



Evaluation of morphometric parameters and hypsometric curve of Arkavathy river basin using RS and GIS techniques

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Abstract

Water availability and water scarcity in a river basin are influenced by the geomorphological processes occurring within a river basin. Therefore, quantitative evaluation of the river basin shape provides a crucial lead in assessment of the impact of geomorphological processes on the hydrology of the basin. Arkavathy river basin has been selected for the present study. The basin with an annual average rainfall of 874.87 mm is a persistent water scarce basin located in Cauvery river basin in south India. The basin has been subjected to rapid urbanization due to which there is an increased water demand over a period of time. Hence, to tackle the growing water scarcity and reoccurrence of droughts in the basin, an attempt has been made in the present study to investigate and understand the basin morphometry and derivation of hypsometric curve of Arkavathy river basin using remote sensing (RS) and geographic information system (GIS) techniques. Quantitative evaluation of basin morphometry has been made, and the impact of basin morphometry on the peak runoff and flooding in the basin has been assessed. The basin hypsometric curve has aided in assessment of the erosion status of the basin and its impact on the risk of sedimentation on water bodies. The morphometric parameters and hypsometric curve are then analysed to investigate the potential impact of the basin morphometry on the water availability and water scarcity afflicting the basin.

Keywords Morphometry · Hypsometric curve · Drainage basin · Geomorphology · Hydrology

Introduction

Drainage or river basin, distinct with “divide” or “inter-fluves”, is the fundamental landscape unit in which collection and distribution of water and sediment occur (Ritter 1995). According to Waikar and Nilawar (2014), the hydrological phenomena occurring in a drainage basin can

be correlated with its physiographic characteristics such as size, shape, slope, drainage density and stream density. Water scarcity and droughts in a river basin are caused due to increase in demand for water over a period of time as a consequence of increase in population, increased food production and energy, variation in rainfall pattern, climate change, etc. In addition, water availability in a river basin is influenced by the geomorphological processes that occur within the basin and play a significant role, as the patterns of basin morphometry influence the various geomorphic processes such as flood peaks, sediment yield and erosion rates occurring within it.

The quantitative evaluation of the basin and its land surface analysis also known as “morphometry” (Guth 2011) offer new insight into the hydrological process occurring within the basin and therefore serves as a crucial lead into the assessment of water scarcity in a river basin. Further, the geomorphic processes occurring within basins and landforms are analysed with the hypsometric curve of the basin which is the non-dimensional measure of the proportions of surface area of a catchment or watershed above a given elevation (Willgoose and Hancock 1998). Hypsometric curves

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assist in investigation of erosional stage of the basins and the lithology controlling the erosion in basin; and provide valuable information about the basin slope and geomorphology of the basin, which finds applications in watershed treatment, basin planning and identification of rainwater harvesting structures (Sarp et al. 2011).

Arkavathy river basin, located in the north-eastern part of Cauvery river basin in south India, faces persistent water shortage. The average annual rainfall of the basin found based on analysis of rainfall data from 1987 to 2014 is 874.87 mm (Table 1). The study area is located in agro-climatic zone, namely “Eastern Dry Zone” with a rainfall range of 679.1 mm to 888.9 mm (Department of Agriculture 2018). Rise in population is observed in the Arkavathy river basin in the past three decades particularly in the metropolitan city of Bengaluru wherein one-third

of the city is located in Arkavathy river basin. Bengaluru city and other cities continue to witness growth in terms of expanse and population. Though population and rainfall continue to influence the water supply and demand, the impact of geomorphological processes on hydrology of the Arkavathy river basin is very important in investigation of the causes of water scarcity that afflicts the basin.

Therefore, the objective/focus of the present study is derivation of morphological parameters and hypsometric curve for the Arkavathy river basin and, with morphometry and hypsometric curve, investigation of the potential impact on the water availability and water scarcity afflicting the basin.

Study area

Arkavathy river sub-basin is located within Cauvery river basin, southern India, and constitutes 5% of the area of Cauvery river basin (Fig. 1). Arkavathy river is a tributary of river Cauvery along with other rivers such as Shimsha, Hemavathy, Kabini, Bhavani, Noyyal and Amaravathy (Fig. 1). River Arkavathy originates at Nandi Hills located partly in Bangalore Rural district and partly in Chikkaballapur District in the north-eastern corner of the sub-basin and joins river Cauvery at Mekedatu, Kanakapura taluk, Ramanagar District (Figs. 2, 3). The total length of Arkavathy river across the longest drainage path is 165 km, and the flow path is located entirely in the state of Karnataka. The total area of Cauvery river basin is 81,155 km², whereas the area of Arkavathy river sub-basin is 4146.39 km². Arkavathy river sub-basin within Cauvery river basin is located between co-ordinates 12° 15'00" N and 13° 25'00" N latitude and 77° 10'00" E and 77° 45'00" E longitude. About 97% of the sub-basin is located in the Karnataka State, whereas only 3% is located in Tamil Nadu State. It spans across 3 districts of Karnataka, namely Ramanagara, Bangalore Rural and Bangalore Urban besides Krishnagiri District of Tamil Nadu (Fig. 3).

Data products

1. Digital elevation model (DEM) of NASA's Shuttle Radar Topography Mission (SRTM) available with Consortium of Space Information (CSI) of CGIAR, i.e. CSI-CGIAR (2018). From this DEM, the portion of Arkavathy basin was extracted in ArcGIS 10.2.
2. Survey of India (SoI) toposheets of 1:50,000 scale.
3. Lithology in Arkavathy river basin derived from the data of Central Ground Water Board (CGWB 2012).

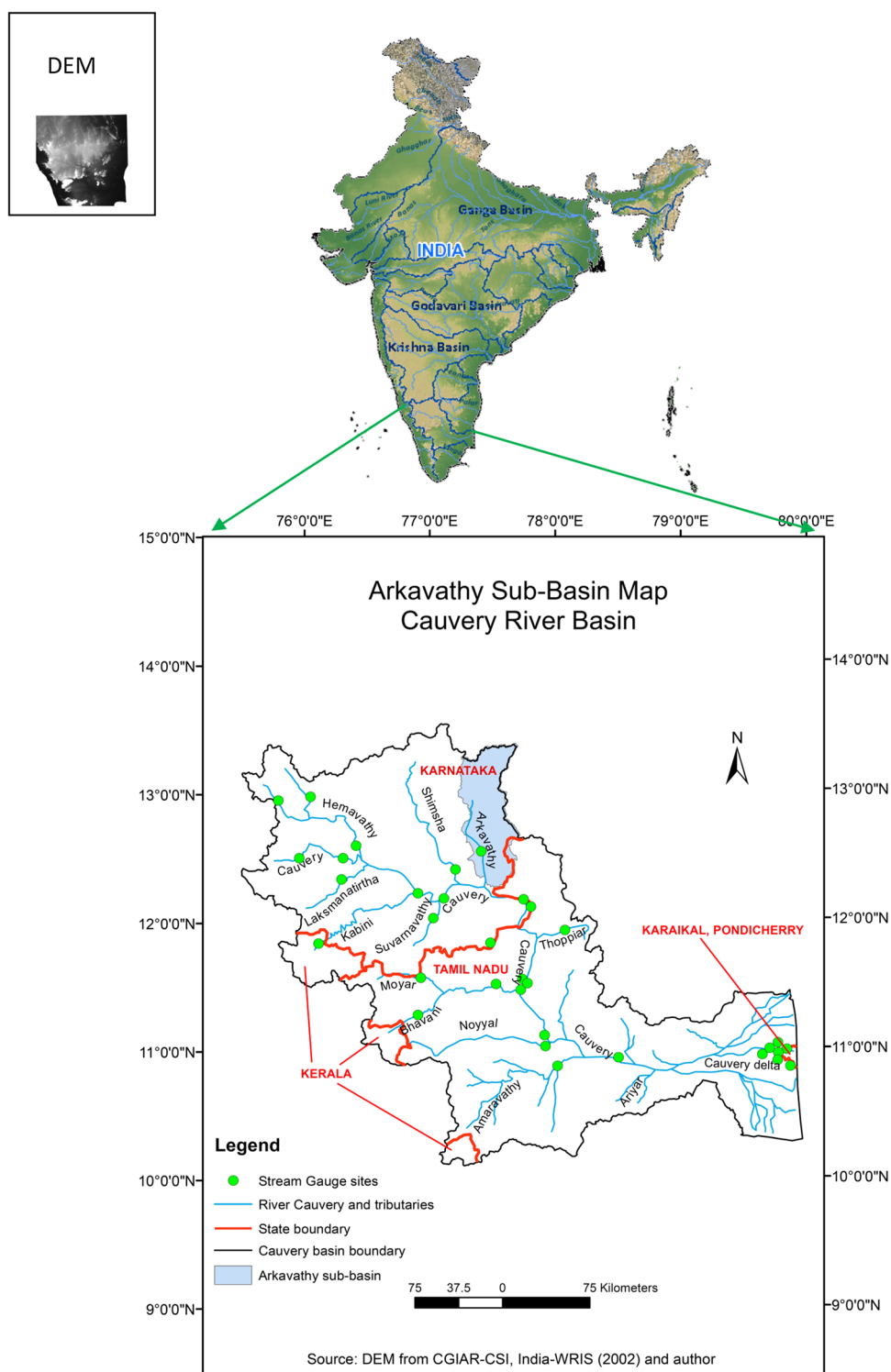
Table 1 Average annual rainfall (water year) in Arkavathy river basin

Year	Average rainfall in water year (mm)	Below or above average
1987–1988	1038.92	Above
1988–1989	786.04	Below
1989–1990	747.73	Below
1990–1991	531.18	Below
1991–1992	1057.78	Above
1992–1993	902.22	Above
1993–1994	1008.77	Above
1994–1995	653.59	Below
1995–1996	757.73	Below
1996–1997	1059.77	Above
1997–1998	922.12	Above
1998–1999	1195.30	Above
1999–2000	937.98	Above
2000–2001	1187.39	Above
2001–2002	747.95	Below
2002–2003	458.92	Below
2003–2004	806.08	Below
2004–2005	1003.11	Above
2005–2006	1206.59	Above
2006–2007	571.21	Below
2007–2008	968.80	Above
2008–2009	1078.21	Above
2009–2010	896.13	Above
2010–2011	1004.10	Above
2011–2012	641.45	Below
2012–2013	537.58	Below
2013–2014	914.86	Above

Average annual rainfall (water year) in Arkavathy river basin = 874.87 mm

Source: Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Government of Karnataka, Bengaluru, and author

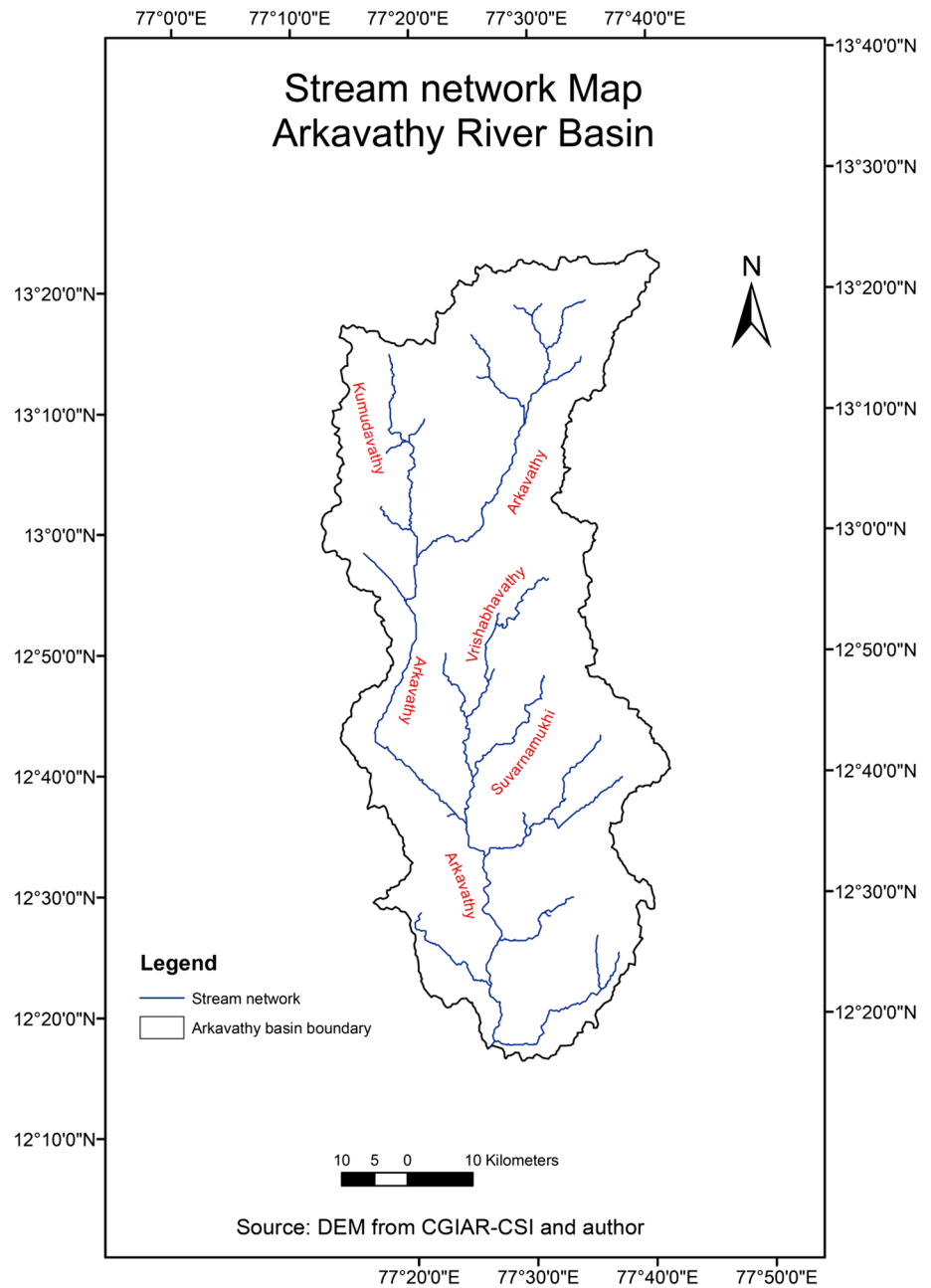
Fig. 1 Location map of Cauvery river basin and Arkavathy sub-basin along with DEM of South India (DEM resolution 90 m at equator)



Methodology

Integrated use of remote sensing (RS) and geographic information system (GIS) techniques/tools has been adopted in the present study to delineate Arkavathy river basin, derive the stream network, derive and analyse morphologic

parameters and hypsometric curve. NASA's Shuttle Radar Topography Mission (SRTM) mosaic digital elevation model (DEM) that covers 80% of globe at a resolution of 90 m at equator and $5^{\circ} \times 5^{\circ}$ tiles has been used to delineate the Arkavathy river basin (CSI-CGIAR 2018). The DEMs have been processed so that "no-data" voids are filled.

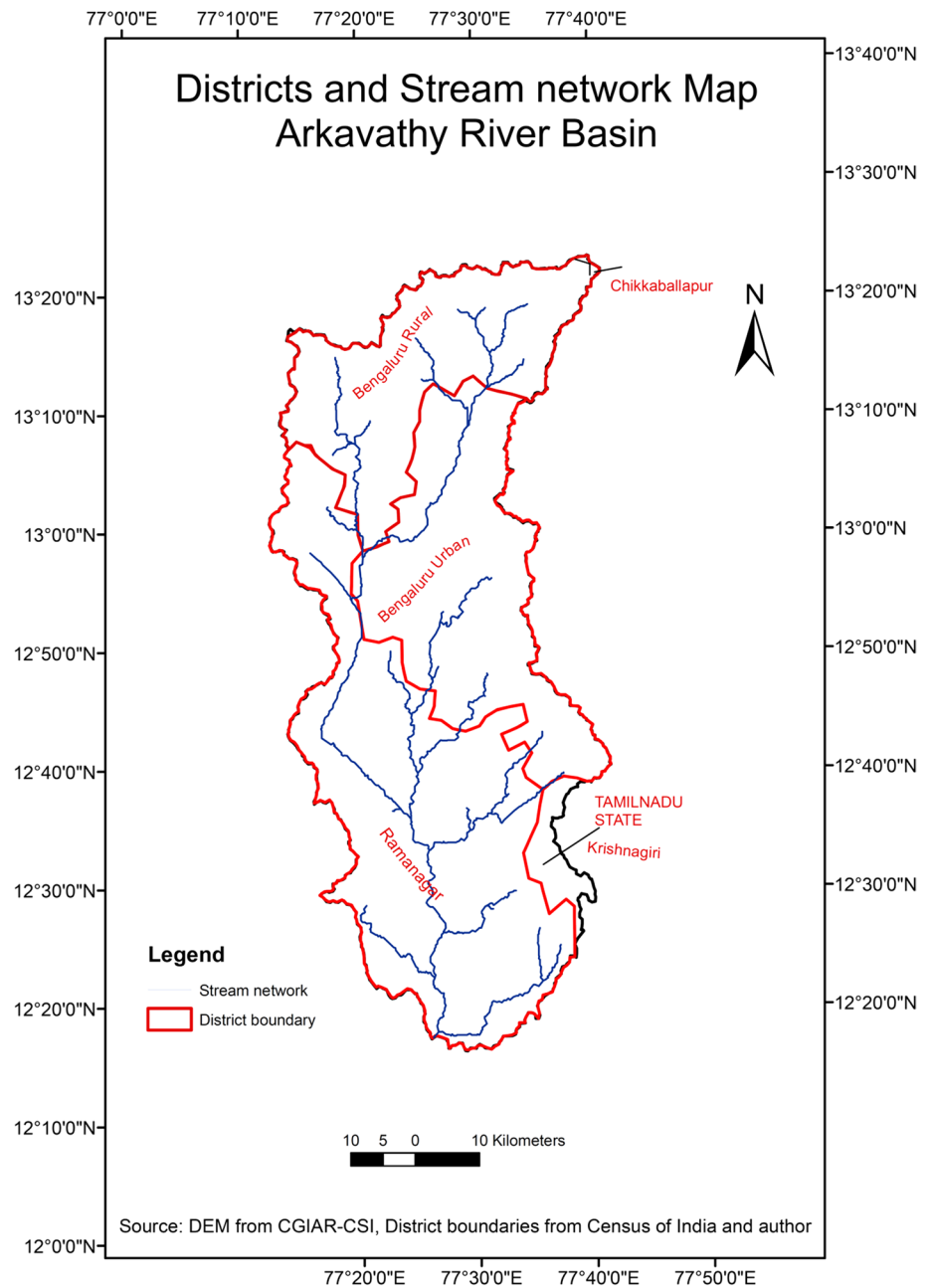
Fig. 2 Stream network in Arkavathy river basin

Survey of India (SoI) toposheets of 1:50,000 scale have also been used to verify the geo-referencing of the DEM. ArcHydro tools in ArcGIS 10.2 have been used to derive basin boundary, drainage pattern and watersheds within the basin to understand the morphological parameters. The steps followed are shown in Fig. 4. The longest drainage length was digitized and converted to vector data using ArcGIS 10.2. The derived basin boundary was then converted to vector data called “shapefile” from which the area and perimeter of Arkavathy river basin was calculated in attribute table of ArcGIS. Stream order in accordance with Strahler (1964) and stream length for each order in Arkavathy river basin

were determined using ArcGIS 10.2. The formulae used to estimate morphometric parameters are shown in Table 2. The results are shown in Tables 3 and 4. Tables 3 and 4 show the morphometric parameters and characteristics of Arkavathy basin, respectively.

Hypsometric curve for Arkavathy river basin is derived using SRTM mosaic DEM and ArcGIS 10.2. In accordance with Vivoni et al. (2008), contour line representations were created in the original DEM of 90 m resolution in ArcGIS 10.2 at vertical resolution of 100 m for the basin relief of 1064 m (1435–371 m). However, close to highlands and lowlands the interval is restricted to 29 m and 35 m, respectively. Using

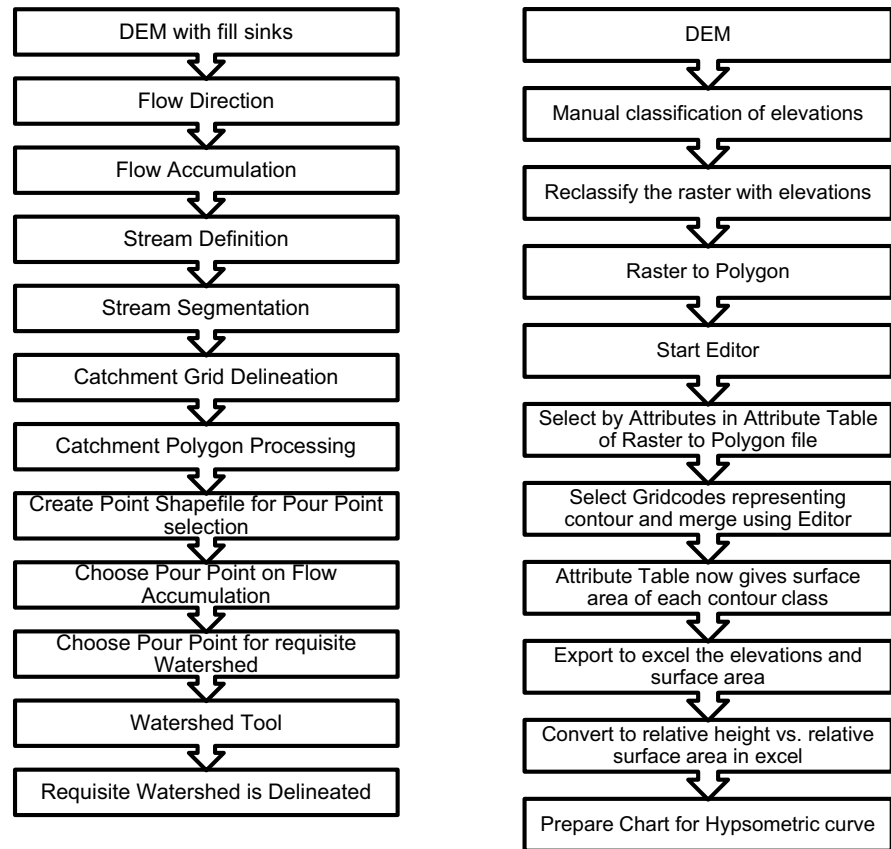
Fig. 3 Stream network across districts Ramanagar, Bengaluru Urban, Bengaluru Rural, Chikkaballapura in Karnataka and Krishnagiri District in Tamil Nadu



the DEM, the elevations between 1435 m (the highest elevation) and 371 m (the lowest elevation) in Arkavathy basin are classified into 12 classes considering the contour interval of 100 m as shown in Table 5. The contours are then derived in ArcGIS 10.2 (Fig. 5). The surface area between contours has been calculated in attribute table after conversion of reclassified raster showing contours to polygon feature in ArcGIS. The surface area within each contour class is merged using merge option in ArcGIS editor and raster calculator. The relative surface area above each contour (in accordance with Willgoose and Hancock 1998) is calculated by dividing the surface area between each contour class by the total area of the basin, i.e.

4146.39 km². The relative surface area is converted to percentage, and then, the cumulative relative surface area is derived in percentage. Similarly, the relative elevation or relative height (in percentage) of the basin is derived as $\frac{(e-371)}{E}$ where “e” is any contour height/elevation and “E” is the relief of the basin, i.e. 1471 m–371 m = 1064 m. The difference of the selected contour elevation of the basin corresponding to the lowest elevation (371 m) divided by basin relief, i.e. 1064 m, gives the relative height of the corresponding contour which is a dimensionless number. The relative surface area and relative height are expressed in percentage (0–100%) for the purpose of better interpretation of hypsometric curve. By plotting the

Fig. 4 Steps to delineate watershed, stream network and hypsometric curve in ArcGIS 10.2



Steps followed for delineation of Arkavathy basin (HEC-GEOHMS, 2013)

Steps followed for derivation of Hypsometric Curve

percentage relative surface area against corresponding relative height of the basin, the hypsometric curve has been derived. The steps to derive the hypsometric curve are shown in Fig. 4. The values of relative surface area and relative height are shown in Table 5.

Results and discussion

The Arkavathy river basin morphological parameters such as linear, relief and areas aspects calculated are shown in Table 3, and the characteristics such as bifurcation ratio, stream length ratio and numbers of segments are shown in Table 4. The hypsometric curve for Arkavathy river basin is shown in Fig. 6a.

Morphometric evaluation of Arkavathy river basin

The morphometric evaluation of Arkavathy drainage basin provides quantitative description of the basin geometry that helps in understanding the geomorphological characteristics, diastrophism, and geology and basin response to various

hydrological processes occurring within the basin (Chatterjee 2006). The evaluation and discussions are made classifying the morphometry of Arkavathy river basin into linear aspects, relief aspects and areal aspects.

Linear aspects

The drainage pattern in Arkavathy river basin is dendritic to sub-dendritic (Fig. 7). The dendritic pattern indicates the presence of uniform resistance of rock to the drainage in the basin. According to Petersen et al. (2017), dendritic patterns tend to develop in areas where the rocks have a roughly equal resistance to weathering and erosion and are not intensely jointed. Data from CGWB (2012) confirm that Arkavathy river basin is underlain with intrusive acidic rock and banded gneissic rock complex that is more or less uniform throughout the basin (Fig. 8). The change in mean stream length values from 1.92 to 44.5 indicates the change in elevation across the topography and the change in slope of the basin. That the basin is also undergoing erosion, despite the uniform resistance of rocks, is confirmed by the hypsometric curve which shows no sign of concavity in the surface area between uplands and lowlands (Fig. 6a). The morphometric

Table 2 Formulae for estimation of morphometric parameters of Arkavathy basin

Morphometric parameters	Formulae	References
Linear aspects		
Stream order (U)	Hierarchical order	Strahler (1964)
Stream length (L_u)	Length of the stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ where L_u = stream length of order “U” and N_u = total number of stream segments of order “U”	Horton (1945)
Stream length ratio (R_L)	$R_L = L_u/L_{u-1}$ where L_u = total stream length of order “U” and L_{u-1} = stream length of next lower order	Horton (1945)
Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$ where N_u = total number of stream segment of order “u” and N_{u+1} = number of segment of next higher order	Schumn (1956)
Areal aspects		
Drainage density (D_d)	$D_d = L/A$ where L = total length of streams and A = area of watershed	Horton (1945)
Stream frequency (S_f)	$S_f = N_s/A$ where N_s = total number of streams and A = area of watershed (km^2)	Horton (1945)
Texture ratio (T)	$T = N_1/P$ where N_1 = total number of first-order streams and P = perimeter of watershed (km)	Horton (1945)
Form factor (R_f)	$R_f = A/(L_b)^2$ where A = area of watershed (km^2) and L_b = basin length (km)	Horton (1932)
Circulatory ratio (R_c)	$R_c = 4\pi A/P_2$ where A = area of watershed (km^2), $\pi = 3.14$, and P = perimeter of watershed (km)	Miller (1953)
Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)/L_b}$ where A = area of watershed (km^2), $\pi = 3.14$, and L_b = basin length (km)	Schumn (1956)
Length of overland flow (L_{of})	$L_{of} = 1/(2D_d)$ where D_d is drainage density	Horton (1945)
Constant of channel maintenance (C)	$C = 1/D_d$ where D_d = drainage density	Horton (1945)
Relief aspects		
Basin relief (B_h)	Vertical distance between the lowest and highest points of watershed	Schumn (1956)
Relief ratio (R_h)	$R_h = B_h/L_b$ where B_h = basin relief (km) and L_b = basin length (km)	Schumn (1956)
Ruggedness number (R_n)	$R_n = B_h \times D_d$ where B_h = basin relief and D_d = drainage density (km/km^2)	Schumn (1956)

study and hypsometric curve reveals that due to progressive erosion, the existing water bodies in the basin are at risk of sedimentation with consequent loss of live storage leading to increased water stress in the basin. This explains partly the fact reported by Srinivasan et al. (2015), Arpita (2018) and Suresh (2001) that the water bodies and major reservoirs of the basin such as Thippagondanahalli and Hesaraghatta, that once supplied water and were lifeline to Bengaluru city, have been silted up.

The stream order in accordance with Strahler (1964) obtained for Arkavathy river basin is six, and therefore, the basin is designated as sixth-order basin. The stream order is derived from DEM and ArcGIS 10.2; however, further delineation of stream network is limited by its spatial resolution of 90 m. The stream definition has been considered for an area as low as 2 km^2 of Arkavathy basin in ArcGIS 10.2 that comprises 239 cells/pixels in ArcGIS for the derivation of sixth-order basin. For the current study, a stream order of six has been considered to minimize errors due to limitation in the resolution of DEM. Table 4 shows number of stream segments of all six-order stream segments in Arkavathy river basin. The geomorphic characteristics of Arkavathy river basin confirm to Horton (1932) that the number of stream segments of different orders decreases with increase in stream order. From the different-order stream segments

in Arkavathy river basin, it is observed that the number of stream segments in stream orders 1 and 2 possesses large number of stream segments. Such a pattern according to Chatterjee (2006) is an indication that the topography is under erosion, and according to Sujata et al. (2013), the pattern is attributed to anomalous basin development, local variation in topography and effect of localized geological disturbance.

Bifurcation ratio is the foremost parameter linking the hydrological regime in a basin (Raj et al. 1999). It is an important indicator of relief and dissection of the basin. In Arkavathy basin, bifurcation ratio shows variation from 2 to 5.50 (with a mean of 3.78) across different stream orders (Table 4). According to Yangchan (2015), any basin with bifurcation ratio within range of 3.0 to 5.0 indicates that the geologic structures do not distort the drainage pattern within that basin, whereas Rao (2016) states that any bifurcation ratio less than 3.0 indicates lack of structural control and that more than 5.0 shows structural control over formation of drainage pattern. In Arkavathy river basin, as the bifurcation ratio for stream order 3 and stream order 5 is less than 3.0 (2.75 and 2, respectively), it can be inferred that there is less structural control for streams of orders 3 and 5. This indicates flat terrain specifically across regions where streams of orders 3 and 5 are located, whereas an increase in bifurcation

Table 3 Morphometric parameters of Arkavathy river basin

Sl. no.	Morphometric parameters	Values for Arkavathy river basin	Unit	Morphometric evaluation
1	Basin area (A)	4146.39	km ²	—
2	Basin perimeter (P)	425.11	km	—
3	Basin length (L)	165.87	km	—
4	Basin width (W)	25	km	—
5	Highest stream order (U)	6	No	—
6	No. of stream segments	716	No	—
7	Stream length (L)	2160.7	km	—
8	Mean stream length	360.11	km	—
9	Mean stream length ratio (R_L)	2.01	No	—
10	Bifurcation ratio (R_b)	Mean 3.78	No	—
11	Length of overland flow (L_{of})	0.96	km	High
12	Form factor (R_f)	0.15	No	Low
13	Texture ratio (T)	1.32	km ⁻¹	Low
14	Circulatory ratio (R_c)	0.288	No	Low
15	Elongation ratio (R_e)	0.25	No	Low
16	Compaction coefficient	1.863	No	High
17	Drainage density (D_d)	0.52	km/km ²	Low
18	Constant of channel maintenance (C)	1.92	km	—
19	Stream frequency (F_s)	0.172	per sq km	Low
20	Basin relief (B_h)	1064	m	High
21	Relief ratio (R_h)	0.007	No	High
22	Ruggedness number (R_n)	546	No	High

Table 4 Morphometric characteristics of Arkavathy river basin

Stream order	No of segments (N_u)	Stream length (L) (km)	Bifurcation ratio (R_b), $N_u/(N_{u+1})$	Mean stream length, (km), $L_u = L/N_u$	Cumulative length, (km)	Cumulative number of segments	Stream length ratio, L_u/L_{u-1}
1	562	1081.4	4.64	1.92	1081.4	562	
2	121	584.8	5.50	4.83	1666.2	683	2.51
3	22	215	2.75	9.77	1881.2	705	2.02
4	8	137	4	17.13	2018.2	713	1.75
5	2	98	2	49	2116.2	715	2.86
6	1	44.5		44.50	2160.7	716	0.91
Total	716	2160.7	Mean 3.78	Mean 21.19			Mean 2.01

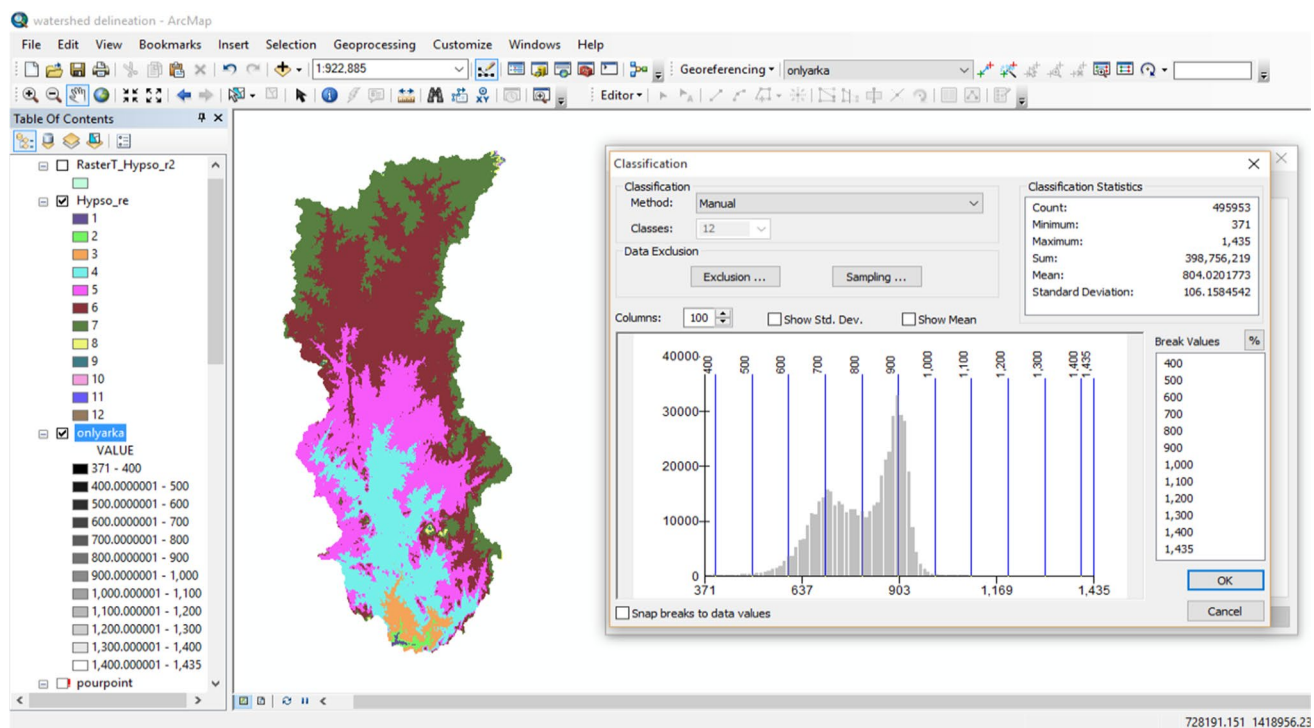
ratio above 3.0 for stream orders 1 and 4 indicates local rugged topography at uplands and lowlands, but specifically at locations where streams of orders 1 and 4 are prevalent. The bifurcation ratio for stream order 2 is 5.5, which is above 5.0, indicating the presence of structural control and geological disturbances in streams of order 2 (Sujata et al. 2013).

The consequence of low bifurcation ratio according to Kulkarni (2015) is that there will be higher possibilities of flooding. Therefore, it can be deduced that, for stream orders 3 and 5 having low bifurcation ratios of 2.75 and 2.0, respectively, water tends to accumulate rather than spreading out. In contrast, possibility of flooding is low for

the stream orders 1, 2, and 4 which have higher bifurcation ratios of 4.64, 5.5 and 4, respectively, because the energy of flow is low, thereby increasing the scope for infiltration in these stream orders (Al Saud 2009). Therefore, coupled with human interventions observed extensively across the basin there is increased flood risk in Arkavathy river basin for streams of orders 3 and 5 that also depends on combination of factors such as the intensity of precipitation, vegetation cover and nature of such human intervention. However, according to Paul and Bayode (2012), the time of peak, time of concentration and the peak discharge are dependent on the shape of the basin. Another important

Table 5 Derivation of hypsometric curve

Sl. no.	Elevation reclassified in ArcGIS (contour interval 100 m b/n SL No.2 to No.11)	Surface area between contours, a (km ²)	Surface area, $\frac{a}{A}$ (%)	Accumulated relative surface area above contour elevation $\frac{a}{A}$ (%)	Contour elevation/ height, e (m)	Relative height/ elevation $\frac{(e-371)}{E}$ (%)
				0	1435	100.00
1	1400–1435	4.50	0.11	0.11	1400	96.71
2	1300–1400	19.36	0.47	0.58	1300	87.31
3	1200–1300	100.31	2.42	2.99	1200	77.91
4	1100–1200	696.24	16.79	19.78	1100	68.52
5	1000–1100	1015.68	24.49	44.28	1000	59.12
6	900–1000	1429.37	34.47	78.74	900	49.72
7	800–900	865.29	20.87	99.61	800	40.32
8	700–800	10.84	0.26	99.87	700	30.92
9	600–700	3.72	0.09	99.96	600	21.52
10	500–600	1.01	0.02	99.99	500	12.12
11	400–500	0.53	0.01	100	400	2.73
12	371–400	0.06	0.00	100	371	0
	Total area (A)	4146.39			$E = 1064$ (1435–371)	

**Fig. 5** Comparison of hypsometric curve of Arkavathy river basin

observation from the results in Table 4 is that the stream lengths of orders 1, 2 and 4 constitute 83.5% of the total length of the stream network that indicate higher scope for infiltration, which can be utilized through construction of ground water recharge structures across these stream orders.

Relief aspects

The relief measure of a basin indicates the potential energy of a drainage basin because a region having a high relief can transfer high energy into the drainage system (Yangchan et al. 2015). The relief in Arkavathy river basin is found to

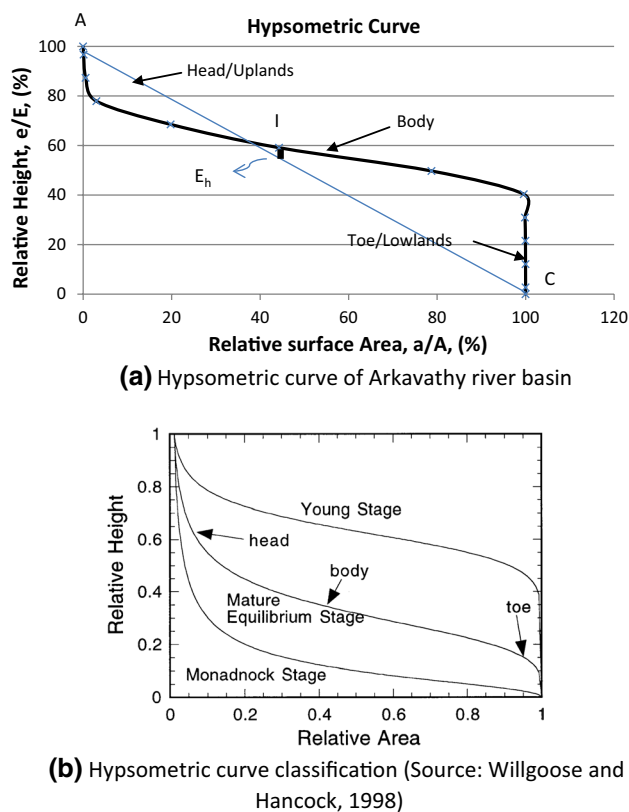


Fig. 6 Classification of Arkavathy river basin as contour line classes at 100-m interval in ArcGIS 10.2 for derivation of hypsometric curve in Arkavathy river basin

be high at 1064 m with the highest elevation 1435 m above the mean sea level found in the north-eastern tip of the basin located in Chikkaballapur District and the lowest elevation of 371 m above mean sea level in the southern tip at the confluence of Arkavathy river with Cauvery river at Mekedatu, Kanakapura taluk, Ramanagara District.

The higher relief found in Arkavathy river basin indicates greater energy available in the drainage system of the basin. Despite higher relief, the infiltration characteristics in the basin depend on numerous variables such as slope of the terrain (such as steep slope of uplands and lowlands in the basin and flat terrain in between), rainfall, vegetation, sub-surface material and the nature of human interference in the basin across various stream orders which is also reflected by the drainage density (Oyatayo et al. 2017; Sukristiyanti et al. 2018). So, the infiltration characteristics vary within the basin. The greater energy at steep uplands and lowlands causes quicker drainage with less scope for infiltration into the ground at these locations, whereas the flat terrain shown by hypsometric curve in between showing moderate to less slope possesses different infiltration characteristics in accordance with (Oyatayo et al. 2017). Another consequence of the higher energy is the scope for erosion in the basin,

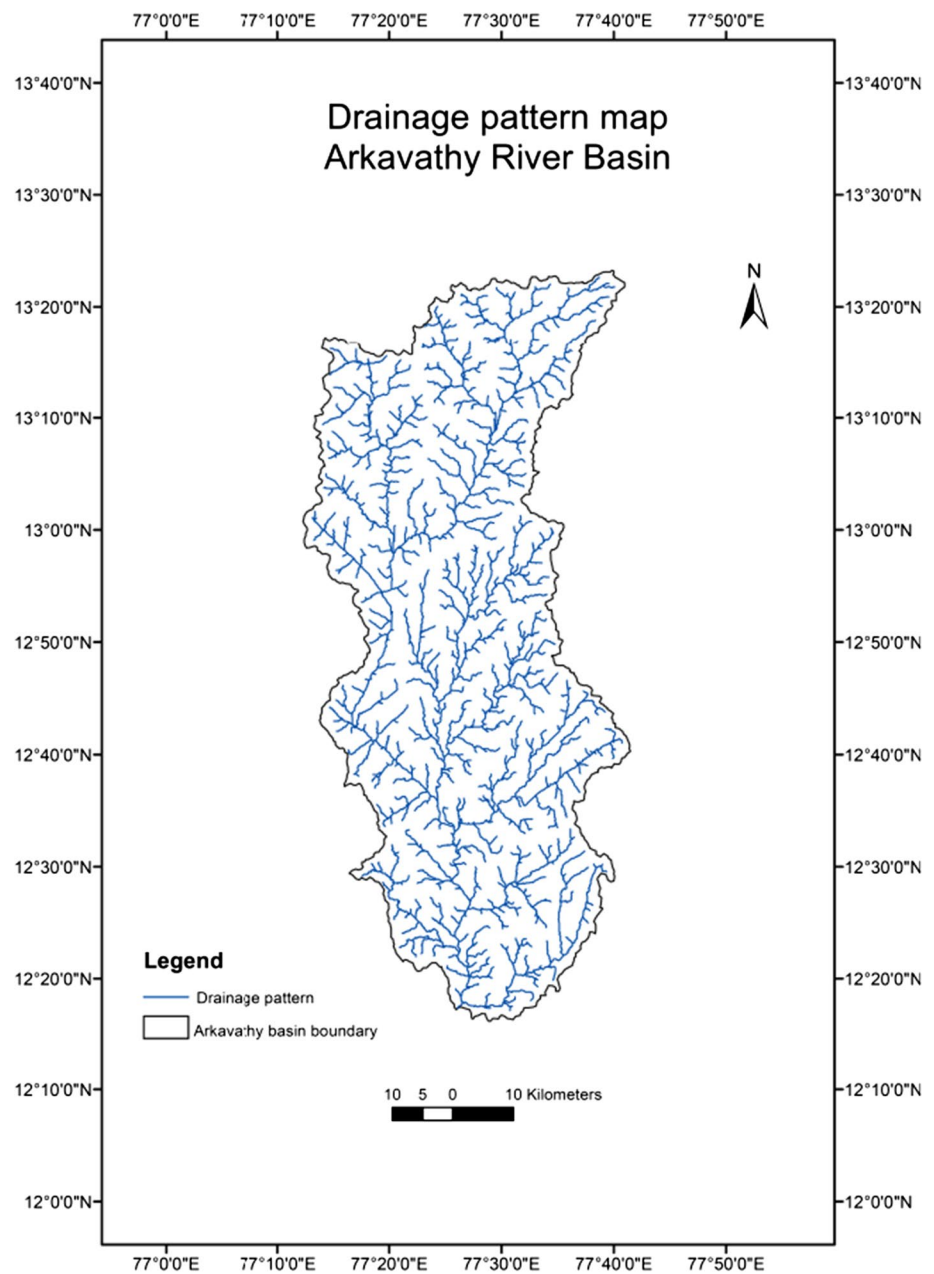
particularly at locations closer to steeper relief. Referring to the hypsometric curve of the basin (Fig. 6a), it is clear that the elevation at lowlands (toe region) is steep, as less surface area (<5%) is covered in the lowlands for elevations of up to 40%, and similarly, about 20% (80 to 100%) elevation at uplands (head region) is covered by the surface area of about 0–5%. The hypsometric curve shows the steepness of topography within 5% of the surface area in both the uplands and lowlands, whereas there is relatively flat surface area in between. So, any runoff generated at uplands and lowlands possesses the tendency to drain out quickly due to the steepness of topography. Due to its steepness, the dissected uplands and lowlands are conducive for construction of surface storage structures, whereas ground water recharge structures and smaller water harvesting structures can be built in the flatter terrain also classified in geomorphological term as pediment-piedmont region.

Areal aspects

Areal aspects of morphometry are crucial in assessment of runoff particularly the contribution of overland flow to the stream network that depends on the shape and slope of the terrain besides relief and linear aspects. Some of the indices that have quantitatively assessed in areal aspects are form factor, elongation ratio, circulatory ratio, compaction coefficient, drainage density, stream frequency and length of overland flow.

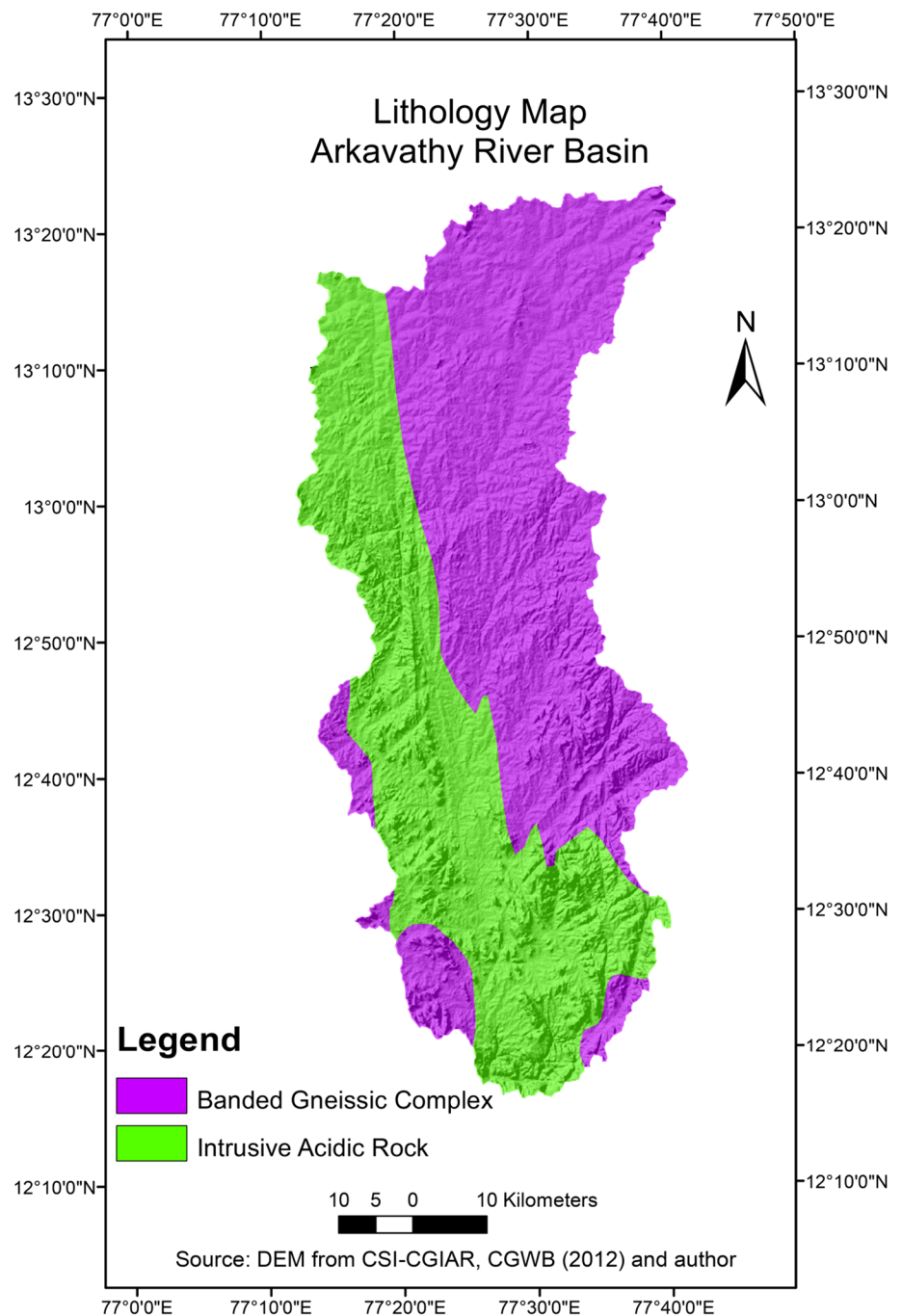
The visual examination of shape of the Arkavathy river basin in (Fig. 2) shows that it is an elongated. But, the areal indices estimated for the basin confirm this assessment. On examination of the indices/parameters shown in Table 3, it is observed that the form factor for Arkavathy river basin is 0.15 which is low. According to Rai et al. (2014), form factor would always be greater than 0.78 for perfectly circular basin and the smaller the value of form factor, the more elongated will be the basin. The circularity ratio and elongation ratio of Arkavathy river basin are 0.288 and 0.25, respectively, which are low. The compaction coefficient of the basin is 1.823 which is high in comparison with the value stated by Paul and Bayode (2012). According to Waikar and Nilawar (2014), basins with elongation ratio higher than 0.9 are circular in shape, and basins with elongation ratio less than 0.7 are elongated. The value of 0.288 circularity ratio and elongation ratio of 0.25 for Arkavathy river basin shows that the basin is highly elongated and possesses steep slope at uplands and lowlands, which is also confirmed by the relief and hypsometric curve of the basin. The consequence of the confirmation of elongated nature of Arkavathy river basin is the reduced peak discharge of runoff in the basin.

Drainage density of a basin evaluates the erosion status of a basin (Bates 1981). Regions with high drainage

Fig. 7 Drainage pattern of Arkavathy river basin

densities possess less infiltration, increase runoff and possess at least moderately erodible surface materials (Petersen et al. 2017). Higher the drainage density, the greater the amount of runoff and the significant the degree of channel abrasion for a given rainfall (Eze and Efiog 2010). From the results for Arkavathy river basin, it is observed that the drainage density for the basin is low, i.e. 0.52. Similarly, the stream frequency is 0.172 which is also low. According to Pallard et al. (2009), one direct effect of decrease in drainage density is decreasing flood volumes that is attributed to long concentration times implying more opportunities for water to infiltrate. The length of overland flow for Arkavathy basin is 0.96 that

confirms longer concentration time and non-existence of young topography Nongkynrih and Husain (2011). However, the drainage density of the basin and the long concentration time are dependent not only on the relief but also dependent on the resistance of rocks across different stream orders, vegetation, rainfall and sub-surface material. The large portion of the basin (80% of the basin) is flatter terrain as depicted by hypsometric curve of the basin. And the average annual rainfall in the basin is lowly 874.87 mm. And the drainage density of the basin shows a low value of 0.52 and long overland flow value of 0.96. Therefore, there is scope for higher infiltration reflected by low drainage density in regions of the flatter terrain.

Fig. 8 Lithology in Arkavathy river basin

Description of head and toe of hypsometric curve

Figure 6a shows the hypsometric curve derived for Arkavathy river basin. Referring to the curve, the downward vertical part is termed as “toe” of the hypsometric curve and the concave upward part at the left hand side of the curve is termed “head” and the part of the curve in between “head” and “toe” is called “body” of the hypsometric curve. The region showing concavity, i.e. “head” and close to “head”, is an indication that the

region is predominated by erosion and the eroded materials are accumulating in the downstream (Chattopadhyay et al. 1996).

Relation between morphological parameters and hypsometric curve

Hypsometry is strongly dependent on drainage network and basin geometry. For example, the width-to-length ratio of the basin also known as “aspect ratio” influences the shape of

the hypsometric curve significantly (Willgoose and Hancock 1998). According to Keller and Pinter (1996), hypsometric curves show the stage of development of drainage network. These curves provide information not only on the erosion status of the basin but also the tectonic, climate and lithological factors controlling it (Sarp et al. 2011). The relief ratio and catchment volume captured through hypsometric curve are useful in determining runoff and other hydrological processes (Vivoni et al. 2008). According to Sinha Roy (2002), as the aspect ratio declines, the drainage network becomes highly branched leading to higher bifurcation ratio. Then, for low aspect ratio, the toe height will be of increasing elevation at the downstream part of the basin.

For Arkavathy river basin, the morphological parameters such as form factor, circularity ratio and elongation ratio show that the basin is elongated. In other words, the basin exhibits low aspect ratio. Therefore, in accordance with Sinha Roy (2002), amongst different stream orders of Arkavathy river basin, it is observed that streams of order no 1, 2 and 4 are in possession of higher bifurcation ratio of more than 3.0. Analysing the number of stream segments (N_u) shown in Table 4, out of the total number of stream segments of 716 identified in the basin, the sum of the number of stream segments for stream order no. 1, 2 and 4 is 691 ($= 561 + 121 + 8$) or about 96.50% of stream segments in Arkavathy river basin possess higher bifurcation ratio. The outcome of the impact of morphological parameters on hypsometric curve can be observed in Fig. 6a that clearly depicts toe in the downstream part of the curve with increased elevation followed by slight concavity.

Comparison of hypsometric curve of Arkavathy river basin

Figure 6a shows the hypsometric curve of Arkavathy river basin, and Fig. 6b shows three different types of hypsometric curve classified as (1) young stage, (2) mature equilibrium stage and (3) monadnock stage (Monadnock stage means subdued terrain with isolated elevated regions of resistant rock as per Willgoose and Hancock 1998). According to Sarp et al. (2011), convex hypsometric curves depict young and slightly eroded regions (the top most hypsometric curve in Fig. 6b), S-shaped curves (like the middle or second curve in Fig. 6b depict moderately eroded regions, and then the concave curves, i.e. the bottom most curve in Fig. 6b, point to old and highly eroded regions.

From the comparison of the hypsometric curve derived for Arkavathy river basin with the classification shown in Fig. 6b, it is clear that the hypsometric curve derived for Arkavathy river basin resembles closer to the convex hypsometric curve shown as top most curve in Fig. 6b with less head in upstream and greater toe height in downstream than

the S-shaped curve in the middle or concave curve in the bottom of Fig. 6b. Therefore, from the comparison it can be inferred that the basin under study certainly has not attained mature equilibrium stage. Rather, the erosion status in the basin has moved beyond young stage but possesses considerable scope for erosion in the future before it attains mature equilibrium stage.

Further, a line A–C has been drawn for the hypsometric curve derived for Arkavathy river basin to verify the departure of the actual landform surface from the line A–C. If “I” is the inflection point of the curve, i.e. the point changing from concave downwards to concave upwards (or convex), and the E_h is the vertical height between “I” and the hypsometric curve, it is clear that E_h is minimal but above the line A–C which is considered as negative by Sinha Roy (2002). According to Sinha Roy (2002), E_h is negative in immature and young landforms when the hypsometric curve lies above A–C, whereas in mature and old landforms, E_h is positive. Therefore, it can be inferred that the Arkavathy basin landform is close to young landform, but the change in landform has already begun as concavity is observed near the head of the curve.

Conclusions

The study of hypsometric curve reveals that Arkavathy river basin is close to young but not old type of basin. Hence, the basin possesses considerable scope for erosion in future. The presence of flatter terrain in midlands in between uplands and lowlands is confirmed by hypsometric curve. And that puts existing reservoirs and water bodies across midlands at risk of sedimentation and loss of crucial live storage which will lead to accentuation of water stress in the basin.

Morphological characteristics of the basin indicate variation in different stream orders that confirms the anomalous basin development and local variation in topography in the basin. The dendritic to sub-dendritic pattern indicates uniform resistance to drainage pattern by major rock types in the basin such as intrusive acidic rock and banded gneissic rock. Along with the combination of factors such as human intervention and intensity of precipitation, flooding is expected across stream orders 3 and 5 due to lower bifurcation ratios, whereas stream orders 1, 2, and 4 possess increased scope for infiltration that facilitate building water harvesting and recharge structures. The steeper slopes at highlands and lowlands depicted by hypsometric curve, particularly at the regions across stream orders 3 and 5, have the potential to conserve water through large surface water harvesting structures.

The areal aspects of the Arkavathy river basin confirm that the basin is elongated and as a consequence Arkavathy river basin experiences low peak flows of runoff for longer

duration despite flood risk. Lower drainage density and length of overland flow in the basin confirm longer concentration times for runoff particularly in the regions of lower relief. Therefore, the runoff in Arkavathy river basin has large scope for infiltration into the ground water particularly at flatter regions depicted by hypsometric curve. However, as Arkavathy river basin possesses moderate- to low-water-bearing aquifer systems such as granite and gneiss rock types, the water infiltrated can only be stored across fluvial deposits across the valley floors and stream channels of the drainage network or in rock fractures. As the aquifer systems in Arkavathy basin are not high-water-bearing systems, considering the water budget of the basin, the cause of loss of water in a basin can be deduced as evapotranspiration. It can be concluded that due to high time of concentration of runoff in the basin, as a consequence of its morphometry, the loss of water due to evapotranspiration rates leads to the persistent water scarcity in the basin.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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References

- Al Saud M (2009) Morphometric analysis of Wadi Aurnah drainage system, Western Arabian Peninsula. *Open Hydrol J* 3:1–10
- Arpita P (2018) 16,000 truckloads of silt to be removed from Hesaraghatta dam. *The Times of India*. 19th June 2018
- Bates N (1981) Valley shapes. In: Knap B (ed) *Practical foundations of physical geography*. George Allen & Unwin, London, pp 25–29
- CGWB (2012) *Aquifer systems of Karnataka*. Ministry of Water Resources. Government of India: Bangalore.
- CSI-CGIAR (2018) Retrieved at <https://cgiarcsi.community/data/srtm-90m-digital-elevation-database-v4-1/>
- Chatterjee A, Tantuley A (2006) Morphometric analysis for evaluating groundwater potential zones. In *Kusangai Jor Watershed Area, Dist. Bolangir, Orissa*. ISPRS. Conference proceedings, XXXVI (4). Retrieved at <https://www.isprs.org/proceedings/XXXVI/part4/>
- Chattopadhyay S, Sajikumar S, Saritha D (1996) Integrated resource evaluation of the Vamanapuram river basin, South Kerala, Centre for Earth Science Studies, Technical Report, 65
- Department of Agriculture (2018) Government of Karnataka, India. Bengaluru. Retrieved at <https://raitamitra.kar.nic.in/stat/kacz.htm>
- Eze BE, Efiog J (2010) Morphometric parameters of the Calabar River Basin: implication for hydrologic processes. *J Geogr Geol* 2(1):18–26
- Guth PL (2011) *Drainage basin morphometry: a global snapshot from the shuttle radar topography mission*. Hydrology and Earth System Sciences. Copernicus Publications. European Geosciences Union. <https://doi.org/10.5194/hess-15-2091-2011>
- HEC-GEOHMS (2013) *Geospatial hydrological modelling extension. User's manual*. Version 10.1. CPD-77. US Army Corps of Engineers, Davis
- Horton RE (1932) Drainage basin characteristic. *Trans Am Geophys Union* 14:350–361
- Horton RE (1945) Erosional development of stream and their drainage basin: hydrological approach to quantitative morphology. *Bull Geol Soc Am* 56:275–370
- Keller EA, Pinter N (1996) *Active tectonics: earthquakes, uplift and landscape*. Prentice Hall, New Jersey
- Kulkarni MD (2015) The basic concept to study morphometric analysis of river drainage basin: a review. *Int J Sci Res* 4(7):2277–2280
- Miller VC (1953) A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee, Proj. NR 389-402. Technical report 3. Columbia University. Department of Geology. ONR, New York
- Nongkynrih JM, Husain Z (2011) Morphometric analysis of the Manas river basin using earth observation data and Geographical Information System. *Int J Geomat Geosci* 2:2
- Oyatayo KT, Bello I, Ndabula C, Godwill GJ, Ademola SJ (2017) A Comparative analysis of drainage morphometry on hydrologic characteristics of Kereke and Ukoghgor Basins on flood vulnerability in Makurdi Town, Nigeria. *Hydrology* 5(3):32–40. <https://doi.org/10.11648/j.hyd.20170503.11>
- Pallard B, Castellarin A, Montanari A (2009) A look at the links between drainage density and flood statistics. *Hydrol Earth Syst Sci* 13:1019–1029
- Paul II, Bayode EN (2012) Watershed characteristics and their implication for hydrologic response in the Upper Sokoto Basin Nigeria. *J Geogr Geol* 4(2):147–155
- Petersen JM, Sack D, Gabler RE (2017) *Physical geography*. CENGAGE Learning, Boston
- Rai PK, Mohan K, Mishra S, Ahmad A, Mishra VN (2014) A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. *Appl Water Sci* 7:217–232. <https://doi.org/10.1007/s13201-014-0238-y>
- Raj R, Maurya DM, Chamyal LS (1999) Evolution of Mahi drainage basin during quaternary: a morphometric approach, Gondwana. *Geol Mag Spl* 4:131–139
- Rao NS (2016) *Hydrogeology: problems with solutions*. PHI Private Limited, New Delhi
- Ritter DF, Kochel RC, Miller JR (1995) *Process geomorphology*. WCB/McGraw-Hill, New York. Retrieved at <https://www.wou.edu/las/physci/taylor/geog522/rittrchp5.pdf>
- Sarp G, Toprak V, Duzgun S (2011) Hypsometric properties of the hydraulic basins located on Western part of Nafz. In: 34th International symposium on remote sensing of environment theme: water a limited and degraded resource, Sydney, Australia
- Schumm SA (1956) *Evolution of drainage systems and slopes in badlands at Perth Amboy*. New Jersey. *Geol Soc Am Bull* 67:597–646

- Sinha Roy S (2002) Hypsometry and landform evolution: a case study in the Banas drainage basin, Rajasthan, with implications for Aravalli uplift. *J Geol Soc India* 60:7–26
- Srinivasan V, Thompson S, Madhyastha K, Penny G, Jeremiah K, Lele S (2015) Why is the Arkavathy river drying? A multiple-hypothesis approach in a data-scarce region. *Hydrol Earth Syst Sci* 19:1905–1917
- Strahler AN (1964) Quantitative geomorphology of drainage basins and channel networks. In: *Handbook of applied hydrology*. McGraw-Hill, New York, pp 439–476
- Sujatha ER, Selvakumar R, Rakasimman UAB, Victor RG (2013) Morphometric analysis of sub-watershed in parts of Western Ghats, South India using ASTER DEM. *J Geomat Nat Hazards Risk* 6:4. <https://doi.org/10.1080/19475705.2013.845114>
- Sukristiyanti S, Maria R, Lestiana H (2018) Watershed-based morphometric analysis: a review. *IOP Conf Ser Earth Environ Sci* 118:012028. <https://doi.org/10.1088/1755-1315/118/1/012028>
- Suresh TS (2001) An urban water scenario: a case study of the Bangalore metropolis, Karnataka, India. In: *Proceedings of symposium. Sixth IAHS Scientific Assembly*. Maastricht, The Netherlands.
- Vivoni ER, Benedetto FD, Grimaldi S, Eltahir EAB (2008) Hypsometric control on surface and subsurface run-off. *Water Resour Res* 44:W12502. <https://doi.org/10.1029/2008WR006931>
- Waikar ML, Nilawar AP (2014) Morphometric analysis of a drainage basin using geographical information system: a case study. *Int J Multidiscip Curr Res* 2:179–184
- Willgoose G, Hancock G (1998) Revisiting the hypsometric curve as an indicator of form and process in transport-limited catchments. *Earth Surf Process Landf* 23:611–623
- Yangchan J, Tiwari AK, Sood A (2015) Morphometric analysis of drainage basin through gis: a case study of sukhna lake watershed in lower Shiwalik, India. *Int J Sci Eng Res* 6(2):1015–1023