A Morphometric Analysis of Wonji Drainage Basins around Central Rift Valley, Ethiopia, using Geospatial Tools

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Abstract: ***The morphometric analysis of the Wonji drainage basin of central Ethiopian Rift valley was carried out using geospatial technique. The study was focused to observe the different aspects of drainage morphometry of the Wonji basin. It was observed that the Wonji basin is of mainly dendritic pattern in the upper reaches and trellis pattern in the lower part of the basin. A fifth order rivers drain the basins and morphometric study shows that the basins are characterized by undulating, highly dissected, moderately sloped region with homogeneous geological materials. The study indicates that the area is having poor to moderate ground water potential. It also illustrates that geospatial technique is an apt technology for drainage analysis.***

Keywords: Geospatial technique, Digital elevation model, Morphometric analysis, Wonji Drainage Basin

1. Introduction

Geomorphic processes are continuing activity on the surface of the earth. During these processes, the existing land forms are transformed and new landforms are evolved. There are number of natural factors like, Climate, Topography, Soil profile, Geology play their vital role on the surface, among these drainage plays a major role. Streams and rivers are powerful fluvial agents of erosion, transportation and deposition.

The drainage system contributes for the overland flow of water in the hydrological cycle. The physiographic characteristics of drainage basins such as size, shape, slope, drainage density, and length of the tributaries can be correlated with the hydrological cycle. The modern approach of quantitative analysis of drainage basin morphology was given inputs by Horton (1945) the first pioneer in this field. Horton's laws were subsequently modified and developed by several geomorphologist, most notably by Strahler (1950, 1952, 1957, 1964 and 1968), Schumm (1954, 1956), Morisawa (1958), Scheidegger (1965), Shreve (1967), Gregory and Walling (1973). Subsequently a number of books by Bloom (2002), Keller and Pinter (1996) have further propagate the morphometric analysis. Stream profile analysis and stream gradient index by Johan T Hack (1973) is another milestone in morphometric analysis. Many workers have used the principles developed by these pioneers to quantitatively study the drainage basin as a tool for landscape analysis (Raj et. al., 1999, Awasthi and Prakash, 2001, Sinha Roy, 2002). Various scholars (Pareta, K. and Pareta U, 201, Rahaman, et. Al.2018) have carried out morphometric analysis of river basins by using remote sensing and geographic information system. Gebreet.a.l, 2015, Fenta et. Al., 2017, Fayeraet.a.l, 2018, have used remote sensing and GIS tools for drainage analysis in Ethiopia. Resmi, et. al., 2019, had carried out the quantitative analysis of the drainage and morphometric characteristics, using bAd calculator (bearing azimuth and drainage) and geographic information system.

The present study on drainage pattern and morphometric analysis of Wonji drainage basin will help to delineate the groundwater potential zones and drainage characteristic in the Central Ethiopian Rift Valley. Hence attempts were made to use cutting edge technology such as geospatial tool to study the characteristic of the Wonji drainage basin. It is expected that this study would contribute to fill in the knowledge gap in the study area and eventually to encourage other researchers and academician to consider real addition. Moreover, the study is vital for assessing basin management, environmental assessment and geological process undergoing in the area.

2. Location of the Study Area

The study area is located in the central part of the Main Ethiopian Rift valley, which is situated in the Upper Valley of the Awash Basin within the East Shoa zone of Oromia National Regional State (Fig. 1). The area lies between $39^0 00''$-39^0 $30''$East and longitude $8^0 5''$ – 8^0 $30''$North. The area is well connected with roads. The Ethiopian plateau and the Rift Valley are the main components of the Awash Basin. The dominant Ethiopian plateau rocks are Tertiary volcanic: basalt tuffs, silica- rich rhyolites, trachytes, tuffs and ignimbrites of Miocene to Pleistocene age. On the floor of the Rift Valley the volcanic rocks are mainly basalts and ignimbrites (Miocene to Pleistocene) with Holocene lavas occurring near active volcanic centers.

The study area is characterized by warm climate with a mean annual temperature of 21^0C and mean annual rainfall of 806.9 mm. The climate is marked by long dry period and short duration of precipitation from June to September. As a result it can be considered as semi-arid to semi-humid climatic zone.

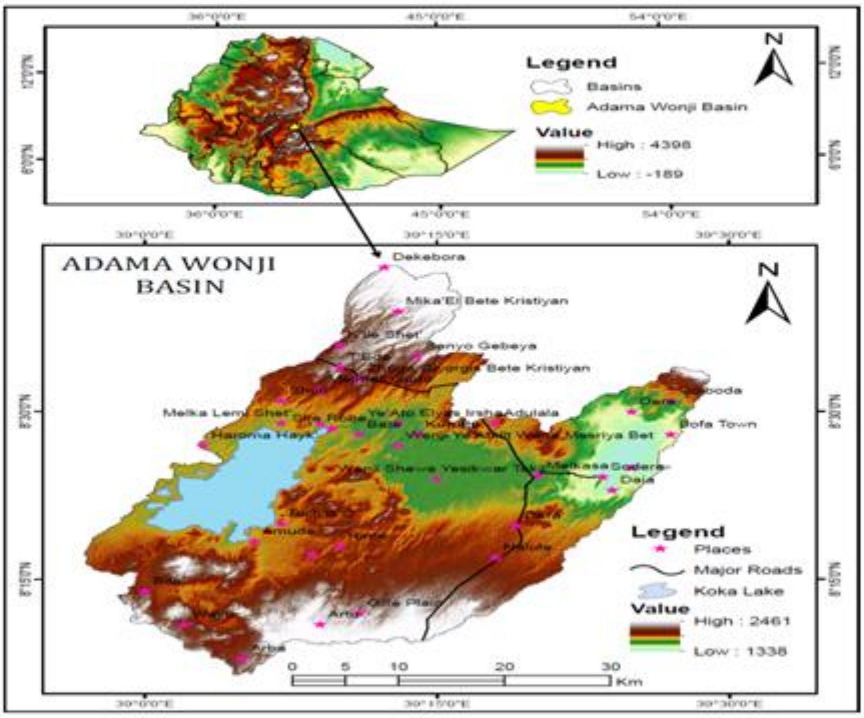

Figure 1: Location Map of the study area

3. Materials and Methods

Morphometric analysis of a drainage system requires delineation of all existing streams. The stream delineation was done digitally using SRTM (DEM) with 90 m spatial resolution using GIS (ARC/INFO) software. Topographical Map, Survey of Ethiopia (SOE) top sheet no. 0839 A4 having scale 1: 50,000 were also used and these topo sheets are geo- referenced, in ArcGIS. In morphometric analysis, the drainage basin parameters such as Stream order, Stream number, Stream length, Basin length, Basin area, Basin perimeter were directly obtained using GIS software. Also standard methods and formula of Strahler's (1950), Horton's(1945, Miller's(1953), Chorley(1969), and Schum (1954) were applied to evaluate linear and aerial morphometric characteristics of drainage basin which includes evaluation of Bifurcation ratio, Length of overland flow, Stream frequency, Drainage density, Infiltration number, Form factor, Elongation ratio, Circularity ratio, Compactness coefficient etc., and is shown in table 1. Relief characteristic such as Absolute relief, Relative relief, Relief ratio, River basin slope, Ruggedness number, are evaluated using DEM data with spatial analyst tools of ArcGIS. Methodology used in this study to delineate drainage lines and calculate morphometric parameter is shown in (Figure 2).

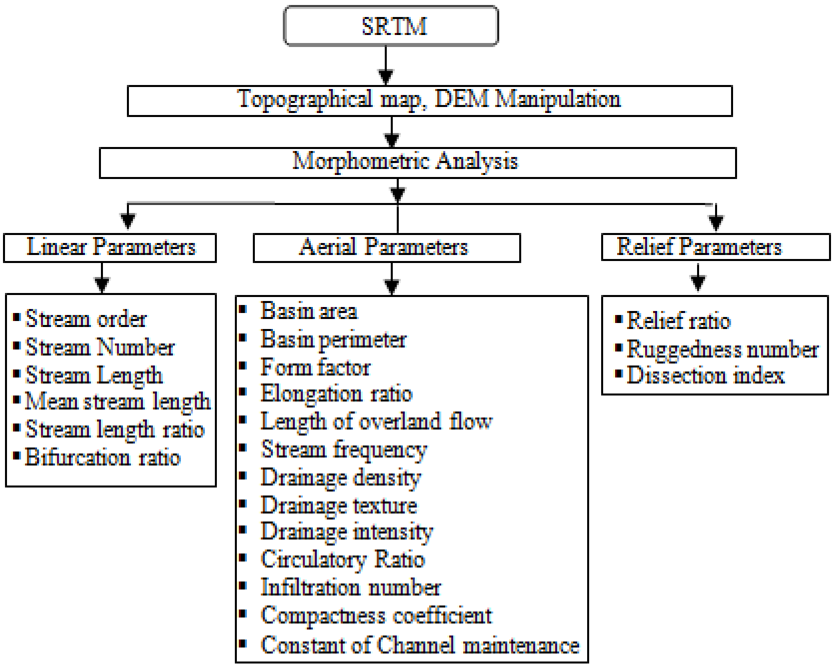

Figure 2: Flowchart showing the methodology of morphometric analysis of river basin

Table 1: Formula for Computation of Morphometric Parameters

No	Parameter	Formula	Previous Work
Linear morphometric parameters			
1	Area (A)	Area of the watershed	-
2	Perimeter (P)	The perimeter is the total length of the watershed Boundary	-
3	Length (Lb)	Maximum length of the basin	-
4	Stream Order (Nu)	Hierarchical rank	Strahler 1957
5	Stream Length(Lu)	Length of the stream	Horton 1945
6	Maximum and Minimum Heights (H, h)	Maximum and Minimum elevation	-
7	Slope (Sb)	Derived from SRTM 90 m DEM	
Derived Parameter			
8	Bifurcation ratio (Rb)	Rb = Nu / N (u + 1)	Schumm 1956
9	Stream length ratio (Rl)	Rl = Lu / Lu-1	Sreedevi et al.2004
10	RHO coefficient (RHO)	RHO = RI / RB	Horton 1945
11	Stream frequency (Fs)	$Fs = \sum Nu/A$	Horton. 1945
12	Drainage density (Dd)	$Dd = \sum Lu/A$	Horton. 1945
13	Drainage texture (T)	T = Dd × Fs	Smith 1950
14	Constant of Channel maintenance (C)	C = 1/ Dd	Schumm 1956
15	Basin relief (R)	R = H – h	Hadley and Schumm 1961
16	Relief ratio (Rr)	Rr = R / L	Schumm (1963)
Shape Parameter			
17	Elongation ratio (Re)	$Re = 1.128 \sqrt{A} / L$	Schumm (1956)
18	Circularity index (Rc)	$Rc = 4\pi A / P^2$	Miller (1953),Strahler (1964)
19	Form factor (Ff)	Ff = A / Lb2	Horton (1945)
20	Compactness coefficient (m)	$0.282 P / \sqrt{A}^{0.5}$	Gravelius (1914)
A = Area ; P = Perimeter; Lb = Length of the basin ; Nu = Stream order; Lu = Stream length; H = Maximum height; h = Minimum Height; RI = Stream length ratio; Rb = Bifurcation ratio ; π = 3.14; R = Basin relief			

4. Results and Discussions

The analysis of the morphometric parameters of the Wonji drainage network are extracted from topographic maps and employing the SRTM Digital Elevation Model. Morphometric analysis, which is all about exploring the mathematical relationships between various stream attributes, used to compare streams and to identify factors that may be exhibiting the difference in character was computed based on the equations given in the table 1. The linear, aerial and relief characteristics of the drainage basin are the principal aspects and accordingly the morphometric analysis for the present study is classified into three groups such as linear aspects, areal aspects and relief aspects. The results on each of the above parameters are given in table 4 and discussed as given below.

4.1 Linear Aspects

The linear characteristics of Wonji drainage basin which were derived include stream order, stream length, mean stream length, bifurcation ratio, and the results of the analysis were exhibited in fig 3, statistics were tabulated in Table-2,3, and 4 and were described as follows.

4.1.1 Stream Orders: The drainage network which was extracted from the SRTM digital elevation model has to be designated. There are several of methods of stream ordering in vogue. However, for more practicability and simplicity Strahlers, 1957method was adopted. In this method the smallest un-branched stream segment was designated as the first order stream. When two of the same order stream joins together, increase the number by one to designate the resultant stream. When two streams of different order join together, the number of the higher order stream is to be retained. The trunk stream is the highest order of the stream segment for that drainage basin. In this method of ordering stream Wonji Basin was designated as the fifth order stream (Fig.1). From the table No.2, it is observed that the stream number is inversely proportional to stream order.

4.1.2 Stream Numbers: The number of stream segments present in the Wonji basin for each order was enumerated and given in table.No.2, and it can be seen that the number of streams decreases as the stream order increases.

4.1.3 The Bifurcation Ratio: It is of fundamental importance in drainage basin analysis as it is the vital parameter to link the hydrological regime of a drainage basin under topological and climatic conditions (Raj et. al., 1999). By relating the number of stream segment of one order to the number of stream segment of next lower order bifurcation ratio were calculated and from these the mean ratio were computed. Employing the Strahlers, 1957, the actual number of streams that are involved in the ratio weighted mean bifurcation ratios were also computed and given in table no. 2.

4.1.4 Stream length: Based on the drainage network of Wonji basin the length of all the stream segments were measured stream order wise, the total length and also the mean length for each order were computed (table no. 3).From the tabulated data it can be synthesized that the mean stream length of the stream increases exponentially with the order which is in direct proportional.

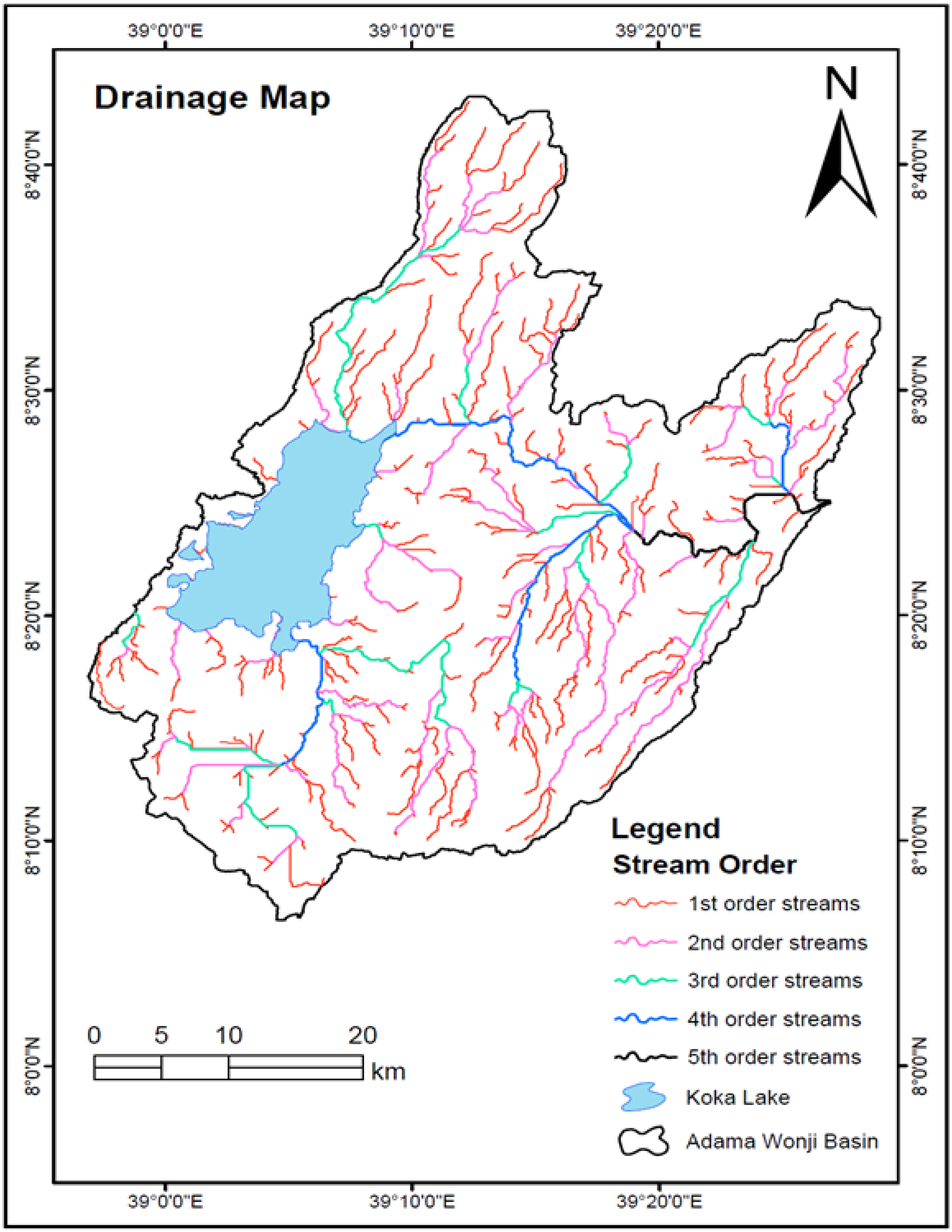

Figure 3: Driange map of Wonji basin, Central Rift valey Ethiopia

Table 2: Stream order, streams number, and bifurcation ratios in Wonji Drainage basin

Stream order	Number of stream	Bifurcation Ratio	Stream Ratio
I	284	4.06	354
II	70	3.89	88
III	18	6.0	21
IV	3	3.0	4
V	1	1.0	-

Table 3: Stream length and stream length ratio in Wonji Drainage basin

Stream Order	Stream length in Kms.		
	Total	Mean	Length ratio
I	665.10	2.34	0.47
II	346.62	4.95	0.67
III	133.73	7.42	0.25
IV	89.57	29.85	1.19
V	25.05	25.05	

4.2 Areal aspects

The areal aspect of a drainage basin mainly represent the two dimensional characteristics of that basin. Areal aspects of a basin of given order is defined as the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order. Based on the remote sensing data the area of the basin which contributes water to each stream segment was delineated. The Areal aspect of Wonji drainage basin which were analyzed are drainage density (Dd), drainage texture (Dt), stream frequency (Fs), form factor (Rf), circulatory ratio (Rc), elongation ratio (Re), length of overland flow (Lof), infiltration number (If), constant of channel maintenance (C) and compactness coefficient (Cc). The statistics generated on the areal aspects of Wonji basin are given in table no..4 and are explained below.

Table 4: Morphometric analysis data of Wonji Drainage basin

Morphometric Parameters	Value
Linear aspect	
Stream Order (U)	5
Basin Length (Lb)	55.9km
Mean Stream Length (Lsm)	252km
Arial Aspect	
Drainage basin area (A)	1919.66km^2
Drainage basin parameter (P)	298km
Drainage density (Dd)	0.66 km/km^2
Drainage texture (Dt)	1.2426776
Stream frequency (Fs)	0.195868
Form Factor (Rf)	0.6141
Circularity Ratio (Rc)	0.2716
Elongation Ratio (Re)	0.88429
Average Length of Over Land Flow (Lg)	0.1617km
Infiltration number (If)	0.1285
Constant channel maintenance (C)	1.5235
Compactness coefficient (Cc)	1.93
Basin Relief aspect	
Total basin relief(H)	1.12km
Relief Ratio (Rh)	0.02
Relative relief (Rr)	0.38
Ruggedness number(Rn)	0.74

4.2.1 Basin area (A):

The area of the drainage basin is one of the important parameter like the length of the stream draining. The volume of water that can be generated from the drainage basin and stream flow is directly related to the drainage basin area. From the Wonji basin drainage map (fig. 3) it is estimated that it covers an area of 1919.66 Sq Kms.

4.2.2 Form factor (Rf):

Horton (1945) defines the form factor (Rf) as a dimensionless ratio of Basin area (A) to the square of the length of the basin (L). The value of form factor would always be less than 0.7854 (for a perfect circular basin). The basin with higher form factor are normally circular and have high peak flows for shorter duration, whereas elongated basin with lower values of form factor have low peak flows for longer duration. For the present study the value of form factor obtained is 0.61 and this indicate that, the Wonji basin is elongated and have low peak flow for longer duration.

4.2.3 Circularity ratio (Rc):

Circularity ratio is the ratio between the areas of basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). The value ranges from 0.2 to 0.8and greater the value more is the circularity ratio. It is the significant ratio which indicates the stage of dissection in the study region. The circularity ratio for present study is 0.27 which indicate that low circularity ratio hence the drainage basin is elongated and is in the youth full stage.

4.2.4 Elongation ratio (Re):

Elongation ratio is the ratio between the diameter of the circle having the same area as the basin and maximum length of the basin (Schumn, 1956). The value of elongation ratio ranges from 0.4 to 1 lesser the value, more is the elongation of the basin. The value calculated for the Wonji basin is 0.88 which indicates that it is not very elongated basin and moderate relief.

4.2.5 Drainage density (Dd):

Drainage density is one of the paramount aspects of drainage analysis which provides a better quantitative expression to the dissection and analysis of land forms, although a function of climate, lithology, structures and relief history of the region. It is defined as the total stream length of all stream order to the total area of basin. Dd is considered to be an important index; it is expresses as the ratio of the total sum of all channel segments within a basin to the basin area i.e., the length of streams per unit of drainage density, which is expressed as Sq.km. It reflects the land use and affects infiltration and the basin response time between precipitation and discharge. Drainage basin with high Dd indicates that a large proportion of the precipitation runs off. On the other hand, a low drainage density indicates the most rainfall infiltrates the ground and few channels are required to carry the runoff (Roger, 1971).

According to Strahler (1957) as the value of the drainage density is less than 5 it is coarse, 5.0-13.7 moderate and 13.7-15.3 fine and 15.3 and above very fine. For the present study the drainage density is 0.66 /km2. This low value of drainage density implies that drainage density is coarse. In other words, drainage basin with low Dd is characterized by highly permeable subsoil material, low relief, low runoff, and high infiltration capacity. Permeable rocks with a high infiltration rate reduce overland flow, and consequently drainage density is low.

4.2.6 Stream frequency (Fs):

Horton (1945) termed Stream Frequency or Channel Frequency or Drainage Frequency (Fs) as the number of stream segments per unit area. In other words, Stream frequency is the total number of stream segments in a basin divided by the area of the basin. The stream frequency varies from basin to basin. The higher the value of stream frequency, the larger will be the number of stream availability. Water with higher stream frequency is characterized by high runoff. As the value is near to 1.0 that means the rocks are fragile and/or high humidity. When it approaches 0.0 it denotes solid type of rocks and/or drought. For present study stream frequency for basin is 0.19 (number/km2) which characterise that the rock type is solid and dry area with low runoff.

4.2.7 Length of overland flow (Lof):

Horton (1945) defined length of overland flow (Lof) as the length of flow path, projected to the horizontal, no channel flow from a point on the drainage divide to a point on the adjacent stream channel. He noted that length of overland flow is one of the most important independent variables affecting both the hydrologic and physiographic development of drainage basins. The shorter the length of overland flow, the quicker the surface runoff from the streams. For the present study average Length of Overland flow is 0.76 and this indicate the flow is not quicker.

4.2.8 Drainage Texture (Dt):

Drainage texture (T) is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. Smith (1950) has classified drainage texture into five different textures: very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8) and very fine (>8). The drainage texture of the Wonji basin obtained is 1.26 and categorized as very coarse drainage texture in nature which can be seen in the fig. 3.

4.2.9 Constant channel maintenance (C):

Schumm (1956) has used the inverse of the drainage density having the dimension of length as a property termed constant of channel maintenance. The drainage basins having higher values of this parameter, there will be lower value of drainage density. All the values are computed and shown in the Table no. 4. Higher value of constant channel Maintenance reveals strong control of lithology with a surface of high permeability. The value obtained is 1.5235.

4.2.10 Infiltration Number (If) :

The infiltration Number is defined as the product of Drainage Density (Dd) and drainage Frequency (Fs). The higher the infiltration number the lower will be the infiltration and consequently, higher will be run off. This leads to the development of higher drainage density. In the present study the infiltration Number is0.13 which indicate the higher the infiltration and lower the runoff. It is observed that the rock is permeable and there will not be much flooding in the area. It also can be inferred that the drainage density is low which can also seen from the table no. 4.

4.2.11 Compactness coefficient (Cc):

Compactness coefficient of river basin is the ratio of perimeter of river basin to circumference of circle of area which is equal to basin area (Gravelius 1914). Compactness coefficient is used to express the relationship of a hydrologic basin with that of a circular basin having the same area as the hydrologic basin. A circular basin is the most hazardous from a drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin. The computed compactness coefficient is 1.93 for the Wonji drainage basin.

4.3 Relief aspects

In the drainage analysis linear and areal aspects have been considered as the two dimensional aspect which lies on a two dimensional plan and the third dimension is the relief aspect. Relief aspects of the basin which studied for the Wonji basin are basin relief (H), relief ratio (Rh), relative relief (Rr), and ruggedness number (Rn).

4.3.1 Basin Relief (H):

By measuring the vertical fall from the head of each stream segment to the point where it joins the higher order stream and dividing the total by the number of streams of that order, it is possible to obtain the average vertical fall. Basin relief is the elevation difference of the highest and lowest point of the valley floor and for Wonji basin Computed basin relief is 1.12 Kms.

4.3.2 Relief Ratio (Rh):

Relief ratio (Rh) is defined as the ratio between the total relief of a basin i.e. elevation difference of lowest and highest points of a basin, and the longest dimension of the basin parallel to the principal drainage line (Schumn 1956). The relief ratio for the present basin obtained is 0.02.Low relief ratio refers to a mild slope and high relief ratio refers to a steep slope region. However, there is no specified range to indicate the scale of severity. The high relief ratio indicates that the basin is prone to soil erosion. The relief ratio measured is very low for the Wonji basin which suggests that the drainage basin is of youthful stage with mild slope having low soil erosion.

4.3.3 Relative Relief (Rr):

Relative relief is the ratio of maximum relief to the perimeter of the drainage basin. This is the percentage relief to the perimeter of the basin. The relative reliefs of Wonji basin is 0.38 meaning that the slope ranges between gentle to moderately steep gradient

4.3.4 Ruggedness Number (Rn):

Strahler (1968) describes ruggedness number (Rn) as the product of maximum basin relief and drainage density and it usually combines slope steepness with its length. The smaller values of ruggedness number occur when slopes of the basin are gentle and short in length. It is computed as 0.74 for the Wonji basin which suggests that the area is gentler slope and less prone to soil erosion.

5. Conclusions

In the present study, various morphometric aspects of Wonji basin of the Central rift valley Ethiopia were carried out using remote sensing and GIS. Morphometric analysis was evaluated for major parameters of three aspects such as linear aspects, areal aspects, and relief aspects. In a drainage system the arrangement of stream explains the drainage pattern which will be reflecting the structure and lithology of the underlying rock. Observing the drainage map (fig.3) it was inferred that the upper part of the basin is of dendritic drainage pattern and as the stream moves downward it is mainly of trellis in nature. Therefore, it can be deduced that the lower part of the terrain is structurally disturbed. A fifth order rivers drain the basins and the proportion of the number of streams in each order indicates that the basins are characterized by undulating, highly dissected, moderately sloped region with mostly homogeneous geological materials. The mean bifurcation ratio of the basins is 3.39 which indicates hilly, moderately sloped terrain and homogeneous in nature which is validated from the geological map. The drainage density, stream frequency, and elongation ratio are 0.66, 0.195 and 0.88 respectively for the basin. This shows that the basin is characterized by flat hydrograph for longer duration and easier for flood management. The overall morphometric analysis indicated that the basin is characterized by a moderately slope and there is a slow concentration of runoff. The study indicates that the area is having poor to moderate ground water potential.

The morphometric analysis using Geographic Information System (GIS) and Remote Sensing Data and techniques play a vital role for the preparation and updating drainage map and evaluation of morphometric parameters. It is suggested that studies using high resolution elevation data should be carried out for better understanding the characteristics of river basins for efficient planning and management. Based on the study it can be stated that the GIS is a predominantly data-handling technology, whereas remote sensing is primarily a data-collection technology.

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Author Profile

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