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Morphometric analysis of Morna River sub basin using geospatial approach

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Abstract
The study area is part of Basaltic hard rock terrain in Central India. The study area is occupied by mainly Purna Alluvium and Basaltic lava flow of upper Cretaceous age. The aquifer characteristics of both the formation are quite different in the study area.. The drainage pattern is dendritic to sub dendritic and the sub basin of Purna River sub basin. The morphometric analysis was carried out for Morna River sub basin using the geospatial technique. The mean stream length (Lsm) values in the subwatersheds range from a minimum of 0.55 km for stream order one and 41.53 km and the mean bifurcation ratio in the study area is 4.62 and the higher values of bifurcation ratio indicates a strong structural control in the drainage pattern while the lower values indicates that the sub basin are less affected by structural disturbances. The drainage density (D) values is 1.87 km/sq. km indicating medium to high drainage density. The circulatory ratio is 0.34 which indicates that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition in the given study area. The elongation ratio values of the sub-basins is 0.10 are less than 0.70 which indicates that sub watersheds are elongated with high relief and steep slope.

Keywords: morphometry, Morna River sub basin, remote sensing and GIS

Introduction

The quantitative analysis of morphometric parameters is of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at micro level. Geology, relief and climate are the key determinants of fluvial ecosystems functioning at the basin scale. Morphometric descriptors represent relatively simple approaches to describe basin processes and to compare basin characteristics (Mesa, 2006) [30] and make possible an enhanced understanding of the geological and geomorphic history of a drainage basin (Strahler 1964) [56]. According to Clarke (1966) [7, 8]. morphometry is the measurement and mathematical analysis of the configuration of the earth surface, shape and dimensions of its landforms. The morphometric analysis is carried out through measurement of linear, areal and relief aspects of the basin and slope contribution (Nag and Chakraborty, 2003) [33, 34, 35]. The measurement of various morphometric parameters namely- stream order, stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb) mean bifurcation ratio (Rbm), relief ratio (Rh) drainage density (D), stream frequency (Fs) drainage texture (Rt), from factor (Rf), circulatory ratio (Rc), elongation ratio (Re), length of overland flow (Lg) has been carried out and the data are presented in Table 1. The aim of this research work is to analyse and identify various drainage parameters to understand the geometry of the basin for the conservation and management of water resources for sustainable development.

Remote sensing technology deals the requirements of reliability and speed, and is an ideal tool for generating spatial information which is pre-requisite for planned and balanced development at watershed level (Ravindran *et al*., 1992). The geographical information system (GIS) technology provides suitable alternatives for efficient management of large databases. Integration of remote sensing data and GIS technologies has proved to be an efficient tool for water resources development and management projects as well as for watershed characterization and prioritization (Kumar *et al*. 2001; Ali and Singh, 2002; Singh *et al*., 2003, Pandey *et al*., 2009, Pandey *et al*., 2010, Manjare, 2020) [37, 29]. Digital elevation model based terrain imaging, processing of topographic aspects in morphometric studies made GIS a dominant tool (Patel *et al*., 2016) in understanding basin structure (Thomas *et al*., 2011, Bali *et al*., 2012, Manjare B.S. and Jagtap Suyog, 2013, Yadav *et al*., 2014, Das S, Patel PP, Sengupta, 2016. Choudhari *et al*., 2018; Yadav *et al*., Manjare *et al* 2017, 2018; Kumar *et al*., 2018; Yadav *et al*., 2020, Manjare, 2020) [29]. Thus, DEM is the principal dataset for various purposes in hydrology, morphometry, etc. (Kumar *et al*., 2017, Kumar *et al*., 2018, Manjare B. S and Pophare A. M, 2019 Manjare, 2020, Manjare *et al* 2021) [29].

Morphometry may be defined as the mathematical analysis of the earth's surface that describes its topographic reliefs (Clarke 1966; Pakhmode *et al*. 2003) [7, 8]. Rastogi and Sharma (1976) mentioned that several phenomena related to hydrology can be correlated with the physiographic characteristics of watersheds. Morphometric analysis gives a comprehensive interpretation about the hydrologic response such as surface runoff generation, infiltration capacity and even groundwater potential. Other basin characteristics such as travel time, time to peak and intensity of erosional processes can be predicted with better insight and accuracy through morphometric analysis (Altaf *et al*. 2013) [1], and it could be a good alternative in ungauged watersheds where information on hydrology, geology, geomorphology and soil are scarce (Lindsay JB, Evans MG, 2008, Rudraiah M, Govindaiah S, Srinivas, 2008, Sreedevi *et al*., 2009, Romshoo *et al*. 2012; Magesh *et al*., 2013, Manjare *et al*., 2014b, Senthamizhan *et al*., 2016 Ready, 2018, Puno and Puno 2019, Jena and Dandabat, 2019, Manjare, 2020, Tukura, *et al*., 2021) [46, 53, 45, 18, 23, 29]. The other factors like Slope, Drainage, structure and Land use/cover and incorporated in characteristic expressions of lithological and geomorphologic (Manjare, 2014a) [23].

Table 1: Formulae adopted for computation of morphometric parameters

Sr. No.	Morphometric parameters	Formula	Reference
1	Stream Order	Heirachial rank	Strahler (1964)
2	Stream Length(Lu)	Length of the Stream	Horton (1945)
3	Mean Stream Length (Lsm)	Lsm= Lu/Nu Where, Lsm= Mean Stream Length? Lu=Total Stream Length of order ‘u’Nu= Total no. of stream segments of order ‘u’	Schumn (1956)
4	Stream Length ratio (RL)	RL=Lu/Lu-1 Where,RL=Stream Length ratio, Lu=The total stream length of the order ‘u’, Lu-1=The total stream length of its next order	Horton (1945)
5	Bifurcation ratio(Rb)	Rb=Nu/Nu+1 Where,Rb= Bifurcation ratio, Nu=Total no. of stream segments of order ‘u’, Nu+1=Number of segments of the next higher order	Schumn (1956)
6	Mean Bifurcation ratio	Rbm=Average of Bifurcation ratios of all orders	Strahler (1957)
7	Releif ratio(Rf)	Rh=H/Lb Where,Rh = Releif ratio, H= Total Relief (Relative Relief) of the basin (km), Lb=Basin length	Schumn (1956)
8	Drainage Density(D)	D= Lu/A Where, D= Drainage Density, Lu=Total stream length of all orders, A= Area of the basin (km^2)	Horton (1945)
9	Stream Frequency(Fs)	Fs= Nu/A Where, Fs= Stream Frequency, Nu=Total no. of streams of all orders, A= Area of the basin (km^2)	Horton (1932)
10	Drainage Texture(Rt)	Rt=Nu/P Where, Rt=Drainage Texture, Nu=Total no. of streams of all orders, P=Perimeter (Km)	Horton (1945)
11	Form Factor(Rf)	Rf= A/Lb^2 Where, Rf=Form Factor, A=Area of the basin(km^2), Lb^2= Square of Basin length	Horton (1932)
12	Circulatory Ratio (Rc)	Rc=4*Pi*A/P^2 Where, Rc=Circulatory ratio, Pi=Pi value ie., 3.14A= Area of the basin(km^2) P^2=Square of the perimeter (km)	Miller(1953)
13	Elongation ratio (Re)	Re= Re=$2\sqrt{(A/\pi)}/Lb$ Where, Re=Elongation ratio, A=Area of the basin(km^2), Pi=’Pi (3.14), Lb= Basin length	Schumn (1956)
14	Length of overland flow (Lg)	Lg=1/D*2 where, Lg=Length of overland flow, D= Drainage Density	Horton (1945)

Study Area
Study area is part of Akola district which one of the important districts of Vidarbha region of Maharashtra. Morna River is tributary of the Purna river and forms the B13TAU031 subwatersheds which is part of Upper Tapi sub basin and It is situated in the south east part of the Akola district and lies between north latitudes 20° 000’ and 20° 35’ east and longitudes 76° 50’ and 77° 00’. The total area of the district is 1000 sq.km and falls in parts of Survey of India degree sheets 55 D/14,15, 55 G and 55 H/2,3 (Fig.1). Latitude and longitude of the study area are 20^0 10’00’’ E to 20^0 55’00’’ and 76^0 45’00’’ to 77^0 10’00’’ respectively. The climate of the district is characterized by a hot summer and general dryness throughout the year except during the south-west monsoon season, i.e., June to September. The mean minimum temperature is 12.6°C and mean maximum temperature is 42.4°C. The normal annual rainfall over the district varies from about 740 mm to 860 mm.

Geology of the study area
Geologically study area mainly covered by the Basaltic lava flows of Cretaceous to Palaeocene age and Purna Alluvium of Quaternary age. The elevation in the study area ranges from 239 m to 553 m above mean sea level which indicating 314 m of relative relief in the study area. In the landuse landcover mapping the area is divided in agriculture land with an area of 837.46 km^2, Builtup area 25.59 km^2, Forest covers159.69 km^2, wasteland 282.48 km^2 and waterbody 28.04 km^2.

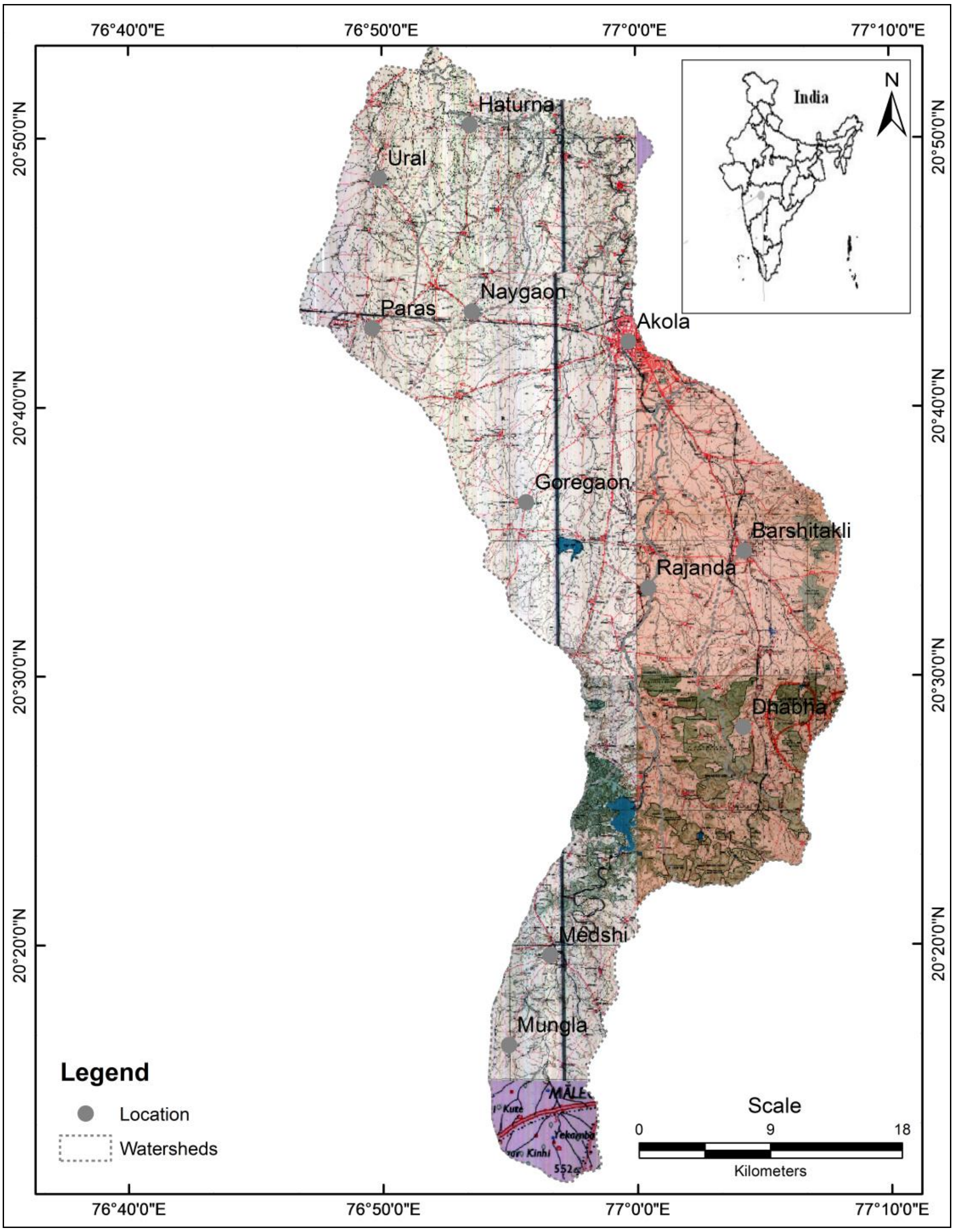

Fig 1: Location map of the study area

Result and Discussion

Linear aspects

The linear aspects include the stream order, stream length, mean stream length, stream length ratio and bifurcation, which were determined and results have been presented in Table 2.

Stream order

Stream order is defined as a measure of the position of a stream in the hierarchy of tributaries. The classification of streams based on the number and type of tributary junctions has proven to be useful indicator of dischargeand drainage area (Strahler 1957, 1958) [54, 55]. In the present study, the channel segment of the drainage basin has been ranked according to Strahler's stream ordering system. (Fig.2 & table 2). It is observed that maximum stream frequency is in case of first order stream and it decrease as stream order increases. The study area is a 6th order drainage basin and total number of streams in all order is 2634.

Stream length

The stream length characteristics of the sub basins validate the laws of stream length, which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio (Horton 1945) [11, 13]. Logarithms of the number of streams of a given order, when plotted against the order, the points lie on a straight line (Horton 1945) [11, 13]. Most drainage networks show a linear relationship with a small deviation from a straight line (Chow 1964) [6]. Generally, the total length of stream segments decreases with stream order. Deviation from its common behaviour indicates that the terrain is characterized by high relief and moderately steep slopes, underlain by different rock formation and probable uplift across the basin (Singh and Singh 1997) [50]. In the study area Lsm values in the sub watersheds range from a minimum of 0.55 km for stream order (Table. 2).

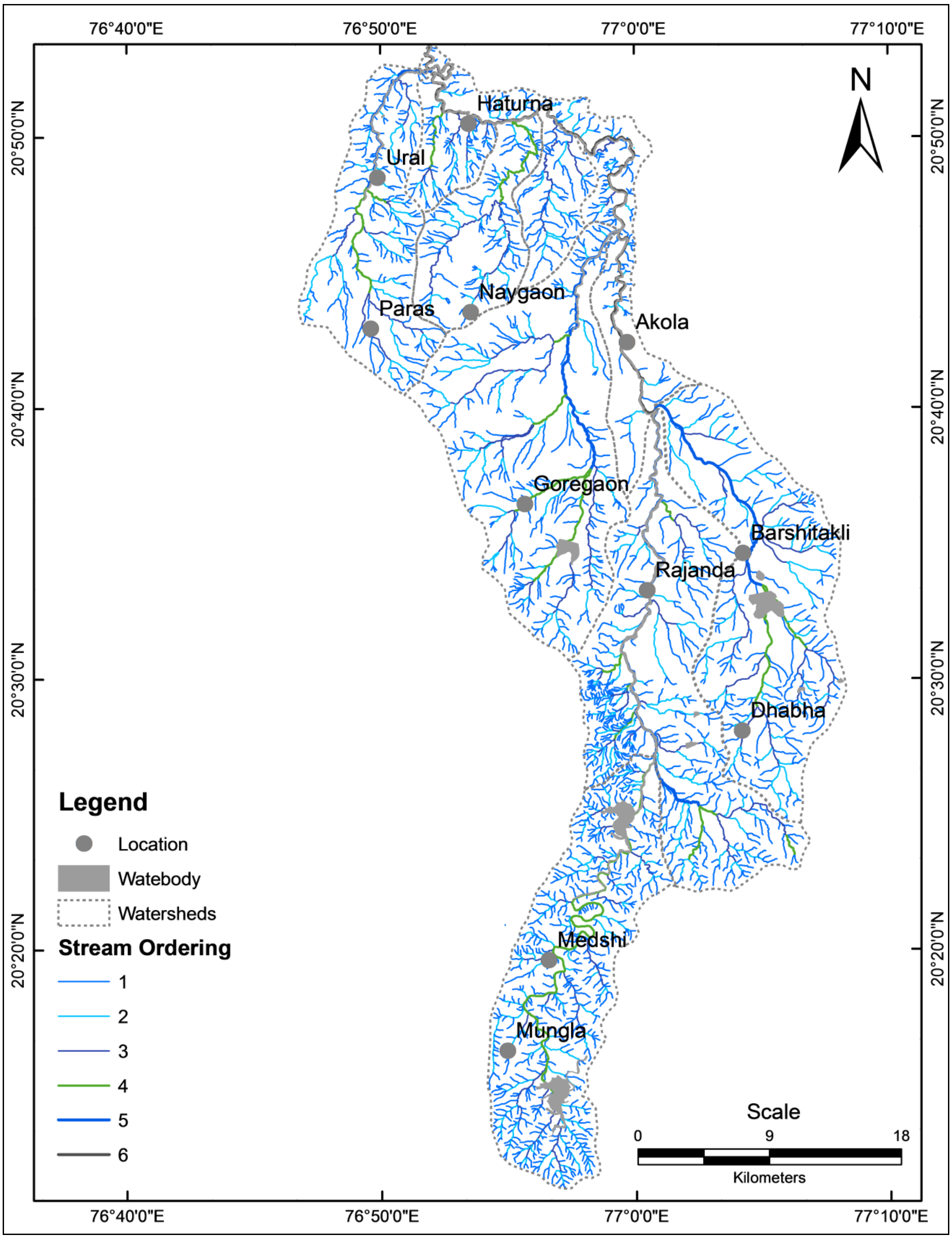

Fig 2: Drainage and stream ordering map of the study area

Stream length ratio

Horton (1945) [11, 13] states that the length ratio is the ratio of the mean (Lu) of segments of order to mean length of segments of the next lower order (Lu-1) which tends to be constant throughout the successive orders of a basin. The RL in the study area presented in the table 2.The stream length ratio between the stream of the different order of the study area shows change in each sub basin. This change of stream length ratio from one order to another order might be due to variation in slope and topography indicating their late youth stage of geomorphic development (Singh and Singh, 1997) [50]. The comparative values of the stream length ratio are given in the table. 2.

Table 2: Calculation of Stream order, Stream Length, Total Relief and Relief Ratio of study area

Morna River sub basin	Stream order	Stream No. (Nu)						Stream Length in km (Lu)					
		I	II	III	IV	V	VI	I	II	III	IV	V	VI
1	VI	1972	528	90	21	04	01	1356.20	467.51	245.73	117.19	83.33	52.31

Bifurcation ratio

According to Schumm (1956) [47, 48], the term bifurfication ratio may be defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher orders. Bifurcation ratio shows a small range of variation for different region or for different environment except where the powerful geological control dominates (Strahler, 1957) [54]. The bifurcation ratio reflects the geological as well as structural characteristics of the watershed (Gajbhiye *et al*. 2014) [9]. Lower value of Rb indicates partially disturbed watershed without any distortion in drainage pattern (Nag, 1998) [32]. High value of Rb indicates severe over land flow and low recharge for the sub-watershed. The value of mean bifurcation ratio in the study area is 4.62 which is shown in table. 3. This difference depends on the geological and lithological development of the drainage basin (Strahler, 1964) [56]. In the area, the higher values of Rb indicates a strong structural control in the drainage pattern whereas the lower values indicate that the sub basin are less affected by structural disturbances (Stahler,1964; Nag 1998; Vittala *et al*., 2004 and Chopra *et al*., 2005) [56, 32, 3].

Relief aspects

Relief is the elevation difference between the highest and lowest point on the valley floor of the region. The relief measurements like relief ratio, basin length and total relief have been carried out and the data are presented in table 2.

Relief ratio

The maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumn, 1956). Relief ratio has direct relationship between the relief and channel gradient. The relief ratio normally increases with decreasing drainage area and size of the watersheds of a given drainage basin. The values of relief ratio are given in table shows 3 4.04. The high values of Rh indicate steepness of the basin (Vittala *et al*. 2004) and are an indicator of intensity of erosion process operating on the slopes of the basin (Table 3).

Aerial aspects

Aerial aspects include different morphometric parameters, like drainage density, texture ratio, stream frequency, form factor, circulatory ratio, elongation ratio and length of the overland flow. The values of these parameters are presented in table 3 and discussed and interpreted.

Drainage density

Horton (1932) [10, 12], introduced the drainage density (D) is an important indicator of the linear scale of landform elements in stream eroded topography. It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of mi/sq. mi or km/sq. km. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed from drainage density measurements made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly resistant, highly permeable subsoil material under dense vegetative cover and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture, slope gradient and relative relief are the main morphological factors controlling drainage density (Strahaler, 1964) [56]. Drainage density is also influenced by various factors such as resistance to erosion of rocks, infiltration capacity of the land and climate (Verstappen 1983).

The drainage density (D) in the study area 1.87km/sq. km indicating medium to high drainage density (Table 3). It is suggested that the high drainage density indicates the basin has permeable subsoil and thick vegetative cover while low drainage density indicates the basin has highly permeable subsoil and thick vegetative cover (Nag, 1998) [32].

Stream frequency /Channel frequency

The total number of stream segments of all orders per unit area is known as stream frequency and is directly related to stream population per unit area of the watershed (Horton, 1932) [10, 12].

The stream frequency values of in the study is 2.11shows the frequency which indicates +ve correlation with the stream density. Higher value of drainage frequency shows the high runoff (Table.3).

Form factor

Form factor may be defined as the ratio of the area of the basin and square of basin length (Horton, 1932) [10, 12]. Basin shape may be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length (Singh, 1998). If the form factor is less than 0.7854 for perfectly circular basin (Rekha *et al*. 2011;

Gajbhiye *et al*. 2014) [9]. Smaller the value of form factor, more elongated will be the basin. In watershed, the smaller value of the form factor shows maximum elongation of the basin. The high value of form factor shows high peak in short duration and vice versa. In this study, it was found that the value of form factor values is 0.32 which indicates that the basin is more elongated (Table 3).

Circulatory ratio

It is that ratio of the area of the basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is the ratio of the area of the basins to the area of circle having the same circumference as the perimeter of the basin. The circulatory ratio is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin (Patel *et al*. 2013) [38]. In the study area circulatory ratio is 0.34 which indicates that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition (Tables 4).

Elongation ratio

Schumm's (1956) [47, 48] used an elongation ratio (Re) defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The value of Re varies from 0 (in highly elongated shape) to unity i.e. 1.0 (in the circular shape). The elongation ratio values in the study area is 0.10 The values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are followed with high relief and steep ground slope (Strahler, 1964) [56].

Length of overland flow

The length of overland flow (Lg) approximately equals to half of reciprocal of drainage density (Horton, 1945) [11, 13]. It is the length of water over the ground before it gets concentrated into definite stream channels. This factor relates inversely to the average slope of the channel and is synonymous with the length of the sheet flow to large degree. The Lg values of the study area is 0.26 (Tables 3).

Table 4: Calculation of morphometric parameters for linear and aerial aspect of study area

Sr. No.	Morphometric parameters	Inferences
1	Mean Stream Length (Lsm) in KM	0.68, 0.88, 2.73, 5.58, 20.83, 52.32
2	Stream Length ratio (RL)	2.89, 1.90, 2.09, 1.40, 1.59
3	Bifurcation ratio(Rb)	3.75, 5.86, 4,28, 5.25, 4
4	Mean Bifurcation ratio	4.62
5	Releif ratio(Rf)	4.04
6	Drainage Density(D)	1.87
7	Stream Frequency(Fs)	2.11
8	Drainage Texture(Rt)	12.40
9	Form Factor(Rf)	0.32
10	Circulatory Ratio (Rc)	0.34
11	Elongation ratio (Re)	0.10
12	Length of overland flow (Lg)	0.26
13	A= Area,	1237.85
14	Basin length=Bl,	77.59
15	Perimeter=P,	210.96

Conclusion

The morphometric analysis of Morna River sub basin shows the variation in stream ratio which might be due to changes in slope in the area as well as presence of different topographic features. The Lsm values in the subwatersheds range from a minimum of 0.55 km (table 2) for stream order one and 41.53 km and its six order stream and that Lsm values of sub basins of given order is greater than that of the lower order and less than that of its next order. the higher values of Rb indicates a strong structural control in the drainage pattern while the lower values show that the sub basin are less affected by structural disturbances. The texture ratio of the Morna River sub basin 12.40 and categorized as medium in nature. The lower values in the study area of texture ratio indicate that the basin is plain with lower degree of slopes. The form factor values 0.34 which indicates that basin is elongated in shape, low discharge of runoff and highly permeable subsoil condition in the study area. The elongation ratio values of the sub-basins shows 0.10 are less than 0.70 (table 4) which indicates that sub watersheds are elongated with high relief and steep slope.

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