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Morphometric Characterization of Gelana Watershed, Awash River Basin, Ethiopia.

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Abstract

Watershed resources analysis and development intervention at the catchment level requires primarily an understanding of the physical morphometry, but it has long been emphasized for hydrological analysis of soil and water conservation initiatives. This research was carried out to assess the morphometric characteristics of the sub-watersheds of Gelana using a geographic information system and remote sensing. The parameters considered were bifurcation ratio (Rb), stream frequency (Fs), drainage density (Dd), drainage texture (Dt), Length of overland flow (LoF), Constant of channel maintenance (CCM), infiltration number (If), elongation ratio (Re), circulatory ratio (Rc), form factor (Ff), compactness coefficient (Cc), basin relief (H), relief ratio (Rh), ruggedness number (Rn), stream power index (SPI), and sediment transport index (STI). Shuttle Radar Topographic Mission Digital Elevation Model 30 m resolution was used as input data to generate the value of these variables.

The results showed that linear parameters ranged from Rb = 1.4–5.0; Fs = 0.33–0.55; Dd = 0.54–0.851 while shape parameters revealed that the sub-watersheds (SWs) as being more elongated (Re = 0.46–0.71; Rc = 0.183–0.37; Cc = 1.62–2.33); LoF= 0.27–0.425; IF=0.19–0.46; CCM= 1.175–1.85. This reflects the dominance of dendric drainage patterns and high flooding susceptibility. In addition, the relief parameter also revealed that 75% of 262 km^2 of the seven sub-watersheds are relatively gentle relief (Rh<1.146). It can be concluded that sloppy terrain and high surface relief with relatively elongated shapes are observed in the northern and northeastern parts of the study sub-watersheds, implying high soil and water conservation priority, while the central and southern parts are characterized by a flat topography.

Keywords: *SRTM DEM; Areal parameters; Linear parameters; Shape parameters*

1. Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface and the shape and dimensions of its landforms, and it has various parameters like linear, areal, and relief aspects (Hlaing et al., 2008). These parameters describe the physical features of the watershed in terms of its ruggedness, overall shape, drainage qualities, and dissection (Horton, 1932).

Several studies have been carried out on the morphometric analysis of watersheds for different applications using the digital elevation model (DEM) in the GIS environment. For example, Chandniha, (2014) has applied watershed morphometric analysis to prioritize sub-watersheds for soil and water conservation measures. Sreedevi, et al. (2013), Aher et al. (2014), and Kumar et al. (2018) have also studied watershed morphometry to see its influence on hydrology. Moreover, Vittala et al. (2004) and Ayele et al. (2017) have evaluated drainage morphometry to better understand the watershed characteristics in general. Furthermore, the morphometric analysis also indicates the responsiveness of the watershed to rain events or its susceptibility to floods and erosion (Ayele et al., 2017). According to Das (2014), it is necessary to understand the topography and drainage patterns of an area for the preparation of a comprehensive watershed development plan, and therefore understanding the morphometry of the watershed has to be taken as a benchmark for the analysis of other characteristics of a watershed (Samal et al., 2015). To this purpose, a geographic information system is a powerful tool in terrain visualization, processing, and quantification of topographic attributes using DEM to morphometric studies.

In countries like Ethiopia, where a majority of the population depends on traditional agriculture for their livelihood and is dominated by rugged topography (Woldeamlak, 2003; Temesgen et al., 2017), studying the morphometry of the watershed is important for understanding the physical landscape and to soil and water conservation planning. Watershed hydrological behavior could be understood through the analysis of morphometry of a watershed, especially in data-scarce areas like the Gelana watershed, and this could be a good opportunity for conservation planners to visualize the nature of this area. However, a few research studies have been undertaken on morphometric characterization in Ethiopian watersheds (morphometry of a watershed as one cause of flood risk (Sitotaw and Hailu, 2018) the implication of drainage morphometry (Ayele et al, 2017) the implication of morphometry on soil and water conservation (Daniel and Getachew, 2019) morphometric analysis for prioritizing sub-watersheds and management planning and practices (Gadisa et al, 2020).

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The purpose of this research is to characterize the morphometric features of Gelana sub-watersheds in Ethiopia's Awash River basin using Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) data on the GIS environment. The findings of this study could be utilized as a supplement in the preparation of a comprehensive watershed development plan, which necessitates a thorough understanding of the topography, erosion susceptibility, and drainage patterns of a given area.

2. Material and Methods

2.1 Description of the study area

The study area, the Gelana watershed, is part of the Awash River basin and administratively found in the North Wollo zone of Amhara National Regional State, Ethiopia. It is located between 11°31'30″ and 11°40'00″N, and 39°35'05″ and 39°45'50″E (Figure 1) covering an area of 262km^2 of land inhabited with a total population of 120,250. The elevation of the Galena watershed ranges from 1,363 to 3,474 m above sea level.

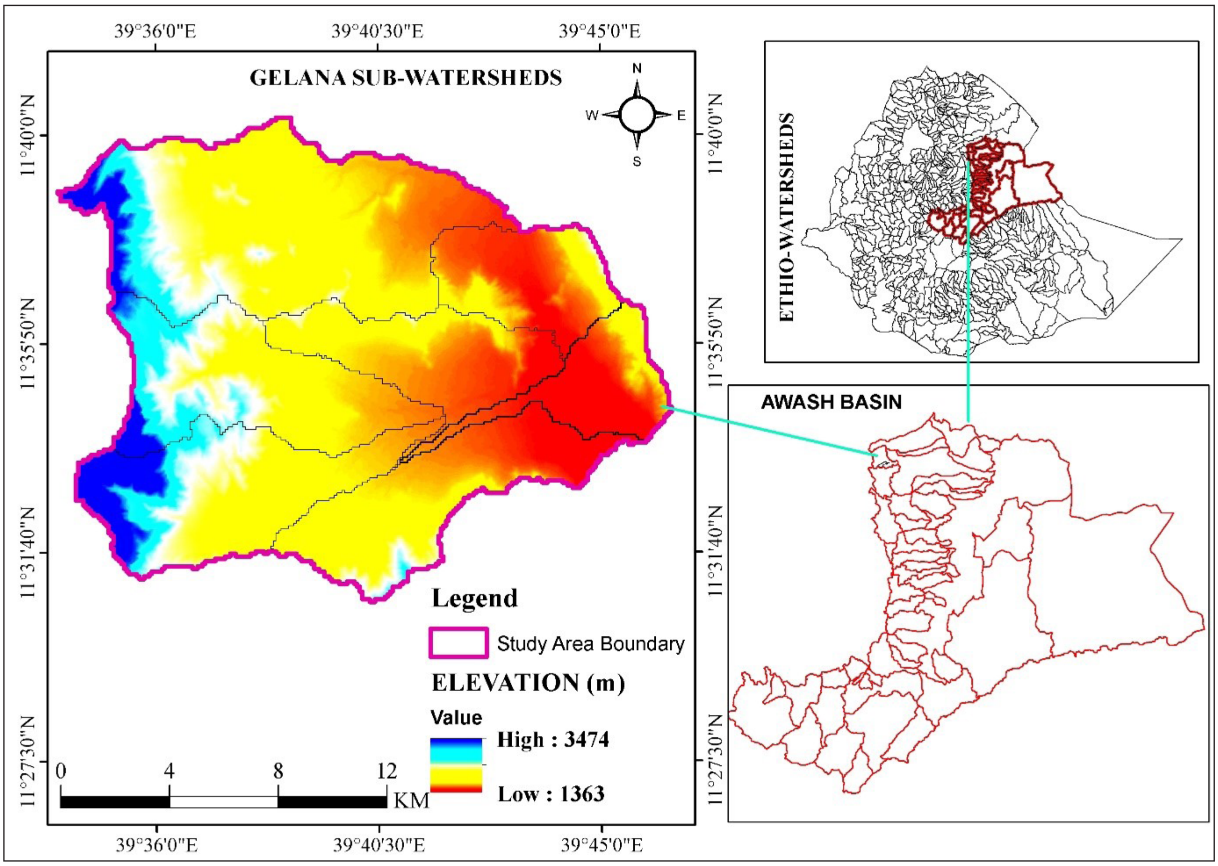

Figure 1. Map of the study area: left— Gelana sub-watershed with elevation (m.a.s.l.) information, top right—Ethiopia watersheds, bottom right—Awash basin

2.2 Input Data and Analytical approach

For the analysis of morphometry of the study watershed, SRTM DEM (https://EarthExplorer usgs.gov) 30 m resolution released on September 2014 was used to delineate and generate the numeric characteristics of different parameters. Identification of smaller geohydrological units is needed for more efficient and better-targeted resource management programs (Sharma and Thakur, 2016). Therefore, the Gelana sub-watershed has been classified into seven sub-watersheds (SWs) using ArcSWAT in ArcGIS 10.4. After creating a shape file of watersheds, the DEM of each catchment was masked. Then, sinks (areas of internal drainage, that is, areas that do not drain out anywhere), were filled to ensure proper delineation of basins and streams (Horton, 1932). If the sinks are not filled, a derived drainage network may be discontinuous. Moreover, a flow accumulation threshold value of 1000 was used and the result stream networks were cross-checked with a toposheet (1:50,000 scale) to have approachable results and generated streams of seven sub-watersheds (Figure 2). The analysis for individual sub-watersheds has been achieved through the calculation of linear, shape, and relief parameters using the formula indicated for each parameter in Table 1.

Table 1. Description of Morphometric Parameters used for this study

SN	Morphometri c Parameters	Definition/ Formula	Description	References
1	Bifurcation ratio (Rb)	Rb = Nu/Nu+1	It is the ratio of the number of streams of the given order u to the number of streams of the next higher order u+1. It shows the complexity and degree of dissection of a drainage watershed.	Schumm (1956); (Strahler, 1964)
2	Stream frequency (Fs)	Fs = Nu/A	It is the ratio of the total number of streams in a watershed to the watershed area.	Horton (1932)
3	Drainage density (Dd)	Dd= Lu/A	It is the ratio of the total length of streams of all orders of a watershed to the area of the watershed	Horton (1932)
4	Drainage texture (Dt)	Dt = Nu/P	It refers to the relative spacing of drainage lines. It is the total number of stream segments of all orders (Nu) per perimeter length of that watershed.	Horton (1945)
5	Compactness Coefficient (Cc)	$Cc = 0.2821P/A^{0.5}$	It is the ratio of the perimeter of the basin to the circumference of a circle with an equal area.	Horton (1945)
6	Form factor (Ff)	$Ff=A/Lb^2$	The form factor is the ratio of the watershed area (A) to the square of the maximum length of the watershed.	Horton (1932)
7	Elongation ratio (Re)	$Re=2/Lb*(A/\pi)^{0.5}$	It is the ratio between the diameters of a circle with the same area as that of the watershed to the maximum length of the watershed.	Schumm (1956)
8	Circulatory ratio (Rc)	$Rc = 4 * \pi * A/P^2$	It is the ratio of the basin area to the area of a circle having the same parameter as the basin.	Miller (1953)
9	Length of overland flow (LoF)	LoF=0.5*Dd	It is the length of water flow over the surface of the ground before it confines into definite stream channels.	Horton (1945)
10	Infiltration Number (IF)	IF=Dd*Fs	It helps to predict the permeability of the surface of the watershed and higher values of 'IF' indicates impermeable surface and resistance to soil loss	Faniran (1968)
11	Constant of Channel Maintenance	CCM=1/Dd	The lower value of CCM indicates higher flood potentiality and young geomorphological adjustment.	Schumm (1956)
12	Basin relief (H)		The difference between the lowest and highest point in a watershed	Hadley and Schumm (1961)
13	Relief ratio (Rh)	Rh = H/Lb	It is a measure of the overall steepness of the drainage area and is an indicator of the intensity of erosion processes operating on the slopes of the watershed.	Schumm (1956)
14	Ruggedness no. (Rn)	Rn = H * Dd	It is the product of the maximum watershed relief and its drainage density. Slope steepness and the length of the watershed affect it.	Melton (1957)
15	Sediment Transport Index (STI)	$(\text{Flow Acc.}/22.13)^{0.6} *(\sin\beta/0.0806)^{1.3}$	It characterizes the process of erosion and deposition and reflects the erosive power of overland flow.	
16	Stream Power Index (SPI)	$(\text{Flow Acc.} + 1) * (\tan\beta)$	It is the product of catchment area and slope and could be used to describe potential flow erosion and related landscape processes.	Florinsky (2012)
17	Land use land cover (LU/LC)*	Landsat 8 image OLI–TRIS**–2018)	Land use indicates how people are using the land while land cover refers to the physical land type.	https://earthexplorer.usgs.gov/

**another parameter **OLI-TRIS-Operational land imager Thermal Infrared Sensor*

The parameters considered in this study are stream order, number of streams, stream length, bifurcation ratio (Rb), stream frequency (Fs), drainage density (Dd), drainage texture (Dt), length of overland flow (LoF), constant of channel maintenance (CCM), infiltration number (If), elongation ratio (Re), circulatory ratio (Rc), form factor (Ff), compactness coefficient (Cc), basin relief (H), relief ratio (Rh), ruggedness number (Rn), slope (S), stream power index (SPI), sediment transport index (STI) and land use land cover (LU/LC).

Landsat OLI images of 2018 have been downloaded from the US Geological Survey https://earthexplorer.usgs.gov/ Web site. A satellite image has been downloaded (website: https://earthexplorer.usgs.gov/) for the year 2018. Then, the supervised classification has been carried out for Land use land cover (LU/LC) by using the ERDAS IMAGINE 2014 software. The sub-watersheds have been classified into five distinct classes' built-up area, forestland, shrubs, cultivated land, and bare lands. The LU/LC processing will be undertaken to crosscheck its relation with the drainage density of catchments.

Moreover, the soil texture of the study sub-watersheds was obtained from the regional agriculture and rural development bureau and compared with the calculated drainage density of the study area. Here, the resulting soil texture vector map was converted into a raster map to better visualize the areal extent of each soil texture type (Figure 4).

3. Results and Discussion

3.1 Linear Morphometric Parameters

Aher et al. (2014) indicated that the classification of stream order is important to index the size and scale of the basin. Using Strahler's (1957) system of stream order, the Gelana watershed has five (5) main streams order, with each stream order in each sub-watershed having a varying number of streams (Table 2).

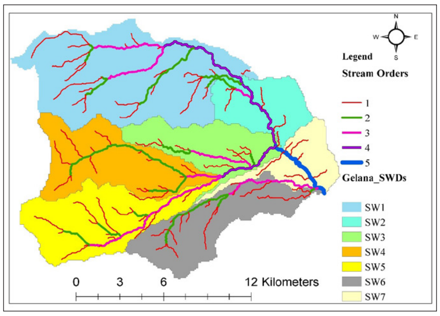

Figure 2. Stream orders of Gelana sub-watersheds.

The study watershed has an area of 261 km^2 with which 116 total streams with a total stream length of 200 km. This means that there are about 0.44 streams in a km^2 and an average of 0.76 km stream length per km^2 area. Considering the sub-watersheds, SW1 is the highest in terms of stream length at 64 km while SW7 has the lowest stream length with a total of 11 km (Table 2).

The result showed that five out of seven sub-watersheds have a bifurcation ratio (Rb) ranging from 3.25 up to 5.0 (Table 1) with a mean of 3.6 which fits with Horton's (1945) natural drainage characteristics (Rb=3.0–5.0). Lower-order streams have a higher bifurcation ratio that reflects the high dissection in the upland area. Lower bifurcation ratios (Rb<3.0) are the characteristics of structurally less disturbed watersheds (Ayele et al., 2017) which were observed in SW2 and SW1.

Horton (1945) noted that the value of stream frequency depends on the total number of streams and the corresponding basin area. In the present study, stream frequency varies from 0.33 to 0.55 (Table 2). In addition, the stream frequency of sub-watersheds showed a positive correlation with the drainage density values of the sub-watersheds indicating the increase in streams concerning an increase in drainage density.

Table 2. Linear morphometric parameters

SW	Parameters	Stream Order					Fs	Dd	Dt
		1st	2nd	3rd	4th	5th			
1	No. of streams	24	7	2	1	-	0.43	0.81	0.56
	Stream Length/km	34	12	11	7	-			
	Ave. length/km	1.4	0.9	2.2	2.33	-			
	Basin Length(km)	17.01							
	Bifurcation ratio	3.42	3.5	2					
	Mean Rb	**2.97**							
2	No. of streams	7	1	-	-		0.36	0.54	0.29
	Stream Length/km	7	5	-	-				
	Ave. length/km	1.0	1.0	-	-				
	Basin Length(km)	7.2							
	Bifurcation ratio	1.4							
	Mean Rb	**1.4**							
3	No. of streams	10	4	1	-		0.55	0.851	0.34
	Stream Length/km	10	5	8					
	Ave. length/km	1.0	1.25	1.6					
	Basin Length(km)	11.08							
	Bifurcation ratio	2.5	4						
	Mean Rb	**3.25**							
4	No. of streams	15	2	1			0.45	0.7	0.39
	Stream Length/km	14	12	2					
	Ave. length/km	0.93	1.0	1.0					
	Basin Length(km)	12.85							
	Bifurcation ratio	7.5	2	-					
	Mean Rb	**4.75**							
5	No. of streams	15	4	1	-	-	0.5	0.85	0.57
	Stream Length/km	18	5	11	-	-			
	Ave. length/km	1.2	0.83	1.37	-	-			
	Basin Length(km)	13.8							
	Bifurcation ratio	3.75	4		-	-			
	Mean Rb	**3.87**							
6	No. of streams	12	2	1	-	-	0.42	0.8	0.32
	Stream Length/km	19	7	2		-			
	Ave. length/km	1.58	1.0	1.0	-	-			
	Basin Length(km)	14.04							
	Bifurcation ratio	6	2		-	-			
	Mean Rb	**4**							
7	No. of streams	5	1	-	-		0.33	0.61	0.13
	Stream Length/km	7	4	-	-				
	Ave. length/km	1.4	1.0	-	-				
	Basin Length(km)	10.6							
	Bifurcation ratio	5	-	-	-	-			
	Mean Rb	**5**							

Drainage density (km/km^2) provides a clue about the density of vegetation cover, soil, and rock characteristics of a watershed. Therefore, the higher the drainage density the lesser density of vegetation cover and impermeable soil and rock surface which lets the movement of overland flow as runoff (Horton, 1945). He also noted that infiltration, controlled by permeability, might influence drainage density by determining at what distance from a divide there will be a sufficient surface flow of water to start gullying erosion. Based on this, the sub-watershed with higher drainage density (SW3 and SW5–0.85) (Table 2) have shown low forest coverage (Figure 3) and manifested with clay, clay loam, and sandy clay soil (Figure 4). Thus, these sub-watersheds are inherently slow soil permeability, which will have significant implications on soil erosion and runoff generation. Ayele et al. (2017) noted that an impermeable surface would generate high drainage density and efficiently carry away runoff, with high peak discharge but low base flow.

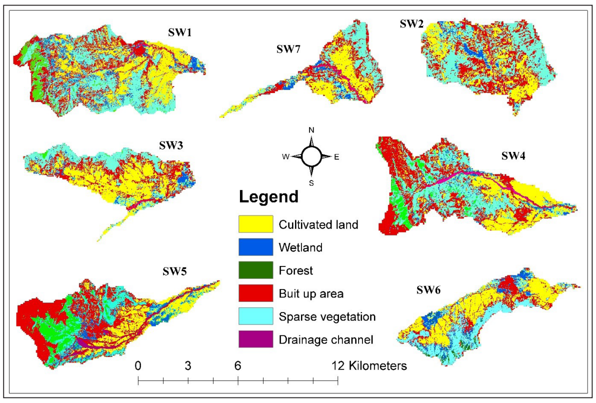

Figure 3. Land use/land cover of Gelana sub-watersheds.

Because drainage texture is the relative spacing of drainage lines, the lower its value means the far apart of drainage lines which are significantly affected by underlying lithology, vegetation, soil type, infiltration capacity, and relief aspect (Horton, 1945; Smith, 1950).

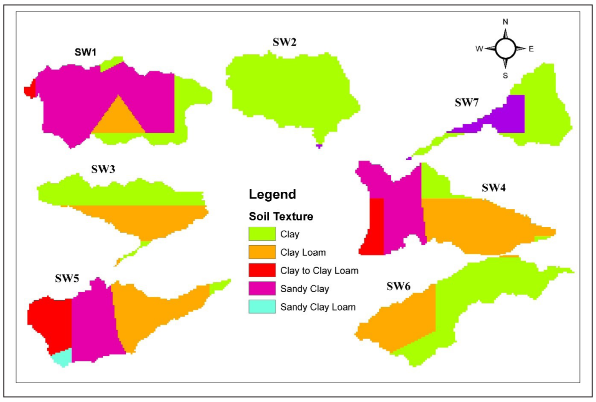

Figure 4. Soil textures of Gelana Sub-watersheds using regional agriculture and rural development bureau soil data.

Smith (1950) has classified a watershed with different drainage textures (very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (>8). In the present study, drainage texture varies from 0.13 (SW7) to 0.57 (SW5) reflecting a very coarser drainage texture.

3.2 Areal Morphometric Parameters

Samal et al. (2015) have revealed that for a perfectly circular basin, the value of the form factor is greater than 0.78. Nevertheless, the highest Form factor in the present study is 0.42 for SW2 indicating the elongated shape of the sub-watersheds. On the other hand, the value of the form factor can also reveal the hydrological behavior of a watershed that is the lower the form factor value, the lesser the peak flow for a longer duration while the higher the form factor, the higher the peak flow for shorter duration (Hlaing et al., 2008). Therefore, the smaller numeric value of the form factor of Gelana sub-watersheds implies that they are relatively elongated and will have a flatter peak flow over an extended time that makes flooding less susceptible.

Table 3. Areal morphometric parameters of the Gelana watershed

SW	A(km^2)	P(Km)	Ff	Re	Rc	LoF	IF	CCM	Cc
1	79	60	0.273	0.551	0.27	0.405	0.348	1.23	1.9
2	22	27	0.42	0.71	0.37	0.27	0.19	1.85	1.62
3	27	43	0.21	0.527	0.183	0.425	0.468	1.175	2.33
4	40	46	0.24	0.553	0.237	0.35	0.31	1.42	2.05
5	40	46	0.2296	0.535	0.237	0.425	0.42	1.176	2.05
6	35	46	0.17	0.467	0.207	0.4	0.342	1.25	2.19
7	18	35	0.15873	1.07	0.184	0.305	0.20	1.63	2.32

A = Watershed Area; P = watershed Perimeter

Strahler (1964) classified Re value into four classes; <0.7– (elongated), 0.7–0.8 (less elongated), 0.8–0.9 (oval), >0.9 (circular). In the present study, the value of the elongation ratio is lower than 0.7 reflecting the elongated ness of Gelana SWs except for SW2–0.71 and SW7–1.07. Elongated watersheds are characterized by high spreading out runoff over time resulting in smaller peak floods. Strahler (1964) and Samal et al. (2015) noted that the Re value approaching 1 is indicative of very low relief, whereas values in the range of 0.6–0.8 are generally associated with strong relief and steep ground slopes.

The circularity ratio is the ratio of the basin area to the area of a circle having the same perimeter as the basin (Miller, 1953). The slope, relief geologic structure of the basin, and land use land cover, influences the circularity ratio. A low Rc value implies an elongated basin shape while a high Rc value indicates a near-circular. In the present study, relatively higher Rc was found at WS2 and WS1 with Rc of 0.37 and 0.27, respectively while the lowest Rc was observed at WS3 (0.183) and SW7 (0.184) (Table 3).

Infiltration number (IF) is a function of drainage density and stream frequency (Odiji et al., 2021). Faniran (1968) noted that areas with higher IF values are an indication of lower infiltration and higher surface runoff. Sub-watersheds with relatively higher IF values are SW3 and SW5 indicating that the amount of water entering into the soil is low and by implication, runoff is high (Table 3).

Length of overland flow (LoF) refers to the length at which rainfall runs over the surface before it drains into a stream channel (Horton 1945). The LoF ranges from 0.27km to 0.425km in the seven sub-watersheds (Table 3) with a mean of 0.36km which implies that the watershed has a short flow path. The values of the LoF are small in the entire sub-watershed which means that surface runoff will enter stream channels rapidly and therefore the areas are highly vulnerable to flooding due to reduced water percolation into the soil.

The constant of channel maintenance (CCM) is inversely related to drainage density (Schumn, 1956). It depends on the rock type, permeability, climatic regime, vegetation cover, and relief as well as the duration of erosion. It decreases with increasing erodibility (Schumn1956). According to Bhagwat et al. (2011), higher values of CCM suggest more area is required to produce surface flow, which implies that part of water may get lost by evaporation, percolation, etc while lower value indicates fewer chances of percolation/infiltration and hence more surface runoff. The SW3 and SW5 have low CCM values of 1.175 km/km2 and 1.176 km/km2, respectively (Table 3) indicating that these sub-watersheds are under the influence of high structural disturbance, low permeability; steep to very steep slopes, and high surface runoff. On the other hand, SW2 and SW7 have the highest CCM values of 1.85km/km2 and 1.65km/km2, respectively, and are under very less structural disturbances and fewer runoff conditions (Table 3).

3.3 Relief Morphometric Parameters

Relief controls the rate of draining water through a watershed and run-off is generally faster in steeper terrain, producing discharges that are more peaked and greater erosive power (Schumn, 1956). In the present study, total relief varies from 602m in SW7 to 1992m SW1 and SW5 while the relief ratio ranges from 0.099 (SW2) to 0.15 (SW5) (Table 4) and that proves the relatively flat terrain of the sub-watersheds. Ruggedness number combines slope steepness and length. Its higher values occur when slopes are not only steep but long as well.

SW1 and SW5 showed higher values of ruggedness number than the other sub-watersheds, with SW5 slightly higher (1.69) than SW1 (1.61).

Table 4. Relief morphometric Parameters of the Gelana watershed

Items	Sub watersheds						
	1	2	3	4	5	6	7
Basin Relief (m)	1992	715	713	1877	1992	930	602
Relief ratio	0.116	0.099	0.064	0.146	0.15	0.66	0.056
Ruggedness number	1.61	0.386	0.606	1.313	1.69	0.744	0.367

3.4 Other Characteristics

The sediment Transport Index (STI) characterizes the process of erosion and deposition and reflects the erosive power of overland flow (Jaiswal et al, 2015). The STI value is higher in SW7—78.16. This may be due to sediments emanating from the whole sub-watershed meeting at this sub-watershed making higher sediment loads.

Table 5. Other characteristics of the Gelana watershed.

Items	Sub watersheds						
	1	2	3	4	5	6	7
STI	30.68	60.99	52.97	29.77	31.19	29.4	78.16
SPI	30.6	40.09	26.78	31.58	35.71	14.07	64.91
TWI	1.5715	1.758	1.81	1.54	1.66	1.74	1.8152

Concerning Stream Power Index (SPI), high stream power was observed in SW7 (64.9) which may be associated with the flow of higher amounts of water from the upper areas. The higher the power of stream water, the greater the probability of washing down vulnerable topsoil leading to land degradation through transporting soil material and sediment to the plain areas. Knighton (1999) noted that stream power may vary in the downstream direction and maximum power lies around the outlet because of the large increase in mid-watershed discharge associated with a series of large, closely spaced tributaries. In this regard, the prevailing variety of geomorphic setting downslope has a significant implication for the movement and storage of materials in the watershed. Therefore, high SPI values represent areas on the landscape where high slopes and flow accumulations exist and thus the flows can concentrate with higher erosive potential.

Table 6. Correlation coefficient between morphometric parameters.

	Rb	Fs	Dd	Dt	Ff	Re	Rc	LoF	IF	CCM	Cc	H	Rh	Rn	STI	SPI	TWI
Rb	1.00																
Fs	0.02	1.00															
Dd	0.20	0.83	1.00														
Dt	-0.19	0.58	0.66	1.00													
Ff	-0.86	-0.21	-0.49	0.17	1.00												
Re	0.23	-0.73	-0.70	-0.71	-0.08	1.00											
Rc	-0.80	-0.35	-0.52	0.19	0.97	-0.06	1.00										
LoF	0.20	0.83	1.00	0.66	-0.49	-0.70	-0.52	1.00									
IF	0.10	0.96	0.95	0.61	-0.37	-0.72	-0.47	0.95	1.00								
CCM	-0.30	-0.80	-0.99	-0.63	0.56	0.67	0.58	-0.99	-0.92	1.00							
Cc	0.75	0.31	0.43	-0.32	-0.93	0.14	-0.99	0.43	0.41	-0.48	1.00						
H	0.16	0.35	0.45	0.87	0.03	-0.49	0.10	0.46	0.37	-0.49	-0.26	1.00					
Rh	0.15	-0.04	0.27	-0.02	-0.33	-0.44	-0.18	0.27	0.11	-0.28	0.14	-0.07	1.00				
Rn	0.16	0.45	0.60	0.92	-0.05	-0.54	0.01	0.60	0.50	-0.62	-0.16	0.98	-0.02	1.00			
STI	-0.07	-0.52	-0.66	-0.80	0.07	0.87	-0.01	-0.66	-0.56	0.67	0.15	-0.78	-0.48	-0.80	1.00		
SPI	0.21	-0.58	-0.62	-0.49	0.01	0.95	0.00	-0.62	-0.61	0.60	0.06	-0.26	-0.64	-0.32	0.79	1.00	
TWI	-0.13	-0.17	-0.23	-0.71	-0.15	0.46	-0.23	-0.23	-0.15	0.28	0.37	-0.92	0.02	-0.84	0.75	0.30	1.00

The correlation matrix (Table 6) shows that a strong positive correlation exists between linear morphometric parameters (IF with LoF, Fs, and Dd; Dd with Fs; LoF with Fs and Dd).

Horton (1945) noted that high transmissibility (as evidenced by infiltration capacity) leads to low drainage density, high base flow, and a resultant low magnitude peak flow. Besides, in impermeable surfaces, runoff is usually accelerated by the development of a greater number of more closely spaced channels and thus higher Fs, Dd, and IF (Ayele et al., 2017). A positive correlation was also observed between Rc and Ff; H and Dt; Rn with Dt and H; STI and SPI with Re. Conversely, CCM with LoF and IF; Cc with Rc has shown a strong negative correlation. Areas with low CCM (i.e limited infiltration) tend to generate more overland flow (Steedevi et al., 2013).

4. Conclusions

The results of this study have demonstrated that the Gelana watershed has five (5) order streams with a mean Rb of 3.6; low drainage density (0.54–0.851 km/km^2) and coarser drainage texture (0.13–0.57) indicating that the sub-watersheds have relatively less dissected terrain features and permeable surfaces.

Results of shape parameters, on the other hand, showed Gelana watershed has an elongated shape (Ff = 0.15–0.42; Re = 0.467–0.71 except SW7 which has Re of 1.07; Rc = 0.183–0.37). The study watershed is characterized by relatively low relief demonstrating the dominance of flat terrain in the sub-watersheds. Moreover, higher LoF and IF have been observed in SW3 and SW5 manifesting a lower probability of runoff in these watersheds with a higher Dd–0.851 and 0.85, respectively while the lower level of CCM– 1.175 and 1.176 implying a higher soil erodibility, low vegetation cover, and low infiltration. The results of this study provide information on drainage morphometry of the Gelana watershed which could be a tool for strategic planning, implementation, and management of watershed resources. However, the morphometric analysis only detects the physical terrain and morphology which does not consider human aspects of the watershed resources, further research should be conducted embedding both natural and human factors-based modeling for conservation prioritization.

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