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Morphometric study of river subbasin using remote sensing and geographic information system (GIS)

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Abstract
During present study, subbasin of Kayadhu river was analyzed for different morphometric aspects. The study basin is located in Hingoli district of Maharashtra state, India and spread across 19°52'11.5" N to 19°45'49.1" N Latitudes and 77°02'20.0" E to 77°09'03.0" E Longitudes. The drainage basin and river streams were delineated from Survey of India (SOI) Topographic maps (1:50000 scale) whereas SRTM DEM data was used for estimation of elevation and relief parameters of the basin. The streams of the study basin were order following Strahler method and different morphometric parameters related to linear, aerial as well as relief aspects were estimated. The subbasin of Kayadhu river under study was 5th order basin with semi-dendritic drainage pattern. The basin was spread across 85.45 sq. km area with 37.76 km perimeter encompassing 189 number of streams of different orders as well as four water reservoirs. The study revealed that the basin had drainage density of 1.69 sq./km, mean stream frequency of 2.21 streams/ sq. km and texture ratio of 3.79. This inferred that the basin had lower surface runoff as well as permeable subsoil making it prone to the flooding and lesser dissected basin. The estimated values of form factor (0.66), circulatory ratio (0.75) and elongation ratio (0.92) suggest that the basin is circular in shape with some structural disturbance and risk of flooding. The calculated values of Constant channel maintenance (0.59 sq.km/km) and stream length ratio concludes that basin is still in late geomorphic development phase. The relief parameters of the basin lead to the conclusion that the basin has steeper slope and related degradation.

Keywords: Drainage basin, morphometric analysis, Kayadhu, Hingoli, toposheets, remote sensing, GIS

Introduction
Hingoli district is situated in the Marathwada region of the Maharashtra state. Kayadhu river is major river system of the district flowing through its central part throughout the district. The Kayadhu river and its tributaries form the major water resource for the district. These water resources are utilised for different purposes including irrigation, drinking, aquaculture and other water-dependent activities.

Understanding the morphometric characteristics of the basin can help in assessing the water availability and planning for the water resource management in the region. Morphometric analysis of a river basin involves the quantitative assessment of various parameters of the basin related to linear, aerial and relief aspects. Such study is useful for understanding the underlying processes that govern the behaviour of the basin and provides a framework for quantifying the spatio-temporal characteristics of a river basin which helps in identifying the variations in the landscape that are critical for understanding the hydrological processes. Such investigation is significant for understanding the hydrological processes occurring within the basin as well as for planning and management of water resources.

Geographic Information System (GIS) and remote sensing are very useful tools for morphometric analysis of basins as these are cost effective, time efficient and less laborious. Therefore, various researchers are working on morphometric study of basins using remote sensing and GIS tools. During the study of two tropical mountain river basins of contrasting environmental settings in the southern Western Ghats, India, Thomas *et al*., (2012) [18] used GIS methods for morphometric study and concluded that drainage network expresses prevailing climate, geology, tectonic framework of basin as well as interrelation between drainage parameters. Their study also discovered that morphometric parameters reveals prevailing climate of the basin. Therefore, analysis of drainage basis is important for establishing correlation of hydrological processes with morphometric characteristics such as size, shape, drainage density, basin order, relief, et

Chougale and Sapkale, 2017 [2] studied Kadvi river basin in Kolhapur, Maharashtra using Cartosat data for different morphometric parameters. Morphometric study of Morar River basin by Singh *et al*., (2013) [12] using GIS techniques leads to the conclusion that the river basin is elongated with low relief, homogeneity in texture as well as high permeability of subsurface formation. They found GIS based approach more appropriate for evaluation of drainage basin was than conventional methods. Waikar and Nilawar (2014) [19] also found Remote sensing and GIS techniques more accurate and efficient tool in drainage delineation as well as its updation during morphometric analysis of drainage basin in Parbhani District.

Therefore, the attempt were made for study of morphometric parameters related to linear, aerial as well as relief aspects of the subbasin of Kayadhu river in Hingoli district using remote sensing and GIS tools.

Study area

The subbasin of Kayadhu river in Hingoli district, Maharashtra, India was studied for estimation of different morphometric parameters. The basin is spread across 19°52'11.5" N to 19°45'49.1" N Latitudes and 77°02'20.0" E to 77°09'03.0" E Longitudes (Map 1). The subbasin drains water from Khandala, Bhandegaon, Satamba, Malselu, Chorjawala, Boralwadi, Jaipurwadi, Jamthi kh., Borala, Pangri, Nandura, Idoli, Incha and Navalgavhan villages of Hingoli Distrct towards Kayadhu river. The study area is situated in the Hingoli district of Marathwada region of the Maharashtra, which is characterised by average annual rainfall of 939.30 mm. The study area had four water reservoirs with catchment area in the hilly areas of the Hingoli.

Methodology

The streams of the basin were delineated using Survey of India (SOI) Topographic Map (56E/6) with 1:50000 scale. Analysis of relief aspects of the basin terrain was performed using Digital Elevation Model (DEM) data from Shuttle Radar Topography Mission (SRTM) with 1 arc-second (~30 m) spatial resolution. The processes of mapping, extraction and analysis of data were carried out using Arc GIS, GRASS and ERDAS Imagine softwares.

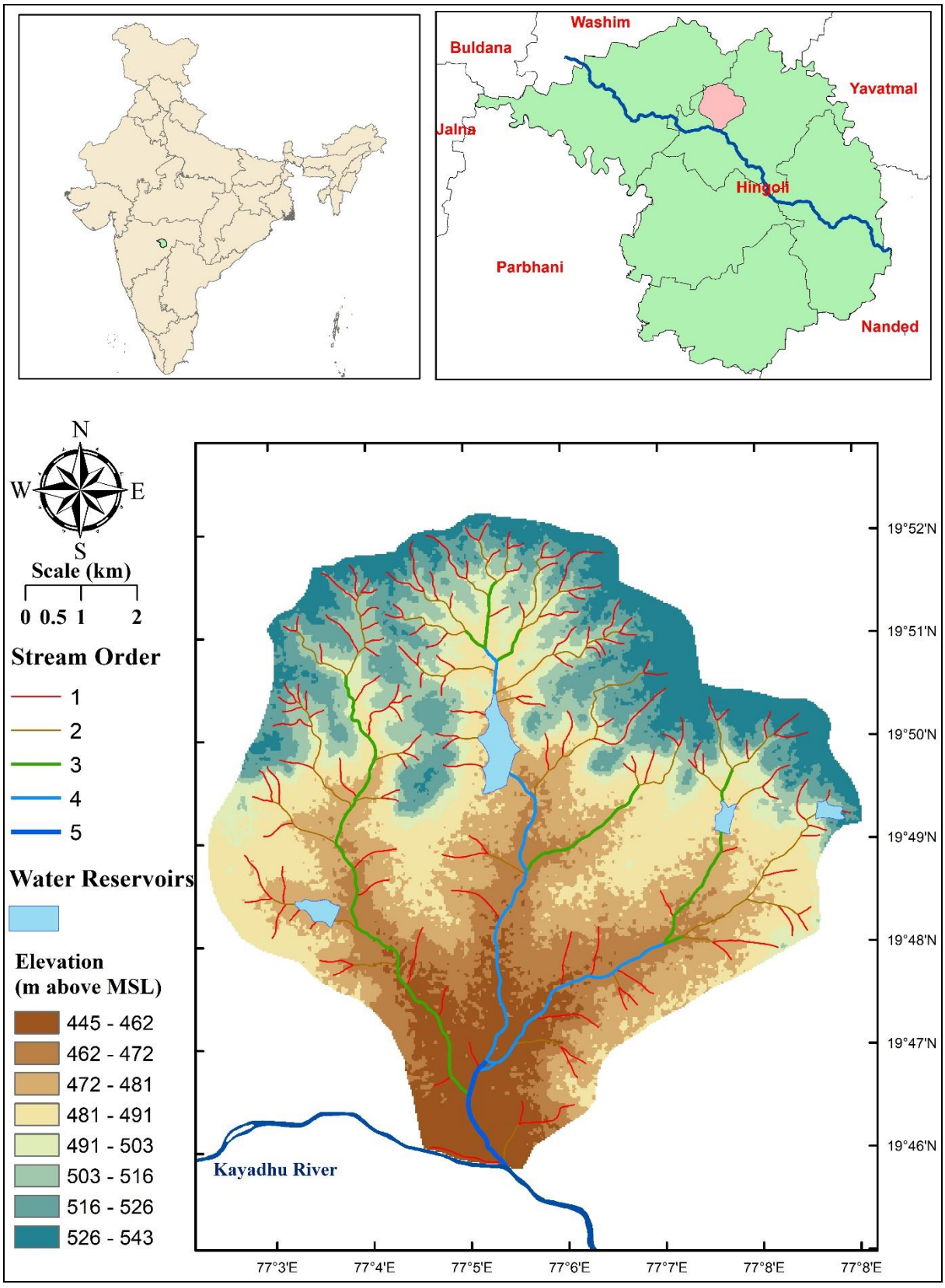
Strahler Method (Strahler, 1964) [15] was followed for ordering the drainage streams while digitizing stream network and basin boundaries. Different morphometric parameters related to linear aspects (Basin Length (Lb), Stream Order (Nu), Mean Stream Length (Lu), bifurcation ratio (Rb) and stream length ratio (RL)) were estimated along with Aerial aspects (Basin area (A), Basin Perimeter(P), Drainage density (D_d), Stream Frequency (Fs), Texture Ratio (T), Length of overland flow (L_g), Form factor (Rf), Elongation ratio (R_e), Circulatory ratio (Rc) and Constant Channel Maintenance (C)) and relief aspects (basin relief (Bh), Relief Ratio (Rh), relative relief (Rbh) and ruggedness number (Rn)) of the drainage basin. The formulae for analysis of different morphometric parameters of the drainage basin are given in Table 1.

Table 1: Formulae for morphometric analysis of drainage basin

Sr. No.	Parameter	Formula	Reference
Linear Aspects			
1	Basin Length (L_b)		
2	Stream Order (N_u)		Strahler, 1957 [14]
3	Stream Length (L_u)		Strahler, 1964 [15]
4	Mean Stream Length (L_{sm})	$L_{sm}=L_u/N_u$	Hortan, 1945 [20]
5	Stream length ratio (R_L)	L_u/L_{u-1}	Hortan, 1945 [20]
6	Bifurcation ratio (R_b)	N_u/N_{u+1}	Hortan, 1945 [20]
Aerial aspects			
1	Basin area (A)		
2	Basin Perimeter(P)		
3	Drainage density (D_d)	L/A	Hortan, 1945 [20]
4	Stream Frequency (Fs)	N_u/A	Hortan, 1945 [20]
5	Texture Ratio (T)	N_1/P, N_1= no of 1st Order Stream	Hortan, 1945 [20]
6	Length of overland flow (L_g)	$1/2D_d$	Hortan, 1945 [20]
7	Form factor (Rf)	$A/(L_b)^2$	Hortan, 1945 [20]
8	Elongation ratio (R_e)	$\sqrt{(A_u/\pi)}/L_b$	Schumn, 1956 [9]
9	Circulatory ratio (Rc)	$4*\pi*A/P^2$	Miller 1953 [6]
10	Constant channel Maintenance (C)	1/Dd	Hortan, 1945[20]
Relief aspects			
1	Basin Relief (B_h)	Vertical distance between lowest and highest point of basin	Schumn, 1956 [9]
2	Relief Ratio (Rr)	Bh/Lb	Schumn, 1956 [9]
3	Relative Relief (Rbh)	Bh/P	Schumn, 1956 [9]
4	Ruggedness number (Rn)	Dd*(Bh/1000)	Schumn, 1956 [9]

Results and Discussion

The subbasin of Kayadhu river under study revealed semi-dendritic drainage pattern with semi parallel streams. The basin under study was spread across 85.45 sq. km area with perimeter of 37.76 km. The relief of 98 m was estimated for the basin with total basin length of 11.38 km. The morphometry of the sub-basin under study is depicted in Map 1. The outcome of the morphometric study of basin are elaborated below.



Map 1: Drainage map of subbasin of Kayadhu river

Linear aspects

The results of morphometric parameters related to single dimensional measurement of basin were analyzed under linear aspect and are given in Table 2.

Table 2: Different linear aspects for morphometric analysis

Sr No	Particulars	Unit	Stream Order					Total
			1	2	3	4	5	
1	Basin Length (L_b)	km	-	-	-	-	-	11.38
2	Stream Order (N_u)	no	143	34	8	3	1	189
3	Stream Length (L_u)	km	76.11	37.49	17.53	11.13	2.23	144.50
4	Mean Stream Length (L_{sm})	km	0.53	1.10	2.19	3.71	2.23	
5	Stream length ratio (R_L)	-	-	0.49	0.47	0.64	0.20	
6	Bifurcation ratio (R_b)	-	4.21	4.25	2.67	3.00	0.00	

Stream Order (U): The sub-basin of Kayadhu river under study was found to be 5th order basin (Strahler, 1957) [14]. A total number of streams in the basin were found to be 189 which included 143 (75.66%) streams of 1st order, 34 (17.99%) streams of 2nd order and 8 (4.23%) streams of 3rd order. There were 3 streams in the basin with 4th order while basin had only one stream with 5th order. The higher proportion of low order streams in basin suggest possibilities of flooding after heavy rains (Chougale and Sapkale, 2017) [2] and structural weakness of the basin (Thomas *et al*., 2012) [18].

Stream Length (L_U): The collective length of 1st order streams in the basin was 76.11 km whereas 2nd order stream had total length of 37.49 km and total length of 3rd order stream was estimated to be 17.53 km. The collective length of 4th order stream was 11.13 km while main stream with 5th order was 2.23 km. The values of stream length, revealing surface runoff traits of the basin, showed reducing trend with corresponding in stream orders. Similar results were reported by Thomas *et al*., 2012 as well as Chougale and Sapkale, 2017 [16, 2].

Mean Stream length (Lsm): The drainage subbasin under study revealed positive relationship with stream order as reported by Thomas *et al*., 2012 [18], Kumar *et al.* 2015 and Chougale and Sapkale, 2017 [5, 2]. The Mean stream lengths were 0.53 km, 1.10km, 2.19 km, 3.17km and 2.23 km for 1st, 2nd, 3rd, 4th and 5th order streams respectively with 0.76 km mean stream length for the basin.

Stream Length Ratio (R_L): The estimated values of stream length ratio for the subbasin did not increased with rise in stream order. The values of R_L was 0.49 for 1st to 2nd, 0.47 for 2nd to 3rd order, 0.64 for 3rd to 4th order and 0.20 for 4th to 5th order streams. This indicates that the basin has not yet achieved matured geomorphic development phase (Horton, 1945 & Rai *et al*., 2017) [4].

Bifurcation ratio (Rb): The mean bifurcation ratio of the basin was found to be 3.53 with range varying from 2.67 to 4.25 which indicates that the basin has lower structural disturbance and basin is dissected (Horton, 1945) [4]. Similar results were obtained Singh *et al*., (2013) [12] in Morar River basin. Thomas *et al*., (2012) [18] in mountain rivers as well as Chougale and Sapkale, (2017) [2] in Kadvi river basin.

Aerial aspects

The results of the two dimensional parameters (Aerial aspects) of sub-basin under study are summarized in Table 3.

Table 3: Results of morphometric analysis of Aerial and relief aspects of Kalamkonda basin

SR	Parameter	Values
Aerial aspects		
01	Basin area (A)	85.45 sq. km.
02	Basin Perimeter(P)	37.76 km
03	Drainage density (D_d)	1.69 km/sq. km.
04	Stream Frequency (Fs)	2.21 no./ sq. km.
05	Texture Ratio (T)	3.79
06	Length of overland flow (L_g)	0.3 sq. km./km
07	Form factor (Rf)	0.66
08	Elongation ratio (R_e)	0.92
09	Circulatory ratio (Rc)	0.75
10	Constant channel Maintenance (C)	0.59 sq. km./km
Relief aspects		
11	Basin Relief (B_h)	98 m
12	Relief Ratio (R_r)	8.61 m/km
13	Relative Relief (Rbh)	2.6 m/km
14	Ruggedness number (Rn)	0.17

Drainage Density (D_d): The value of drainage density was found to be 1.69 km/sq. km for the study basin. The low drainage density of the basin infers that the basin has lower runoff permeable subsoil which makes it highly susceptible to the flooding (Strahler, 1964) [15]. Sukristiyanti *et al*., 2017 and Singh *et al*, 2013 [16, 12] reported lower drainage densities for their study basins having permeable soil and low surface runoff whereas Thomas *et al*. (2012) [18] reported higher drainage densities for mountain river basins indicating highly dissected-steep terrain with underlying impervious rocks.

Stream Frequency (F_s): The estimated value of the stream frequency for the basin was 2.21 no./ sq. km. The lower value of stream frequency leads to the deduction that the basin has low surface runoff (Thomas *et al*. 2010, Sukristiyanti *et al*., 2018 & Chougale and Sapkale, 2017) [17, 16, 2].

Texture Ratio (T): The texture ratio of the basin was found to be 3.79. The moderate value of texture ratio suggests that the basin risk of erosion and lesser dissection (Chougale and Sapkale, 2017 & Sukristiyanti *et al*., 2018) [2, 16].

Form factor (F_f): The sub-basin under study had form factor of 0.66 which indicates that the basin is more or less circular with moderate risk of flooding (Sukristiyanti *et al*., 2018 & Waikar and Nilawar, 2014) [16, 19].

Circulatory Ratio (R_c): The estimated value of circulatory ratio of the basin was 0.75. This leads to the conclusion that the basin is circular with some structural disturbance on basin under study (Miller, 1953, Singh *et al*., (2013) [6, 12], Waikar and Nilawar (2014) [19] & Sukristiyanti *et al*., 2018) [16].

Elongation ratio (Re): The estimated value of elongation ratio (0.92) of the basin ascertains that the basin is circular in shape with high relief (Strahler, 1964 and Sukristiyanti *et al*., 2018) [15, 16]. The elongation ratio of 0.7 estimated for drainage basin with moderate to slightly steep slope by Waikar and Nilawar (2014) [19] whereas Singh *et al*., (2013) [12] reported lower elongation ratio of 0.327 for elongated river basin with low runoff.

Length of Overland Flow (Lg): The basin under study had length of overland flow of 0.3 sq. km./km inferring that the basin had moderate relief with medium runoff and infiltration (Sukristiyanti *et al*., 2017) [16].

Constant channel Maintenance (C): The estimated value of Constant channel maintenance (C) for the basin was found to be 0.59 sq.km/km which suggest that the basin had stronger lithology (Chougale and Sapkale, 2017) [2].

Stream Length Ratio (R_L): The estimated values of stream length ratio did not increase with corresponding increasing in stream order. Stream Length Ratio of the basin did not showed increase with corresponding increase in stream order. This is indicate that the basin is still in late geomorphic development phase (Horton, 1945 and Rai *et al*., 2017) [4].

Relief aspects

The drainage sub-basin of Kayadhu river under study had total relief of 98 m. The estimated value of relief ratio was 8.61 m/km with relative relief (Rbh) of 2.6 m/km. These relief parameters indicates that the basin has steepness and related degradation (Miller, 1953 and Sharma & Sharma, 2013) [6, 11]. Different researchers have interpreted these values differently (Singh *et al*., 2013, Waikar and Nilawar, 2014) [12, 19]. The estimated value of Ruggedness number (0.17) of the basin infers that the basin is relatively smother (Kumar *et al*. 2015) [5].

Conclusion

The subbasin of Kayadhu river under study is 5th order basin. The basin is well dissected and structurally weak with possibilities of flooding after heavy rains. The basin is in maturing phase of geomorphic development with lower structural disturbance. The basin has lower runoff and permeable subsoil making it prone to the flooding. The subbasin was found to be circular in shape with structural disturbance. The basin has higher relief and which may lead to degradation and erosion. The remote sensing and Geographic Information system (GIS) techniques were found cost effective and time efficient for study of river basin.

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