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MORPHOMETRIC CHARACTERISTICS OF A TROPICAL RIVER BASIN, CENTRAL KERALA, INDIA USING GEOSPATIAL TECHNIQUES

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Abstract
The Thutapuzha watershed (TW) is one among the major tributaries of Bharathapuzha – the largest west flowing river in Kerala, India. Morphometric analysis was carried out to determine the spatial variations in the drainage characteristics and to understand the prevailing geologic variation, topographic information and structural setup of TW using Survey of India topographic maps and ASTER-DEM. Geoprocessing techniques has been used for the delineation and calculation of the morphometric parameters of the watershed. The TW sprawled over 1107 Km^2 and the study revealed that the watershed includes a sixth order stream and lower order streams mostly dominate the basin with a drianage density of 1.36 m/Km^2 exhibiting highly resistant subsoil, dense vegetation, and low relief of surface nature. The study indicate that rainfall has a significant role in the drainage development whereas the drainage pattern is controlled by structure and relief. The watershed of TW is moderate to well-drained and exhibited a geomorphic maturity in its physiographic development. The shape parameters revealed the elongated nature of TW having less prone to flood, lower erosion and sediment transport capacities and drainage network development in the watershed. This study strongly brings to light that the drainage morphometric parameters have the enormous potentiality to unveil the hydro-morphologicalcharacteristics of the river basins. Integrating hydro-morphological characteristics with conventional watershed assessment methods would have a beneficial effect on judicious watershed management, which helped to formulate a comprehensive watershed management plan.

Keywords: Thuthapuzha Watershed (TW), Morphometry, DEM, Central Kerala, Geospatial techniques

1. Introduction

Morphometry is defined as the measurement and mathematical analysis of the configuration of the Earth's surface, and the shape and dimensions of its landforms. Morphometric examination of a watershed provides a quantitative description of the drainage system which is a key aspect of the characterisation of watersheds (Strahler 1964). The advantages of drainage pattern analysis in characterizing geomorphic features and inferring the degree of structural and lithological controls in the evolution of fluvial landforms were emphasized by early research investigations of Horton (1945), Thornbury (1954), and Strahler (1964). Geology, relief, and climate are the key determinants of running water ecosystems functioning at the basin scale (Lotspeich – Platts 1982; Frissel et al. 1986). The hydrological response of a river basin can be interrelated with the morphological of the drainage basin, such as size, shape, slope, drainage density and size, and length of the streams, etc (Chorley 1969; Gregory – Walling, 1973). So one of the essential step to get a better understanding of watershed is the morphometric analysis. Morphometric analysis was employed for the prioritization of micro watershed (Ratnam et al. 2005), for the characterization of watersheds (Nag 1998; Vittala et al. 2004), and for the development of groundwater resources (Sreedevi et al. 2004, 2009). In terrain characterization studies, and especially on spatial variabilities of morphometric parameters, the contributions of Mather – Doornkamp (1970), Gardiner (1978), and Gregory (1978) are considered immensely important. In the Indian regional context, morphometric analysis was employed for characterizing watersheds (Nag 1998; Vittala et al. 2004), for the prioritization of micro watersheds (Ratnam et al. 2005) and for the development of groundwater resources (Sreedevi et al. 2004, 2009).

In recent times many authors have attempted to generate more specific data on morphometric parameters using geospatial techniques (Ozdemir – Bird 2009; Mesa 2006; Thomas et al. 2010, 2011; Manu – Anirudhan 2008; Magesh et al. 2013; Sreedevi et al. 2005; Vijith – Satheesh 2006). The present study employed primarily focuses on the description and nature of spatial variations of physical characteristics of the drainage system of the Thuthapuzha Sub-basin (TW) in order to describe and evaluate the linear, areal, and relief characteristics, using data aggregated from Survey of India (SOI) toposheets (scale, 1:50,000) and corresponding ASTER (Advanced Spaceborne Thermal Emission and Reflection, 30m resolution DEM (Digital elevation model) was downloaded from http;//earthexplorer.usgs.gov.

2. Materials and methods

The SOI topographic maps (1:50,000) and Satellite-borne ASTER (Advanced Spaceborne Thermal Emission and Reflection, 30 m resolution DEM (digital elevation model) was downloaded from http://earthexplorer.usgs.gov were used as a base for delineation of TW. Downloaded ASTER data was correlated with georeferenced toposheets and projected into same coordinate system (UTM WGS 84 Zone 44). The automated extraction of watershed method was employed to construct the watershed boundary with the help of hydrology tool in ArcGIS 10.3 software (Al-Saady et al. 2016; Arulbalaji – Gurugnanam 2016). The drainage orders have been calculated based on Strahler method of stream orders. For morphometric analysis, the detailed assessment was carried out in three different approaches, such as linear, aerial, and relief aspects. These three different approaches of computations are given in Table 1. The morphometric characteristics such as basin length, basin perimeter, stream order, stream length, mean stream length, stream number, stream length ratio, bifurcation ratio, mean bifurcation ratio, drainage density, drainage texture, stream frequency, elongation ratio, circulatory ratio, form factor, infiltration number, relief ratio and ruggedness number were considered for the morphometric analysis.

Table 1. Parameters used for the morphometric analysis

Sl. No.	Parameters	Symbol	Formula	References
1.			Linear Aspects	
1.1	Basin Length	Lb	Lb=1.312×A0.568 A=Area of the basin	(Sreedevi et al. 2005
1.2	Basin perimeter	P	P= Outer boundary of drainage basin measured in Kilometers	(Sreedevi et al. 2005)
1.3	Stream Order	U	Hierarchical rank	(Strahler 1964)
1.5	Mean Stream Length	Lsm	Lsm= Lu/Nu, Where Lu= Total stream length of order'u', Nu= Total no. of stream segments of order 'u'	(Strahler 1964)
1.6	Stream Number	Nu	No. of Streams in each order	(Sreedevi et al. 2013)
1.7	Stream Length ratio	RL	RL=Lu/Lu-1, Where Lu= The toal stream length of the order'u' Lu-1= Total stream length of its next lower order	(Horton 1945)
1.8	Bifurcation ratio	Rb	Rb= Nu/Nu+1, Nu= Total no. stream segments of order 'u', Nu+1= Number of segments of the next higher order	(Schumm 1956)
1.9	Mean Bifurcation ratio	Rbm	Average of bifurcation ratios of all orders	(Strahler 1964)
2			Areal Aspects	
2.1	Drainage Density	Dd	Dd= Lu/A where, Lu= Total stream length of all orders and A= Area of the basin (km^2)	(Horton 1932)
2.2	Drainage texture	Rt	Rt= Nu/P, Where, Nu= Total No. of streams of all orders, P= Perimeter (Km)	(Smith 1950)
2.3	Stream Frequency	Fs	Fs=Nu/A, where Nu= Total no. of streams of all orders, A= Area of the basin (km^2)	(Horton 1945)
2.4	Elongation ratio	Re	Re=2/Lb ×(A/π)0.5 Where, A= Area of the basin, Lb = Basin length (km)	(Schumm 1956)
2.5	Circulatory ratio	Rc	Rc= 4×π× A/P2, Where, π= 3.14, A= area of the basin, P2= Square of the perimeter (km)	(Strahler 1964)
2.6	Form factor	Rf	Rf= A/Lb2, Where A= Area of the basin (km^2), Lb2= Square of basin length	(Horton 1945)
2.7	Infiltration Number	If	If=Dd×Fs Where. Dd= Drainage density and Fs=Drainage frequency	(Umrikar 2017)
3			Relief Aspects	
3.1	Basin Relief	Bh	Vertical distance between the lowest and highest points of basin	(Schumm 1956)
3.2	Relief ratio	(Rh)	Rh= Bh/Lb, where Lb=Basin Length	(Schumm 1956)
3.3	Ruggedness Number	(Rn)	Rn=Bh×Dd Where, Bh= Basin relief, Dd-Drainage density	(Strahler 1958)

3. Study Area

The TW (n= 6th, L= 63km, Area = 1107 km2; N Lat. 10°50′–11°15′ and E Long. 76°05′–76°40′), located within the Palakkad and Malappuram districts of Kerala. Thuthapuzha has four tributaries draining to it, namely Kuntipuzha, Nellipuzha, Kanhirapuzha and Thuppanadpuzha. The average annual discharge of the sub-basin is 1750 MCM (CWC 2012). The study area falls within the midland (7.5–75 m elevation above mean sea level) and the highlands (>75 m elevation above mean sea level) region of Kerala and experiences a humid tropical climate. The Silent Valley Reserve Forest is located at the north-eastern corner of the sub-basin.

Geological setting

The TW is underlain by Precambrian crystalline rocks like charnockite, charnockitic gneiss, hornblende biotite gneiss, garnet biotite gneiss, khondalites, migmatites, etc (Ravindrakumar and Chacko 1994). The various geological units were demarcated and delineated based on the geological map of the Geological Survey of India. Based on geology, the study area is divided into nine units (Fig. 2). The major portion of the basin is covered by charnockite group of rocks and migmatite complex (441 and 437 km2 respectively) followed by basic rocks - 108 km2, peninsular gneissic complex – 103 km2, sand and silt (sedimentary deposits) 9.9 km2, high grade metasedimentary rocks- 6.8 km2 and khondalite group of rocks -1.9. km2 Pegmatite/Aplite/ Quartz vein and laterite formations are very less in the study area. The precambrian crystalline rocks are well foliated at many places, striking WNW-ESE with a southward dip of 30º -50º (John – Rajendran 2005). Laterite capping is observed over the major part of the study area with a maximum thickness of 20 m along the western part. Laterite is either absent or observed as thin capping over the country rock towards the eastern part.

The major lineaments in the study area have a trend of NNW-SSE to NW-S-E and E-W direction (Fig. 3). There are many minor lineaments in the study area, also trending in the NW-SE and N-S directions. Most of the lineaments in the area found to be along the drainages.

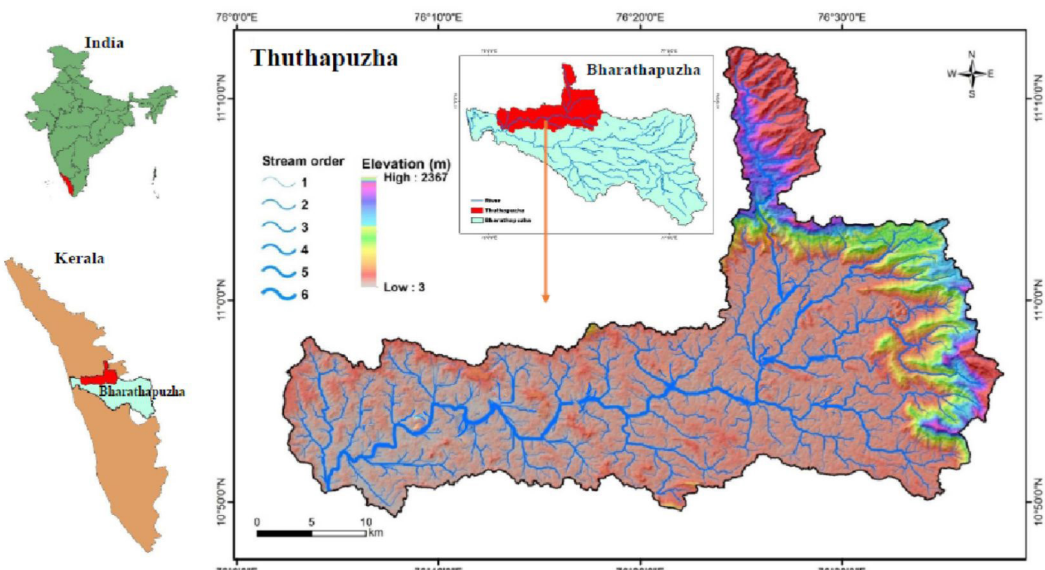

Fig. 1. Location Map of the study area

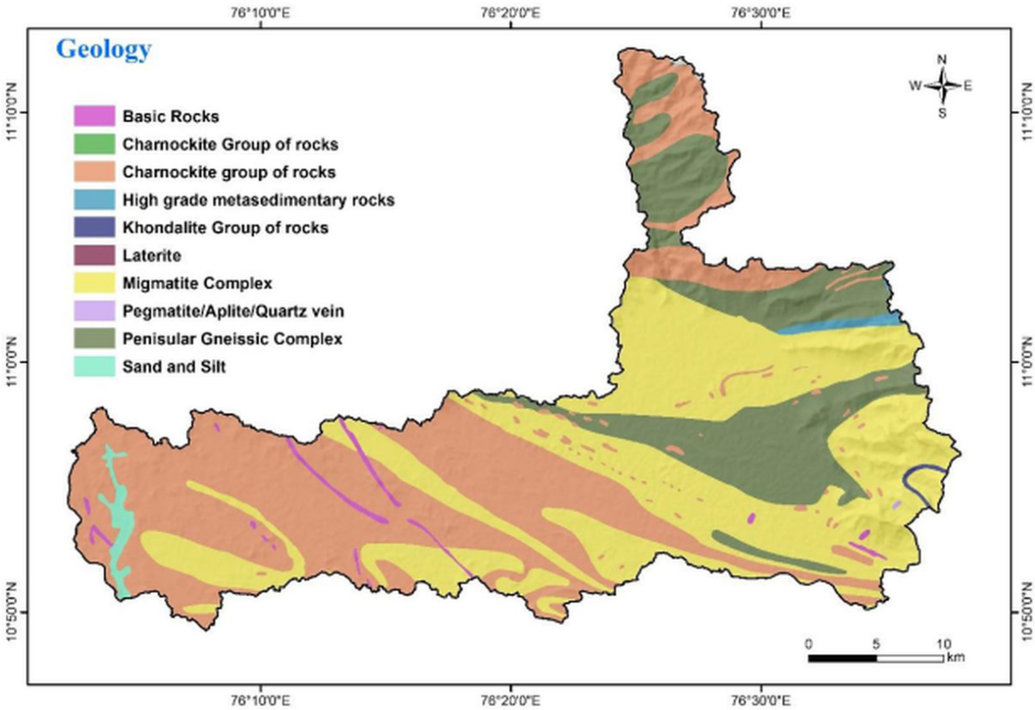

Fig. 2. Geology map of TW

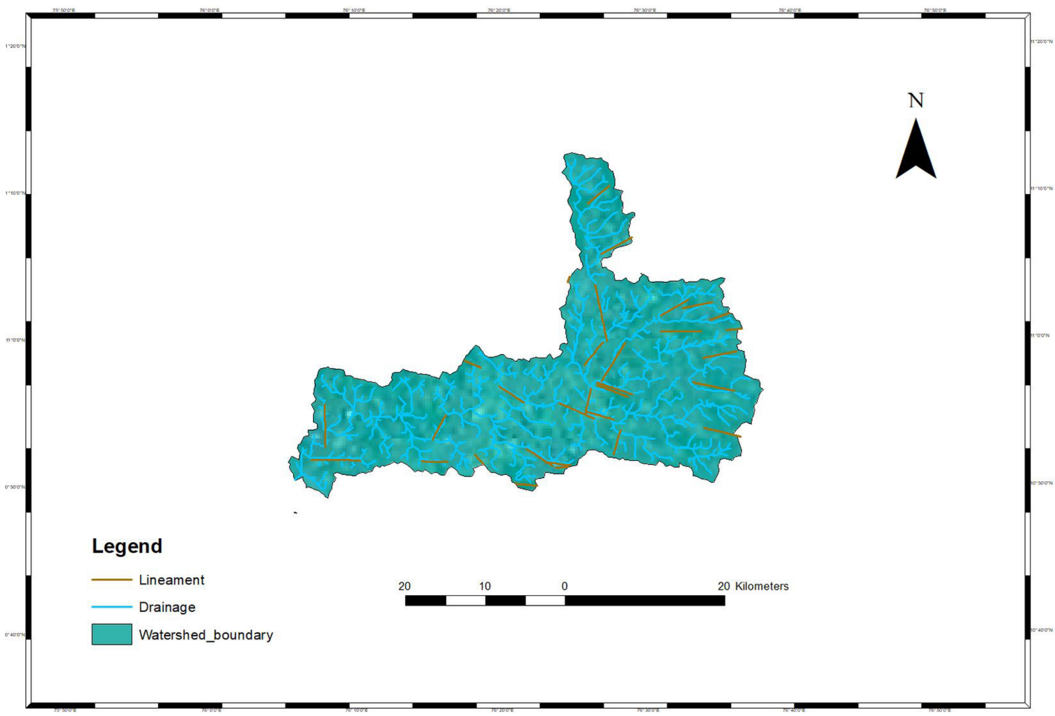

Fig. 3. Lineanment map of TW

Climate

The rainfall data of TW during the year 2016 is analysed in the study. The annual rainfall ranges varied from 1526 to 3102 mm. This is higher than the average annual rainfall (1822 mm) of entire Bharathapuzha River Basin (Nikhil Raj and Azeez 2012) and the average annual rainfall (2817 mm) of Kerala state (Krishnakumar et al., 2009). Based on maximum and minimum value the rainfall has been reclassified into five classes such as very low (1526 – 1842 mm), Low (1842 – 2157 mm), Moderate (2157 – 2472 mm), High (2472 – 2787 mm) and Very High (2787 – 3102 mm) rainfall. Infiltration depends on intensity and duration of rainfall. High intensity and short duration rain influences, the less infiltration and more surface runoff; Low intensity and long duration rain influences high infiltration than the run-off (Ibrahim-Bathis – Ahmed 2016).

4. Results & Discussion

Thutapuzha water shed (TW) boundary including the stream network is shown in Figure 1 and the linear, areal, and relief parameters for the morphometric characterization are given in Table 2. The parameters have been examined and detailed below along with the highlights of the results.

Linear aspects

Linear aspects such as stream order, stream number for various orders, bifurcation ratio, stream length for various stream orders and length ratio were determined and results have been presented in Tables 2.

Stream number and Stream order (Nu)

The order-wise total number of stream segments is known as stream number. The data reveal that the number of stream segments gradually decreases as the stream order increases. A total of 1081 drainage channels were noticed in the Thuthapuzha river basin, out of which 76.13 % (823) is 1st order, 18.77 % (203) is 2nd order, 3.70 % (40) is 3rd order, 1.11 % (12) is 4th order, 0.185 % (2) is 5th order, 0.092 % (1) is 6th order stream. High values of first-order streams indicate that there is a possibility of sudden flash floods after heavy rainfall in the down streams (Chitra et al. 2011). A high proportion of first order streams (>70%) indicates structural breaks, chiefly as, lineaments and fractures of the watershed as shown in Fig. 3.

The classification of streams based on the number and type of tributary junctions, has proven to be a useful indicator of stream size, discharge, drainage area and its age (Strahler 1957). Stream order gives an idea of its size and approximate index of stream flow. Higher stream order has a major role in the terms of greater discharge (Farhan et al. 2016; Umrikar 2017) and the high stream frequency indicates less permeability and infiltration capacity of the surface. The Thutapuzha River is a sixth order basin with dentritic and sub-dentritic pattern. Ranking of streams has been carried out based on the methods proposed by Strahler (1957). First and second order streams were dominating the river basin. The number of first-order streams indicates the mature stage of topography (Dhruv Sen Singh – Amit Awasthi 2011).More number of first-order streams is observed in the hilly region of the Thuthapuzha river basin, which points towards terrain complexity and compact nature of the bedrock lithology Stream length (Lu)

The mean and total stream length of each stream order is tabulated in Table 2. Stream length stands for the surface runoff characteristics of a river basin or catchment (Arulbalaji – Gurugnanam 2016). The mean length of channel segments of a given order is more than that of the next lower order, but less than the next higher order, indicating that the watershed evolution follows erosion laws acting on geologic material with homogeneous weathering erosion characteristics (Nag – Chakraborty 2003). Mostly, first order stream length is high and it decreases while stream order increases (Waikar – Nilawar 2014). High stream length depicts the flatter gradients, as well as small stream length represents high slope and fine texture. Appropriate of the steep slope, the Ist, IInd and IIIrd order streams are predominantly founds in the hilly area with longer stream lengths. The IVth, Vth, VIth, and VIIth order streams are for the most part in the lesser slope with gentle and flat surface. The total length of all stream orders comes to 1543 km. The total length of the Ist and IInd order streams covers about 75% of total stream length and remaing stream orders constitutes only 25% of total stream length because of the stream length is higher in the Ist and IInd order The results of stream length reveal that the first-order streams are short in length and are found in the upstream area; similar observations are conformed by Chitra et al. (2011). Streams with relatively short lengths are representative of areas with steep slopes and finer texture, whereas longer lengths of stream are generally indicative of low gradients (Strahler 1964).

Table: 2. Morphometric parameters of TW

Parameters	Results					
Area (Km^2)	1107					
Perimeter (km)	279					
Basin Length (km)	71					
Stream Order	6					
Number of Streams in each order (Nu)	I	II	III	IV	V	VI
	823	203	40	12	2	1
Total Stream of all order			1081			
Stream length in each order (Lu) km	796	373	191	108	16	59
Total length of streams in all order (km)			1543			
Bifurcation ration (Rb)	I/II	II/III	III/IV	IV/V	V/VI	
	4.05	5.07	3.33	6	2	
Mean Bifurcation ration (Rbm)			4.069			
Mean stream length (Lsm)	I	II	III	IV	V	VI
	0.96	1.83	4.77	9	8	59
Stream length ratio (RI)	I/II	II/III	III/IV	IV/V	V/VI	
	0.46	0.51	0.56	0.15	3.68	
Basin Max.rel-Min.rel	2364					
Total relief (km)	2.364					
Relief Ratio (Rh)	0.033					
Drianage Density (D)	1.36					
Stream Frequency (Fs)	0.96					
Infiltration Number	1.3					
Drianage Texture (Rt)	3.87					
Form factor (Rf)	0.22					
Circularity ratio (Rc)	0.18					
Elongation Ratio (Re)	0.53					
Ruggedness Number	3.21					

Mean stream length (Lsm)

The mean stream length was computed by the method of total stream length of stream order divided by the total number of stream order (Strahler 1964). The Lsm values for the TW vary from 0.96 to 59 km with a mean Lsm value of 13.92 km (Table 2). It is noted that Lsm of any given order is greater than that of the lower order and less than that of its next higher order in the basin. The Lsm values differ with respect to different basins, as it is directly proportional to the size and topography of the basin. Strahler (1964) indicated that the Lsm is a characteristic property related to the size of drainage network and its associated surfaces. The result indicates that the mean stream length is minimum in I^{st}, II^{nd} and III^{rd} stream order and maximum in IV^{th}, V^{th} and VI^{th} stream order (Table 2).. The mean stream length has direct relationship to mean annual rainfall runoff; the highest mean stream length specifies relatively high mean annual rainfall runoff and relatively low mean annual rainfall runoff shows less mean stream length. The TW depicts that the mean annual rainfall runoff is higher in IVth, Vth and VIth order stream as well as less in Ist IInd and IIIrd order stream.

Stream length ratio (RL)

Horton (1945) has defined the stream length ratio is the higher order of stream length divided by the next lower order stream segments. Stream length ratio has a significant relation with the surface flow, discharge and erosion phase of a river basin (Arulbalaji – Gurugnanam 2016). The mean Rl of TW is 2.416 and varies from 0.15 to 3.68 in the sub-watersheds (Table 2). Similar observations are noted in Aiyar basin (John Wilson et al. 2012) and it shows an important relationship with the surface flow discharge and the erosional stage of the basin. The variability in Rl, among successive stream orders, is a reflection of differences between slope and topography and hence it has an important control on discharge and erosional stage (of the watershed (Sreedevi et al. 2004; Farhan et al. 2016). Though, the RL between successive orders of streams does not obey anyempirical rule or follow any systematic variations, some anomalous values were observed in the ratio in certain orders. The anomaly may be interpreted as a sign of disequilibrium in the drainage system. It must also be associated with either as downstream extension of the higher order segment or an upward extension of tributaries or inception (Thomas et al. 2010). Wide variability among the Rl values of TW suggests the domination of local geology over length of channel segments. The increase of Rl from lower to higher orders is exemplified by TW may be indicative of attainment of geomorphic maturity. Bifurcation ratio (Rb)

The ratio of number of segments of a given order (Nu) to the number of segment of higher order (Nu+1) is termed as bifurcation ratio (Strahler 1964). Bifurcation ratio directly has a relationship with the physiography, slope, climatic conditions and also branching pattern of a drainage pattern. Relatively high bifurcation ratio symbolizes early hydrograph peak with a possibility of flash flooding during the storm events. Bifurcation ratio, a measure of the degree of ramification of drainage network (Mesa 2006), exercises a significant control over the ‘peakedness’ of runoff (Chorley 1969). The Rb values usually fall in the range of 3.0 and 5.0 for networks formed on homogeneous rocks (with least/minimum structural disturbances), on the one hand and hits values higher than 10.0, where structural controls play dominant roles on the other (Mekel 1970; Chowet al. 1988). The mean bifurcation ratio (Rbm) characteristically ranges between 3.0 and 5.0 for a basin when the influence of geological structures on the drainage network is negligible (Verstappen 1983). In respect of TW, Rb attains a values of 4.09 with Rb indicating geologic structures do not implement a dominant control on the drainage pattern, which is comparable to mountainous or highly dissected area (Horton 1945). However, as suggested by Chow (1964), these values may indicate the area is not influenced powerfully by geological structures.The morphometric analysis of Achankovil River, flowing through the Achankovil Shear Zone in the Southern Kerala reported Rb values in the range of 3.46 and 5.50 (Manu - Anirudhan 2008). The higher Rb value for the stream orders IV/V and II/III are 6 and 5.07 in TW indicating a mature topography.which is comparable to that of mountainous or highly dissectedareas (Horton 1945).

Areal aspects

The area of the basin was computed by converting the map of the basin into a polygon form. Area of the basin has a direct relationship to the storm of the hydrograph, peak magnitudes, and also has a strong relationship of mean annual rainfall runoff (Ahmed et al. 2010). The total area of TW is 1107 km^2 and perimeter is 279 km.

Drainage density (Dd)

Drainage density is a parameter sensitive to the erosional development and provides a link between form attributes of a watershed and processes operating along the stream course (Strahler 1954, Gregory – Walling 1973). According to Verstappen (1983) and Colombo et al. (2007), Dd measures the degree of fluvial dissection and is under the influence of numerous factors, but the resistance to erosion of rocks, infiltration capacity of land and climatic conditions rank high. Low drainage density points out the highly resistant rock, dense vegetation, and low relief of surface nature (Ahmed et al. 2010). High drainage density indicates weak or impermeable material, sparse vegetation and high relief (Hajam et al. 2013). The Dd of TW is 1.36 which points out the highly resistant rockl, dense vegetation and low relief of surface nature. While comparing the TW with Tamiraparani sub-basin, a relatively high Dd is observed in the later. However, the Dd values of both the basin are less than 5.0, which indicate that both the basins have similar drainage density features.

Drainage texture (T)

Smith (1950) has designed the drainage texture is the number of stream segments of all orders per perimeter of that area. Coarse drainage texture reflects low drainage density, and fine drainage texture point out the high drainage density. Smith (1950) has used the drainage texture ratio to describe the closeness of one stream to another stream. The drainage texture is classified into five classes. The drainage texture < 2 is very coarse, between 2 to 4 is related to coarse, between 4 to 6 is moderate, between 6 to 8 is fine, and > 8 is very fine texture. The T value of TW is 3.87 indicating moderate texture. The drainage texture of the Bharathapuzha basin is 7.78, which indicates intermediate drainage texture and this ratio can be attributed to the presence of high relief in the western part of the study area (Magesh et al. 2013). In case of other tropical basins (Aiyar and Tamiraparani), the texture value exceeds 10 and 15 because these basins have fine to ultra-fine texture possibly formed by the cumulative effect of various geomorphological processes.

Stream frequency (Fs)

Stream frequency is the total number of stream segments of all orders per unit area (Horton 1932). Schumm (1956) stated that low values of stream frequency indicate presence of a permeable subsurface material and low relief. The channel segment numbers for unit areas are difficult to be enumerated (Smith 1950). Stream frequency mainly depends on the lithology of the basin and reflects the texture of the drainage network.. The stream frequency value of the TW area is 0.96 which indicates low stream frequency. The value of stream frequency for the basin exhibits positive correlation with the drainage density of the area indicating the increase in stream population with respect to increase in drainage density The stream frequency is dependant more or less on the rainfall and the physiography of the region. Similar observations are noted in Huai Bong sub-watershed (Ket-ord et al. 2013) which has highly permeable surface and dense vegetation.

Elongation ratio (Re)

According to Schumn (1956) elongation ratio is the ratio of the diameter of a circle (D) of the same area in the basin to the maximum basin length (Lb). Based on the classification by Strahler (1964), elongation ratio has been classified as circular (Re > 0.9), oval shape (0.90 > Re > 0.80), less elongated (0.80 > Re > 0.70) and elongated (Re < 0.70). The elogation ratio (Re) of TW is 0.53, which indicates steep slopes and and elongated shape. The elongated shape of the watersheds with high relief and steep slope with a smooth hydrograph which is explained by greater time lag for water from upper regions of the catchment to reach outlet. The Re value of Bharathapuzha basin is 0.57 (Magesh et al. 2013), which indicates moderate relief with steep slope and elongated in shape. However, the Re value of Tamiraparani sub-basin (Magesh - Chandrasekar 2012) is 0.75, which indicates that the sub-basin is less elongated with high relief and steep slope.

Circulatory ratio (Rc)

The circularity ratio is expressed as the ratio of the basin area (A) and the area of a circle with the same perimeter as that of the basin. The Rc values can attain a maximum of 1.0 where the outline of the watershed is approaching near circularity (Miller 1953). The capacity of drain out the water of a watershed or river basin can be determined by circulatory ratio (Kusre 2016). Stream frequency, geological structures, land use land cover, climate, relief, slope and drainage pattern are the major criteria for circulatory ratio (Das et al. 2012; Sreedevi et al. 2005). The low, medium and high values of the circulatory ratio are indications of the youth mature and old stages of the life cycle of the tributary basins.. TW is in the youth stage of its development with a circulatory ratio of 0.18. The result showed that the TW has Rc value of <0.5, indicating elongated shape. In addition, Miller (1953) described Rc as a significant ratio that indicates the dendritic stage of a watershed. This is mainly due to the diversity of slope and relief pattern of the basin. However, in the case of Tamiraparani sub-basin, the Rc value is equal to 0.5 indicating more or less circular shape (Magesh and Chandrasekar 2012).

Form factor (Ff)

Horton (1945) has described the form factor is determined by the ratio of the basin area to the square of the basin length. Long-narrow basins have larger lengths and hence smaller form factors. Circular basins have intermediate form factors, which are close to one. For a perfectly circular basin, the value of the form factor will be greater than 0.78. Short-wide basins have the largest form factors. Ff is a parameter also used to predict the flow intensity of a watershed of a defined area and this has a direct linkage to peak discharge (Horton1945; Gregory – Walling 1973). The high form factor occurrence indicates larger peak flows of shorter duration, and low form factor occurrence indicates lower peak flows of longer duration (Waikar – Nilawar 2014). The form factor of the TW is 0.22 implying elongated basin with lower peak flows of longer duration. However, if we compare the Ff of the study area with Tamiraparani sub-basin, the later have an Ff value of 0.45 that means Tamiraparani sub-basin is less elongated than the present study area.Infiltration number

The infiltration number describes the relationship between drainage density and drainage frequency and it gives an idea about the rate of infiltration, impermeable bedrock of the watershed or river basin (Sreedevi et al. 2013; Umrikar 2017). The infiltration number of the TW is 1.3 implying high run-off and moderately low infiltration capacity.

Relief aspects

Basin relief (R)

R is a parameter that determines the stream gradient and influences flood pattern and volume of sediment that can be transported (Hadley – Schumm 1961). It may be unduly influenced by one isolated peak within the watershed. Basin relief is an important factor in understanding denudational characteristics of the basin (Sreedevi et al. 2004). The TW is endowed with an R of 2364 m. The larger R values are a result of the erosion forces and the denutational rates in the TW. Moreover the high relief value of basin indicates the gravity of water flow, low infiltration and high runoff conditions.

Relief ratio (Rr)

Rr is a dimensionless height to length ratio, i.e. basin relief and basin length and widely accepted as an effective measure of gradient aspects of the watershed (Schumm, 1956). The relief ratio increases with decreasing drainage area and size of the river basin (Arulbalaji – Gurugnanam 2016). The highest value of relief ratio specifies steep slope and high relief, while the lower relief ratio specifies the low degrees of slope. The relief ratio of the TW is 0.03, indicating the exposure of basement rocks as small ridges and mounds with lower slope values (Vittala et al. 2004). However, in Muthirapuzha watershed (Thomas et al. 2010) there is a slight increase in relief ratio (0.05), but this increae is negligible as both the basin indicates the intensity of erosion processes operating on the slopes of the basin.

Ruggedness number (Rn)

The ruggedness number is expressed as the product of basin relief and drainage density (Strahler 1958). An extremely high value of ruggedness number occurs when both variables are large and the slope is steep but long as well (Kusre 2016). The Rn value of TW is 3.21 which indicate moderate slope and the relief and drainage density are medium.

5. Conclusion

The evaluation of morphometric characteristics of TW unveiled the importance of morphometric studies in terrain categorization and basin evolution studies. The drainage network of the TW is supplemented with a large number of first and second order streams and are well-developed and systematically organized to provide sufficient draining indicatings structural breaks, chiefly as, lineaments and fractures of the watershed. The TW confirms the drainage network development through homogeneous weathering. The Rb values of TW indicating geologic structures do not implement a dominant control on the drainage pattern, which is comparable to highly dissected mountains watershed with mature topography and higher drainage integration. The Dd values provide sufficient insight into surface geology (i.e. impervious basement and steeper slopes) causing higher surface run off, and humid climate resulting in a moderate to well-drained basin. The relief parameters indicate that TW is structurally complex with mountain landscape. The infiltration number of the TW implies high run-off and moderately low infiltration capacity. Again, it is inferred that the drainage pattern in the watershed is controlled by relief rather and structure.

TW watersheds are elongate in shape and hence the sub-units will tend to have lower flood peaks but longer duration flood flows hence affording flood management. The spatial variations in the distribution of tributary channels of Thutapuzha, is indicative of the role of the drainage network in determining the hydrological regime. The higher bifurcation ratios, along with higher drainage density and low elongation ratios and form factors suggest the geological control on drainage organization. Though the hydrological system is highly complex, the analysis of the morphometric parameters provides adequate information about both terrain characteristics and hydrological behavior of the watersheds. Hence, it would be concluded from the study that the drainage morphometric parameters have the huge potentiality to unveil the hydro-morphological characteristics of any river basin and integrating this with conventional watershed assessment methods would have a beneficial effect on judicious watershed management.

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