite data such as: Landsat-8 Operational Land Imager (OLI) has been used to update the present's drainage network area.

(ii) Calculation of the various drainage morphometric parameters using the standard formula of the Megech River's sub-watersheds, and

(iii) To prioritize sub-watersheds using the compound factor method and rank the sub-watershed for protection, preparation, and administration of the soil resource in the present study area.

There have been no such studies using this current method in the present study area, and hence, the current study is the leading of its kind in the present study area.

2. Materials and Methods

2.1. Study area

In the present study, drainage morphometric analysis and prioritization has been carried out in the Megech River catchment, Lake Tana Basin. The Megech River catchment lies between latitudes 12°15′48″ to 12°45′17″ N and longitudes 37°21′31″ to 37°36′56″ E in northwestern Ethiopia is shown in Figure 1. The elevation ranges from 1781 to 2896 m above mean sea level. The Megech River catchment has a rough terrain with a slope ranging from 0° to 74° (Figure 2). It has an area of 560 km^2 and forms a part of the Lake Tana Basin, and establishes one of the Blue Nile River source basins. According to EMS (2019), the average maximum temperature ranges between 18.4°C and 29.2°C, and the average minimum temperature is between 8.3°C and 13.1°C. As per the Ethiopian standard Agro-climate classification system, the Megech River catchment falls between Dega (cold and humid) and Woinedega (cool sub-humid) agro-climatic regions. The land use of the catchment is mostly agricultural, followed by woody and shrub lands.

The Megech River instigates from the Semen Mountains and then flows to a southern course and ends into Lake Tana. It is one of the major rivers flowing into Lake Tana from the northern part of Ethiopia. The upper northern part of the Megech River catchment is characterized by a rugged mountainous, whereas the lower part, around Lake Tana, is characterized by flat low-lying land (WWDSE and TAHAL GROUP, 2008). The study area’s elevation and slope maps were prepared from the ASTER-DEM. Figure. 2 show the elevation map of the Megech watershed. The Megech watershed has a gentle slope to extremely steep slopes and the slope values ranging from 0° to 74°. According to the Ethiopian Geological Survey (GSE, 2011), the catchment area comprises upper basaltic lava flows, trachytes with different weathering natures, and lacustrine sediments. According to FAO (2006), the main soil types in the present study area are luvisols, regosols, vertisols, fluvisols, and cambisols.

2.2. Materials

The following datasets/materials have been used in the present study, and the description of the data and its sources have been discussed in the following section. ASTER (Advanced Space-borne Thermal Emission and Reflection), 30 m resolution, and tile number (N12°E37°) were downloaded from the following website (https://search.earthdata.nasa.gov/search/). Moreover, it is used to delineate the sub-watersheds and drainage networks have done by using Spatial Analyst and Arc Hydro extension of ESRI ArcGIS v10.6.1. The cloud-free Landsat-8, Operational Land Imager (OLI) optical satellite data with path-row numbers 170-051, dated 22-February-2018, were downloaded from the United States Geological Survey (USGS) Global Visualization Viewer (GLOVIS) portal (http://earthexplorer.usgs.gov/). Furthermore, the same has been used to update the drainage network of the study area.

2.3. Extraction of drainage networks and demarcation of sub-watersheds boundaries

The extraction of drainage networks and demarcation of the four sub-watersheds boundary were completed with ArcMap 10.6.1 coupled with ArcHydro tools using ASTER (DEM). The following DEM processing methods (fill sinks, flow direction, flow accumulation, stream definition, stream segmentation, and catchment grid delineation) were carried out to extract the drainage network and demarcate the sub-watershed's boundary. The Megech River basin is divided into four sub-watersheds (WS-1, WS-2, WS-3, and WS-4). The Megech River catchment's drainage network and sub-watershed boundaries are shown in Figure 3.

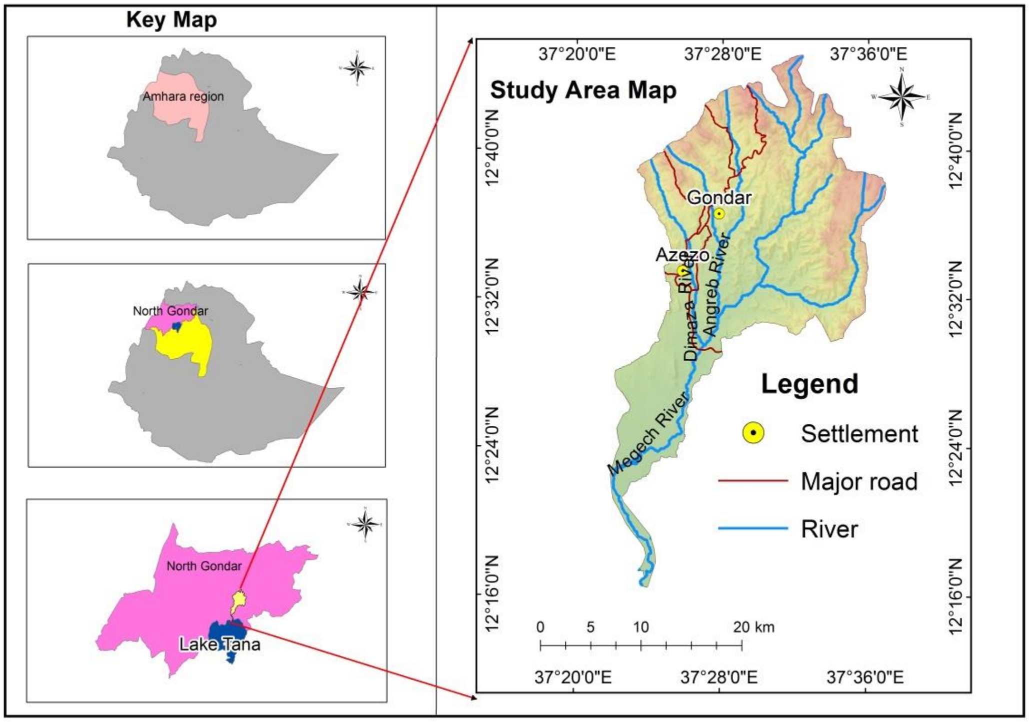

Figure 1: Study area map

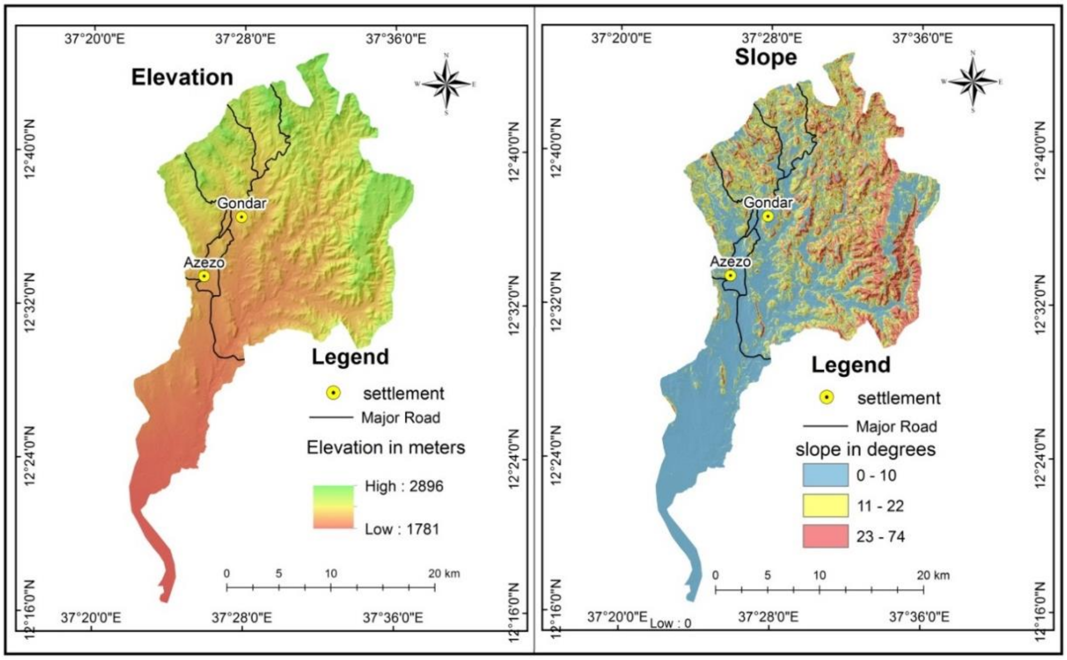

Figure 2: Elevation and Slope map

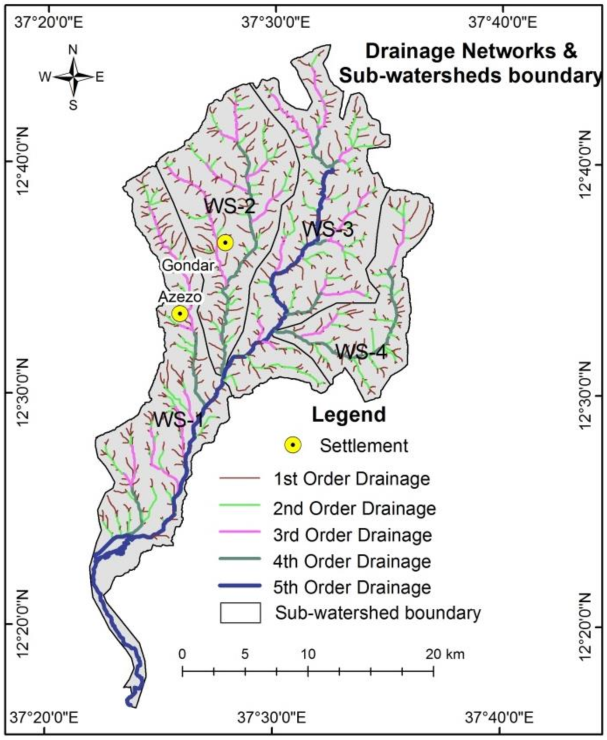

Figure 3: Drainage network and sub-watershed boundary map

3. Results and Discussions

The standard formula was used to calculate the following drainage morphometric parameters viz; area, perimeter, 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 (N_u), stream length (L_u), bifurcation ratio (R_b), mean stream length (L_{sm}), and stream length ratio (R_l). Areal drainage morphometric parameters calculated include drainage density (D_d), drainage frequency (F_s), circulatory ratio (R_c), form factor (F_f), elongation ratio (R_e), and length of overland flow (L_g). Morphometric parameters and their corresponding standard formulae are shown in Table 1.

3.1. Linear morphometric parameters

The first step in the drainage morphometric characterization of a river catchment is the description of stream order and stream order, as suggested by Strahler (1964) used for the present study area. Stream order always increases from upstream to downstream, Horton (1945). In the present study, fifth-order drainage order (Figure 3) attained for morphometric characterization. WS-1 and WS- 3 exhibit the Vth order drainage pattern; WS-2 and WS-4 exhibit IVth order. The study area exhibits the dendric drainage pattern and it is exhibiting the presence of the hard rock in the major part of the study area. The order-wise drainage numbers are shown in Table 2. A total of 5076 streams were recognized in the entire Megech River catchment. Of these, 49.37% (2506) are first-order, 21.45% (1089), second-order, 14.58% (740), third-order, 9.93% (504) fourth-order, and 4.67% (237) contain fifth-order streams. The total length of streams calculated in WS-1 is 247 km, 188 km in WS-2, 232 km in WS-3, and 104 km in WS-4. We give the results of stream orders in (Table 2).

The mean stream length is a typical property connected to the drainage network and its related surface. The mean stream length (Lsm) was calculated by dividing the total stream length (Lu) of order ‘u’ by the total number of streams (Nu) of order ‘u’. The mean stream length (Lsm) calculated is 0.11 for WS-1, 0.15 for WS-2, 0.18 for WS-3, and 0.2 for WS-4. The stream length ratio (RL) was measured as the ratio of the mean stream length of one order to the next lower order of the stream segment. Stream length sections of individual of the successive orders of a basin tend to be a direct symmetrical series with stream length increasing towards higher streams (Horton, 1945). We give the stream length ratio calculated for each sub-watershed in Table 3.

The bifurcation ratio (Rb) is the ratio of the number of streams of the given order “Nu” to the number of streams of higher-order “u+1”. The bifurcation ratio reveals the shape of the basin. An elongated basin is likely to have a high Rb, whereas a circular basin is likely to have a low Rb (Schumm, 1956). Thus, from the values of the bifurcation ratio, WS-4 exhibits an elongated shape, whereas SW- 2 is nearly circular. In the study, each sub-watershed bifurcation ratio was calculated, which varies from 1.83 in WS-1, 1.57 in WS-2, 1.98 in WS-3, and 2.65 in WS-4 (Table 4). The mean bifurcation ratio (Rbm) is defined as the average of the bifurcation ratio of all orders.

The basin length is an essential morphometric parameter of the drainage basin. The basin length is maximum in WS-3 and minimum in WS-2. The basin length varies from 24 km in WS-1, 21 km in WS-2, 25 km in WS-3, and 16 km in WS-4 (Table 4).

Table 1: Morphometric parameters with formulae

S.No	Morphometric parameters	Formulae/definition	References
		Linear morphometric parameters	
1	Stream order (*u*)	Hierarchical rank	Strahler (1964)
2	Stream number (N_u)	Total number of stream segments of the order ‘*u*’	Horton (1945)
3	Stream length (L_u)	The total length of the stream segments of that particular order	Horton (1945)
4	Bifurcation ratio (R_b)	$R_b = N_u/N(u+1)$ where Nu = total number of stream segments of the order ‘*u*’ and N(u+1) = number of stream segments of the next higher order	Schumm (1956)
5	Mean bifurcation ratio (R_{bm})	R_{bm}=average of bifurcation ratios of all orders	Strahler (1957)
6	Mean stream length (L_{sm})	$L_{sm} = \Sigma Lu/Nu$ 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)
7	Stream length ratio (R_l)	$R_l = L_u/L(u-1)$ 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)
8	Basin length (L_b)	$1.312*A^{0:568}$ where, L=basin length (km), A=area of the basin (km^2)	Nooka et al. (2005)
		Areal morphometric parameters	
9	Basin Perimeter (P) (km)	GIS analysis	Schumm (1956)
10	Drainage frequency (D_f)	$F_s = \Sigma Nu/A$ where Nu = total number of stream segments of the order ‘u’ and A = area of the watershed (km^2)	Horton (1932)
11	Drainage density (D_d)	$D_d = \Sigma L/A$ where L = the total length of streams; A = area of the watershed	Horton (1932)
12	Form factor (F_f)	$R_f = A/Lb^2$, where A = area of the basin and Lb = (maximum) basin length	Horton (1932)
13	Circulatory ratio (C_r)	$C_r = 4\pi A/P^2$ where A = area of the basin (km^2) and P = perimeter of basin (km)	Miller (1953)
14	Drainage texture (D_t)	$D_t = N1/P$ where N1 = the total number of first-order streams; P = the perimeter of the watershed)	Horton (1945)
15	Elongation ratio (E_r)	$E_r = 2\sqrt{(A/\pi)}/Lb$ where A = the area of watershed, π = 3.14, Lb = the basin length	Schumn (1956)
16	Compact coefficient (C_c)	$C_c = P/2\sqrt{\pi A}$ where P = perimeter of basin (km) and A = area of the basin (km^2)	Horton (1945)
17	Length of overland flow (L_g)	$L_g = 1/2Dd$ where Dd = drainage density of basin or $Lg = (1/Dd)/2$	Horton (1945)

Table 2: Results of the morphometric analysis of the sub-watersheds

Sub-WS	Number of Streams of each Order (Nu)							Stream Length of each Order (Lu) in km						
	1st	2nd	3rd	4th	5th	6th	Total	1st	2nd	3rd	4th	5th	6th	Total
WS-1	896	373	370	121	139	----	1899	114	47	32	12	42	----	247
WS-2	579	273	149	193	-----	----	1194	103	36	28	21	----	----	188
WS-3	704	310	196	56	98	----	1364	112	52	35	10	23	----	232
WS-4	327	133	25	134	-----	----	619	54	25	8	17	----	----	104

Table 3: Results of the morphometric analysis of the sub-watersheds

Sub-WS	Stream length ratio (R_l)					Mean	Mean stream length (L_{sm})						Mean
	2/1	3/2	4/3	5/4	6/5								
WS-1	0.41	0.68	0.38	3.5	----	1.24	0.13	0.13	0.09	0.10	0.13	0.30	0.11
WS-2	0.35	0.78	0.75	1.0	----	0.72	0.18	0.13	0.19	0.11	0.18	-----	0.15
WS-3	0.46	0.67	0.29	2.3	---	3.72	0.16	0.17	0.18	0.18	0.16	0.23	0.18
WS-4	0.46	0.32	2.13	----	----	2.91	0.17	0.19	0.32	0.13	0.17	-----	0.20

Table 4: Results of the morphometric analysis of the sub-watersheds

	Bifurcation ratio					R_{bm}	L_b
Sub-watersheds	1/2	2/3	3/4	4/5	5/6		
WS-1	2.40	1.01	3.06	0.87	-----	1.83	24
WS-2	2.12	1.83	0.77	-----	-----	1.57	21
WS-3	2.27	1.58	3.50	0.57	-----	1.98	25
WS-4	2.46	5.32	0.19	-----	-----	2.65	16

Where R_{bm} = mean bifurcation ratio, and L_b =length of basin kms

3.2. Areal morphometric parameters

The calculated basin perimeter varied from 115 km in WS-1, 57 km in WS-2, 109 km in WS-3, and 58 in WS-4 (Table 5). The area of the sub-watershed is an additional significant morphometric parameter. In the present study, each sub-watershed area was calculated, which varies from 168 km^2 in WS-1, 134 km^2 in WS-2, 177 km^2 in WS-3, and 80km^2 WS-4 given in (Table 5).

The compactness coefficient calculated for the study area varies from 2.50 in WS-1, 0.72 in WS-2, 0.43 in WS-3, and 0.55 in WS-4 (Table 5). The compactness of the coefficient has a direct relationship to the soil erosion proneness. Lower values of compactness coefficient signify lesser soil erosion vulnerability risk, while higher values show great soil erosion proneness and represent the need to implement soil conservation measures.

High form factor values usually form the watershed's circular shape and have high peak flows over a short period. In contrast, elongated basins with low form factors have low peak flows over long durations. The calculated form factor value varies from 0.16 to 0.22, which shows an elongated circular shape and suggests a flatter peak flow with a longer duration. Form factor values are shown in Table 5.

An elongation ratio calculated varied from 0.61 in WS-1, 0.62 in WS-2, 0.60 in WS-3, and 0.63 in WS-4. An elongation ratio close to 1.0 is typically a region of shallow relief, whereas that of 0.6–0.8 is associated with high relief and steep ground slope (Strahler, 1964). The elongation values can be grouped into three categories: >0.9 circular, 0.9–0.8 oval, and <0.7 elongated (Strahler, 1964). The elongation ratio values of the study area sub-watershed are <0.7, representing the basin's elongated shape. The elongation ratio values of each sub-watershed are shown in Table 8. Each sub-watershed circulatory ratio was calculated and varied from 0.16 in WS-1, 0.52in WS-2, 0.19 in WS-3, and 0.30 in WS-4 (Table 5). A maximum circulatory ratio of 0.52 was observed in WS-2 and represented the circular shape of sub-watershed.

Table 5: Results of the morphometric analysis of the sub-watersheds

Sub-watersheds	A	P	D_f	D_d	F_f	C_r	D_t	E_r	C_c	L_g
WS-1	168	115	11.30	1.47	0.29	0.16	7.79	0.61	2.50	0.340
WS-2	134	57	8.91	1.40	0.30	0.52	10.16	0.62	1.39	0.357
WS-3	177	109	7.71	1.31	0.28	0.19	6.46	0.60	2.31	0.382
WS-4	80	58	7.74	1.30	0.31	0.30	5.64	0.63	1.83	0.385

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

Drainage density shows the underlying rock's physical properties of the area. Drainage density in the present study area varies from 1.47 km/ km^2 in (WS-1) 1.40 km/ km^2, in (WS-2) 1.31 km/ km^2 in (WS-3) and 1.30 km/ km^2 in (WS-4) (Table 5). The study area's overall drainage density ranges from 0 km/ km^2 to 3.30 km/ km^2. Permeable subsoil material, thick vegetation, low elevation, and coarse drainage texture indicate low drainage density (Nag, 1998). High drainage density is the subsequent impermeable subsurface material, thin vegetation, mountainous relief, and fine drainage texture. In this study, each sub-watershed shows a different stream of frequency value. Higher stream frequency values have observed in WS-1 and WS-2, representing impervious sub-surface media, whereas less stream frequency resulted in WS-3 and WS-4 and represented the porous sub-surface media with low elevation. Table 5 shows the stream frequency values.

3.3. Priority ranking of sub-watersheds

The present study emphasizes prioritizing the four sub-watersheds of the Megech River based on a drainage morphometric parameter analysis. The following morphometric parameters like drainage density (D_d), drainage frequency (D_f), circulatory ratio (C_r), bifurcation ratio (B_r), elongation ratio (Er), drainage texture (D_t), form factor (Ff), compactness coefficient (C_c), and length of overland (Lg) were measured and ranked accordingly. Morphometric parameters like R_b, D_d, L_g, and D_f have a direct relationship with soil erosion proneness (Biswas et al. 1999; Nooka et al. 2005; Javed et al. 2011). Rank1 was assigned to the highest value of the above-mentioned morphometric parameters, rank 2 to the second-highest value of the morphometric parameters, and rank 3 given the lowest value of the above-mentioned drainage morphometric parameters. The following drainage morphometric parameters, circulatory ratio (R_c), form factor (F_f), Drainage texture (D_t), and Compactness co-efficient (C_c) have a reverse relationship with soil erosion proneness as stated by (Biswas et al. 1999; Nooka et al. 2005; Javed et al. 2011). Subsequently, rank 1, assigned to the lowest value of the above-mentioned morphometric parameters, the following lower value has been assigned a rank of 2, and rank 3 is assigned to the highest value of the above-mentioned drainage morphometric parameter. Thus, the ranks were allocated to each drainage morphometric parameter of the four sub-watersheds based on their flood proneness is shown in Table 6.

The compound factor was calculated by summing the assigned ranks of the various drainage morphometric parameters and dividing them by the number of parameters used to prioritize the sub-watersheds (Patel et al., 2012). In the present study, sub-watershed-3 got very highly prioritized with the lowest compound factor value of 2.11. The sub-watershed with the highest compound factor value of 2.88 (WS- 2) has a low priority rank. The sub-watershed, which has the lowest value of the compound factor, is highly vulnerable to soil erosion. Sub-watershed-wise compound factor values and their prioritization rankings are shown in Table 7 and Figure 4. In this present study, sub-watershed-3 has identified sub-watershed-3 as a high-priority ranked watershed, and it needs immediate soil conservation measures for efficient watershed planning and management.

Table 6: Estimation of 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	1	3	2
Compound factor value	2.33	2.88	2.11	2.67

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

Sub-watersheds	Compound	Priority ranking
WS-1	2.33	High
WS-2	2.88	Low
WS-3	2.11	Very high
WS-4	2.67	Medium

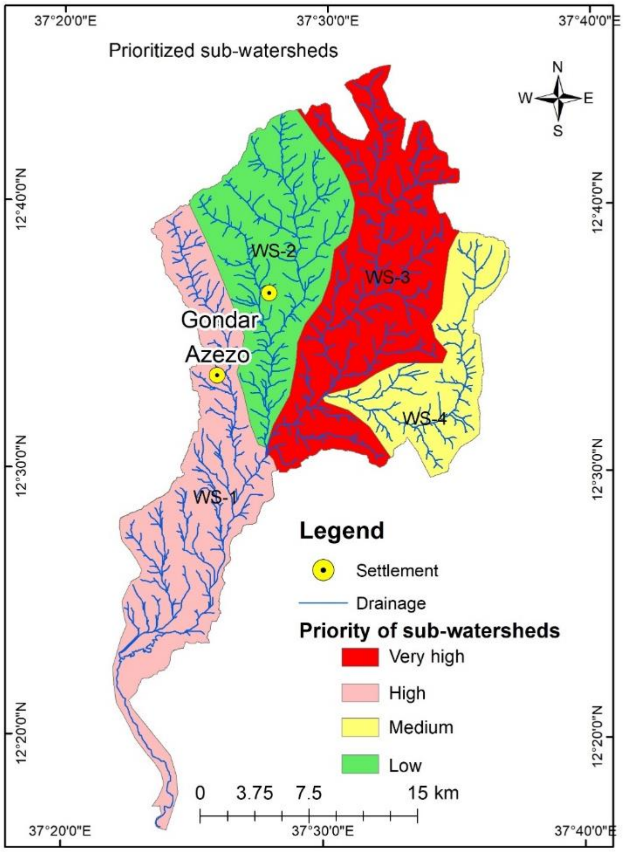

Figure 4: Sub-watersheds wise prioritization for soil erosion map

4. Conclusion

The present study shows the effectiveness of the ASTER DEM, Landsat-8 OLI image, and GIS techniques in the quantitative drainage morphometric analysis. Therefore, remote sensing data and GIS techniques are more efficient for understanding individual sub-watershed morphological characteristics. The linear, areal, and relief morphometric aspects established the watershed's hydrologic performance, and it is the same. It is beneficial for the sub-watershed wise prioritization. In the present study, four sub-watersheds were considered for the drainage morphometric analysis. The selected drainage morphometric parameters were calculated using the standard formula. The morphometric parameters such as bifurcation ratio, drainage density, length of overland flow, and drainage frequency are directly connected with soil erosion proneness. Hence, rank 1 is assigned to the highest values of the parameters mentioned above, followed by second-rank to second-highest value, and rank third given the above parameters' lowest value. The morphometric parameters such as circulatory ratio, form factor, elongation ratio, and drainage texture and compactness coefficient have a reverse relation with soil erosion proneness. Hence, rank 1 is assigned to the lowest values of those parameters, followed by rank two to the second-lowest value, and ranks three, given the above parameters' highest value. Thus, the ranks are 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. Through the present analysis, sub-watershed-3 has been identified as the very-high soil erosion-prone watershed. Furthermore, it needs immediate soil conservation remedial measures for efficient soil resource management planning. The present study results are useful for resource planners, decision-makers, or government-private agencies who attempt to take up soil resources, conservation measures, or fixation of soil conservation structures in the present study area.

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