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ORIGINAL ARTICLE

Evaluation of morphometric parameters derived from Cartosat-1 DEM using remote sensing and GIS techniques for Budigere Amanikere watershed, Dakshina Pinakini Basin, Karnataka, India

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Abstract The quantitative analysis of drainage system is an important aspect of characterization of watersheds. Using watershed as a basin unit in morphometric analysis is the most logical choice because all hydrological and geomorphic processes occur within the watershed. The Budigere Amanikere watershed a tributary of Dakshina Pinakini River has been selected for case illustration. Geoinformatics module consisting of ArcGIS 10.3v and Cartosat-1 Digital Elevation Model (DEM) version 1 of resolution 1 arc Sec ($\sim$32 m) data obtained from Bhuvan is effectively used. Sheet and gully erosion are identified in parts of the study area. Slope in the watershed indicating moderate to least runoff and negligible soil loss condition. Third and fourth-order sub-watershed analysis is carried out. Mean bifurcation ratio (R_b) 3.6 specify there is no dominant influence of geology and structures, low drainage density (D_d) 1.12 and low stream frequency (F_s) 1.17 implies highly infiltration subsoil material and low runoff, infiltration number (I_f)1.3 implies higher infiltration capacity, coarse drainage texture (T) 3.40 shows high permeable subsoil, length of overland flow (L_g) 0.45 indicates under very less structural disturbances, less runoff conditions, constant of channel maintenance (C) 0.9 indicates higher permeability of subsoil, elongation ratio (R_e) 0.58, circularity ratio (R_c) 0.75 and form factor (R_f) 0.26 signifies sub-circular to more elongated basin with high infiltration with low runoff. It was observed from the hypsometric curves and hypsometric integral values of the watershed along with their sub basins that the drainage system is attaining a mature stage of geomorphic development. Additionally, Hypsometric curve and hypsometric integral value proves that the infiltration capacity is high as well as runoff is low in the watershed. Thus, these mormometric analyses can be used as an estimator of erosion status of watersheds leading to prioritization for taking up soil and water conservation measures.

Keywords Morphometry · Cartosat-1DEM · Budigere Amanikere watershed · Dakshina Pinakini · Hypsometric curve and hypsometric integral and RS and GIS

Introduction

Drainage basin is a basic unit in morphometric investigation because all the hydrologic and geomorphic processes occur within the watershed where denudational and aggradational processes are most explicitly manifested and is indicated by various morphometric studies (Horton 1945; Strahler 1952, 1964; Muller 1968; Shreve 1969; Evans 1972, 1984; Chorley et al. 1984; Merritts and Vincent 1989; Ohmori 1993; Cox 1994; Oguchi 1997; Burrough and McDonnell 1998; Hurtrez et al. 1999). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, and dimension of its landforms (Agarwal 1998; Obi Reddy et al. 2002; Clarke 1996). A most important

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consequence in geomorphology over the past several decades has been on the growth of quantitative physiographic process to describe the progression and actions of surface drainage networks (Horton 1945; Leopold and Maddock 1953). River drainage morphometry plays vital role in comprehension of soil physical properties, land processes, and erosional features.

Remote sensing techniques using satellite images are convenient tools for morphometric analysis. The satellite remote sensing has the ability to provide synoptic view of large area and is very useful in analyzing drainage morphometry. The image interpretation techniques are less time consuming than the ground surveys, which coupled with limited field checks yield valuable results. The satellite data can be utilized effectively for morphometric analysis and accurate delineation of watershed, sub-watershed, mini-watersheds and even micro-watersheds and other morphometric parameters (Ahmed et al. 2010).

The fast emerging spatial information technology, remote sensing, GIS, and GPS have effective tools to overcome most of the problems of land and water resources planning and management rather than conventional methods of data process (Rao et al. 2010). Using the LPS method for sensor geometry modeling the extraction of the corresponding DEM produced good results that are suitable for the operational use in planning and development of natural watersheds. The DEM accuracy, analyzed both at the point mode and the surface mode, produced good results (Murthy et al. 2008). Cartosat-1 stereo data can be considered as high accuracy (Dabrowski et al. 2008). The images acquired by the satellite can be safely used for the purposes it has been designed for (Srivastava et al. 2007), i.e., gathering elevation data with accuracy sufficient for maps with the scale of 1:25,000.

The drainage delineation shows better accuracy and clear demarcation of catchment ridgeline and more reliable flow-path prediction in comparison with ASTER. The results qualify Indian DEM for using it operationally which is equivalent and better than the other publicly available DEMs like SRTM and ASTERDEM (Muralikrishnan et al. 2013).

Strahler (1952) interpreted the shapes of the hypsometric curves by analyzing numerous drainage basins and classified the basins as young (convex upward curves), mature (S-shaped hypsometric curves which is concave upwards at high elevations and convex downwards at low elevations) and peneplain or distorted (concave upward curves). These hypsometric curve shapes described the stages of the landscape evolution, which also provide an indication of erosion status of the watershed.

The hypsometric integral is also an indication of the 'cycle of erosion' (Strahler 1952; Garg 1983). The 'cycle of erosion' is defined as the total time required for reduction of a land topological unit to the base level i.e. the lowest level. This entire period or the 'cycle of erosion' can be divided into three stages, viz., monandnock (old) (H_{si} 0.3), in which the watershed is fully stabilized; equilibrium or mature stage (0.3 H_{si} 0.6); and inequilibrium or young stage (H_{si} 0.6), in which the watershed is highly susceptible to erosion (Strahler 1952).

Study area

The watershed area of Budigere Amanikere River is 141 km^2 (Fig. 1) and located between latitude 13°06′00″N to 13°12′00″N and longitude 77°36′00″E to 77°46′00″E. The Budigere River originates from the Narayanapura Village and flows towards east meets the Dakshina Pinakini River at Budigere. The study area falls within Survey of India (1:50,000) toposheet numbers $57^{G}/_{12}$ and $57^{G}/_{16}$ are used. Annual normal rainfall of the area is 810 mm, major rainfall of 350–500 mm will be received by South–West monsoon in the months from June to September.

Study area has a tropical savanna climate (Köppen climate classification) with distinct wet and dry seasons. Due to its high elevation, Budigere Amanikere watershed usually enjoys a more moderate climate throughout the year, although occasional heat waves can make summer somewhat uncomfortable. The coolest month is January with an average low temperature of 15.1 °C (59.2 °F), and the hottest month is April with an average high temperature of 35 °C (95 °F). Northern fringe of the study area is holds of reserved forest with an area of 3.5 km^2 and in the southern fringe protected forest of area 1.5 km^2. Apart from the forest area 134 km^2 is having agriculture land, different types of wastelands like Barren rocky, Stony waste, Sheet rock, and gullied land is involving moderate to steep slope results gradient surface runoff, also in these wasteland water bodies are formed in abandoned quarry acts as recharge zones.

Erosion classification scheme

The displacement of soil material by water can result in either loss of topsoil or terrain deformation or both. This category includes processes such as sheet erosion, rill, gully erosion, and ravines. Erosion by water in the study area is the most important land degradation process that occurs on the surface of the earth. Rainfall, soil physical properties, terrain slope, land cover, and management practices play a very significant role in soil erosion. A brief description of various erosion classes in the study area by water is given below (Fig. 2) (Erosion Map of India 2014):

1. *Sheet Erosion:* It is a common problem resulting from loss of topsoil. The soil particles are removed from the whole soil surface on a fairly uniform basis in the form of thin layers. The severity of the problem is often difficult to visualize with naked eyes in the field.

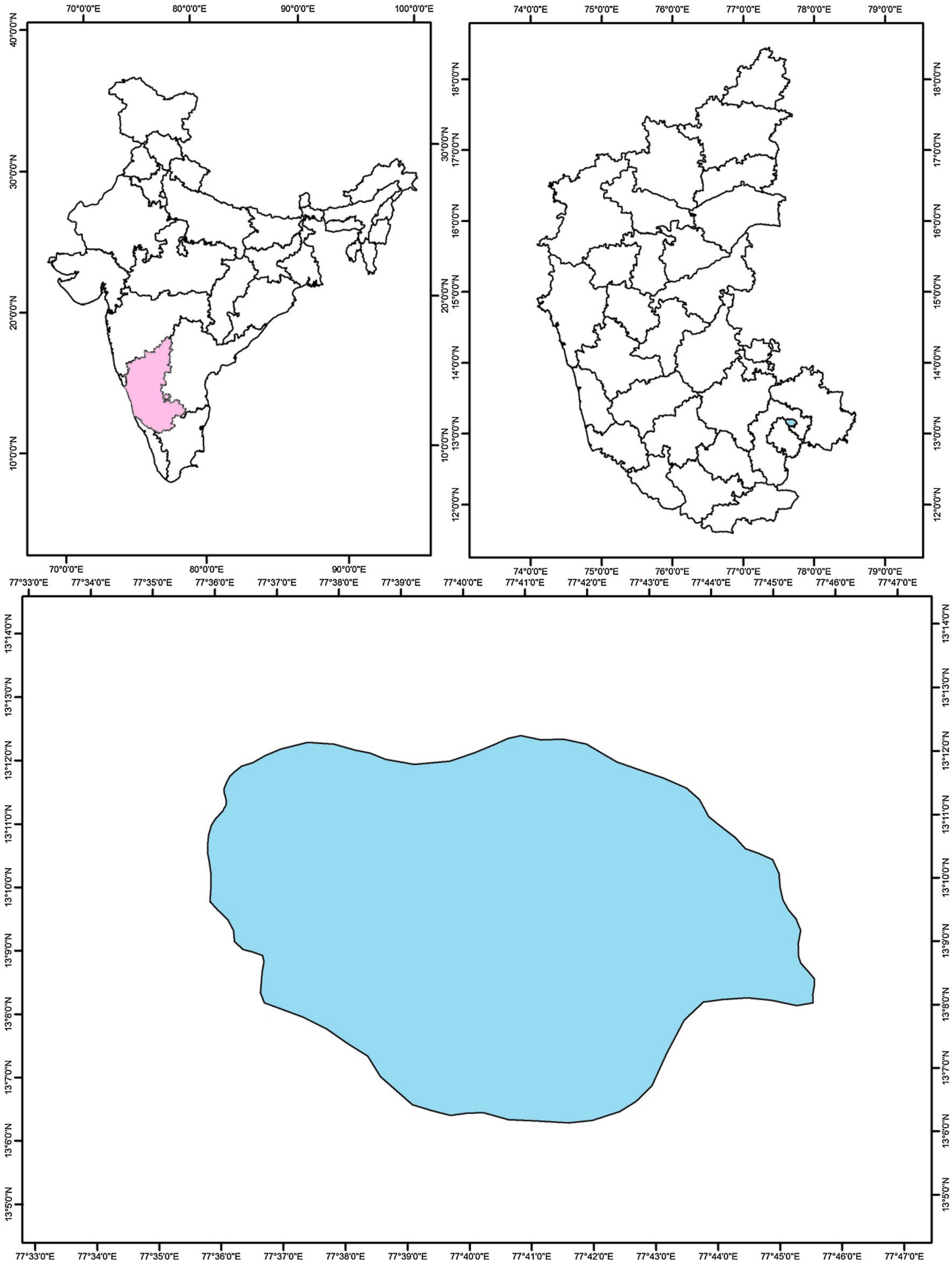


Fig. 1 Location of Budigere Amanikere watershed

2. *Gully Erosion:* Gullies are formed as a result of localized surface runoff affecting the unconsolidated material resulting in the formation of perceptible channels causing undulating terrain. They are commonly found in sloping lands, developed as a result of concentrated runoff over fairly long time. They are mostly associated with stream courses, sloping grounds with good rainfall regions, and foothill regions.

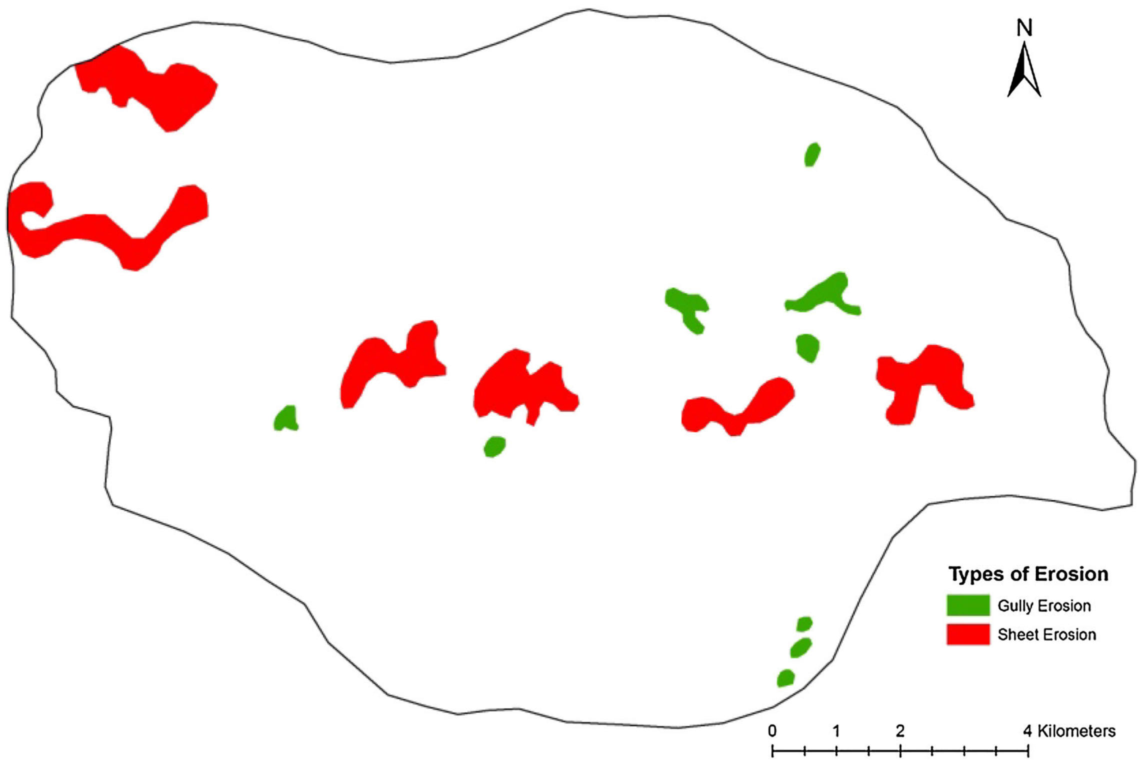


Fig. 2 Types of erosion

Materials and methodology

Cartosat-1 stereo datasets are proved in high accuracy compared to SRTM and ASTERDEM (Muralikrishnan et al. 2013) and tile extent/spatial extent of 1° × 1° from *X* in 77–78 E and *Y* in 13–14 N is used to achieve drainage network. The extracted stream network, slope, drainage density, and basin are projected to the regional projection (WGS_1984_UTM_Zone_43 N).

The unique characteristics of CartoSAT-1 stereo data and planned products are given below:

Name of the dataset: C1_DEM_16b_2006-2008_V1_77E13N_D43R

Theme: Terrain

Spheroid/datum: GCS, WGS-1984

Original source: Cartosat-1 PAN (2.5 m) stereo data

Resolution: 1 arc s (32 m)

Sensor: PAN (2.5 m) stereo data

File format: Geotiff

Bits per pixel: 16 bit

Extraction of drainage network and watershed

Extraction of stream orders using Hydrology tool from spatial analyst Arc toolbox is used and Eight Direction (D8) Flow Model (Fig. 3) is adopted in ArcGIS 10.3v Software (Advanced License type). The Cartosat-1 DEM and the pour point are the two inputs parameters required for the extraction function. The steps are as given below to obtain watershed and stream orders derived from Cartosat-1 DEM (Fig. 4) are as follows:

- Fill the sinks in the Cartosat:1 DEM
- Apply the flow direction function to the filled Cartosat:1 DEM
- Apply the flow accumulation function on the flow direction grid

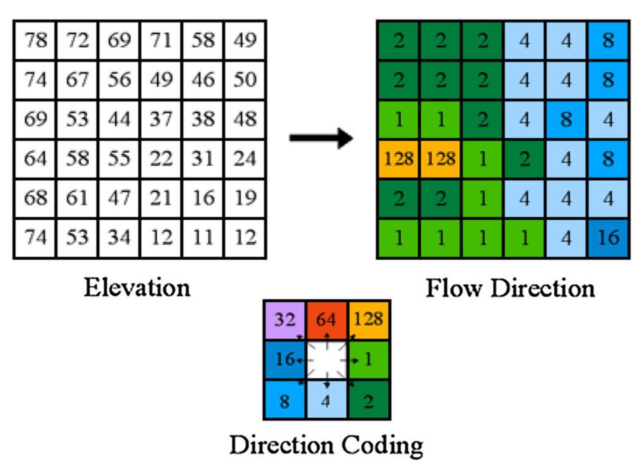


Fig. 3 Eight-direction (D8) flow model

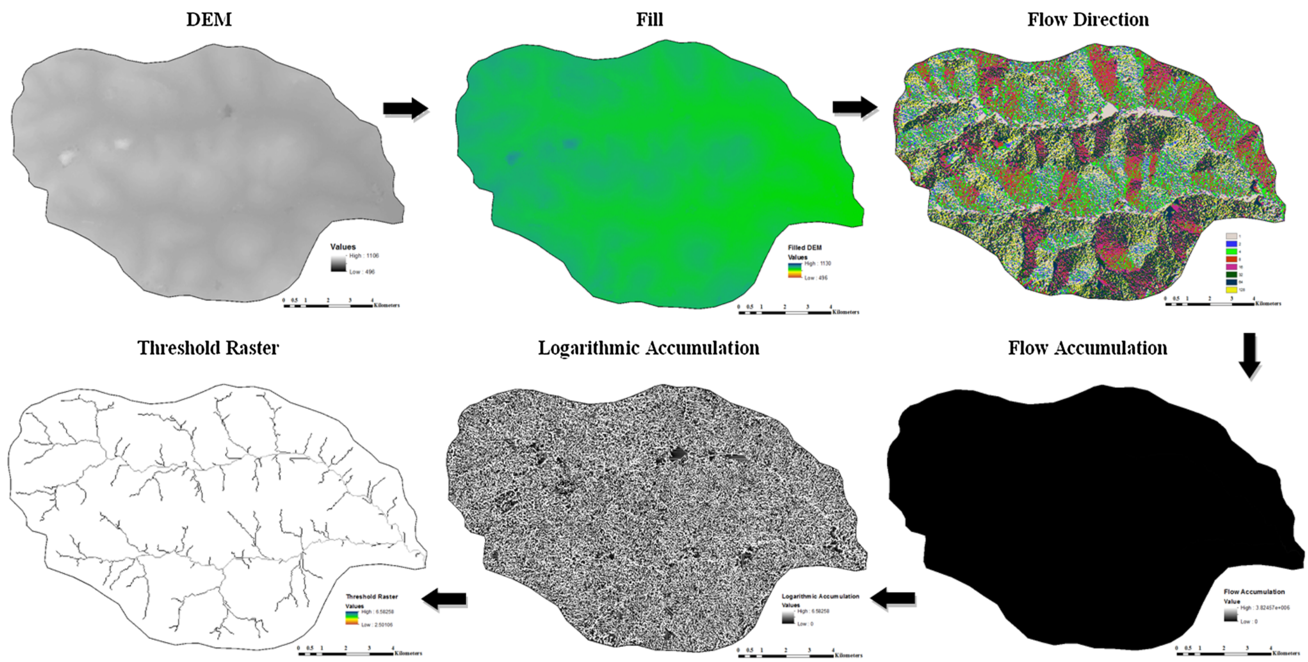


Fig. 4 Method of delineating stream order from Cartodat-1 DEM

- Apply the logarithmic accumulation function from raster calculator
- Apply the conditional function from raster calculator
- Apply a threshold condition to the conditioned flow direction grid
- Obtain a streams grid from the threshold condition grid
- Obtain the stream links grid
- Obtain watersheds grid from the streams grid
- Vectorise the streams grid
- Vectorise the watershed grid.

One of the keys to deriving hydrologic characteristics about a surface is the ability to determine the direction of flow from every cell in the raster. This is done with the flow direction function. This function takes a surface as input and outputs a raster showing the direction of flow out of each cell. If the output drop raster option is chosen, an output raster is created showing a ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centers of cells and is expressed in percentages. If the force all edge cells to flow outward option is chosen, all cells at the edge of the surface raster will flow outward from the surface raster.

There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight-direction (D8) flow model, and follows an approach presented in Jenson and Domingue (1988).

The Flow Accumulation function calculates accumulated flow as the accumulated weight of all cells flowing into each down slope cell in the output raster. If no weight raster is provided, a weight of one is applied to each cell, and the value of cells in the output raster will be the number of cells that flow into each cell.

The direction of flow is determined by the direction of steepest descent, or maximum drop, from each cell. This is calculated as follows:

$$\text{Maximum drop } = \text{change in } z \text{ value/distance } \times 100.$$

The hypsometric curve (HC) and hypsometric integral (HI) were calculated using GIS. The attribute feature classes that accommodate these values were utilized to plot the hypsometric curves for the watershed, from which the HI values were calculated using the elevation-relief ratio method elaborated by Pike and Wilson (1971). The elevation-relief ratio method is found to be easy to apply and more accurate to calculate within the GIS environment. The relationship is expressed in the following equation is mentioned in Plotting of Hypsometric Curves (HC) and estimation ofHypsometric Integrals (HI) heading.

Results and discussion

The morphometric analysis for the basic parameters of stream order, stream length, mean stream length and derived parameters of bifurcation ratio, stream length ratio, stream frequency, drainage density, texture ratio, drainage texture, length of overland flow, compactness constant, constant of channel maintenance and the shape parameters of elongation ratio, circularity ratio, Form factor for the Budigere Amanikere watershed is achieved the formulas described in Table 1. The total drainage area of the

Table 1 Methods followed to calculate morphometric parameters

Morphometric parameters	Formula and description	References
Basic parameters		
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'	Horton (1945)
	N_u = Total number of stream segments of order 'U'	
Derived parameters		
Bifurcation ratio (R_b)	$R_b = N_u/N_u + 1$; where N_u = Total number of stream segment of order 'u'; $N_u + 1$ = Number of segment of next higher order	Schumm (1956)
Stream length ratio (R_l)	$R_l = L_u/L_{u-1}$; where L_u = Total stream length of order 'U', Lu-1 = Stream length of next lower order.	Horton (1945)
Drainage density (D_d)	$D_d = L/A$ where	Horton (1945)
	L = Total length of streams; A = Area of watershed	
Drainage frequency (F_s)	$F_s = N/A$; where	Horton (1945)
	N = Total number of streams; A = Area of watershed	
Infiltration number (I_f)	$I_f = D_d \times F_s$	Zavoiance (1985)
	where D_d = Drainage density (km/km^2) and	
	F_s = Drainage frequency	
Drainage texture (T)	$R_t = N_u/P$; where N_u = total number of stream segments of all order in a basin; P = Perimeter	Horton (1945)
Length of overland flow (L_g)	$L_g = 1/2\ D_d$; where D_d = Drainage density	Horton (1945)
Compactness constant (C_c)	$C_c = 0.2821 \times P/A^{0.5}$;where P = Perimeter of the basin(km), A = Area of the basin (km^2)	Horton (1945)
Constant of channel maintenance (C)	$C = 1/D_d$; where D_d = Drainage density	Schumm (1956)
Shape parameters		
Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$; where A = Area of watershed, $\pi = 3.14$, Lb = Basin length	Schumm (1956)
Circulatory ratio (R_c)	$R_c = 4\pi A/P^2$; where A = Area of watershed,	Miller (1953)
	$\pi = 3.14$, P = Perimeter of watershed	
Form factor (R_f)	$R_f = A/(\mathrm{Lb})^2$; where A = Area of watershed,	Horton (1932)
	L_b = Basin length	

Budigere Amanikere watershed is 141 km^2. The drainage pattern is dendritic in nature and is influenced by the geology, topography, and rainfall condition of the area. Geology in the area is peninsular gneissic complex of 2600–2350 m.y belonging to Archean to Proterozoic age.

Slope

Slope analysis is a significant parameter in geomorphological studies for watershed development and important for morphometric analysis. The slope elements, in turn, are controlled by the climatomorphogenic processes in areas having rock of varying resistance (Magesh et al. 2011; Gayen et al. 2013). A slope map of the study area is calculated based on Cartosat-1 DEM data using the spatial analysis tool in ArcGIS 10.3. Slope grid is identified as ''the maximum rate of change in value from each cell to its neighbors'' (Burrough 1986). The degree of slope in Budigere Amanikere watershed varies from 0.3° to >11° (Table 2). Higher slope degree results in rapid runoff and increased erosion rate (potential soil loss) with less ground water recharge potential, whereas in the study area lower slope of degree present in peninsular gneissic mountain range (Figs. 5, 6). The loss of soil is very negligible.

Table 2 Types of slope

Sl no.	Types of slope	Slope in degree
1	Nearly level	0.3–1.1
2	Very gentle slope	1.1–5.0
3	Gentle slope	5.0–8.3
4	Moderate slope	8.3–11.0
5	Strong slope	11 and more

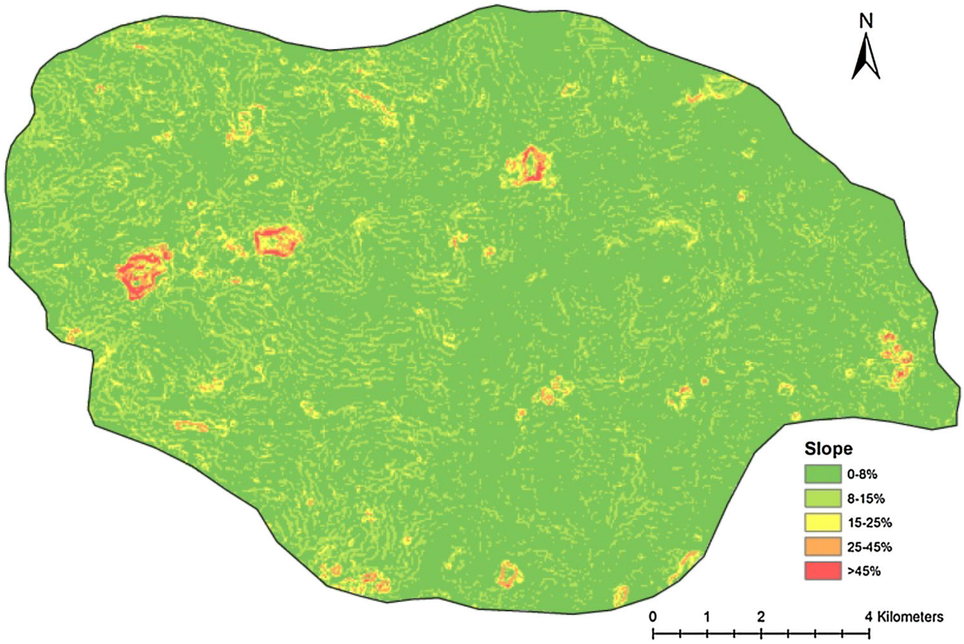


Fig. 5 Slope map

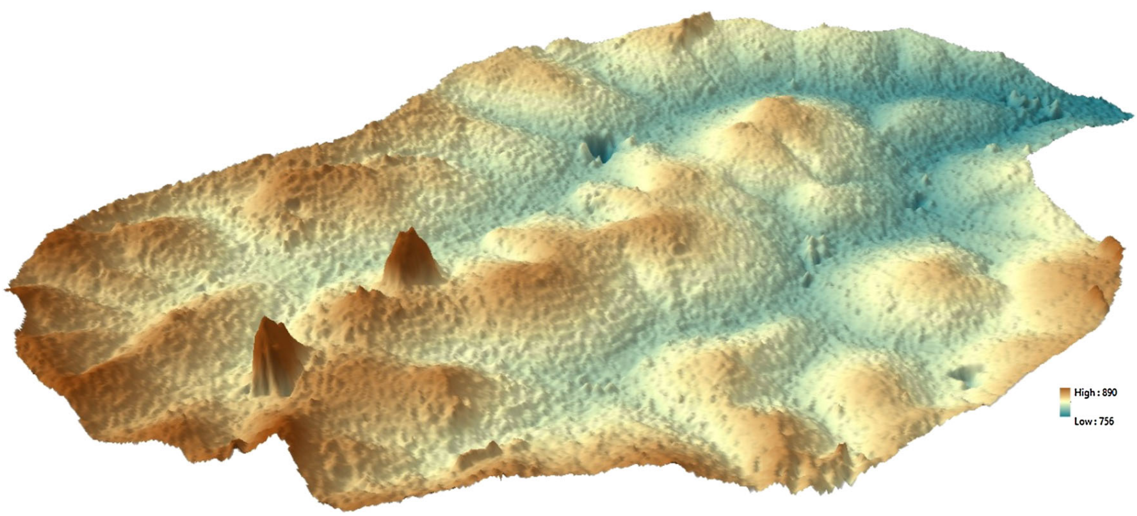


Fig. 6 3D model of Budigere Amanikere watershed

Basic parameters

Area of a basin (A) and perimeter (P) are the important parameters in quantitative geomorphology. Basin area directly affects the size of the storm hydrograph, the magnitudes of peak, and mean runoff. The perimeter (P) is the total length of the drainage basin boundary. The perimeter of the Budigere Amanikere Watershed is 48.5 km. The area of the watershed (A) is 141 km^2. The length of the basin (L_b) measured parallel to the main drainage line, i.e., from west to north-east direction and is 21.8 km. In addition, sub-watersheds of fourth-order and third-order parameters were also calculated and are mentioned in Table 3.

Stream order (N_u)

The count of stream channels in each order is termed as stream order. The streams of the study area have been ranked; when two first-order streams join, a stream segment of second order is formed. When two second-order streams join, a segment of third order is formed, and so on. In the present study, fifth-order drainage order (Fig. 7) is

Table 3 Basic parameters of Budigere Amanikere Watershed

Watershed details	Area in km^2	Perimeter in km	Basin length in km	Stream order	Number of streams	Total number of streams	Stream length in km	Total stream length in km
NW-1	12.98	15.07	4.83	1	8	12	7.82	14.12
				2	3		4.05	
				3	1		2.25	
NW-2	8.5	12.01	4.88	1	7	10	4.19	9.48
				2	2		2.16	
				3	1		3.13	
SW-1	11.45	15.56	4.7	1	10	14	7.84	13.68
				2	3		2.93	
				3	1		2.91	
SW-2	3.9	8.16	3.41	1	5	8	1.32	4.18
				2	2		0.81	
				3	1		2.05	
S-1	13.08	15.46	5.25	1	10	14	5.06	12.84
				2	3		5.72	
				3	1		2.06	
S-2	5.6	9.98	3.36	1	5	8	3.63	6.03
				2	2		1.92	
				3	1		0.48	
North (fourth order)	75.68	42.71	20.99	1	68	85	46.04	86.55
				2	14		19.11	
				3	2		5.38	
				4	1		16.02	
South (fourth order)	63.02	35.64	17.23	1	58	77	32.85	68.1
				2	14		14.95	
				3	4		7.51	
				4	1		12.79	
Entire Budigere Amanikere watershed	141	48.5	22.92	1	128	165	79.65	157.31
				2	28		34.06	
				3	6		12.89	
				4	2		28.81	
				5	1		1.9	

acquired to morphometric analysis. Budigere Amanikere watershed is consisting of dendritic type of drainage network with nearly even terrain (Table 3). Total of 165 stream line is recognized in the whole basin, out of which 77.57% (128) is 1st order, 17% (28) 2nd order, 3.6% (6) third order, 1.21% (2) fourth order, and 0.6% comprises 5th order stream (1). Sub-watershed stream orders were also estimated and are mentioned in Table 3.

Derived parameters

Stream length (L_u) and mean stream length (L_{sm})

The stream length and mean stream length of various orders has been calculated from Horton's law of stream length method. It supports the theory of geometrical similarity preserved generally in the basins of increasing category. Mean length of channel segments of an existing order is greater than that of the next lower order but less than that of the next higher order. Bifurcation ratio is the ratio of the number of stream channels of an order to the number streams of the higher order.

Stream length ratio (R_l)

Stream length ratio (Horton's law) states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with streams length increasing towards higher order of streams. The R_l

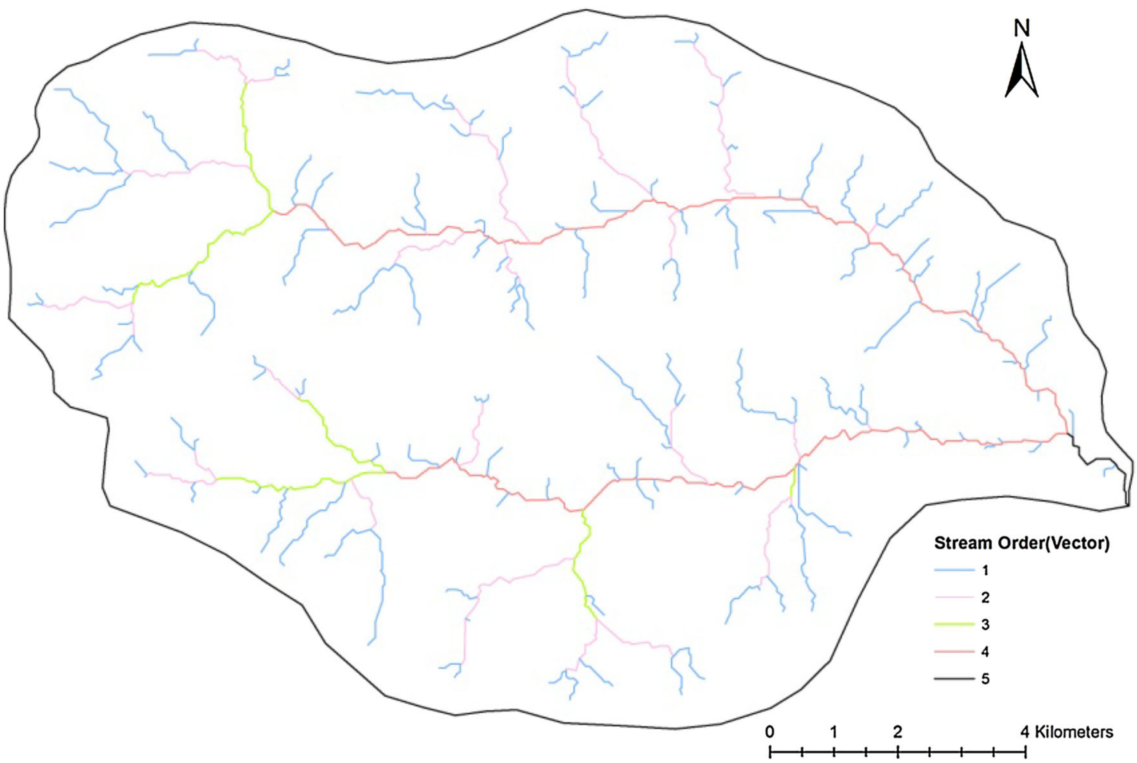


Fig. 7 Stream order in vector

between streams of different order in the Budigere Amanikere watershed area reveals that there is a variation in R_l.

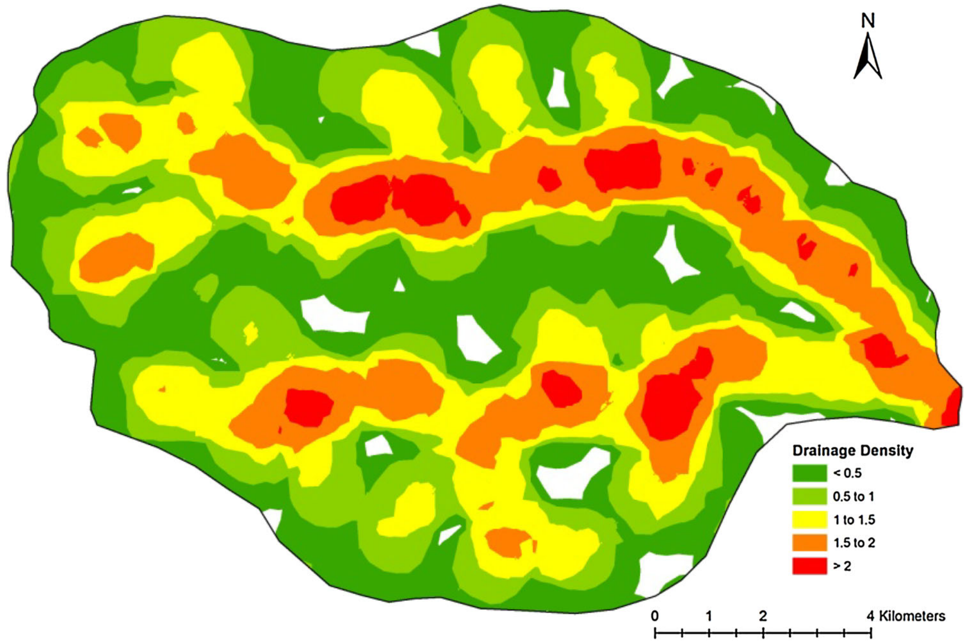
Bifurcation ratio (R_b)

Bifurcation ratio is closely related to the branching pattern of a drainage network (Schumm 1956). It is related to the structural control on the drainage (Strahler 1964). A lower R_b range between 3 and 5 suggests that structure does not exercise a dominant influence on the drainage pattern. Higher R_b greater than 5 indicates some sort of geological control. If the R_b is low, the basin produces a sharp peak in discharge and if it is high, the basin yields low, but extended peak flow (Agarwal 1998). In well developed drainage network the bifurcation ratio is generally between 2 and 5. Study area prominently showing some sort of geological control. From the Table 4 mean bifurcation ratio of third-order sub-watersheds varies from 2.3 to 3.2, fourth-order sub-watersheds varies 3.9 and 4.6. The entire watershed is showing 3.6 and is revealed that the watershed

Table 4 Derived parameters of Budigere Amanikere Watershed

Watershed details	Mean Bifurcation ratio (R_b)	Drainage density (km/km^2)	Stream frequency (F_s)	Infiltration number (I_f)	Drainage texture (T)	Length of overland flow (L_g)	Compactness constant (C_c)	Constant of channel maintenance (C)
NW-1	2.8	1.09	0.92	1.01	0.80	0.46	0.30	0.92
NW-2	2.8	1.12	1.18	1.31	0.83	0.45	0.34	0.90
SW-1	3.2	1.19	1.22	1.46	0.90	0.42	0.33	0.84
SW-2	2.3	1.07	2.05	2.20	0.98	0.47	0.41	0.93
S-1	3.2	0.98	1.07	1.05	0.91	0.51	0.31	1.02
S-2	2.3	1.08	1.43	1.54	0.80	0.46	0.38	0.93
North (fourth order)	4.6	1.14	1.12	1.28	1.99	0.44	0.21	0.87
South (fourth order)	3.9	1.08	1.22	1.32	2.16	0.46	0.21	0.93
Entire Budigere Amanikere watershed	3.6	1.12	1.17	1.30	3.40	0.45	0.17	0.90

Fig. 8 Drainage density



is in mature stage of erosion and structure does not exercise a dominant influence on the drainage pattern.

Drainage density (D_d)

The drainage density is an important indicator of the linear scale of landform elements in stream-eroded topography. It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of mi/sq.mi or km/sq.km. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed from drainage density measurements made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly resistant of highly permeable subsoil material under dense vegetative cover, and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation, and mountainous relief. Low drainage density leads to coarse drainage texture, while high drainage density leads to fine drainage texture (Strahler 1964). On the one hand, the D_d is a result of interacting factors controlling the surface runoff; on the other hand, it is itself influencing the output of water and sediment from the drainage basin (Ozdemir and Bird 2009). D_d is known to vary with climate and vegetation (Moglen et al. 1998), soil and rock properties (Kelson and Wells 1989), relief (Oguchi 1997), and landscape evolution processes. It is a measure of the length of stream per unit (Horton 1932) in the watershed. It is significant point in the linear scale of landform elements in stream-eroded topography and does not change regularly with orders within the basin. From Table 4, drainage density of third-order sub-watersheds varies from 0.98 to 1.19, and fourth-order sub-watersheds varies from 1.08 and 1.14. Low (<2.0 km/km^2) drainage density from third order, fourth order, as well as entire Budigere Amanikere watershed is 1.12 (Fig. 8), leading to highly permeable subsoil material.

Stream frequency (F_s)

Stream frequency defined as the total number of stream segments of all orders per unit area (Horton 1932). The occurrence of stream segments depends on the nature and structure of rocks, vegetation cover, nature and amount of rainfall, and soil permeability. Table 4 indicating stream frequency of third-order sub-watersheds varies from 0.92 to 2.05, fourth-order sub-watersheds varies 1.12 and 1.22. In Budigere, Amanikere watershed shows 1.17 of low (below 2.5/km^2) stream frequency of low relief and high infiltration capacity of the bedrock pointing towards the increase in stream population with respect to increase in drainage density. The stream frequency of Budigere Amanikere basin shows that the basin has good vegetation, medium relief, high infiltration capacity, and later peak discharges owing to low runoff rate. The stream frequency shows positive correlation with the drainage density. Lesser the drainage density and stream frequency in a basin, the runoff is slower, and therefore, flooding is less likely in basins with a low to moderate drainage density and stream frequency (Carlston 1963).

Infiltration number (I_f)

Infiltration number plays a significant role in observing the infiltration characteristics of the basin. It is inversely proportional to the infiltration capacity of the basin. The infiltration number of the third-order watersheds varies from 1.01 to 2.20, fourth-order watersheds varies from 1.28 to 1.32, and entire Budigere Amanikere watershed is 1.30 (Table 4) and considered as very low. It indicates that runoff will be very low and the infiltration capacity very high.

Drainage texture (T)

According to Horton (1945), Drainage texture (T) is the total number of stream segments of all orders per perimeter of that area. It is one of the important concepts of geomorphology which means that the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. Five different texture ratios have been classified based on the drainage density (Smith 1950). In the study area texture ratio (Table 4) of third-order watersheds varies (<2) from 0.80 to 0.98 and are indicating very coarse, fourth-order watersheds varies (<2 and 2–4) from 1.99 to 2.16 indicates very coarse to coarse drainage texture and entire Budigere Amanikere watershed (2–4) is 3.40 indicates related to coarse texture.

Length of overland flow (L_g)

It is the length of water over the ground before it gets concentrated into definite streams channels (Horton 1932). This factor depends on the rock type, permeability, climatic regime, vegetation cover and relief as well as duration of erosion. The length of overland flow approximately equals to half of the reciprocal of drainage density. Length of overland flow of third-order sub-watersheds varies from 0.42 to 0.51, fourth-order sub-watersheds varies from 0.44 to 0.46 and the entire Budigere Amanikere watershed (Table 4) is 0.45 km. Length of overland flow in all the watersheds is greater than 0.25 are under very less structural disturbance, less runoff conditions, and having higher overland flow. A larger value of length of overland flow indicates longer flow path and thus gentler slopes.

Compactness constant (C_c)

Compactness constant is defined as the ratio between the area of the basin and the perimeter of the basin. Compactness constant is unity for a perfect circle, and increases as the basin length increases. Thus, it is a direct indicator of the elongated nature of the basin. The third-order sub-watersheds varies from 0.30 to 0.41, fourth-order sub-watersheds are 0.21, and the entire Budigere Amanikere watershed (Table 4) is 0.17 values indicating lesser elongated watershed however, a lesser elongated pattern facilitates the runoff is low, thereby favoring to development of erosion is low.

Constant of channel maintenance (C)

Constant of channel maintenance is the inverse of drainage density (Schumm 1956). It is also the area required to maintain one linear kilometer of stream channel. Generally, a higher constant of channel maintenance of a basin indicates higher permeability of rocks of that basin, and vice versa. It is inferred that the third-order sub-watersheds varies from 0.84 to 1.02, fourth-order sub-watersheds varies from 0.87 to 0.93, and the entire Budigere Amanikere watershed is 0.90 having more than 0.6 km^2 area to maintain 1 km length stream channel, which in turn indicates higher permeability of subsoil.

Shape parameters

Elongation ratio (R_e)

Elongation ratio is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. Analysis of elongation ratio indicates that the areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin (Singh and Singh 1997). The elongation ratio and shape of basin are generally varies from 0.6 to 1.0 over a wide variety of climate and geologic types. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6–0.8 are usually associated with high relief and steep ground slope. The Elongation ratio of third-order sub-watersheds varies from 0.65 to 0.84, fourth-order sub-watersheds varies from 0.47 and 0.52, and the entire Budigere Amanikere watershed Budigere Amanikere catchment is 0.58 (Table 5) falling in sub-circular category.

Circularity ratio (R_c)

The circularity ratio is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin (Miller 1953). It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the watershed. In the present study (Table 5), the R_c values of third-order sub-watersheds varies from 0.59 to 0.74, fourth-order sub-watersheds varies from 0.52 to 0.62 and the entire Budigere Amanikere watershed is 0.75. This anomaly is due to

Table 5 Shape parameters of Budigere Amanikere watershed

Watershed details	Elongation ratio (R_e)	Circulatory ratio (R_c)	Form factor (R_f)
NW-1	0.84	0.72	0.56
NW-2	0.67	0.74	0.36
SW-1	0.81	0.59	0.52
SW-2	0.65	0.74	0.34
S-1	0.78	0.69	0.47
S-2	0.79	0.71	0.50
North (fourth order)	0.47	0.52	0.17
South (fourth order)	0.52	0.62	0.21
Entire Budigere Amanikere watershed	0.58	0.75	0.26

diversity of slope, relief and structural conditions prevailing in the watershed.

Form factor (R_f)

Form factor is defined as the ratio of basin area to square of the basin length (Horton 1932). The value of form factor would always be greater than 0.7854 (for a perfectly circular basin). Smaller the value of form factor, more elongated will be the basin. It is noted that the R_f values of third-order sub-watersheds varies (Table 5) from 0.34 to 0.56, fourth-order sub-watersheds varies from 0.17 to 0.21, and the entire Budigere Amanikere watershed is 0.26, and the sub-watershed and the entire Budigere Amanikere watershed are belonging to sub-circular to less elongated.

Plotting of hypsometric curves (HC) and estimation of hypsometric integrals (HI)

Hypsometric analysis aims at developing a relationship between horizontal cross-sectional area of the watershed and its elevation in a dimensionless form. Hypsometric curve is obtained by using percentage height (h/H) and percentage area relationship (a/A) (Luo 1998). The relative area is obtained as a ration of the area above a particular contour to the total area of the watershed encompassing the outlet (Fig. 9).

In the present study, the hypsometric integral was estimated using the elevation-relief ratio method proposed by Pike and Wilson (1971). The relationship is expressed as:

$$E \approx H_{is} = \frac{\text{Elev}_{mean} - \text{Elve}_{min}}{\text{Elev}_{max} - \text{Elve}_{min}},$$

where E is the elevation-relief ratio equivalent to the hypsometric integral H_{is}; Elev_{mean} is the weighted mean elevation of the watershed estimated from the identifiable contours of the delineated watershed; Elev_{min} and Elev_{max} are the minimum and maximum elevations within the watershed.

It was observed from the hypsometric curves of the watershed along with their sub basins (Figs. 10, 11) that the

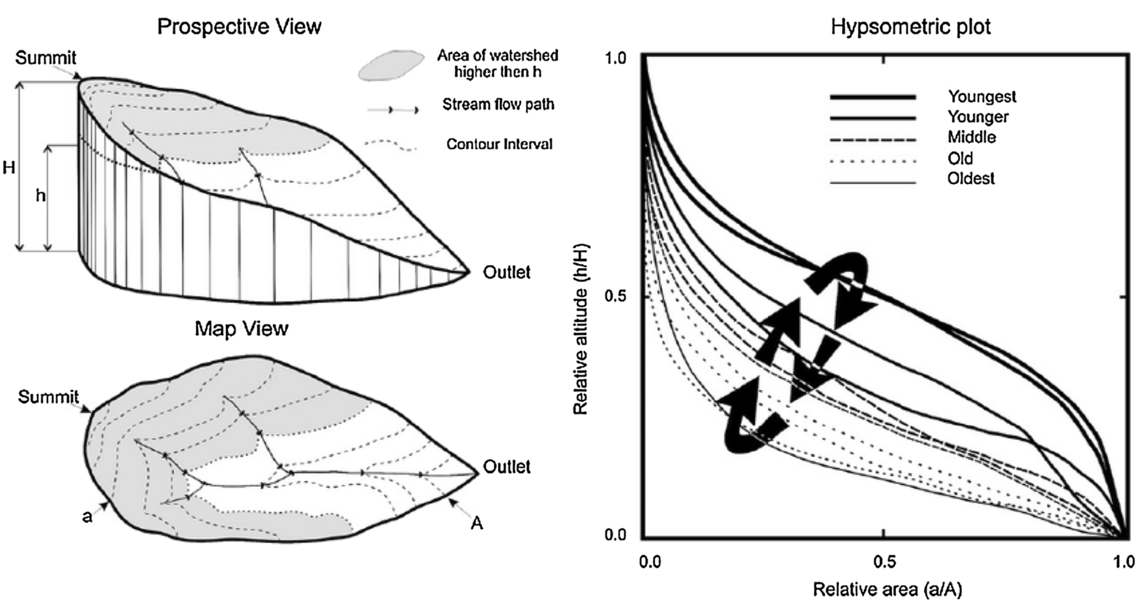


Fig. 9 Calculation of hypsometric curve and their interpretation. **a** Schematic diagram shows procedure for calculating hypsometric *curves* using percentage height (h/H) and percentage area relationship (a/A) (Luo 1998) and **b** Interpretation of different hypsometric *curves*: *convex curves* represent youthful stages, s-shaped and *concave curves* represent mature and old stages. This behavior depends on variation in orogenic elevation during a geomorphic cycle (Perez-Pena et al. 2009)

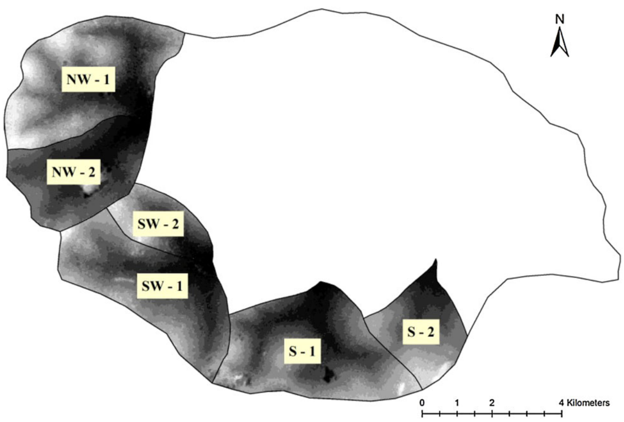


Fig. 10 Third-order sub-watersheds

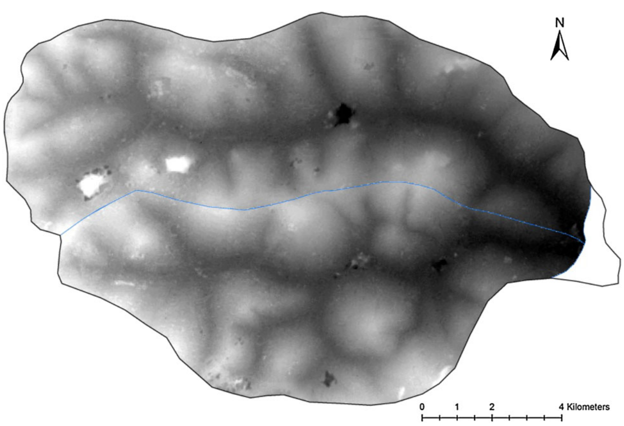


Fig. 11 Fourth-order sub-watersheds

drainage system is attaining a mature stage of geomorphic development. The comparison between these curves shown in Figs. 12 and 13 indicated a minor variation in mass removal from the main watershed and their sub basins. It was also observed that there was a combination of concave up and S shape of the hypsometric curves for the watershed and their sub basins. This could be due to the soil erosion from the watershed and their sub basins resulting from the down slope movement of topsoil and bedrock material, washout of the soil mass.

The HI value (Table 6) can be used as an indicator of the relative amount of land from the base of the mountain to its top that was removed by erosion (aeration). Statistical moments of different hypsometric curves can be used for further analysis (Harlin 1978; Luo 1998; Perez-Pena et al. 2009). The HI value (Table 6) for third-order sub-watersheds are 0.50, fourth-order sub-watersheds varies from 0.50 to 0.51, and the entire Budigere Amanikere watershed is 0.51. It was observed from the HI value that the basin falls under mature stage of fluvial geomorphic cycle.

Conclusions

Morphometric analysis of drainage system is prerequisite to any hydrological study. Modernize technologies like ArcGIS 10.3v Software have resulted to be of immense utility in the quantitative analysis of the geomorphometric and hypsometric aspects of the drainage basin; in addition, cartosat-1 stereo spatial data can be effectively used

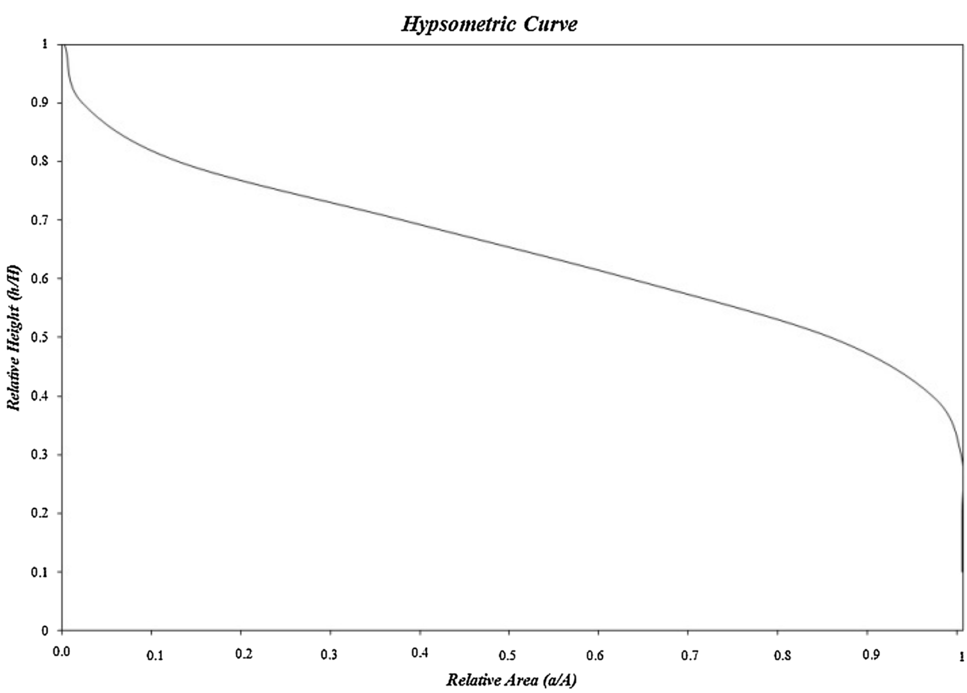


Fig. 12 Hypsometric curve of Budigere Amanikere watershed

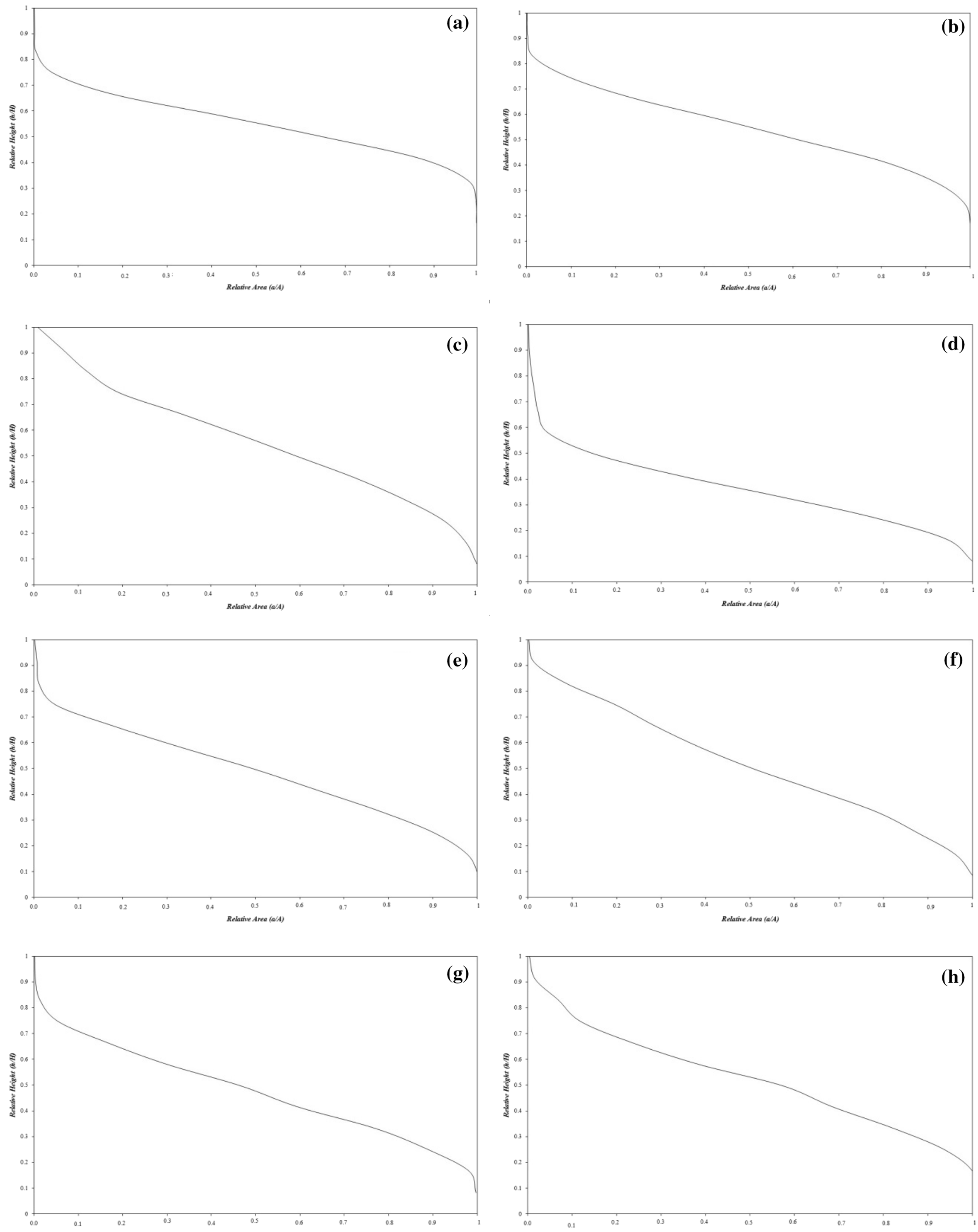


Fig. 13 Hypsometric curves for fourth-order sub-watersheds, viz., **a** North, **b** South and third-order sub-watersheds, viz., **c** NW-1, **d** NW-2, **e** SW-1, **f** SW-2, **g** S-1 and **h** S-2

Table 6 Estimated hypsometric integral values of the Budigere Amanikere watershed and Sub-watersheds

Sl no.	Basin description	Area (km^2)	Minimum elevation (m)	Maximum elevation (m)	Mean elevation(m)	Hypsometric integral	Erosional stage
1	NW-1 (third order)	12.98	809	857	833	0.50	Mature stage
2	NW-2 (third order)	8.50	809	890	849.5	0.50	Mature stage
3	SW-1 (third order)	11.45	802	862	832	0.50	Mature stage
4	SW-2 (third order)	3.9	803	846	824.5	0.50	Mature stage
5	S-1 (third order)	13.08	797	851	824	0.50	Mature stage
6	S-2 (third order)	5.6	785	854	820.4	0.51	Mature stage
7	North (fourth order)	75.68	756	890	824.5	0.51	Mature stage
8	South (fourth order)	63.02	771	862	817	0.50	Mature stage
Entire Budigere Amanikere watershed		141	756	890	824.5	0.51	Mature stage

towards morphometric analysis and cartosat-1 stereo spatial data resemble the manual outcome. Slope in the watershed indicating moderate to least runoff and negligible soil loss condition. Budigere Amanikere watershed and their sub-watersheds of third and fourth order have been has been found with dendritic pattern drainage basin. These sub basins are mainly dominated by lower order streams. The morphometric analysis is carried by the measurement of linear, aerial and relief aspects of basins. The maximum stream order frequency is observed in case of first-order streams and then for second order. Hence, it is noticed that there is a decrease in stream frequency as the stream order increases and vice versa. The values of stream frequency indicate that the basin shows +ve correlation with increasing stream population with respect to increasing drainage density. The study reveals that the Budigere Amanikere basin is passing through a mature stage of the fluvial geomorphic cycle. Sheet and gully erosion are identified in parts of the study area.

From the basic parameters, derived parameters and shape parameters indicate there is no geological or structural control over the basin. The mean R_b indicates that the drainage pattern is not much influenced by geological structures and in mature stage of erosion. Horton's laws of stream numbers, stream lengths, and basin slopes conform to the basin morphometric state. The D_d and F_s are the most useful criterion for the morphometric classification of drainage basins that certainly control the runoff pattern, sediment yield, and other hydrological parameters of the drainage basin. From the derived parameters the watershed is low resistant, high permeable subsoil and overburden materials with less runoff conditions and high overland flow indicating longer flow path and thus, gentler slopes. Texture ratio (T) indicating the sub-watersheds are falls under very coarse to course drainage texture, wherein the entire watershed is belongs to related to course and permeable subsoil. The shape parameters implies sub-circular to less elongated basin with high infiltration capacity. Hypsometric curve and hypsometric integral study reveals for sub-watershed as well as entire watershed is passing through a mature stage of the fluvial geomorphic cycle. Hence, from the study, it is highly comprehensible that GIS technique is a competent tool in geomorphometric analysis for geohydrological studies of drainage basins. These studies are very useful for planning and management of drainage basin.

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