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Climate and Structurally Controlled Markandeya River Basin, Belgavi District, Karnataka, India delineated through Morphometry and Hypsometry: A GIS and Remote Sensing Approach

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ABSTRACT

Morphometry and hypsometry analyses are important tools in planning and developing management programs for river basins, soil and water conservation and natural resources management of river basins. These tools were used to evaluate the climate and structural control over Markandeya river basin (MRB) of northern part of Karnataka state, India. The basin stretches over Kaladgi Supergroup of rocks, Deccan Traps and laterites. The present paper evaluates morphometric parameters *viz.,* linear, aerial and relief aspects of MRB by Geographical Information System (GIS) and Remote sensing techniques. The MRB is a structurally controlled basin, which has been delineated into 30 sub-basins. Majority of the sub-basin has low drainage density, reveals most of the rainfall infiltrates into the ground. In MRB all 3rd, 4th, and 5th order sub-basins have been coarse and very coarse texture, except Bellari nala which has a fine texture. The computed value of form factor, circularity and elongation ratio suggests that the MRB has elongated in shape and flatter peak flows for longer duration.

Hypsometric analysis carried out using 30m ASTER DEM revealed nine sub-basins are early youth geomorphic stage; and four sub-basins of late youth stage are influenced by neotectonic activities. Ten sub-basins are approaching early mature stage, and five sub-basins late mature stage. These fifteen sub-basins are experiencing more erosion; these sub-basins are lying within tropical climate zone. The MRB shows old or monadnock stage. The denudational history is understood through basin relief, revealing sub-basins of moderate to high relief.

Keywords: Morphometry, Hypsometry analysis, GIS and Remote Sensing, Markandeya River Basin.

INTRODUCTION

These days' basin analysis is most commonly done through morphometry to understand fluvially originated landforms. These are important in planning sustainable development of management programs of river basins. The rising population is putting a lot of stress on natural resources like soil, land and water. The comprehensive understanding of the extent and quantum of these resources can help plan their judicious use. It will also help design and implement measures of soil, water conservation and erosion control. Also, quantitative morphometric characterization of drainage basin is a significant method for proper planning for integrated river basin management.

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Magesh *et al.* (2011) studied the morphometric evaluation of two Tamil Nadu watersheds lying within Western Ghats. It unraveled that rainfall affects the development of stream segments within the watershed and high drainage density developed when the climate was wet in the past. Morphometric analyses of varying river basins of India have been investigated using standard technique (Herlekar and Wavare, 2014; Sarkar and Soman, 1983; Jobin Thomas *et al*., 2012; Bagyaraj and Gurugnaonam, 2011; Sreedevi *et al.,* 2005; Kale and Shejwalkar, 2008).

Hypsometric analysis is a useful tool to study landforms, particularly to understand the causative factors of their evolution. The shape of the hypsometric curve (HC) is dependent on the basin area, aspect ratio, the extent of drainage network, fluvial and diffusive erosion processes and the age of landforms (Sinha-Roy, 2002). The hypsometric curve and the hypsometric integral are non–dimensional measures of the proportion of the catchment above a given elevation. Hypsometric analysis has been used to characterize the distribution of elevations for continental regions so that dependent variables such as regional rainfall and sediment yield may be estimated (Hutchinson and Dowling, 1991; Wyatt, 1993). Strahler (1952, 1964) identified different types of landforms representing different characteristic shapes of hypsometric curves, dividing landforms into youth, mature and old stage (monadnock). The monadnock is a landform of subdued topography with isolated elevated regions of resistant rocks or landforms of recent uplift. The well graded mature stage of the Golvan basin, north of Malvan, Maharashtra probably attained during Post Pleistocene period, has suffered incision and entrenchment (Sarkar and Soman, 1983).

The Earth’s landform is the time amalgamates effect of two main parameters. The first being tectonics, which can develop landforms and sustain relief through endogenetic and exogenetic forces (Whipple, 2004; Wobus *et al.,* 2006). The second is climate, which influences the weathering processes that wash away mountainous areas over time (Allen, 2008) and deposition in a basinal area.

The HC are related to geomorphic and tectonic evolution of drainage basins in terms of their forms and processes (Leopold *et al.,* 1964; Hurtrez *et al.,* 1999). Soares and Riffel (2006) developed palaeosurface mapping tool, using hypsometric curves and DEM, and applied it to three hydrographic basins in the coastal ranges of Brazil. Babu *et al*. (2014), studied hypsometry and geomorphic evolution of a Chalakudy basin, suggesting lithology played a very important role in the erosional cycle of the Chalakudy river. Lalwani (1988) inferred geology of the area around Gokak based on aerial photographs and field check.

The present paper reports the morphometric and hypsometric characteristics of Markandeya river basin (MRB), in northern part of Karnataka state, India to understand their erosional behavior through remote sensing and GIS approach.

STUDY AREA

The study area falls in the northern part of Karnataka state, India. The Markandeya River is one of the major tributaries of Ghataprabha river and subsequently joins the Krishna river. The Markandeya river originates at Bailur of Sahyadri hill ranges. The flat top hillocks are made up mainly of sandstone, shale and conglomerates of Kaladgi Supergroup of rocks; Deccan Traps and laterites, which are dissected by a number of streams. These have moderate to steep relief. The maximum elevation within the study area is 1026 m asl located in the southwest part, whereas the minimum elevation is at Gokak, which is 542 m. The Markandeya river basin (MRB) is traversed by a number of lineaments trending N-S, NW-SE which show evidence of rejuvenation during different periods. The MRB has elongated shape, the drainage being dendritic, rectangular and parallel. The river originates in tropical wet climatic region, and then flows through semi-arid region of Belgaum district, Karnataka state, India (Fig. 1). The average annual rainfall is about 500 mm.

The basement rock is seen to be exposed at Muchandi, and is NNW-SSE trending Chitradurga schist, Archean gneiss and younger granitic intrusion (Fig. 2). Chitradurga Group of rocks are mainly pelitic and metabasic schists with thin bands of quartzite and banded hematite quartzite (BHQ) at Muchandi and peninsular gneissic rocks are exposed in Markandeya river at Gokak (Fig. 3a and b).

Quartz arenite and conglomerate of Badami Group are exposed in the central part of study area. Rocks belonging to Kaladgi Supergroup, sandstone and conglomerate, are seen to be resting unconformably on the Dharwarian metasediments, which include hornblende schist (Day *et al.,* 2009). It shows varying lithofacies in different colors and sedimentary patterns. Intercalation of ferruginous shales is also seen in the down dip direction (Fig. 3c).

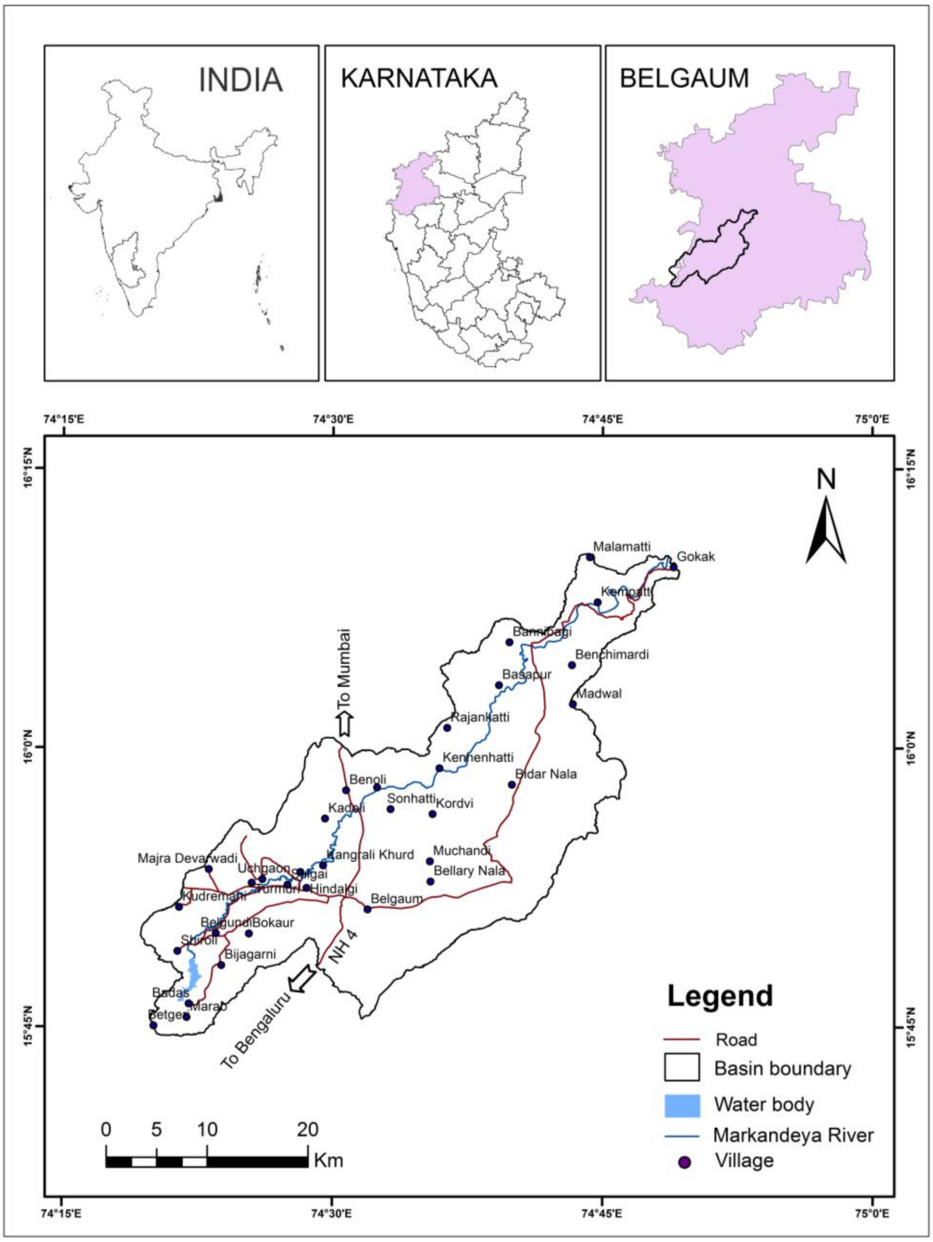


Fig. 1: Location map of study area.

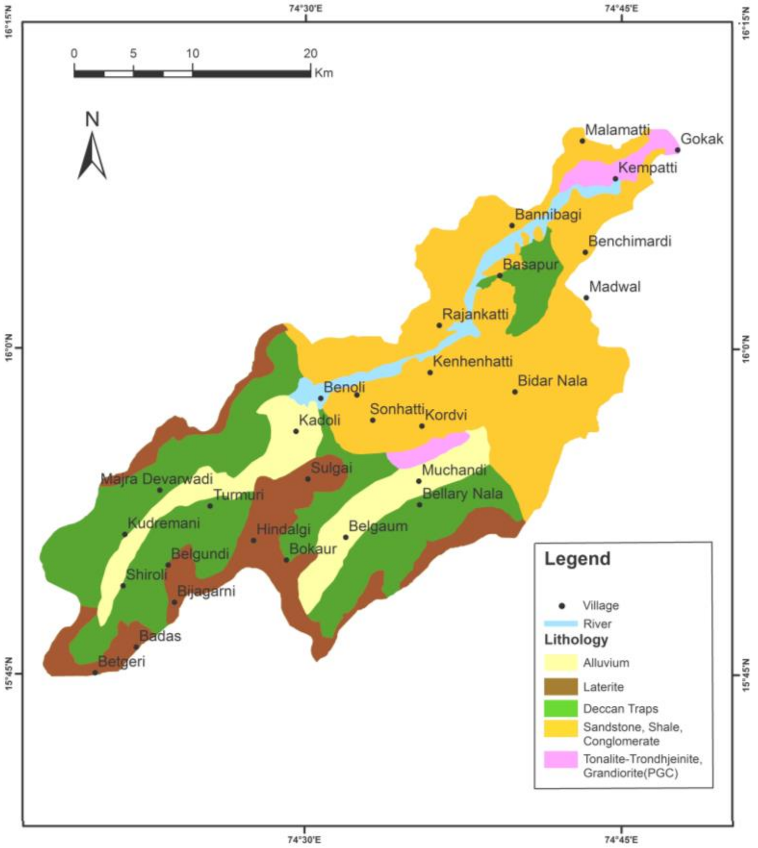


Fig. 2 Geological map of study area.

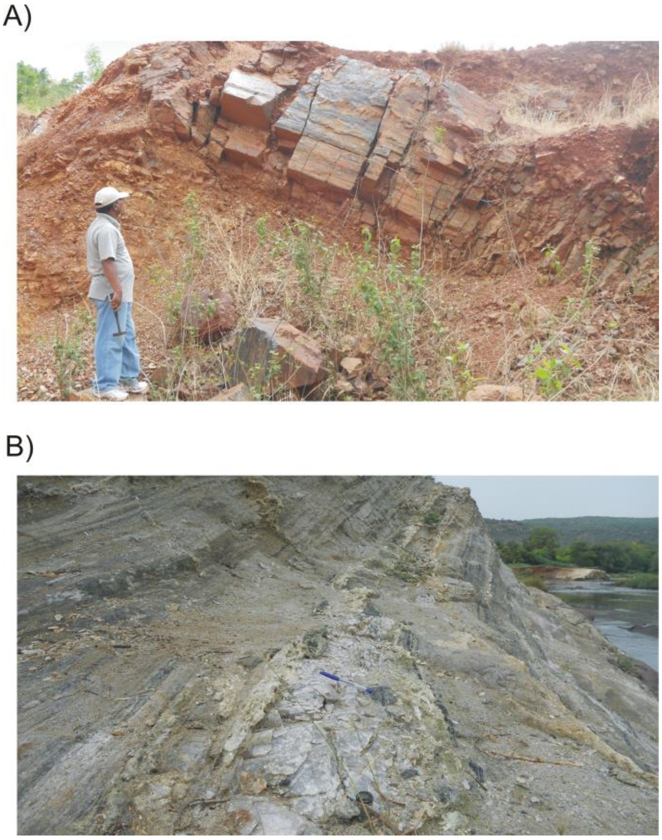


Fig. 3: A) Chitridurga Group of rocks exposed at Muchandi. B) Peninsular Gneissic rocks are exposed at Gokak C) Intercalation of sandstone and ferruginous shale exposed Kodali.

METHODOLOGY

The topographical information of the study area was georeferenced and digitized from Survey of India toposheets number 48 I/5, 48 I/9, 47 L/12 and 47 L/16, scale 1: 50,000; using Arc GIS 10.3. The streams were digitized and ordering was done using Strahler's method (Fig. 4). Quantitative morphometric analysis of basin characteristics such as area, perimeter, length of overland flow and basin relief etc. have been calculated from linear, areal and relief parameters using the mathematical equations (Table-1).

Table-1: Formulae adopted for computation of Morphometric parameters.

Sr. No.	Morphometric Parameters	Formula/Definition	References
1	Stream order (U)	Hierarchical order	Strahler,1964
2	Stream Length (LU)	Length of the stream	Hortan, 1945
3	Mean stream length (Lsm)	Lsm=Lu/Nu; Where, Lu=Mean stream length of a given order (km), Nu=Number of stream segment.	Hortan, 1945
4	Stream length ratio (RL)	RL= Lu / Lu-1 Where, Lu= Total stream length of order (u), Lu-1=The total stream length of its next lower order.	Hortan, 1945
5	Bifurcation Ratio (Rb)	Rb = Nu / Nu+1 Where, Nu=Number of stream segments present in the given order Nu+1= Number of segments of the next higher order	Schumn,1956
6	Basin relief (Bh)	Vertical distance between the lowest and highest points of basin.	Schumn,1956
7	Relief Ratio (Rh)	Rh = Bh / Lb Where, Bh=Basin relief, Lb=Basin length	Schumn,1956
8	Ruggedness Number (Rn)	Rn=Bh×DdWhere,Bh= Basin relief, Dd=Drainage density	Schumn,1956
9	Drainage density (Dd)	Dd=L/A Where, L=Total length of stream, A= Area of basin.	Hortan, 1945
10	Stream frequency (Fs)	Fs=N/A Where, L=Total number of stream, A=Area of basin	Hortan, 1945
11	Texture ratio (T)	T=N1/P Where, N1=Total number of first order stream, P=Perimeter of basin.	Hortan, 1945
12	Form factor (Rf)	Rf=A/(Lb)2 Where, A=Area of basin, Lb=Basin length	Hortan, 1945
13	Circulatory ratio (Rc)	Rc=4πA/P2Where A= Area of basin,π=3.14, P= Perimeter of basin.	Miller,1953
14	Elongation ratio (Re)	Re=√(Au/π)/ Lb Where, A=Area of basin, π=3.14, Lb=Basin length	Schumn 1956
15	Length of overland flow (Lg)	Lg=1/2Dd Where, Drainage density	Hortan, 1945
16	Constant of channel maintenance(C)	Ccm=1/Dd Where, Dd= Drainage density	Hortan, 1945
17	Hypsometric integral	HI = (E mean - E min) **/** (E max - E min) Where, E mean is the mean elevation, E min and E max are the minimum and maximum elevations within the river basin.	Pike and Wilson 1971

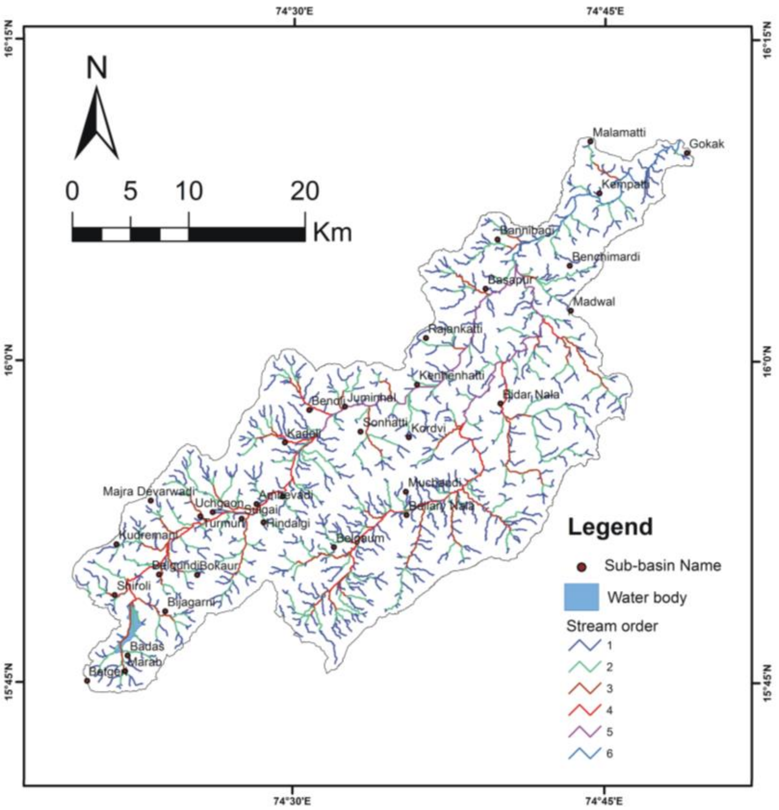


Fig. 4: Drainage map of study area.

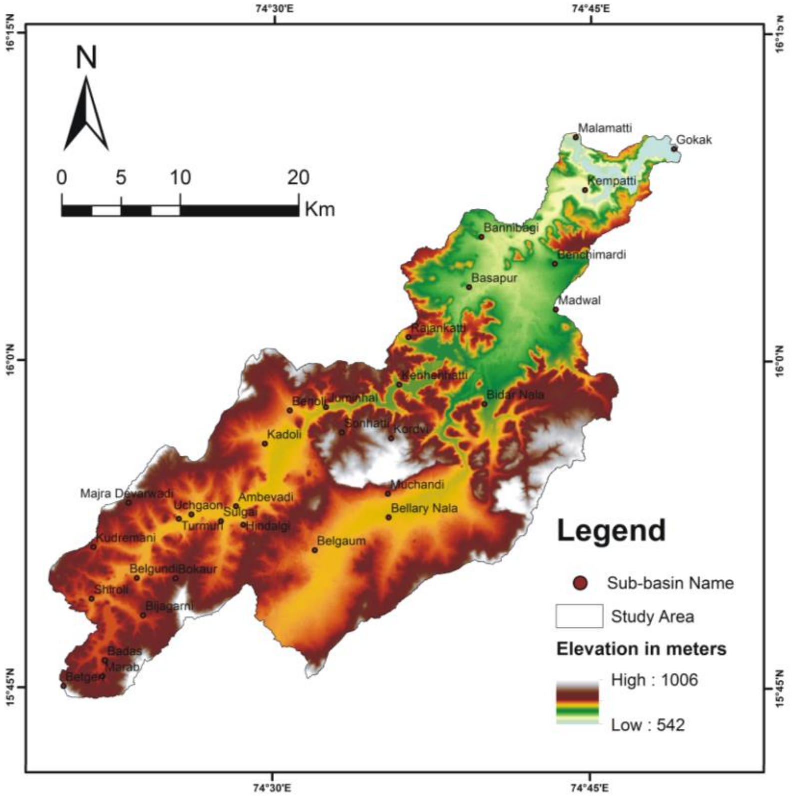


Fig. 5: DEM of study area.

The MRB has been delineated into 30 sub-basins. The contours were digitized to create the line feature class in Arc GIS which was further procedure using spatial analysis module to generate the digital elevation model (DEM; Fig. 5). Hypsometric analysis was carried out for thirty sub-basins using 30 m ASTER DEM. The hypsometric integral is obtained from the hypsometric curve and is equivalent to the ratio of the area under the curve to the area of the entire square formed by covering it. Hypsometric curves for all the third, fourth and fifth order basins, within the MRB were prepared and the percentage hypsometric integral value for each basin was calculated. The shape of hypsometric curves represents different stages of land degradation.

RESULTS AND DISCUSSION

Linear aspect

Stream order (u): The ordering of stream is classified by Strahler's method (1964). The stream length and stream numbers of MRB has been presented in Table-2 (a, b, c and d). The unbranched stream are designated as 1st order, the confluence of two 1st order streams give a stream segment of 2nd order, two 2nd order streams join to form a 3rd order and so on.

Table-2a: Linear aspects of third order sub-basin of Markandeya river basin (MRB).

Sub-basin	Stream order And No.			Total No. of Streams	Stream Length			Bifurcation Ratio		
	N_1	N_2	N_3		L1	L2	L3	Rb_1	Rb_2	Mean
Kempatti	6	2	1	9	6	1	2	3	2	2.5
Benchimardi	6	2	1	9	4	0.5	1.25	3	2	2.5
Kordvi	7	2	1	10	4.25	1.5	0.5	3.5	2	2.75
Bannibagi	16	4	1	21	11.5	5	3	4	4	4
Kenhenhatti	11	2	1	14	5	1.5	1.5	5.5	2	3.75
Benoli	7	3	1	11	3	5	0.5	2.33	3	2.6
Malamatti	25	6	1	32	12.5	4	4.5	4.16	6	5.08
Ambevadi	6	2	1	9	4.25	2.5	2.5	3	2	2.5
Turmuri	12	4	1	17	10	5	6	3	4	3.5
Majra Devarwadi	7	3	1	11	6	1.5	4	2.33	3	2.66
Kudremani	4	2	1	7	4	1.5	1	2	2	2
Shiroli	14	4	1	19	12.5	6	5	3.5	4	3.75
Betgeri	8	2	1	11	5	2.5	1.5	4	2	3
Badas	7	2	1	10	5	1.5	3	3.5	2	2.75
Belgundi	5	2	1	8	3	1.5	4	2.5	2	2.25
Bokaur	6	2	1	9	4.5	3.5	1.5	3	2	2.5
Hindalgi	10	3	1	14	4	4.5	1	3.33	3	3.16
Kangrali Khurd	7	2	1	10	4	3	1.5	3.5	2	2.75

Table-2b: Linear aspects of Fourth order sub-basin of Markandeya river basin (MRB).

Sub-basin	Stream Order And Number				Total number of Stream	Stream Length				Bifurcation Ratio			
	N_1	N_2	N_3	N_4		L_1	L_2	L_3	L_4	Rb_1	Rb_2	Rb_3	Mean
Madwal	34	8	2	1	45	25	10	5.5	2	4.25	4	2	3.41
Juminhal	39	9	3	1	52	31.5	10	5	6	4.33	3	3	3.44
Kadoli	25	8	2	1	36	24	7.5	2.5	4.5	3.12	4	2	3.04
Sonhatti	20	5	2	1	28	13	10.25	2.5	2.5	4	2.5	2	2.83
Rajankatti	28	6	2	1	37	19	7	3	1.5	4.6	3	2	3.03
Basapur	30	7	3	1	41	21	5.5	8	2	4.28	2.31	3	3.16
Uchgaon	17	5	2	1	25	18	6	8	1	3.4	2.5	2	2.63
Marab	13	5	2	1	21	10	3.5	1.5	1	2.6	2.5	2	2.3
Bijagarni	26	4	2	1	33	5.5	6	3	3.5	4	3	2	3
Sulgai	39	13	4	1	57	22	11	4.5	6.5	3	3.5	4	3.41

Table-2c: Linear aspects of fifth order sub-basin of Markandeya river basin (MRB).

Sub-basin No	**Stream Order And No.**					**Total No Of Stream**	**Stream Length**					**Bifurcation Ratio**				
	N_1	N_2	N_3	N_4	N_5		L_1	L_2	L_3	L_4	L_5	Rb_1	Rb_2	Rb_3	Rb_4	Mean
Bidar Nala	85	22	4	2	1	114	76	23	11.5	12	6	3.86	5.5	2	2	3.34
Bellari Nala	184	56	13	4	1	258	141	82	42	20	16	3.28	4.30	3.25	4	4

Table-2d: Linear aspects of Markandeya river basin (MRB).

Sub-basin No.	**Stream Order And No.**						**Total No Of Stream**	**Stream Length**					**Bifurcation Ratio**				
	N_1	N_2	N_3	N_4	N_5	N_6		L_1	L_2	L_3	L_4	L_5	Rb_1	Rb_2	Rb_3	Rb_4	Rb5
Markandeya river	704	197	48	16	2	1	968	515	234	142	63	22	3.57	4.10	3	8	2

Stream number: It's the number of stream segments of various orders within MRB. Furthermore, availability of large number of streams indicates the topography is still undergoing erosion. In the sixth order MRB under study, there are two fifth order, 10 fourth orders and 18 third order basin are present.

Bifurcation Ratio (Rb): This ratio is used to express the ratio of the number of streams present of any given order to the number of streams in next higher order (Schumm, 1956). Bifurcation ratio above two reflects flat topography and between 3 and 4 indicates mountainous or highly dissected drainage basin, whereas ratios greater than 5 indicate structurally controlled drainage basin (Horton, 1945). The basins within the alluvial plains having higher order ratios of approximately 2 indicate the lower part of the basin is flat, whereas ratios of lower order when high indicate streams of highly dissected drainage basins.

Eighteen third-order sub-basins are present in MRB. Out of these eighteen, there are two sub-basins *viz.,* Kenhenhatti and Malamatti whose bifurcation ratio ranges between 2 to 5.5 and 4.16 to 6.0 respectively. This suggests they are structurally controlled basins. The rest of the sixteen sub-basins bifurcation ratio ranges between 2 and 4. This suggests them to be natural stream system. The bifurcation ratio of the lower order streams displays higher values, reflecting high dissection of the upland area (Table-2a). For the fourth order ten sub-basins, the bifurcation ratio ranges between 2 and 4.6, indicating natural stream system (Table-2b). Bidar nala sub-basin is a fifth order for which the bifurcation ratio ranges between 2 and 5.5. These values suggest it to be structurally controlled drainage system (Table-2c). In this sub-basin two prominent N-S trending lineaments are present. Bellari nala bifurcation ratio ranges between 3.25 and 4.30, indicating it to be a natural stream. The overall bifurcation ratio of MRB ranges between 2 to 8. Hence, it is structurally controlled drainage network (Table 2-d).

Drainage Density (Dd): It is the ratio of total stream length, cumulated for all orders within a basin, to the basin area, which is expressed in terms of km/km^2 (Horton, 1932). Drainage density has been recognized as topographic characteristic of fundamental significance. Permeable rocks, with a high infiltration rate, reduce overland flow, as a consequence of which the drainage density becomes low. Low drainage density generally results in areas that are highly resistant to erosion and weathering or contain permeable sub-soil material, dense vegetative cover and low relief (Nag, 1998). Thus, drainage density is a sensitive parameter which in many ways provides the link between the forms attributes of the basin and the processes operating along the stream course (Gregory and Welling, 1973). It also reflects the landuse and affects infiltration and the basin response time between precipitation and discharge. It is also of geomorphological interest particularly for the development of slopes. Basin with high Dd indicates that a large proportion of the precipitation runs off. On the other hand, a low drainage density indicates rainfall infiltrates the ground and few channels are required to carry the runoff (Roger, 1971).

Table-3a: Aerial aspects of third order sub-basin of Markandeya river basin (MRB).

Sub-basin Name	Dd	DT	Fs	Ccm	Re	Rc	Ff	Lg
Kempatti	2.09	1	2.09	0.478	0.75	0.66	0.45	0.24
Benchimardi	1.3	1.12	2.0	0.78	0.74	0.87	0.44	0.59
Kordvi	2.4	1.66	3.78	0.46	0.69	0.92	0.37	0.20
Bannibagi	1.8	1.31	1.95	0.55	0.59	0.53	0.27	0.27
Kenhenhatti	1.7	1.33	2.68	0.58	0.54	0.59	0.23	0.29
Benoli	2.4	0.57	0.41	0.42	1.73	0.92	1.0	0.21
Malamatti	1.90	3.55	2.90	0.52	0.79	1.70	0.50	0.26
Ambevadi	1.5	0.90	1.43	0.67	0.69	0.39	0.38	0.33
Turmuri	2.3	1.06	1.88	0.42	0.52	0.44	0.21	0.22
Majra Devarwadi	0.6	1.10	0.61	1.55	0.95	1.12	0.71	0.83
Kudremani	0.50	0.35	0.53	0.64	0.58	0.82	0.27	1.0
Shiroli	2.0	1.31	1.61	0.63	0.77	0.70	0.47	0.25
Betgeri	1.3	0.95	1.56	0.78	0.85	0.66	0.57	0.38
Badas	1.9	1.11	2.04	0.51	0.50	0.75	0.20	0.26
Belgundi	1.6	0.80	1.58	0.59	0.59	0.32	0.28	0.31
Bokaur	1.4	0.85	1.27	0.70	0.70	0.42	0.38	0.36
Hindalgi	2.11	1.80	3.11	0.47	0.75	0.94	0.44	0.24
Kangrali Khurd	2.4	0.95	1.44	0.414	0.40	0.41	0.12	0.21

Table-3b: Aerial aspects of fourth order sub-basin of Markandeya river basin (MRB).

Sub-basin Name	Dd	DT	Fs	Ccm	Re	Rc	Ff	Lg
Madwal	1.43	1.59	1.51	0.69	0.64	0.47	0.33	0.35
Juminhal	1.88	2.42	1.86	0.53	0.74	0.75	0.34	0.5
Kadoli	1.57	1.87	1.46	0.63	0.50	0.83	0.20	0.32
Sonhatti	2.02	1.80	2.0	0.49	0.76	0.72	0.46	0.25
Rajankatti	2.3	2.46	2.82	0.43	0.85	0.73	0.57	0.22
Basapur	1.7	2.10	1.92	0.58	0.85	0.70	0.57	0.29
Uchgaon	1.73	1.39	1.31	0.57	0.70	0.74	0.38	0.29
Marab	2.06	1.75	2.71	0.484	0.87	0.67	0.60	0.24
Bijagarni	0.9	2.06	1.71	1.07	0.76	0.95	0.46	0.55
Sulgai	1.5	2.42	1.92	0.67	0.62	0.67	0.31	0.33

Table- 3c: Aerial aspects of Fifth order sub- basin of Markandeya river basin (MRB).

Sub-basin Name	Dd	DT	Fs	Ccm	Re	Rc	Ff	Lg
Bidar Nala	1.65	1.25	0.41	0.60	0.69	0.52	1.07	0.30
Bellari Nala	1.08	6.0	3.35	0.92	0.58	0.42	0.11	0.46

Table-3d: Aerial aspects of Markandeya river basin.

Sub-basin Name	Dd	DT	Fs	Ccm	Re	Rc	Ff	Lg
Markandeya River	1.01	5.23	0.92	1.01	0.39	0.38	0.12	0.50

Dd-Drainage density, DT-Drainage Texture, Fs-Stream frequency, Ccm-Constant of Channel maintenance, Re-Elongation ratio, Rc-Circularity ratio, Ff-Form factor, Lg-Length of overland flow

Within MRB the following are third order drainage sub-basins which have Dd low values ranging between 0.50 and 2.0 km/km^2. They are Benchimardi, Bannbagi, Kenhenhatti, Ambevade, Majra Devarwadi, Kudremani, Shiroli, Betgeri, Badas, Belgundi and Bokaur. The Dd values indicate them to be of low drainage density. For Kempatti, Kordvi, Benoli, Turmuri, Hindalgi and Kangrali Khurd sub-basins, the Dd values ranges between 2.10 to 2.4 km/ km^2 reflecting moderate drainage density (Table-3a). Sonhatti, Rajankatti and Marab sub-basin, Dd value ranges between 2.02 and 2.3 km/ km^2. It indicates moderate drainage density (Table-3b).

Fourth order drainage sub-basins viz., Bijagarni, Madwal, Kadoli, Basapur, Uchgaon, Juminhal and Sulgai, Dd values range between 0.9 and 1.57 km/km^2, indicating low drainage density (Table 3-c). Fifth order Bidar and Bellari drainage sub-basin, have Dd value from 1.65 to 1.08 km/ km^2 respectively; indicative of low drainage density (Table-3c). The overall Dd for MRB is quite low, 1.01 km/km^2.

Stream Frequency (Fs): The number of streams per unit area is known as stream frequency (Horton 1945). 'Fs' is an index of various stages of landscape evolution. It is found that the third, fourth and fifth order sub-basin have low values of stream frequency. Low Fs values indicate gentle slope and high permeability of rocks within a basin.

Drainage Texture (Rt): Horton (1945) defined drainage texture is the total number of stream segments of all orders in a basin per perimeter of the basin. Smith (1950) has classified drainage texture into 5 different textures *i.e.,* very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). In MRB all third, fourth and fifth order sub-basins are seen to have coarse to very coarse texture, except Bellari nala which has a fine texture. Overall, MRB has moderate texture (Table-3, a, b, c and d).

Length of Overland Flow (Lg): The term 'Lg' is used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels. In the study area 'Lg' of the third order sub-basin ranges between 0.2 -1.0; fourth order sub-basin ranges between 0.22-0.55; and fifth order sub-basins ranges between 0.30 -0.46. More the 'Lg' values represent long time of flow in the basin. In MRB, only Kudremani and Majra Devarwadi sub-basins have high 'Lg', indicating long flow time. The remaining sixteen third order sub-basins have low Lg indicating quick surface runoff with higher slope.

Constant of Channel Maintenance (Ccm): The 'Ccm' parameter has been suggested by Schumm (1956). It is an inverse of drainage density. A higher 'Ccm' is indicative of higher permeability of the rocks of the basin and vice versa. The third order sub-basin of MRB has 'Ccm' that ranges between 0.41 and 1.55; the fourth order sub-basin between 0.43 and 1.07; and fifth order is from 0.60 and 0.92. The overall MRB Ccm is 1.0 (Table 3-a, b, c and d). This high value of 'Ccm' reveals strong control of lithology with a surface of high permeability.

Areal Aspect: The areal aspect is a two dimensional property of a basin. It is possible to delineate the area of the basin which contributes water to each stream segment.

Elongation Ratio (Re): Elongation ratio (Re) defined as, 'the ratio of diameter of a circle of the same area as the basin to the maximum basin length Schumm (1956). These values can be grouped into four categories, namely; elongated- (<0.7), less elongated-(0.8-0.7), oval–(0.9-0.8), and circular- (>0.9).

Based on 'Re' the third order sub-basins like Kordvi, Bannibagi, Kenhenhatti, Ambevadi, Turmuri, Kudremani, Badas, Belgundi, Bokaur and Kangrali Khurd are inferred to have elongated shape; while Kempatti, Benchimardi, Malamatti, Shiroli and Hindalgi sub-basin are inferred to be less elongated. The Betgeri sub-basin is deduced to have oval shape and Benoli and Majra Devarwadi sub-basin have circular shape (Table-3a). The fourth order Madwal, Kadoli, Uchgaon and Sulgi sub-basins are elongated, whereas Juminhal, Sonhatti and Bijagarni sub-basin are inferred to be less elongated. The Rajankatti, Basapur and Marab sub-basins have oval shape (Table-3b). The fifth order Bidar and Bellari nala are considered to be elongated (Table-3c).

Overall, the MRB is inferred to be elongated (Table-3d), since it has greater time for the water from the upper regions of the basin to reach the outlet (Verstappen, 1983). A lower 'Re' value of the basin indicates lesser vulnerability to flash floods and consequently easier flood management (Jobin Thomas *et al.,* 2012).

Circularity ratio (Rc): The circularity ratio is a measure similar to elongation ratio. Miller (1953) defined as, 'the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter'.

The circularity ratio for third order sub-basins in MRB is in the range of 0.32 to 1.0. The Belgundi, Bokaur and Kangrali Khurd sub-basin exhibit the lowest value, whereas Malamatti and Majra Devarwadi show a high value of 1.0. The circularity ratio for fourth order sub-basin is in the range of 0.47 to 0.95. The Madwal sub-basin shows the lowest value (0.47), whereas, Bijagarni sub-basin shows high value. Fifth order Bidar and Bellari nala shows elongated shape. The MRB reveals it has the lowest value, indicating elongated shape of the basin.

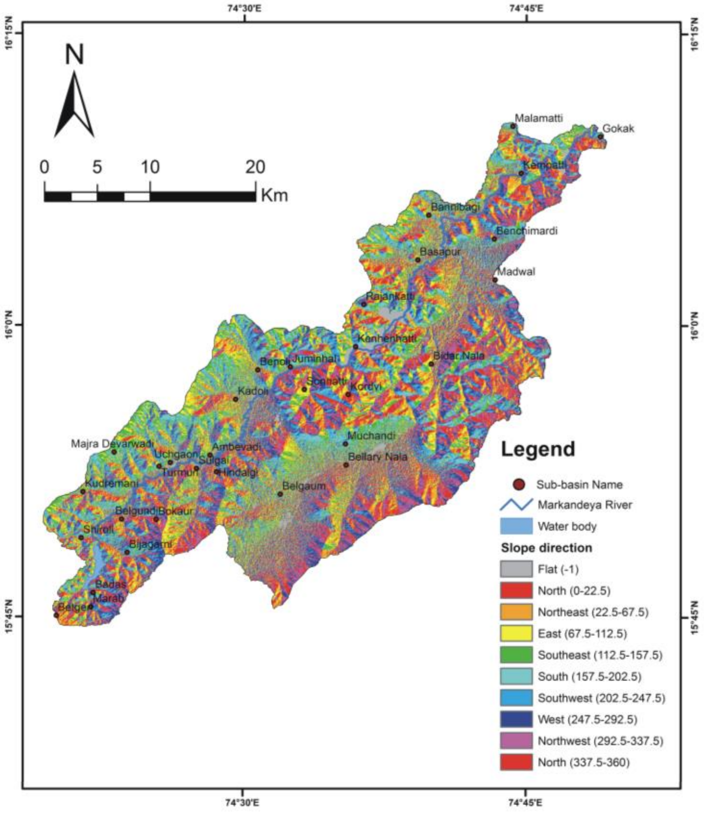


Fig. 6: Aspect map of study area.

Form factor (Ff): The alluvial basins are seen to show low Ff, which represent elongated in shape. High Ff values reveal maximum water flows of short duration, and elongated basins with low Ff show minimum water flow of longer duration. The third order sub-basin Ff value was found to be between 0.12-1.0; for fourth order it is between 0.20-0.60; and fifth order is between 0.11-1.0. Overall MRB has low Ff value (0.12) indicating it to be an ideal elongated shaped basin.

Relief aspect: It is a significant parameter of drainage basin and has great impact on the hydrologic response, which is seen to depend on the stream type and relative relief of the basin.

Aspect Map: Aspect map interpret the direction to which a mountain slope faces. The aspect map of MRB is shown in Fig. 6. From the visual interpretation it is observed that east, NE and SE facing slopes occur in the Kadoli, Sulgai, Sonhatti, Shiroli, Kudremani, Turmuri, Majra Devarwadi, Uchgaon, Bellari and Bidar Nala sub-basin. Remaining sub-basins it is clearly seen that west and southwest facing slope.

Slope Map: A slope map provides data for planning, settlement, soil and water conservation practices (Sreedevi et al., 2005). A slope map of the study area has been prepared with the help of SRTM data using ARC-GIS software (Fig. 7). The degree of slope in MRB varies from 0° to >35°. The sub-basins *viz.,* Majra Devarwadi, Turmuri, Uchgaon, Betgeri, Bokaur, Marab, Benoli, Juminhal, Madwal and Bidar nala have higher degree of slope.

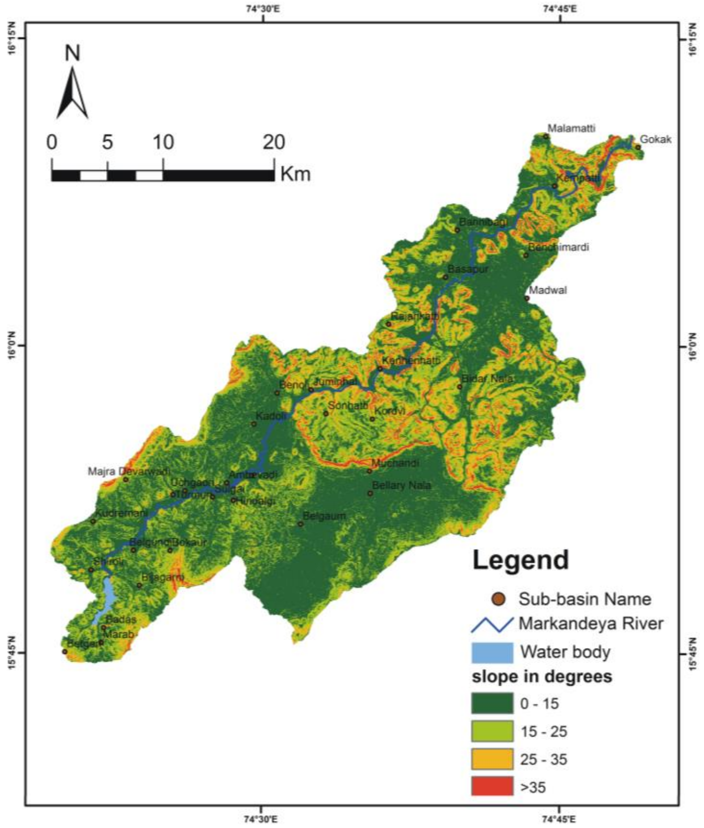


Fig. 7: Slope map of study area.

Basin Relief (R): Basin relief is the elevation difference of the highest and lowest point of the drainage basin (Schumm, 1956). It is a significant parameter in understanding weathering, erosion and transportation of the basin. Basin relief parameter determines the stream gradient and influences flood pattern and volume of sediment that can be transported (Hadley and Schumm, 1961). In third and fourth order sub-basin, basin relief value ranges from 20 to 240 m (Table-4a, b). Fifth order Bidar and Bellari nala contain basin relief value of 220 and 322 m respectively (Table-4c). The Markandeya River, basin relief value is 484 m which reveals old stage of development of the basin (Table-4d). Third order Bannibagi, Turmuri and Majra Devarwadi sub-basins have moderate relief. Fourth order Uchgaon and Sulgai sub-basins have high relief and remaining eight sub-basins contain moderate relief.

The fifth order Bidar and Bellari nala sub-basins have moderate relief, and mature to old stage development of the basin respectively.

Table-4a: Computed parameter of Area, Perimeter, Highest and Lowest elevation points, relief, Stream length and Relief ratio of third order sub-basin.

Sub-basin	A	P	HE	LE	R	Lb	HI	IF
Kempatti	4.3	9	761	620	141	3.1	0.76	EY
Benchimardi	4.48	8	760	640	120	3.2	0.60	M
Kordvi	2.64	6	780	680	100	2.65	0.88	EY
Bannibagi	10.76	16	940	700	240	6.25	0.62	LY
Kenhenhatti	5.21	10.5	820	720	100	4.75	0.84	EY
Benoli	26.4	19	720	680	40	3.35	0.44	M
Malamatti	11	9	750	560	190	4.7	0.78	EY
Ambevadi	6.27	10	760	740	20	4.05	0.74	EY
Turmuri	9.01	16	980	740	240	6.5	0.48	LM
M. Devarwadi	17.85	10	940	740	200	5.0	0.48	LM
Kudremani	13.1	20	900	740	160	7.0	0.52	EM
Shiroli	11.8	14.5	870	740	130	5.0	0.52	EM
Betgeri	7.03	11.5	820	760	60	3.5	0.48	M
Badas	4.88	9	920	760	160	5.0	0.52	EM
Belgundi	5.05	10	850	760	90	4.25	0.56	EM
Bokaur	7.05	10.5	860	760	100	4.25	0.46	LM
Hindalgi	4.5	7.75	770	740	30	3.2	0.68	LY
Kangrali K.	6.9	10.5	820	740	80	7.5	0.66	LY

Table-4b: Computed parameters of Area, Perimeter, Highest and Lowest elevation points, relief, Stream length and Relief ratio of Fourth order sub-basin.

Sub-basin	**A**	**P**	**HE**	**LE**	**R**	**Lb**	**HI**	**IF**
Madwal	29.72	28.25	733	659	71	9.5	0.56	EM
Juminhal	27.9	21.5	840	740	100	8.0	0.6	EM
Kadoli	24.5	19.2	910	730	180	5.6	0.56	EM
Sonhatti	13.9	15.5	860	720	140	5.5	0.64	LY
Rajankatti	13.12	15	850	680	170	4.8	0.88	EY
Basapur	21.37	19.5	740	680	60	6.1	0.52	EM
Uchgaon	19.00	18	940	720	220	7.0	0.36	LM
Marab	7.75	12	780	760	20	3.6	0.48	M
Bijagarni	19.3	16	890	760	130	6.5	0.54	EM
Sulgai	29.60	23.5	980	740	240	9.75	0.7	EY

Table-4c: Computed parameters of Area, Perimeter, Highest and Lowest elevation points, relief, Stream length and Relief ratio of Fifth order sub-basin.

Sub-basin	**A**	**P**	**HE**	**LE**	**R**	**Lb**	**HI**	**IF**
Bidar Nala	77	43	900	680	220	14.2	0.52	M
Bellari Nala	276	90	1002	680	322	32	0.34	O

Table- 4d: Computed parameters of Area, Perimeter, Highest and Lowest elevation points, relief, Stream length and Relief ratio of Fifth order sub-basin.

Basin	A	P	HE	LE	R	Lb	HI	IF
Markandeya River	1052	185	1026	542	484	94	0.32	O

A-Area (Sqkm), P-Perimeter (Km), HE- Elevation of Highest point on Basin (m), LE-Elevation of Lowest point on Basin (m), R-relief, Lb- Stream length, Rr-Relief ratio, HI-Hypsometric integral, IF-Inferences

Hypsometric analysis: Hypsometric analysis (area-altitude analysis) is the study of the distribution of horizontal cross-sectional area of a landmass with respect to elevation (Strahler, 1952). Naturally, hypsometric analyses have been used to differentiate between erosional landforms at different stages during their evolution (Strahler, 1952; Schumm, 1956). Hypsometric integrals (HI) and curves can be interpreted in terms of degree of basin erosion and relative landform age: Convex-up curves with high integrals are typical for youthful stage, undissected landscapes; smooth, 'S'-shaped curves crossing the centre of the diagram characterize mature (equilibrium stage) landscapes, and old stage of basin is related to concave-up with low integrals indicate highly eroded, deeply dissected landscapes (Strahler, 1952). The hypsometric curves for these basins are illustrated in Fig. 8 (a and b) and the hypsometric integral values for individual basin are given in Table-4 (a, b, c and d). Out of eighteen third order basins, eight sub-basins, *viz.,* Kempatti, Bannibagi, Kordvi, Kenhenhatti, Malamatti, Ambevadi, Hindalgi and Kangrali Khurd reveal HI values between 0.62 and 0.98, indicating youth geomorphic stage of development. The curve characteristics and integral values are indicative of youthful stage where large proportion of upland surface has not yet transformed into valley wall slopes (Fig. 8a and b). The sub-basins like Kempatti, Kordvi, Kenhenhatti and Malamatti belong to early youthful stage. These four basins are located in semi-arid climatic region. The third order sub-basins showing youth geomorphic stages lie on Kaladgi sandstone, Deccan Trap basalt and laterites. Ten sub-basins, Benchimardi, Benoli, Turmuri, Majra Devarwadi, Kudremani, Badas, Belgundi, Shiroli, Betgeri and Bokaur show hypsometric integral values between 0.44 and 0.56, indicating equilibrium–mature geomorphic stage of the development (Fig. 8a). These mature stage third order sub-basins form part of Deccan Trap basalt and laterites, lying within tropical climate zone.

In fourth order basins like Sonhatti, Rajankatti and Sulgi hypsometric integral values are found to be from 0.64 to 0.88 and show concave-convexity in the central and lower parts of the curves (Fig. 8b). These curve characteristics and integral value are indicative of youthful geomorphic stage. Low hypsometric integrals indicate old and more eroded area, whereas higher values indicate young and less eroded area. This means the basin with lower hypsometric values has less total runoff; whereas higher values reflect higher total runoff. At the same time, Sulgi, Rajankatti and Sonhatti sub-basins show concavity in the upper part indicating some relief in the dividing area. These sub-basins are located within semi-arid climatic zone. These youthful fourth order basins lie on Kaladgi sandstone; pebbly feldspathic conglomerate and Deccan Trap basalts. The fourth order other seven sub-basins, viz., Madwal, Juminhal, Kadoli, Basapur, Uchgaon, Bijagarni and Marab show hypsometric integral values between 0.36 and 0.60. The hypsometric curve for these sub-basins approximately through the centre of the plots and suggests mature geomorphic stage of development (Fig. 8b). Kadoli, Uchgaon, Bijagarni and Marab lie in tropical wet climatic zone. These fourth order basins are underlain by Kaladgi sandstone, Deccan Trap basalt and laterites. The sub-basins, Madwal, Juminhal and Basapur are within semi-arid climatic zone, and lie on Kaladgi sandstone and shale intercalations.

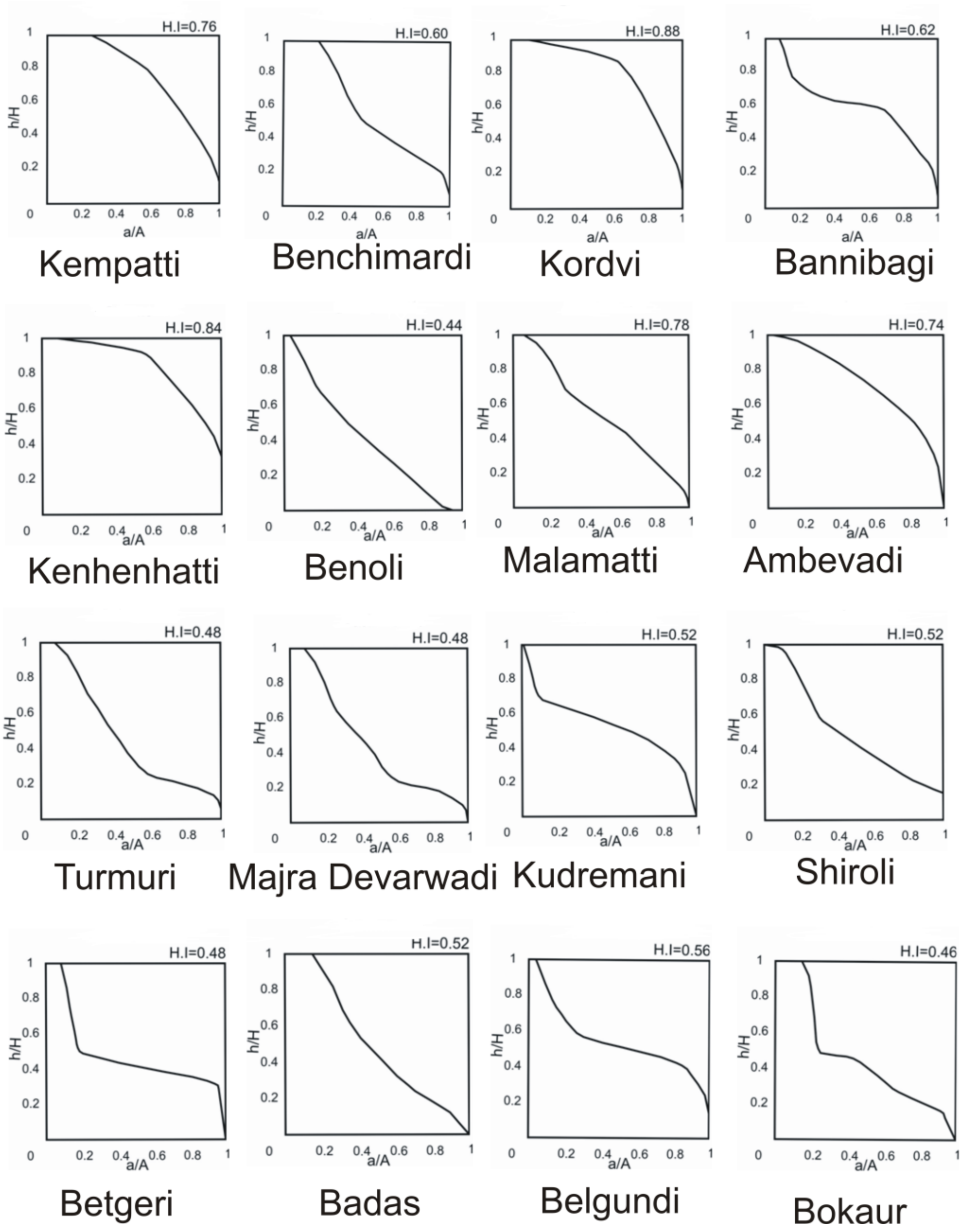
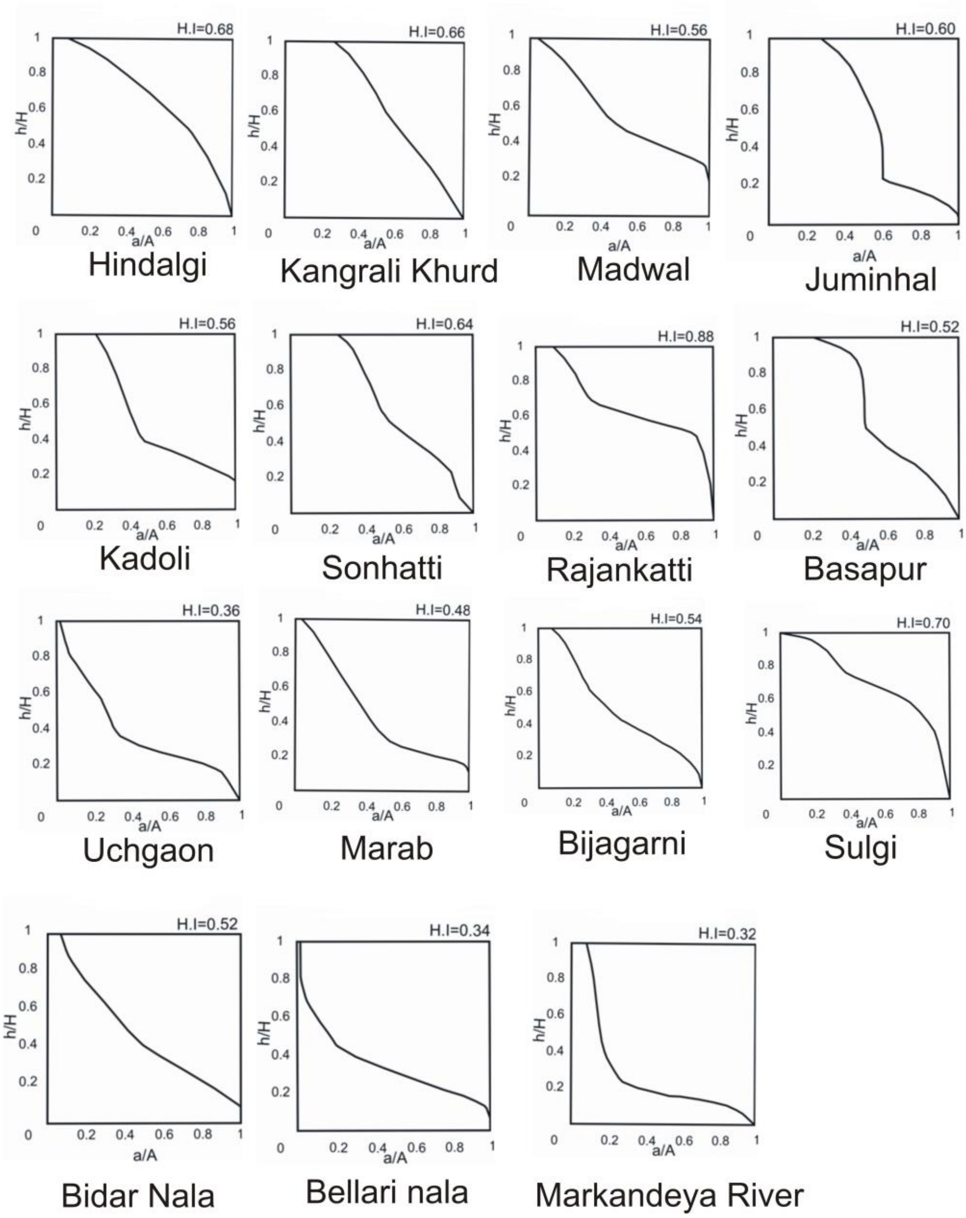


Fig. 8a: Hypsometric curve of third order sub-basin of Markandeya river basin.

For the two fifth order basins, namely Bellari and Bidar nala, the hypsometric integral values are between 0.34 and 0.52 respectively. The Bellari Nala curve shows a very steep slope in the upper part with slightly concave form in the central part. These curve characteristics and the integral value below 0.35 is suggestive of development of old or monadnock stage. These basins are underlain by Kaladgi sandstone, intercalations shale, Deccan Traps basalt, laterites and alluvium. For Bidar nala hypsometric integral value is 0.52 and is suggestive of early mature geomorphic stage. In this basin, sandstone and conglomerate are observed (Fig. 7b). The calculated hypsometric integral value for sixth order MRB is 0.32. The hypsometric curve for this basin are on the lower side from across the centre of the diagram and show concave shape in the centre with a very steep slope in the upper part of the curves. The integral value below 0.35 and concave shape in the centre of the hypsometric curve are characteristics of monadnock stage of development. The hypsometric integral values between 0.35 (35%) and 0.60 (60%) are indicative of equilibrium; greater than 0.60 (60%) indicate inequilibrium; and less than <0.35 (35%) indicate a temporarily monadnock or old stage of development (Strahlar, 1952). The hypsometric integral (HI) values obtained for MRB is computed to be 0.32, which reveals that only 32% of the landmass remain in the basin to be eroded.



Hindalgi
Kangrali Khurd
Madwal
Juminhal
Kadoli
Sonhatti
Rajankatti
Basapur
Uchgaon
Marab
Bijagarni
Sulgi
Bidar Nala
Bellari nala
Markandeya River

Fig. 8b: Hypsometric curve of fourth, fifth order sub-basin and Markandeya river basin.

To summarize, the situation with respect to availability of water for drinking and other purposes is getting quite alarming. The Indian peninsular region especially the Krishna river basin is beset with water scarcity, which is exacerbated by the seasonality of the Indian monsoon. The rising population is putting immense strain on the water needed for drinking and agriculture. The MRB a sub basin of the Krishna River lies within one of the driest regions of India and impacts thousands of people living within the basin. The streams flowing within the MRB are seen to be structurally controlled at some places and are coursing through the natural stream system. The moderate to high relief, especially in the upland area, is dissected effectively by the streams. However, the lineaments and possible faults are seen to control flow of some of the streams in the low gradient areas. However, the bifurcation ratio for the entire MRB indicates it has structurally controlled drainage network. The MRB is characterized by low to moderate drainage density over some of the regions. However, the overall drainage density for MRB is quite low, 1.01 km/km^2. This indicates the spread of flow is evenly distributed over the basinal region. It also has moderate texture. The water management task can be carried more effectively when the need arises during the time of an emergency. The run off pattern of the drainage is quite curious and is influenced by the lithology present in the basin. The MRB is situated on the Kaladgi and Deccan Trap basalts as well as the recent alluvium which has an appreciable quantum of porosity and permeability. It means the loss of water to atmosphere is minimal. It also means the recharge of depleted aquifers can be very fast or gradual. The knowledge of vigorous replenishment of subsurface waters and long runoff of drainage can aid in helping managing the water for drinking and agriculture. The study carried on MRB has indicated it to be an elongated basin. The implication of this finding is that the water has more time to reach its mouth from origin. This will preclude vulnerability to flash floods and easy flood management. The river has old or monadnock stage. The MRB is prone and quite amenable for judicious water management techniques.

CONCLUSIONS

The analysis of morphometric parameters and hypsometric integral are found to be a significant work in river basin evaluation, for soil and water conservation. In order to understand the erosional stages and structural control on various landforms, morphometric and hypsometric analysis has been carried out for the Markandeya river basin (MRB) along with their thirty sub-basins. The MRB are structurally controlled basin. The low value of drainage density, stream frequency and length of overland flow reveals that the basin is composed of permeable sub-surface materials and moderate relief causing lower surface runoff and a lower level of erosion with moderate texture. The computed value of circularity ratio, elongation ratio and form factor suggests that the MRB has elongated in shape and flatter peak flow for longer duration. The analyzed relief parameters of the area indicate moderate to high relief, moderate runoff and structural control of the basin with high susceptible to erosion. The results of Hypsometric analysis for MRB suggests the monadnock or old stage of landscape and only 32% of the landmass remain in the basin to be eroded. This research work will contribute to take proper assess to preserve soil and water resources for sustainable development of the basin area.

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