JOURNAL OF GEOINTERFACE, Vol.1, No.1, July 2022 pp.28-35

Morphometric analysis of two milli-watersheds in Deccan Volcanic Province of Dangs District, Gujarat, India

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Abstract: The present study emphasizes evaluation of morphometric parameters of two milli-watersheds represented as MWSD-1 (Begu-Nala milli-watershed) and MWSD-2 (South-East of Begu-Nala milli- watershed) and their influence on the hydrological characteristics. Arc GIS 10.4 is used for preparing slope map from SRTM DEM and to evaluate the linear, areal and relief aspects of milli-watersheds. MWSD-1 shows trellis, whereas MWSD-2 manifests dendritic to sub-dendritic drainage pattern. The north-eastern part of both the milli-watersheds shows fine texture compared to coarse texture in south-western part. The values of bifurcation ratio suggest that the drainage system occurs in homogeneous lithology with less dominant geological structures. High drainage density values can be attributed to less transmissible n ature of the subsurface strata of milli-watersheds. Elongated nature of milli-watersheds is supported by values of circulatory and elongation ratio. The results of morphometric analysis will be used to understand the hydrological response of milli- watersheds.
Keywords: Morphometric analysis, Milli-watershed, Remote sensing and GIS, Deccan Volcanic Province, South- Gujarat.

Introduction

With an unprecedented increase in the population and socio-economic activities, the demand of water resource has increased manifolds. To meet the increased demand of water resources in an efficient manner, an appropriate watershed development and management programmes are necessary (Umrikar, 2017). In order to frame an efficient watershed development and management programme, the sound knowledge of drainage morphometry is a fundamental requirement. By definition morphometry is the measurement and mathematical analysis of configuration of the earth's surface, its shape and dimension of its landforms (Clarke, 1966). A detailed morphometric analysis is necessary to understand the hydrological characteristics of the basin. The analysis of area-height relationships, determination of erosional surfaces, slopes, relative relief and terrain characteristics, evaluation of river basin in context to occurrence of groundwater, prioritization of watershed for soil and water conservation activities can be easily carried out using simple methods available for morphometric studies (Kanth, 2012). Numbers of researchers have carried out morphometric analysis on different river basins using conventional methods (Strahler, 1957; Smith, 1950; Horton 1945) as well as available modern day remote sensing and GIS techniques (Umrikar, 2017; Sreedeviet al., 2009; Sreedevi et al., 2005; Biswas et al., 1999). Morphometric studies provide us an insight to the geo-hydrologic response of the river basin towards processes like surface runoff, soil erosion, river shifting, channel sedimentation etc. additionally, they also give us an idea about the prevailing climate, geological setting, geomorphological configuration and structural control existing in the area (Kulkarni 2015, Garde, 2005). In recent years the use of GIS in morphometric analysis has emerged as a powerful tool because it provides a flexible platform for manipulating and analyzing the spatial information (Hajam et al., 2013, Umrikar et al., 2013). The present study intends to use GIS software to quantify the linear, aerial and relief aspects (Horton, 1945; Melton, 1957; Miller, 1953; Schumm, 1956; Strahler, 1964) for two milli- watersheds viz. MWSD-1 (Begu-Nala milli-watershed) and MWSD-2 (South-East of Begu-Nala milli- watershed) (Fig. 1) located in Deccan Volcanic Province (DVP) of south Gujarat.

Study area

MWSD-1 "Begu-Nala milli watershed" and MWSD-2 South-East of "Begu-Nala milli watershed" are rivulets of river Khapri; a tributary of river Ambica located in the Dangs district of Gujarat, India (Fig. 1). The areal extent of MWSD-1 and MWSD-2 are 16.07 km2 and 8.79 km2 respectively. The highest elevation in the study area is 407 m above mean sea level and lowest elevation is 43 m above mean sea level. The area is located between 73° 31' 04" and 73° 32' 42" East longitudes and 20° 47' 38" and 20° 53' 21" North latitudes respectively according to SOI topographic map 46 H/9. The area is connected by road and is about 27 km away from the Ahwa, the headquarters of Dangs district. The study area receives SW monsoon. The district receives the maximum rainfall in the state around 1941 mm from June to September (N. Kumar et al., 2017).

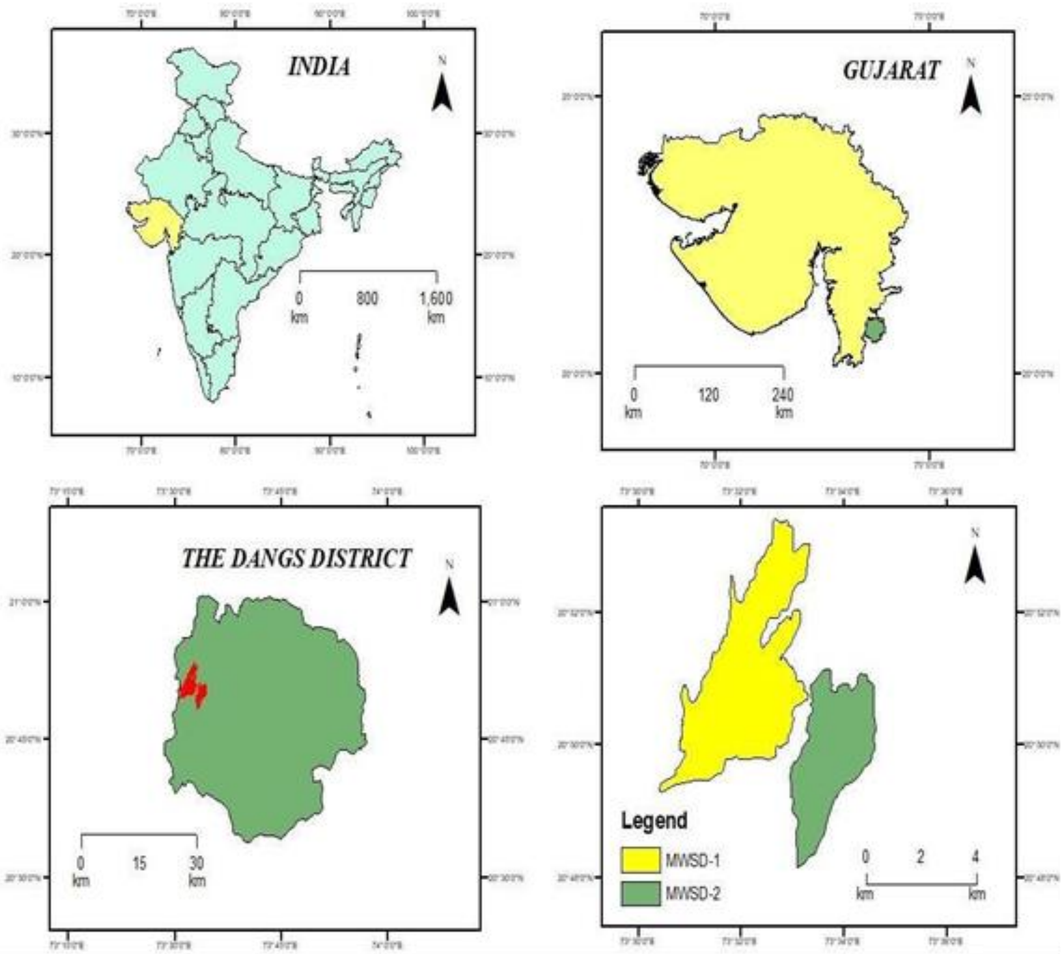

Fig. 1. Location map of the study area.

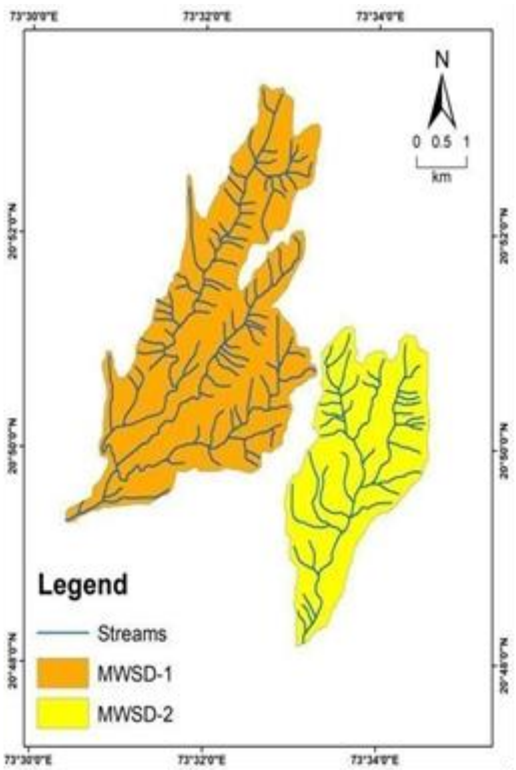

Fig. 2. Drainage Map of the study area.

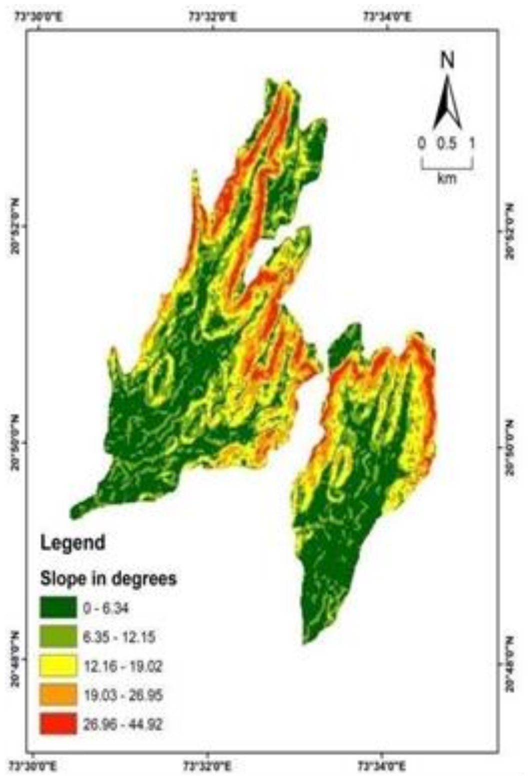

Fig. 3. Slope Map of the study area.

Drainage characteristics and Geology

Streams in the milli-watershed attain the 4th order and ultimately drains into river Khapri. The drainge map shows presence of two distinct types of drainage patterns i.e. trellis and dendritic to sub- dendritic (Fig. 2). The drainage basins have moderate to steep slopes (Fig. 3). Study area is dominantly consisting of basaltic rocks belonging to the Cretaceous to Eocene age.

Methodology

Morphometric analysis of the two milli-watersheds has been carried out at a scale of 1:50000 using the Survey of India (SOI) topographic map and SRTM (Shuttle Radar Topography Mission) DEM data (USGS earth explorer). The topographic map is geo-referenced and projected in Arc-GIS 10.4. The streams are manually digitized from SOI topographic map and slope map is prepared using SRTM DEM. Further, the morphometric parameters such as linear (one dimension), aerial (two dimensions) and relief aspects (third dimension) are computed for two milli-watersheds viz. MWSD-1 and MWSD-2 in Arc GIS 10.4.

Results and Discussions

Morphometric parameters in the present study viz., stream length, stream order, mean stream length, bifurcation ratio, mean bifurcation ratio, stream length ratio, relief ratio, drainage density, stream frequency, form factor, circulatory ratio, drainage texture, elongation ratio, length of overland flow, constant channel maintenance are computed using the formula mentioned in Table 1.

Stream order

Determining the hierarchical position of the stream is referred to as stream ordering. Highest order is assigned to the trunk stream and subsequent lower orders to the tributaries (Strahler, 1964). It is clear from the Table 2 that MWSD-1 and MWSD-2 are both of 4th order having a total of 98 and 48 stream segments of different orders respectively (Fig. 4). The number of streams decreases with an increase in stream order (Fig. 6). Generally, on plotting logarithm of the number of streams against the order, the points lie on a straight line (Horton, 1945). However, in the present study MWSD-1and MWSD-2 show deviation from straight line in order II and III respectively. This could be attributed to the moderately steep slopes occurring in the basin.

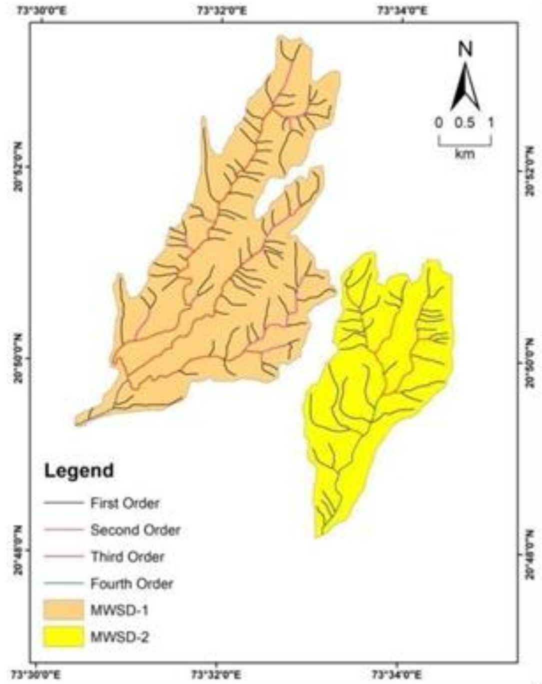

Fig. 4. Stream Orders of the study area.

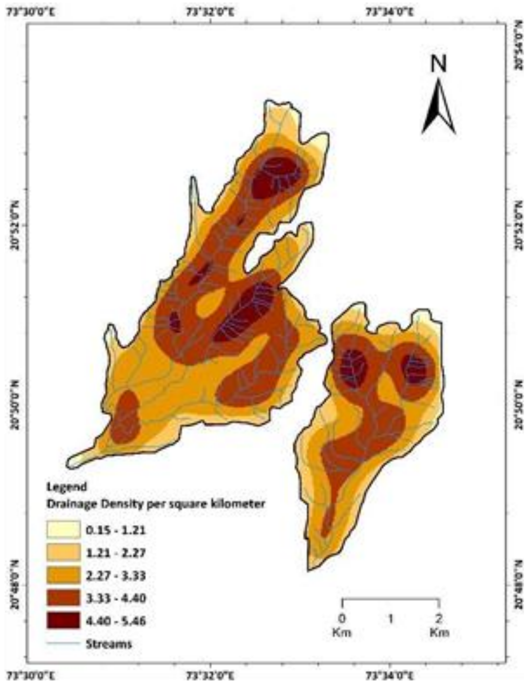

Fig. 5. Drainage Density of the study area.

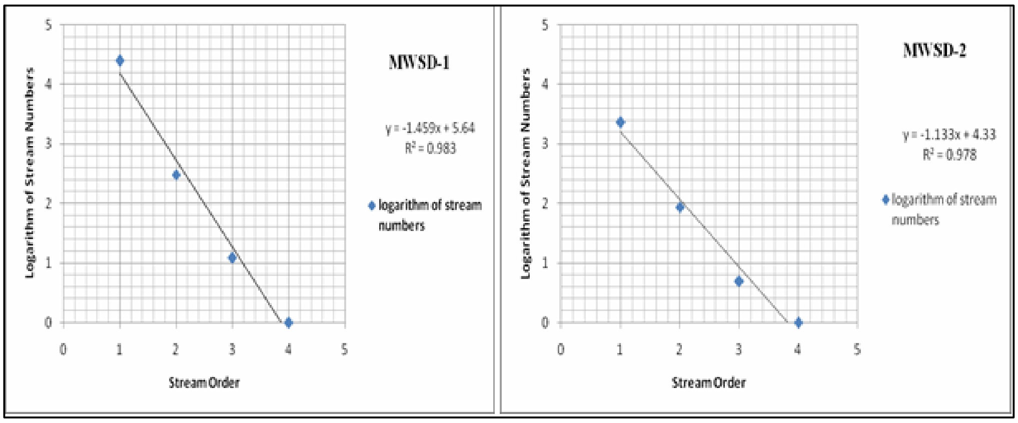

Fig. 6. Plot of logarithm of stream numbers versus stream order.

Table 1. Formulae used to estimate morphometric parameters.

Morphometric Parameters	Formula	Reference
Stream Ordering	Hierarchical rank	Strahler (1964)
Stream Length (Lu)	Length of the streams	Horton (1945)
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"	Strahler (1964)
Stream Length Ratio (RL)	RL = Lu/Lu-1 Where, RL = Stream Length Ratio, Lu = Total stream length of order "u", Lu-1 = Number of segments of next lower order	Horton (1945)
Bifurcation Ratio (Rb)	Rb = Nu/ Nu+1 Where, Rb = Bifurcation Ratio, Nu = Total number of stream segments of order "u", Nu+1 = Number of segments of the next higher order	Schumm (1956)
Mean Bifurcation Ratio (Rbm)	Rbm = Average Bifurcation Ratio of all orders	Strahler (1957)
Relief Ratio (Rh)	Rh = H/Lb Where, Rh-Relief Ratio H = Total relief (Relative Relief) of basin (Km), Lb = Basin Length	Schumm (1956)
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 (1932)
Stream Frequency (Fs)	Fs = Nu/A, Where, Fs = Stream Frequency Nu = Total number of streams of all orders A = Area of the basin (Km^2)	Horton (1932)
Drainage Texture (Rt)	Rt = Nu /P Where, Rt = Drainage Texture Nu = Total number of streams of all orders P=Perimeter (Km)	Horton (1945)
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)
Circulatory Ratio (Rc)	$Rc = 4*\pi*A/p^2$ Where, Rc = Circulatory Ratio, A = Area of the Basin (Km^2) P=Perimeter (Km)	Miller (1953)
Elongation Ratio (Re)	Re = 1.128 √(A/Lb) Where, Re = Elongation Ratio, A = Area of the Basin (Km^2), Lb = Basin length	Schumm (1956)
Length of Overland flow (Lg)	Lg = 1/D*2 Where, Lg = Length of overland flow, D = Drainage Density	Horton (1945)
Constant Channel Maintenance (C)	C = 1/D Where, D = Drainage Density	Schumm (1956)

Stream length

Total length of all the streams belonging to a particular order is referred to as stream length. The streams belonging to each order are identified, counted and measured for length. In general, the total length of stream segment decreases with increasing order. For MWSD-1 and MWSD-2 the minimum cumulative stream length is represented by fourth order stream, while the maximum is for first order streams (Table 2). This signifies that higher order streams are flowing over gentle gradients (Chinmay et al., 2022).

Mean stream length and stream length ratio

Dimensional property which reveals the size of the drainage system components and its contributing basin surfaces is mean stream length (Strahler, 1964). It is computed by dividing the total length of streams in particular order by the number of streams. Table 2 indicates that the mean stream lengths for MWSD-1 and MWSD-2 respectively range from 0.46 to 6.05 and 0.55 to 3.19. The range of stream length ratio for MWSD-1 and MSD-2 is 0.09 to 1.93 and 0.24 to 1.38, respectively. The high stream length ratio (1.93) in MWSD-1 for second and third order streams and MWSD-2 (1.38) for third and fourth order stream imply that areas drained by it are relatively permeable with gentle to moderate gradients (Chinmay et al., 2022).

Table 2. Results of morphometric parameters for MWSD-1 and MWSD-2.

Milli-Watershed	Stream Order	Basin Area (km^2)	Stream Order				Stream Length (Lu) km				Perimeter km	Basin Length km
			I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**		
MWSD - 1	IV	16.07	82	12	3	1	37.7	7.83	15.15	1.51	29.86	8.38
MWSD - 2	IV	8.79	38	7	2	1	21.03	5.05	2.31	3.19	15.44	5.71

Milli-Watershed	Bifurcation Ratio (Rb			Mean Bifurcation Ratio (Rbm)	Drainage Density (D) km/km^2	Stream Frequency (Fs)	Form Factor (Rf)	Circulatory Ratio (Rc)	Length of overland flow (Lg)
	I/II	II/III	III/IV						
MWSD -1	6.83	4	3	4.61	3.87	6.09	0.22	0.22	0.12
MWSD -2	5.42	3.5	2	3.64	3.59	5.45	0.26	0.46	0.13

Milli-Watershed	Mean Stream Length (Lsm) km				Stream Length Ratio (RL)			Basin Relief	Relief Ratio (Rh)	Elongation Ratio (Re)	Texture Ratio (Rt)
MWSD - 1	0.46	0.65	6.05	1.51	0.2	1.93	0.09	298	0.035	0.53	3.28
MWSD - 2	0.55	0.72	1.15	3.19	0.24	0.45	1.38	328	0.05	0.77	3.10

Bifurcation ratio

The ratio of number of streams of particular order to the number of streams of subsequent higher order is the bifurcation ratio (Schumn, 1956). According to Horton (1945), the bifurcation ratio is an index of relief and dissection. Large variations in bifurcation ratio are observed in the areas with significant structural control (Strahler, 1957). Bifurcation ratio varying from 3 to 5 indicates the natural drainage system within a homogeneous lithology (Kale and Gupta, 2001) and geological structure has minimum or no influence on drainage (Chow, 1964; Babu et al., 2016). Low bifurcation ratio values suggest a flat or rolling topography of watershed. Basins with higher bifurcation ratio have very less chances of flooding (Eze and Efiong, 2010). Table 2 shows that the mean bifurcation ratio for MWSD-1 and MWSD-2 are 4.61 and 3.64 respectively. The values suggest that the drainage system is within a homogenous lithology and has less influence of geologic structures.

Relief ratio

Relief ratio is the maximum relief of the watershed to the horizontal distance along the longest dimension of the basin essentially parallel to the principle drainage line (Schumn, 1956). Measurement of overall steepness of the basin can be done using relief ratio. It indicates the intensity of the erosion process actively occurring on the slope of the drainage basin. It represents the erosion process occurring on the slope of the drainage basin and is inversely proportional to basin length (Lb) (Schumm, 1956). In the study area relief ratio ranges from 0.035 (MWSD-1) to 0.05 (MWSD-2) indicating presence of moderate to steep slopes (Schumn, 1956) (Table 2).

Drainage density

Drainage density describes the closeness of the channel spacing (Chopra et al., 2005). Drainage density is the stream length per unit area of watershed (Selvan et al., 2011, Goudie, 2004, Horton, 1945). Langbein (1947) identified the importance of drainage density as a factor determining the travel time of water within the basin and suggested that for humid regions it varies between 0.55 and 2.09 km/km^2. Higher values of drainage density reflect a highly dissected drainage basin and rapid hydrologic response of drainage basin to rainfall events, and vice versa (Selvan et al., 2011, Hajam et al., 2013). As per Horton (1932) drainage density is an excellent indicator of permeability of the drainage basin and the values of 1.5 to 2.0 are considered impervious for areas of high precipitation. The drainage density values for MWSD-1 and MWSD-2 are 3.87 km/km^2 and 3.59 km/km^2 respectively (Fig. 5). High drainage density values are suggestive of less permeable nature of the subsurface strata (Venkatesan, 2014).

Stream frequency

Total number of stream segments of all orders per unit area is referred to as stream frequency (Horton, 1932). Stream frequency is dependent on lithology and provides information regarding the response of basin to runoff process (Selvan et al., 2011). Stream frequency is directly proportional to the infiltration number. The values for the stream frequency for MWSD-1 and MWSD-2 are moderate at 6.096 and 5.455 respectively (Venkatesan, 2014) (Table 2).

Drainage texture

According to Horton (1945), drainage texture is the total number of stream segments of all orders per perimeter of the basin. Drainage texture is influenced by natural factors such as climate, vegetation, rainfall, lithology, soil type, infiltration capacity, relief and stage of development (Smith, 1950). Drainage texture includes the drainage density as well as stream frequency (Thornbury, 1954). In the present study, the values of drainage texture for MWSD-1 and MWSD-2 are 3.28 and 3.10 respectively (Table 2). Fine drainage texture in north-eastern part of MWSD-1 and MWSD-2 suggest less infiltration, whereas coarse drainage texture in south-western part of MWSD-1 and MWSD-2 indicates relatively more infiltration (Fig. 2).

Circulatory ratio

Circulatory ratio is defined as the ratio of the basin area to the area of a circle whose circumference is equal to its perimeter (Miller, 1953). Factors like length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin influences the circulatory ratio (Chopra et al., 2005). Circulatory ratio values range from 0 to 1. Values close to zero suggest that the basin is relatively elongated and vice-versa (Umrikar, 2017). For MWSD-1 and MWSD-2 the values of circulatory ratio are 0.22 and 0.46 respectively. These values suggest that the basins are not circular in shape.

Form factor

Form factor is the ratio of the basin area to square of the basin length (Horton, 1932). Smaller form factor values are indicative of relatively elongated basin. In other words, the gorges (narrow and deep channels) have low form factors whereas wider channels have high form factors (Umrikar, 2017). MWSD-1 and MWSD-2 have lower of form factor values of 0.22 and 0.26, respectively. These values indicate the slightly elongated form of the basin and nature of flow is the flat peak flow that lasts for longer duration of time.

Elongation ratio

The elongation ratio is the ratio of the diameter of a circle having the same area as the basin to the maximum basin length (Schumn, 1956). Elongation ratio varies from 0.6 to 1.0 and is related to wide range of climate and geologic conditions (Chopra et al., 2005). The regions with low relief have values close to unity, while regions with high relief and steep ground slopes have values of elongation ratio between 0.6 to 0.8 (Strahler, 1964). Values of elongation ratio can be categorized into three: circular (>0.9), oval (0.9-0.8) and less elongated (<0.7) (Chopra et al., 2005). Elongation values for MWSD-1 and MWSD-2 are 0.53 and 0.77, respectively (Table 2). These values suggest that the basins are less elongated in nature.

Length of overland flow

The length of overland flow is the distance that water travels on the ground surface before entering into the stream channels (Horton, 1945). Length of overland flow is inversely proportional to the average of the channel slope and is approximately half of the reciprocal of drainage density (Horton 1945). Table 2 shows the values of length of overland flow which are 0.12 and 0.13 for MWSD-1 and MWSD-2, respectively. It indicates the existence of moderate to high relief, rapid run-off and less infiltration (Chandrashekhar et al., 2015 and Chinmay et al., 2022).

Constant of channel maintenance

According to Schumn (1956), the inverse of drainage density is referred to as constant of channel maintenance. The value of constant of channel maintenance is an expression of the relative size of the landform unit in a drainage basin (Gabale et al., 2015). In other words, it provides us the number of square kilometers of watershed surface necessary to sustain one linear stream channel of 1 km. The value of constant of channel maintenance for MWSD-1 and MWSD-2 are 0.25 and 0.27 respectively. It indicates less transmissible nature of underlying rocks (Yadav et al., 2014, Chinmay et al., 2022).

Conclusions

Geographical Information System is an efficient platform to perform morphometric analysis. The fourth order basins MWSD-1 and MWSD-2 exhibit dendritic to sub-dendritic and trellis drainage pattern. The drainage system is occurring in homogeneous lithology and has very less influence of geological structures. The MWSD-1 is more elongated compared to MWSD-2. The morphometric analysis indicates that the upper reaches of MWSD-1 and MWSD-2 are characterized by moderate to steep slopes, less permeable nature of underlying rocks, high drainage density, fine drainage texture which results in high runoff and less infiltration. Whereas, lower reaches are characterized by moderate to gentle slopes, low drainage density, relatively coarse drainage texture responsible for more infiltration compared to upper reaches. The results of morphometric analysis serve as an efficient input to understand the hydrological response and locating the groundwater potential zones.

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Manuscript received: 23-05-2022
Manuscript accepted: 22-06-2022