VOL 7(1), 97-118
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ISSN: 2523-1901 (Online)
URL: http://jessd.mwu.edu.et/
Email: JESSDeditorials@mwu.edu.et

JESSD Journal of Equity in Sciences & Sustainable Development

DOI: https: //doi.org/10.20372/mwu.jessd.2024.1556

Full Length Research Paper

Characterizing and Analyzing Morphometric Parameters and Their Implications on Watershed management in Sub-upper Wabe Shebele Drainage Basin, West Arsi Zone, Ethiopia

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Article Info

Article History

Received: 01 Sept 2023

Accepted: 29 Jan 2024

Keywords:

Drainage basin, GIS, Morphometric parameters, Melka Wakena, RS and Wabe Shebele.

Abstract

This study was aimed at characterizing and analyzing the morphometric parameters and their implications on the watershed in the sub-upper part of the Wabe Shebele drainage basin in the Melka Wakena sub-basin. To achieve the objective of the study, descriptive and empirical research methods were employed using different data types, such as DEM (30 mx 30 m), Ethio GIS 2007, and GCPs. The collected data were processed and analyzed using ArcGIS 10.3 tools and formulas coined by different scholars into basins with linear, areal, drainage, and relief aspects. Data analysis was carried out in a range of stages to determine the morphometric parameters of the study drainage basin. The study area covers 4372 km2. The finding indicates that the basin has a fourth-order drainage basin, with lower and middle-order streams dominating. The study discovered that large portions of the basin's topography are suitable for agriculture, with 54.33% being highly suitable, 42.97% being moderately suitable, and only 2.7% being unsuitable. The findings from the upper Wabe Shebele River Basin could provide useful empirical data for developing a strong physical soil and water resource conservation structure and management plan for long-term watershed management.

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1. Introduction

A drainage basin is defined as the area of the earth's surface that is drained by a stream, river, or its tributaries and that is separated from others by drainage divides (Taylor and Francis, 2011; Ohal, 2015; Elsoghier, 2017). It is also called the catchment area of a river whose runoff is channeled through a single outlet (Tesfaye and Wondimu, 2014). Geological processes form basins; their pattern and density depend on factors like land surface relief, climate, soil types, vegetation, and human impacts on the basin environment (Rama, 2014; Damilola, Mustafa, et al., 2016).

Drainage basin inquiry is crucial for hydrological investigations, including groundwater potential assessment, management, pedology, and environmental considerations (Hajam et al., 2013). Additionally, Jayappa and Markose (2011) explain that morphometric analysis is used in various hydrologic investigations, including groundwater potential assessment, pedology, water resource management, flood control, environmental impact assessment, and pollution studies. The hydrologic characteristics of drainage basins, including size, shape, slope, density, and relief, are interrelated (Shi et al., 2003; Waikar and Aditya, 2014; Mustafa et al., 2016). Comprehensive morphometric analysis helps understand the influence of drainage networks on landforms (Hajam et al., 2013). Moreover, Rama (2014) explains that this analysis is essential for basin planning, providing information on slope, topography, soil condition, runoff characteristics, and surface and groundwater potential.

A quantitative technique for measuring and analyzing the arrangement, shape, and dimensions of land surfaces is called morphometry (Jesuleye et al., 2016; Agarwal, 1998; Obi-Reddy, 2002). Morphometry helps to visualize the spatial characteristics of drainage basins, including linear, areal, drainage, and relief aspects (Pidwimy, 2006; Tesfaye and Wondimu, 2014; Ayele, 2017). Drainage morphometric analysis is used to understand geological variation, topographic information, and the structural settings of basins.

Drainage basin analysis is crucial for water resource development and management, environmental assessment, and understanding geological variation, topographic information, and structural settings (Damilola, Mustafa, et al., 2016). Hydrologists and geomorphologists have identified a significant relationship between runoff and drainage system characteristics (Elsoghier, 2017). Morphometric analyses have been increasingly used to model surface processes like soil erosion and flooding (Sumira et al., 2013; Akinwumiju, 2015).

GIS and satellite remote sensing have become essential tools for analyzing, updating, and measuring periodic changes (Ayele, 2017; Tattao, 2010). The advancement in geospatial technology has significantly transformed the methods and data used to extract fundamental drainage basin characteristics. Remote sensing systems like DEMs and images have proven more flexible and precise than topographic maps, and GIS has become the best technology for efficiently delineating drainage basins and exploring properties (Mason, 2000; Gopalan et. al., 2003; Lima and Correa, 2011). RS offers synoptic coverage, inaccessible data, and a quick method for creating a base map without detailed land surveys (Ayele, 2017). The statistical analysis quantifies the unique attributes of drainage basins using formulas developed by various scholars.

Community living in the upper stream and lower stream of study basin are dependent up on the resources of watersheds in the basin for various reasons. However, these resources are under human pressure causing deforestation and subsequent soil erosion and sedimentation of the streams and the reservoirs. Therefore, quantitative analysis of morphometric parameters of the watersheds in the study basin is of immense utility in the development and prioritization of the conservation of soil and water at a watershed level.

Several studies (Tasfaye & Wandu, 2014; Estifanos, 2014; Girma & Bhole, 2015; Ayele, 2017) have been conducted on morphometric parameters in various parts of the country (in the northern, northwestern, eastern, and western), but there are discrepancies due to topographic differences. In the similar manner some studies have conducted in the **Sub-upper Wabe Shebele Drainage Basin**. for instance, a study by Dereje (2015) in the Melka Wakena hydroelectric power reservoir focused on modelling sediment yield and mitigation measures but did not characterize hydrometric or morphometric parameters. Another study by Hussien et al. (2016) also highlighted land degradation and land use changes on surface runoff but did not consider morphometric parameters and their relationships. Furthermore, academic research in Ethiopia often lacks detailed drainage basin studies due to various reasons (Ayele, 2017). This study aims to address these gaps by utilizing DEM data, GCPs and shape file using remote sensing, GIS, and different statistical manipulation formulas coined by scholars in the upper Wabe Shebele river basin in the Melka Wakena catchment.

To better understand the impact of morphometric parameters on the study drainage basin, the study aimed to identify and map rivers and streams, characterize and analyze the morphometric parameters of the study drainage basin, and describe their implications on the watershed. The outcome of the study could be useful for managers and planners in the basin while implementing soil and water conservation measures. Moreover, this research is crucial for developing a well-developed geodatabase of the basin.

2. Materials and Methods

Study Area

The sub-upper Wabe Shabele drainage sub-basin is located in south-eastern Ethiopia within the Melka Wakena sub-basin. The total area of the study sub-basin is about 4372 km^2 and lies between 6.5^0 and 7.5^0 North Latitude and 39^0 and 39.7^0 East Longitude. The study sub-basin comprises seven woredas, with six from the West Arsi zone and one from the East Arsi zone. The mean annual temperature in the study sub-basin ranges between 2–15 °C in higher elevation areas and 16–24 °C in lower plateau areas. The mean annual rainfall ranges from 1200mm to 2940mm. The drainage sub-basin has a variety of soil types, with Calcic Cambisols, Pellic Vertisols, Orthic Luvisols, Chromic Luvisols, Eutric Nitosols, and Eutric Cambisols covering 29.11%, 24.86%, 17.77%, 17.42%, 10.20%, and 0.63% of the total area, respectively (FAO, 2007).

The drainage sub-basin is rich in numerous rivers and streams, including seasonal and persistent ones like Totolamo, Ashoka, Ukuma, Lensho, Kerensa, Maribo, Furuna, Nanisha, Ashiro Wekentera, Geredela, Uruba, Melka Wekena (Tesema, 2015; Hussien et al., 2016), Tamela, and Kakawa. These rivers are mainly used for livestock and housekeeping, while some are used for small-scale irrigation, except for the artificial lake, Melka Wakena, which serves as a hydroelectric powerhouse. The diverse climate and topographic occurrences create a broad variety of natural environments that form beneficial habitats for various fauna in the study catchment. The forest resources of the sub-basin are used by the local community for fuel wood, pasture, timber, wild fruits, and medicinal herbs. The distribution and vegetation types vary from wooded grasslands to afro-alpine vegetation (Hussein et al., 2016). According to the CSA 2007 Population and Housing Census projection, the total population of the study catchment was 1,468,441, with 723,617 males and 744,823 females in 2018. Agriculture is the most important livelihood base and economy in the area, with wheat covering the largest portion of cultivated land. Farmers use crop rotation, animal dung, and fallowing to maintain soil fertility and yield (Hussien et al., 2016).

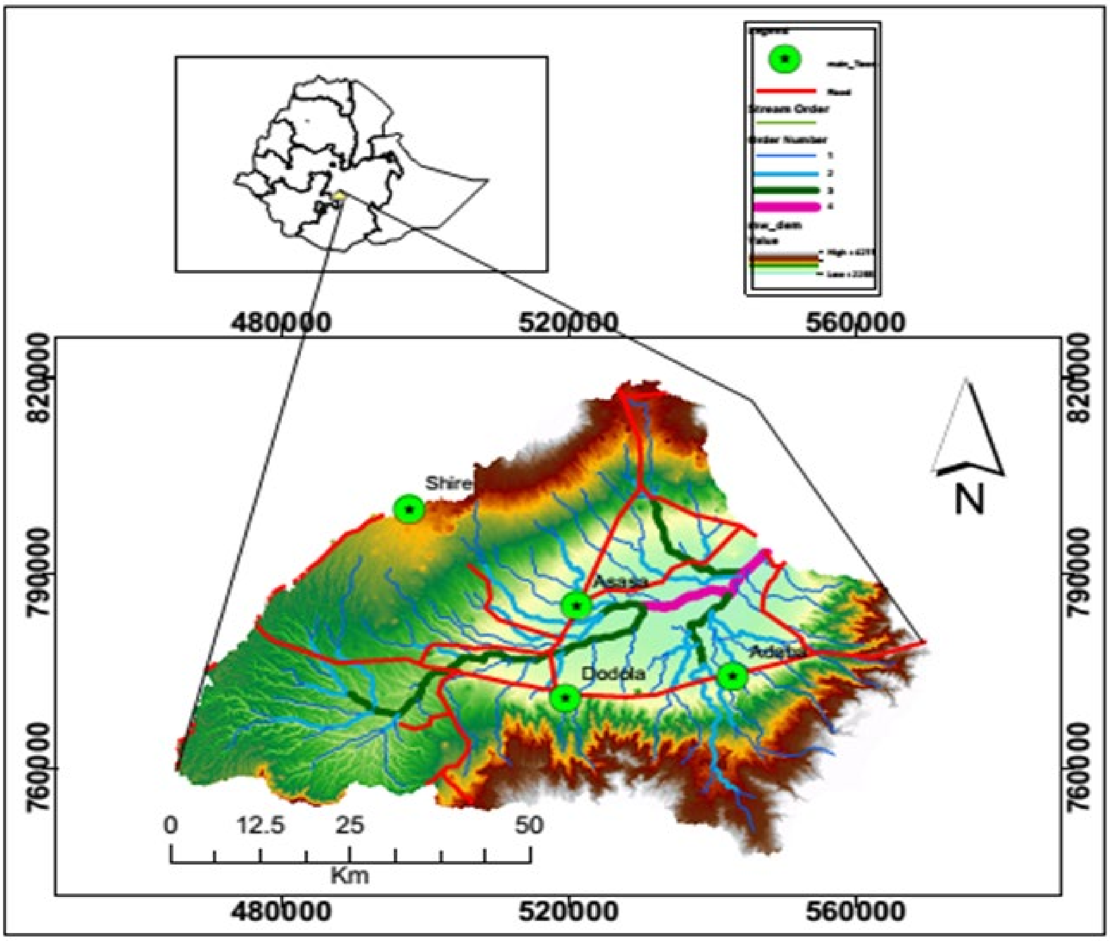


Figure 2.1. Study Area map

The assessment of drainage sub-basin morphometric characteristics is a complex process that requires multiple perspectives to characterize various variables at various spatial scales. It integrates methodologies like GIS, remote sensing, field data collection, and data analysis.

Data such as topographic data, DEM data and a boundary shape file was obtained from the NASA Shuttle Radar Topographic Model and Madda Walabu University's GIS and Land Resource Management departments. Field spatial data was collected randomly using GPS (GCPs) and digital cameras (digital image), from each woreda for ground truth.

Table 2.1. Data Types Utilized for this Research

No	Types of data	Source	Descriptions	Purpose
1	DEM	USGS	30mx30m	For delineation of the study sub-basin boundary, characterizing and analyzing basic morphometric parameters
2	Shape file	Ethio-GIS 2007		For identifying, extracting and making study area map

3	GCPs	Field survey	Random coordinates from few tributaries using ATLAS GPS	For ground truth
4	Image	Personal	Digital camera	For image capturing during field observation and data collection

For characterizing and analyzing drainage sub-basin morphometric parameters and their implications, DEM satellite images, and GCP points were used. The Sub-Upper Wabe Shebele drainage sub-basin in Melka Wekena catchment was delineated from the DEM with the help of the hydrology tool in ArcGIS 10.3, and at the same time, the spatial analyst tool was utilized to prepare a topographic map of the drainage sub-basin. The delineated drainage sub-basin from the DEM was later transformed into a shape file. Flow Direction creates a raster of flow direction from each cell down the gradient; Flow Accumulation produces a raster of collected flow into each cell. The stream order tool in the Strahler method, which allocates a numeric order to fragments of a raster, signifying divisions of a linear network, and stream-to-feature tools helped to discover patterns of streams in the study area. A pour point was selected to outline the drainage sub-basin boundary from the main river confluence points of the upper Wabe Shebele River in the Melka Wakena Drainage Sub-basin. The determined morphometric parameters were calculated from four viewpoints: linear aspect, areal aspect, drainage aspect, and relief aspect. The primary stage involved the determination of basic (independent) morphometric parameters such as stream length, sub-basin area, sub-basin perimeter, sub-basin length, sub-basin relief, sub-basin width, maximum order of streams, and number of streams in each order, which were manipulated directly from the DEM using ArcGIS 10.3 facilities.

These parameters were used to find out other determinant factors or derived parameters, like bifurcation ratio, stream frequency, elongation ratio, circulatory ratio, form factor, length of overland flow, drainage density, drainage texture, total relief, relief ratio, and leminiscate ratio, among others. These morphometric parameters were analyzed based on formulas coined by scholars such as Horton (1932, 1945), Strahler (1952, 1956, 1964), Schumn (1956, 1965), Miller (1953), Gregory & Wasing (1973).

Table 2.2: Drainage Morphometric Parameters, Symbols and Formulas

No	Features	Parameters	Symbol	Formula	Reference
1	Linear aspect	Stream order	Su	Hierarchical Rank	Straheler(1952)
2		Number of streams	Nu	Nu=N1+N2…+Nn	Horton(1945)
3		Stream Length	L u	Lu=L1+L2…+Ln	Straheler(1964)
4		Stream length Ratio	Rl	Rl =Lu\Lu-1, Lu-1 = next lower order	Straheler(1964)
5		Mean Stream length Ratio	Lsm	Lsm = average of stream length of all orders	Horton(1945)
6		Bifurcation Ratio	Rb	Rb=Nu/Nu+1, Nu+1 = next higher order	Straheler(1964)
7		Main channel Length	Cl	GIS Software	-
8		Rho Coefficient	ρ	ρ=Rl/Rb	Horton(1945)
9	Sub-basin Geometry	Sub-basin Area	A	GIS Software(area of the drainage sub-basin separated from opposite by ridge line)	Schumm(1956)
10		Sub-basin length	Lb	GIS software (Lb = (farthest distance from outlet)	Schumm(1956)
11		Mean Sub-basin Width	Wb	Wb= A/Lb	Horton(1932)
12		Sub-basin perimeter	P	GIS software(P = outer boundary of drainage sub-basin measured in kilometer)	Schumm(1956)
13		Relative perimeter	Pr	Pr=A/P	Schumm(1956)
14		Lumniscate	K	$K=Lb^2/A$	Chorley(1957)
15		Factor Form	Rf	$Rf = A / Lb^2$	Horton(1932)
16		Circulatory ratio	Rc	$Rc = 4\pi A / P^2$	Miller(1953)
17		Elongation ratio	Re	$Re = 2/Lb * \sqrt{(A/\pi)}$	Schumm(1956)
18		Texture Ratio	Rt	Rt=N1/P	Schumm(1956)
19		Drainage Texture	Dt	Dt=Nu/P	Horton(1945)
20	D ra	Stream frequency	Fs	$Fs = \Sigma Nu / A$	Horton(1932)

21		Drainage density	Dd	Dd = Σ Lu ⁄ A, Dd in (Km\Km2)	Horton(1932)
22		Constant channel maintenance	Lof	Lof = 1 ⁄ Dd	Schumm(1956)
23		Drainage intensity	Di	Di=Fs/Dd	Faniran(1968)
24		Infiltration Number	If	If=Fs*Dd	Faniran(1968)
25		Drainage Pattern	Dp	-	Horton(1932)
26		Length of overland flow	Lg	Lg = 1 ⁄ 2Dd	Horton(1945)
27	Relief Aspect	Height of Sub-basin Mouth	H_{min}	GIS Analysis from DEM	-
28		Maximum of the Sub-basin	H_{max}	GIS Analysis from DEM	-
29		Sub-basin relief	Bh	Bh = H_{max}- H_{min}	Straheler(1952
30		Relief ratio	Rh	Rh = Bh ⁄ Lb	Schumm(1956)
31		Relative Relief	Rr	Rr=H*100/p, H should be in km	Melton(1957)
32		Ruggedness number	Rn	Rn = Dd*(Bh/1000) to be in km	Patton& Baker (1976)
33		Melton Ruggedness Number	MRn	MRn=Bh/√A	Melton(1965)

34		Slope	S	Vertical difference over horizontal difference	

The slope map of identified drainage sub-basins was computed from DEM of 30 m spatial resolution using ArcGIS's spatial analysis tool, classified using FAO's 2014 classification system (0–8%, 8–30%, and >30%), and established into agriculture suitability classes. Data layers were prepared for further analysis.

Drainage sub-basin margins are crucial in hydrological studies and are used for water availability, erosion monitoring, flood prediction, and public policy. The study utilized ArcGIS 10.3 hydrology tools for drainage sub-basin delineation, utilizing raster analysis to identify drainage arrangements in catchment areas. Data on flow direction, accumulation, stream definition, segmentation, and drainage sub-basin demarcation were derived from raster analysis. The data was then used to create a raster and vector representation of catchments and drainage outlines. The study also used a Digital Elevation Model (DEM) in ESRI grid format for the delineation.

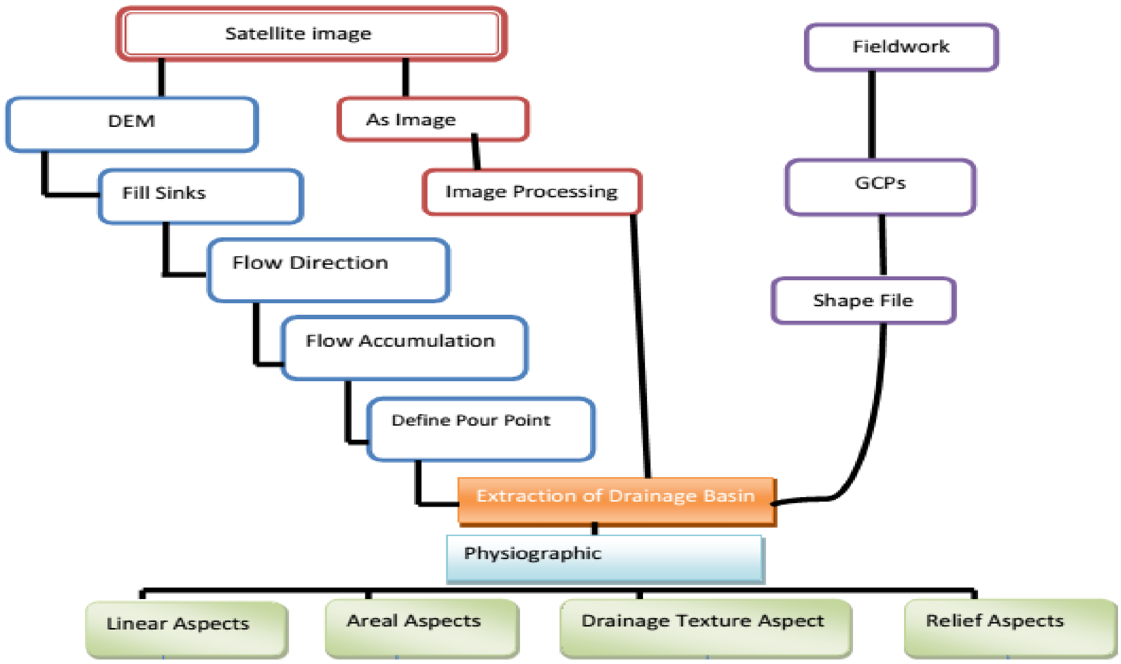


Figure 2. 2. Flow Chart Showing the Step Followed in Drainage Sub-basin Analysis

3. RESULT AND DISCUSSIONS

This study measured morphometric/morphometric parameters from four aspects: drainage network, sub-basin geometry, drainage texture, and relief features.

Linear Aspect

Linear aspects of drainage channels and branches create a drainage pattern controlled by local landscape and subsurface geology, influenced by parameters like sub-basin length, stream order, stream number, and stream length.

Stream order is a crucial aspect of drainage sub-basin analysis, assessing the geometry of drainage networks on different scales. Stream order is the first step in the quantitative analysis of the drainage sub-basin. Based on the stream ordering methods proposed by Strahler (1957), the sub-upper Wabe Shabele drainage sub-basin in Melka Wakena catchment is of the fourth-order type, spreading over an area of 4372 km^2 with a perimeter of 416 km (see table 3.1 and Fig. 3.1). The drainage pattern of the study area is almost dendrite, which indicates the presence of homogenous rocks and a uniform soil type in the sub-basin area.

The stream number is the number of stream segments present in each order. The study area contained 140 streams, with 71 first-orders, 35 second-orders, 26 third-orders, and 8 fourth-orders. Stream numbers are declining with increasing order, indicating topographic erosion and sudden floods, as per Horton's (1945) and Chitra et al. (2011) findings. This implies that a higher number of streams in the upper reaches indicates the occurrence of young topography, which is responsible for erosion and runoff.

Stream length is the average length of streams in each of the different orders in a drainage sub-basin. In the study area, the total stream length of the sub-upper Wabi Shebelle sub-basin was 1123.25 km, with first-order and second-order streams having a length of 750.23 km and 250.64 km, respectively, constituting nearly 90% of the entire sub-basin stream length. The third and fourth-order stream lengths were 99.23 km and 23.25 km, respectively. Relatively, shorter stream lengths are in areas of steep slopes and finer texture, whereas longer stream lengths are in areas of lower slopes (Strahler, 1964). Longer streams indicate flatter gradients and lower erosive capacity, confirming Horton's law of stream length. Therefore, the study river sub-basin exhibits lower erosive and higher infiltration capacities. The length of the first-order stream is 59.68 km, the second-order stream is 42.04 km, the third-order stream is 22.61 km, and the fourth-order stream is 9.7 km. The stream of relatively smaller length is characteristic of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of a flatter gradient. Likewise, Pidwirny (2006) indicates that stream length measurement helps understand drainage coverage and bedrock hydrological characteristics. In efficient catchments with porous bedrock, only a few longer streams exist, while less permeable areas have numerous shorter streams. Generally, the total length of stream segments is the maximum in a first-order stream and decreases as stream order increases.

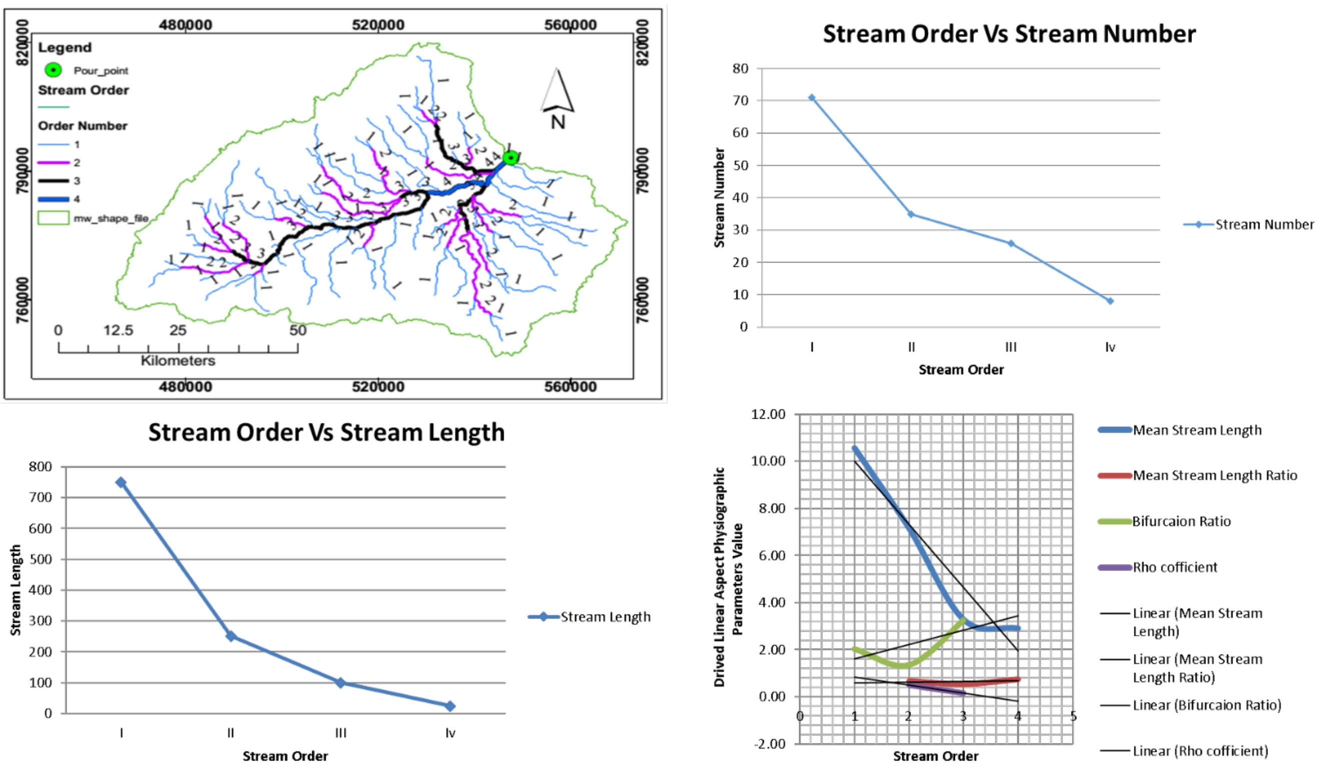


Figure 3.1. Linear aspect pictures

The relationship between stream orders and stream numbers revealed a rapid decrease from lower-order streams to higher-order streams and a negative association between stream orders and stream numbers (Figure 3.1).

Mean stream length is a dimensional property that reveals the size of drainage network components and their contributing areas. It is calculated by dividing the total stream length order by the number of streams. The mean stream length of first-order streams is 10.57 km, while second, third, and fourth-order streams are 7.16 km, 3.82 km, and 2.91km, respectively, and the total mean length was 8.02 km. See table 3.1. Relatively higher Lsm values (first and second-order) in the upper reaches of the sub-basin are indicative of low erosion potentiality, which in turn denotes old erosional landform development. The evolution of the drainage sub-basin follows erosion laws acting on similar geologic material with unchanging weathering erosion characteristics, with Lms of a given order being higher than the next higher order. The stream length ratio is the ratio of the mean stream length of a given order to the mean stream length of the next lower order and has an important relationship with surface flow and discharge (Horton, 1945). The stream length ratio (RL) value of the study sub-basin varies from 0.68 to 1.97, indicating there are variations in slope and topography dissimilarities due to slope and topography variance.

The bifurcation ratio is defined as the ratio of the number of stream segments of a given order (u) to the number of stream segments of the next higher order. It is considered an important parameter, denoting the water-carrying capacity and related flood potentiality of any sub-basin and related to the forking of river systems. In a study area, Rb ranged from 1.35 to 3.25, suggesting less geological structure or poor structural disturbance that affected the drainage pattern.

The Rho coefficient is the ratio between the stream length ratio and the bifurcation ratio. The Rho coefficient, a crucial parameter influencing drainage density and morphometric development, aids in estimating drainage network storage capacity (Horton, 1945). The study area's Rho values range from 0.23 to 0.39, with a mean value of 0.32 suggesting low hydrologic storage, possibly due to climatic, geologic, biologic, geomorphologic, and anthropogenic factors.

Table 3. 1. Distribution of stream linear aspect morphometric parameters

Stream Order (U)	Stream Number (Nu)	Stream Length (Lu)	Mean Stream Length (Lm) (Lu/Nu)	Mean Stream Length Ratio (Rl) (Lm/Lm-1))	Bifurcation Ratio (Rb) (Nu/Nu+1)	Rho Coefficient (ρ) (Rl/Rb)	Main Channel Length
I	71	750.23	10.57	-			
II	35	250.64	7.16	0.68	2.03	0.33	
III	26	99.23	3.82	0.53	1.35	0.39	185.64
IV	8	23.25	2.91	0.76	3.25	0.23	
Total	140	1123.35		1.97	6.62	0.96	
Mean			8.02	0.66	2.21	0.32	

Drainage Sub-basin Geometry

According to Ayele (2017), lithology, topography, climate, and geographical arrangement all have an impact on a drainage sub-basin's geometry, which can vary from narrow and elongated to semicircular or circular shape. The shape principally directs the degree to which water is delivered to the main network. In this study, numerous morphometric parameters were measured for characterizing and analyzing drainage sub-basin shape, which is a significant morphometric parameter from a hydrological viewpoint.

The sub-basin length is the aerial distance between the drainage confluence and the utmost point on the sub-basin's edge (Gregory and Walling 1973). The Wabe Shebelle river sub-basin source originates from Ilka particular area (2765 m amsl), in Kokosa Woreda, and drains to Melka Wakena reservoir. The study area's 88.63 km of sub-basin length indicates moderate coverage.

Sub-basin area is the total area projected onto the horizontal plane of a watershed. It is the most important watershed characteristic since it directly reflects the volume of water in a sub-basin. The nature of the sub-basin area affects precipitation volume, overflow formation, and stream discharge. Smaller sub-basins may have faster rainwater joining the main channel and causing flooding and sedimentation, and vice versa for larger sub-basin areas. The area of the study sub-basin is 4372 sq. km, which is relatively large with fewer erosion and sedimentation effects. The study area's mean sub-basin width, calculated as the ratio of the sub-basin's area to its length, is 49.33 km, indicating a significant area difference.

The sub-basin perimeter (P) is the exterior boundary of a drainage sub-basin, measured along the divide between sub-basins. It indicates drainage size and shape; the study area drainage sub-basin has a 416 km perimeter.

The leminiscate ratio (k) measures the gradient of a sub-basin (Chorely et al., 1957), with higher values indicating higher runoff. In the study area, the ratio is 1.80, indicating low runoff.

The form factor is the ratio of the watershed area (A) to the square of the watershed length (Lb). The smaller the value of the form factor, the more elongated the watershed (Strahler 1964). The catchment's form factor value of 0.56 indicates a moderate value and an oval sub-basin with a moderate to steep slope and low to high relief characteristics. Consequently, the flood of this type of sub-basin is easier to manage than that of circular sub-basins with a high form factor.

Texture ratio, defined as the quotient of first-order streams and sub-basin perimeter, is a critical component of drainage morphometric analysis that is impacted by lithology, infiltration capacity, and terrain relief, according to Schumm's 1965 research. The texture ratio has a very fine drainage texture consisting of larger particles with a range greater than 8 units. Fine drainage texture includes relatively smaller particles, falling within the range of 6 to 8 units. Moderate drainage texture represents particles of moderate size, ranging from 4 to 6 units. Lastly, coarse drainage texture comprises larger particles within the range of 2 to 4 units and very coarse ranges from 2 to 0 (Prabhakaran and Jawahar, 2017). In this study, the texture ratio of 0.17 indicates a very coarse drainage texture due to large and resistant rocks.

Drainage texture refers to the total number of stream segments per area's perimeter. Its nature depends on lithology, infiltration capacity, and terrain relief. The classification of drainage texture ratio, drainage texture, and drainage density is the same. The sub-basin's texture, 0.34, falls within the very coarse classification, indicating low infiltration potential and erosion.

The elongation ratio (Re) is a crucial index in understanding the shape of a drainage sub-basin, providing insight into its hydrological character. The elongation ratio index categorises drainage basin slopes into circular (0.9–0.10), oval (0.8–0.9), less elongated (0.7–0.8), elongated (0.5–0.7), and more elongated (<0.5) (Singh, 1998). The study area's elongation ratio of 0.84 indicates an oval drainage sub-basin, with varying slopes categorised by the ratio. Strahler's research indicates that this ratio is a significant factor in determining the hydrological character of drainage sub-basins.

Circulatory Ratio: The circulatory ratio (Rc) is defined as the proportion of sub-basin area to the area of a circle with the same perimeter (Miller, 1953). It is affected by several variables, including slope, temperature, relief, geological structure, length, and frequency of streams. The circularity ratio ranges from 0 (in a line) to 1 (in a circle), with higher values indicating greater circularity in the basin's shape (Singh, 1998). The study area has a medium Rc value of 0.32, indicating an oval sub-basin shape and higher groundwater potential.

Table 3. 2. Distribution of stream areal aspect morphometric parameters

Sub-basin length	Sub-basin Area (A)	Mean Sub-basin Width	Sub-basin Perimeter (p)	Relative Perimeter (pr)	Lumniscate (K) (Lb^2/A)	Form Factor (Ff)	Elongation Ratio	Circulatory Ratio (Rc)	Texture Ratio (Rt)	Drainage Texture (Dt) (Nu/P)
88.63	4372	49.33	416	10.51	1.80	0.56	0.84	0.32	0.17	0.34

Drainage Aspect Analysis

Drainage aspects indicate landscape dissection by a waterway system, influenced by geomorphological fundamentals like lithology, geological arrangement, landscape, flora, hydrology, and climate. These parameters highlight the dynamic nature of the network and the area of the drainage sub-basin.

Stream frequency is defined as the sum of stream fragments per unit area, indicating stream network scattering (Horton, 1932). Higher frequencies indicate larger surface runoff, steeper ground, impermeable subsurface, infrequent vegetation, and high relief conditions. Low frequencies indicate high-permeable geology and low relief. The study area's stream frequency of 0.03 stream fragments per km^2 indicates low relief, less steam, and permeable subsurface material, indicating mature topography with low erosion and surface runoff.

Drainage density is the sum of stream lengths per unit area and determines water travel time. It depends on climate, geology, vegetation cover, erodiability, infiltration ability, and the permeability of the underlying rock and soil. There are five drainage density classes, ranging from very coarse (<2), coarse (2-4), moderate (4-6), fine (6–8), and very fine (>8), with values in km/km2 (Prabhakaran and Jawahar, 2017). The drainage density (Dd) of the study area is 0.26 km2/km2. This low value of drainage density designates permeable sub-surface layers, a gentle slope, and a very coarse drainage feature of an area.

The constant of channel maintenance (1/D) is the area needed to sustain a one-kilometer-long stream network (Schumm, 1956). In a study area, 3.89 km^2 of surface area is required for each kilometer of channel length. Higher values indicate better lithology control, higher infiltration rates, moderate surface runoff, and less dissection.

Drainage Intensity: Faniran's (1968) definition is defined as the ratio of stream frequency to drainage density. Drainage intensity is low in this study area, with a Di of 0.12, suggesting that density does not significantly influence surface lowering by denudation agents. This results in slow surface runoff in the drainage sub-basin.

Infiltration number is the product of drainage density and stream frequency, which determines the infiltration number (If) in a drainage sub-basin, with higher numbers indicating lower infiltration and higher runoff (Strahler, 1964). There are three classes of infiltration numbers: low value (< 6), moderate value (7–10), and high value (>10) (Prabhakaran and Jawahar, 2017). The study area's infiltration number is 0.01, which is a low value, indicating higher infiltration potential, low runoff, and a reduced risk of flooding.

Drainage pattern is the pattern formed by the streams, rivers, and lakes in a particular drainage sub-basin. In this study, dendritic drainage patterns were dominant, typically developing in homogeneous rock areas without fundamental geologic structure control.

Overland flow is the length of rainwater that flows over the earth before it becomes concentrated in fixed stream networks. It is a measure of erodibility and hydrologic response in drainage sub-basins. Low overland flow values indicate high relief, short flow tracks, extra runoff, and less infiltration, making them more vulnerable to flash flooding. There are three classes of length of overland flow: low value (< 0.2), moderate value (0.2–0.3), and high value (>0.3) (Sukristiyanti et al., 2018). A low value of Lof specifies high relief, short flow tracks, extra runoff, and a smaller amount of infiltration, which points to being more vulnerable to flash flooding, and the reverse is the case. The study area's overland flow value of 1.95 indicates a gentle slope, a long flow path, more infiltration, slow erosion, and low runoff.

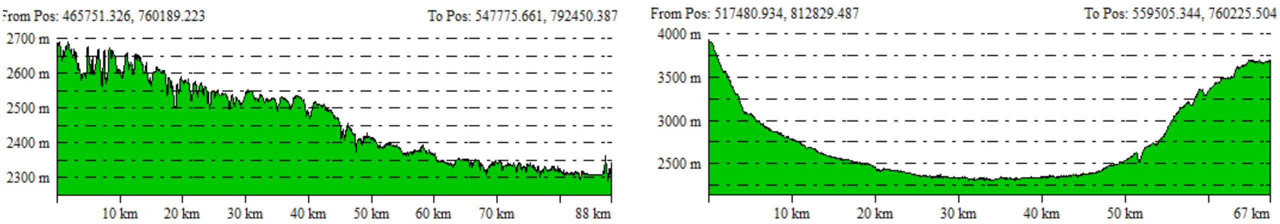
Table 3. 3. Distribution of stream drainage aspect morphometric parameters

Stream Frequency (Fs) (Nu/A)	Drainage Density (Dd) (Lu/A)	Constant Channel Maintenance (C=1/Dd)	Drainage Intensity (Di) (Fs/Dd)	Infiltration Number (If) (Fs*Dd)	Length of overland flow Lof(1/(2Dd)	Drainage Pattern
0.03	0.26	3.89	0.12	0.01	1.95	dendritic

Relief Aspect

Vertical inequalities control precipitation distribution, surface water features, and groundwater occurrence. Relief aspects, including elevation differences, help identify landforms, drainage network development, overland flow, and erosional properties. This study considers morphometric characteristics to illustrate drainage sub-basin relief, crucial for hydrological analysis.

Sub-basin relief, the variance between the maximum and minimum elevations in a sub-basin, plays a crucial role in influencing sediment transport and flood patterns (Hadely & Schumm 1961). In the study area sub-basin, the maximum height is 4211 m.a.s.l., while the lowest is 2266 m.a.s.l., resulting in a relief of 1945 m.a.s.l., which shows a high slope difference between the highest pick and the lowest point in the study area. It is an important factor in understanding the denudational characteristics of the sub-basin.



(a) (b)

Figure3.3. Slope Profile (a) Across River flow and (b) Kaka mt to the left and Bale Maintains to the right of figure b

Schumm (1956) defined *the relief ratio* (Rh) as the ratio between a sub-basin's total relief and its longest dimension parallel to the main drainage line. Relief ratio measures the overall steepness of a drainage sub-basin and is an indicator of the intensity of the erosion process operating on the slope of the sub-basin (Schumm, 1956). It has been classified into three classes: low (0–0.15), medium (0.15–0.3), and high (0.3–0.5) (Aznarul and Suman, 2019). In a study area, the average Rh is 0.02, and this low value of relief ratios is mainly due to the resistant basement rocks of the basin and the low degree of slope difference.

Relative Relief: The study area's maximum sub-basin relief (Rhp) was calculated using Melton's formula: Rhp = (H*100) / P, where P is the perimeter in meters and p is in km. Relative relief measures altitude variation in a region, considering slopes and terrain dynamics, providing insight into morphogenesis and landscape changes for comprehensive understanding (Ayale, 2017). The result should be divided by 1000. The result was 0.47 for the study area.

The Ruggedness Number (Rn) is a measure of a drainage sub-basin's structural complexity and resistance to soil erosion. It combines slope steepness and length, with higher values occurring when slopes are both steep and long. The classification ranges from level terrain surfaces to extremely rugged. Riley et al. (1999) classified ruggedness into seven categories: level terrain surface (0–80), nearly level surface (81–116), slightly rugged surface (117–161), intermediately rugged surface (162-239), moderately rugged surface (240–

497), highly rugged surface (498–958), and greater than 959, extremely rugged. A study area with a ruggedness number of 0.50 indicates less erosion and a gentle slope due to less fragmentation of relief and drainage density.

The Melton Ruggedness Number is a slope table that measures relief ruggedness within a drainage sub-basin (Melton, 1965). The study area's drainage sub-basin has a low (0.03) MRn value, indicating regular movement in the main stream without debris flow.

Table 3. 4. Distribution of stream relief aspect morphometric parameters

Height of Sub-basin Mouth (H_{min})	Maximium height ((H_{max})	Sub-basin Relief (Bh) (H_{max}-H_{min})	Relief Ratio (Rh) (Bh/Lb)	Relative Relief (Rr) Bh*100/p	Ruggedness (Rn) (Dd*Bh)	Melton Ruggedness Number (MRn=Bh/√A)
2266	4211	1945	0.02	0.47	0.5	0.03

Slope: The slope of a sub-basin is a crucial hydrological factor that indicates the momentum of run-off and the time of concentration. Steep slopes require higher surface run-off and low infiltration rates, leading to accelerated erosion, especially on barren slopes. Slope analysis is crucial for estimating land erosion and managing it. Based on the FAO (2014) classification of land suitability for agriculture into three major areas: flat, moderate, and non-suitable, in the study area, 54.333% of the slope is flat and highly suitable, while 42.97% is moderately suitable. About 2.7% of the topography is not suitable for agriculture due to steepness above 30%.

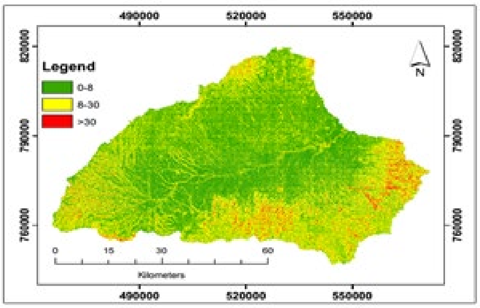


Figure 3. 3. Slope map of Sub-upper Wabe Shabele Drainage Sub-basin

4. CONCLUSIONS

This paper discusses the use of GIS and RS techniques for analyzing morphometric parameters, highlighting their cost-effectiveness and time efficiency. It aims to evaluate these parameters, emphasizing variations in their value ranges, implications, and data outputs. The paper categorizes the results of specific parameters as high or low and details the conditions under which they were obtained. The morphometric parameter characteristics analysis was carried out through measurement of linear aspects, areal aspects, drainage aspects, and relief aspects of the drainage sub-basin with different 34 morphometric parameters. The paper concludes by providing an in-depth examination of each parameter's characterization, including the range of values, the data products generated, and the applicability of Horton's as well as other scholars fundamental laws. This study aims to enhance understanding of morphometric parameters' characteristics and their implications in different geographic circumstances. The paper serves as a valuable resource for researchers and practitioners seeking detailed insights into morphometric parameter analysis using advanced techniques. The study has achieved its objectives, but further improvements in software, methodology, and data quality are needed for accurate findings. conducting detailed studies using high-resolution DEM data is required for effective planning and administration, as well as conducting further sub-basin level, runoff, sediment, and yield analysis for effective natural resources management.

Acknowledgements

The authors acknowledge first the almighty Allah and secondly we owe our deepest gratitude to Madda Walabu University for creating the opportunity and department of GIS and Land Resource Mmanagement of Madda Walabu for providing us some of the data that have been used in this study.

Conflicts of Interest

This article was done without the support of any financial. The authors declare that they have no known financial or personal interests that could influence the work reported in this article

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