Quantitative Morphometric Assessment of Bhima Lower sub-basin using Remote Sensing and GIS

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Abstract**:** *The Bhima lower sub-basin, a tributary of the Krishna River, was opted for the morphometric assessment so as to understand the relation between the drainage system and the lithology as well as the topography of the area. The Cartosat-1 DEM with a spatial resolution of 2.5m was used for the watershed delineation and stream network extraction. ArcGIS 10.3 software was used as the computational as well as analytical tool and for the preparation of thematic maps. The sub-basin was fractionated into 26 watersheds and 12 micro-watersheds with each of them having a least 3rd order stream as the main channel. More than 25 morphometric parameters were studied which included the linear, aerial, shape as well as relief aspects of the morphometry. The Bhima River forms the trunk stream with an order of 7, while WS11 was found to be the largest watershed within the sub-basin and the WS11f was found to be the longest. The drainage is very much controlled by the lithology of the area. The terrain was found to be rough, elongated with some watersheds having a high risk of flooding. The study forms a base for further watershed management and sustainable development works.*

Keywords**:** Morphometry, Bhima lower, DEM, ArcGIS

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I. Introduction

Life without water is beyond imagination and this has created a fasciation to study this precious natural resource with its source and sink, since ages. River basins form one such dynamic sink where the tributaries and streamlets work with the congregation and channeling of this invaluable resource to the main waterbody. Population explosion along with the stressed climatic condition puts forward a challenging environment for the resource to replenish and meet the ever-growing demands. Decreased precipitation and an overexploitation of this resource has created a negative impact on life.

The quantitative measurement and mathematical analysis of the earth's surface, shape, and numerous dimensions of its landforms [1] are referred to as morphology[2]. For a clear insight into a basin's hydrological behavior as well as its prevailing climatic conditions in the area, the lithological, geomorphological variation, structural maturity of a region and the quantitative morphometric analysis is carried out [1]. The Bhima Lower sub-basin, a tributary of the Krishna River, was chosen for the study [3]. The basin covers parts of Maharashtra, Karnataka and Telangana state of India. The region is semi-arid in nature with frequent drought cases[4]–[6]. Although the upper Bhima basin has been studied thoroughly [7]–[10], the lower Bhima sub-basin has received limited attention from researchers [2], [11] . The study forms a base for further watershed management and sustainable development work.

II. Study area

A tributary of the Krishna River basin, the Bhima lower sub-basin, covers approximately 9.28% of the total basin area [12]. The watershed commences at the Bhima-Sina confluence in Solapur district of Maharashtra at 17°22'40''N. 75°53'58''E and terminates at the Krishna-Bhima confluence in Raichur taluk of Karnataka at 16°24'34''N 77°17'18''E. The watershed is spread through 3 states covering 11 districts including, Latur, Osmanabad, Sangli, and Solapur in Maharashtra, Bidar, Bijapur, Gulbarga, and Yadgir in Karnataka, and Medak, Mahbubnagar, and Rangareddi in Telangana (Fig. 1) with Gulbarga district covering around 53.6% of the watershed by area. According to a 2014 survey, by the Government of India, 38 micro-watersheds have been identified in the area (Fig. 2).

Fig. 1. Location map of Bhima lower sub-basin covering parts of the Indian districts along with the major stream channels: [Inset- Map of India showing watershed location].

The Geology in the watershed is dominated by the Deccan basalts covering approximate 70% of the area, followed by

Bhima Group, Closepet as well as some peninsular gneisses and minor amounts of laterite, and Mangalur group of rocks belonging to Dharwar supergroup (Fig. 3).

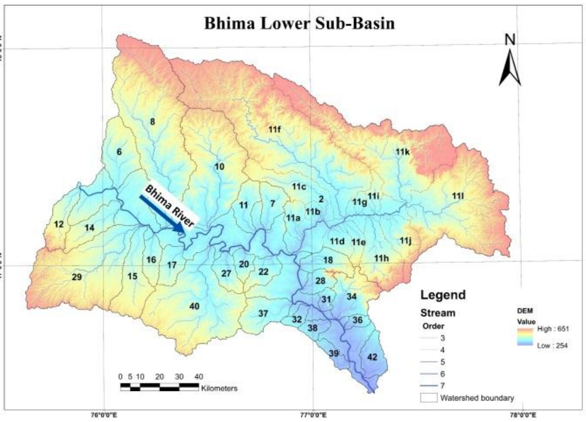

Fig. 2. Digital elevation map of Bhima lower sub-basin with delineated watersheds (1-26), micro-watersheds (11a - 11l).

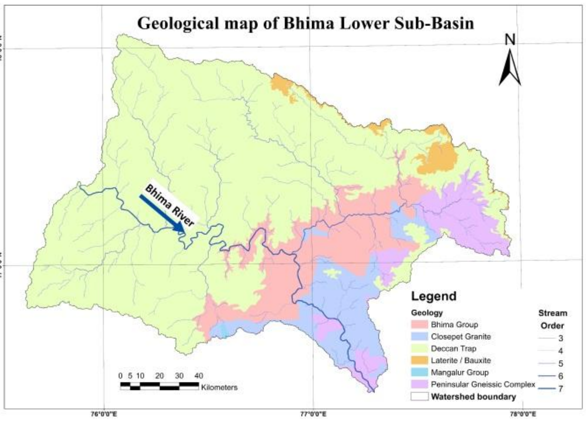

Fig. 3. Geological map of Bhima lower sub-basin with major drainage

III. METHODOLOGY

For the present study, Digital Elevation Model (DEM) acquired by the Cartosat-1 (CARTODEM Version-3 R1) satellite with 2.5m PAN resolution at 16-bit radiometric resolution and 1 arcsec spatial resolution was used[13]. Since the sub-basin covers a large area, 8 DEM raster data were downloaded from the Bhuvan portal (Table I). The raw data was first mosaiced to form a single DEM, which was preprocessed and a raster calculation of flow accumulation >2000 was applied. The stream order (Strahler's method) was then processed and the resultant raster was converted into the vector format so as to delineate the watersheds using the pour-point tool. ArcGIS 10.3 was used for preprocessing, watershed delineation (Fig. 4), stream network extraction as well as map creation. The analysis was done for the Bhima lower sub-basin along with its 36 watersheds (including 12 micro-watersheds). The conventional mathematical formulas were used for the determination of the various morphometric aspects.

IV. RESULT

To understand the relationship between the basin geometries, the river basin network, the sediment transport or the transmission of water through the basin, an assessment of the morphometric parameters of the basin is a necessity.

TABLE I. THE DEM FILES USED FOR THE ANALYSIS, ALONG WITH THE BOUNDING EXTENT.

Sl no.	Toposheet no.	Bounding Box
1	E43V	75E16N-76E17N
2	E43W	76E16N-77E17N
3	E43X	77E16N-78E17N
4	E43P	75E17N-76E18N
5	E43Q	76E17N-77E18N
6	E43R	77E17N-78E18N
7	E43J	75E18N-76E19N
8	E43K	76E18N-77E19N

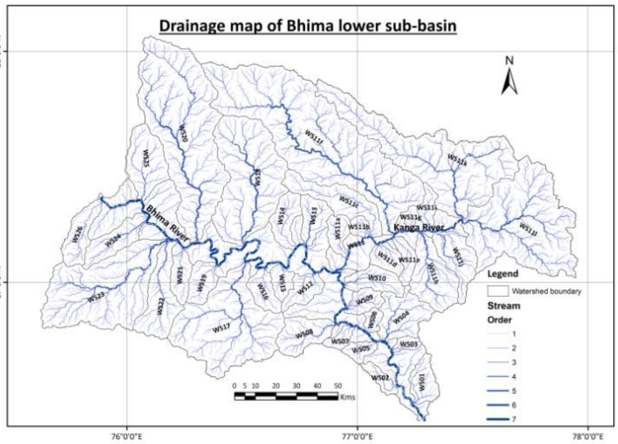

Fig. 4. Map showing the drainage network of the Bhima lower sub-basin along with the stream orders (1 to 7).

The assessment of the morphometric parameters includes a computational analysis of the linear, aerial, including shape aspects, as well as the relief aspects, which are produced as follows:

A. Basin geometry

a) Area (A)

The river basin's total catchment area can be defined by joining the watershed-divides which allow precipitation to be collected and to drain into a single water channel. The Bhima lower sub-basin has an area of 24571 km sq., as calculated digitally using the ArcGIS software, which forms nearly 9.5% of the total Krishna basin. The different watersheds range in area from 70.27 km^2 (WS03) to 9622 km^2 (WS11) (Table 2). The WS11 refers to the Kanga River watershed which is the largest tributary here. This watershed was thus further subdivided into 12 micro watersheds, of which WS11g acquired the smallest area and WS11f the largest. It was marked that the watersheds underlain by basaltic terrain were larger compared to those underlain by other lithounits.

b) Perimeter (P)

The basin boundary or perimeter (P) refers to the total length of the boundary of the drainage basin [14]. The Bhima lower sub-basin has a total perimeter of 1420km (Table II).

The micro-watersheds have basin parameters ranging from 39.40 km (WS11b) to 720.46 km (WS11).

TABLE II. THE BASIN PARAMETER OF BHIMA LOWER SUB-BASIN WATERSHEDS

Watershed	Area (A) Km^2	Perimeter (P) Km	Basin length (Lb) Km
WS01	224.62	84.25	25.64
WS02	107.11	68.65	20.96
WS03	70.27	45.81	14.61
WS04	436.22	132.52	29.41
WS05	109.83	59.36	13.92
WS06	77.92	47.41	12.65
WS07	89.15	52.84	16.65
WS08	346.97	96.17	29.43
WS09	155.95	68.98	20.03
WS10	256.03	93.13	25.08
WS11	9622.28	720.46	112.62
WS11a	162.20	69.04	21.87
WS11b	71.58	39.40	10.75
WS11c	486.97	161.85	49.92
WS11d	162.04	62.93	18.58
WS11e	140.03	75.66	23.59
WS11f	3124.45	395.22	120.87
WS11g	57.64	39.80	12.46
WS11h	535.56	127.02	40.4
WS11i	125.20	67.03	22.88
WS11j	364.44	117.28	37.47
WS11k	1922.75	375.14	94
WS11l	1907.27	287.92	53.69
WS12	203.43	79.22	25.55
WS13	235.54	84.40	24.61
WS14	252.87	89.13	27.32
WS15	131.11	57.89	17.66
WS16	202.88	70.34	22.32
WS17	1619.77	230.49	58.7
WS18	1513.72	215.96	61.9
WS19	218.68	75.51	20.46
WS20	2366.77	311.24	100.97
WS21	190.80	79.87	27.5
WS22	521.57	149.53	48.12
WS23	1594.30	230.92	71.96
WS24	320.35	109.05	36.52
WS25	479.81	112.18	37.47
WS26	296.51	103.81	35.31
Bhima lower	24571	1420	185.45

c) Basin length (Lb)

The aerial distance of a basin computed parallel to the trunk stream is referred to as its basin length. The length of the sub-basin as a whole was found to be 221.52 km. Within the micro-watersheds the basin WS11b has the smallest basin length of 10.75 km whereas the basin WS11f is the longest with 120.87km (Table II), WS11 was found to be the longest watershed.

B. Linear aspects

a) Stream Order and Stream Number (Nu)

Ordering of the streams is the primary step in the morphometric analysis of a river basin[15], [16]. Stream order refers to the system of classification of stream systems on the basis of branching or bifurcation[17]. The stream ordering method as specified by Strahler's was used [18], [19] where the highest order is given to the mainstream and the lowest to the fingertip streams which converge to form the higher order streams. The total number of streams in a basin, which signifies the portion of a single watershed's streams, is represented by the number of streams of a given order [18], [19].

In the Bhima lower sub-basin, the stream that possesses the highest stream order (7) is the Bhima river itself (Fig. 4). The 6th order stream is the Kanga river which traverses from northeast to southwest and confluences with the main Bhima river. The lower order streams join either Bhima or Kanga river at variable distances. The 5th order stream is small in number (9 streams) while the 4th, 3rd and 2nd are 41, 165 and 746 respectively. The first-order stream is 3604 in number, contributing to almost 79% of the total streams (Table III). The watershed has an aggregate of 4567 streams.

b) Stream Length (Lu)

Stream length refers to the distance along the stream channel from source [20] to the point of confluence. The distance was measured using ArcGIS software. The arithmetic sum of individual streams of all order is the total stream length. The total stream length of the watershed was found to be 13544.81kms. The total stream length varies from 33km to 5401km in the watersheds (Table III). The sum of stream length networks was found to be maximum for the 1st order streams which decreased progressively with an increase in stream order as proposed by Horton [17], [18].

c) Mean stream length (Lsm)

Mean stream length is the ratio between the total stream length of a particular order and the total number of streams within the same order in a watershed [13], [21]. Being a dimensionless property, it provides information on the typical size of drainage network components and their contributing watershed surfaces [1], [18], [19]. The stream length variation is attributed to the change in slope and topographic conditions [18], [22]. The mean stream length is directly proportional to the stream order, such that the Lsm is greater than the previous stream order and less than the next higher order [11], [15], [18], [20]. In the present study, the Lsm not only increases with the order but also decreases in some cases (Table III). In such cases, the Lsm increased at first and then decreased at the highest order reflecting a change in slope and topography with respect to higher stream order. For the watershed, the Lsm increases with respect to stream order.

d) Steam length ratio (Rl)

The stream length ratio (RI) is the ratio of one order's mean stream length to the next lower order [18], [23]. The stream length ratio for individual stream orders of the watersheds ranges from 0.08 to 15.52, whereas for the sub-basin as a whole it ranges from 0.19 to 3.90 (Table IV).

e) Bifurcation ratio (Rb)

The bifurcation ratio is the ratio of the number of stream segments of one order to the number of segments of the next higher level [18], [24]. It ranges from 9 to 1 for the Bhima lower sub-basin; the ratio was also calculated for individual micro-watersheds and their value ranges from 2 to 12. The lower values indicate that the geological structures have no influence on the drainage pattern [25] whereas the higher values indicate otherwise [26], [27]. The bifurcation ratio changes with topography, lithology, land use etc., of an area [21].

TABLE III. THE TOTAL STREAM LENGTH (LU) AND THE MEAN STREAM LENGTH (LSM) OF EACH WATERSHED FOR EACH ORDER OF THE STREAM IN THE SUB-BASIN

Water-shed	Total stream length (Lu) km	Mean Stream Length (LSM)						
		1	2	3	4	5	6	7
WS01	175.31	3.63	5.93	11.42	4.24			
WS02	53.31	1.61	3.61	19.93				
WS03	42.44	2.46	3.27	8.04				
WS04	264.50	1.74	3.71	8.05	12.26	4.61		
WS05	57.94	1.62	4.86	12.50				
WS06	44.73	1.70	2.67	8.62				
WS07	48.61	2.19	8.84	2.50				
WS08	196.18	1.88	4.76	10.57	19.89			
WS09	106.13	2.32	5.21	8.95	3.69			
WS10	141.75	1.42	3.67	14.54	8.36			
WS11	5401.47	2.03	4.23	9.08	15.43	54.21	85.65	
WS11a	85.67	1.56	3.59	22.09				
WS11b	40.05	1.40	4.00	8.42				
WS11c	254.82	2.39	3.79	58.86				
WS11d	85.76	1.75	4.61	6.37	0.49			
WS11e	72.56	2.06	5.53	14.85				
WS11f	1700.74	2.06	4.19	8.87	15.62	127.41		
WS11g	33.88	2.91	5.59	2.34				
WS11h	322.29	2.34	4.52	4.34	14.17	15.90		
WS11i	66.97	1.79	2.80	18.07				
WS11j	220.96	1.86	6.07	4.90	22.29			
WS11k	1044.67	1.84	4.05	9.94	15.06	32.29		
WS11l	1160.90	3.28	4.13	8.28	18.13	40.73		
WS12	106.49	1.65	3.96	9.13	4.53			
WS13	129.86	1.84	3.38	7.08	17.19			
WS14	130.85	1.78	4.70	25.74				
WS15	73.53	2.81	3.17	12.77				
WS16	106.76	2.15	4.23	19.18				
WS17	866.99	1.97	4.83	9.85	23.51	35.94		
WS18	788.37	1.67	5.11	10.10	9.97	58.48		
WS19	120.37	1.89	5.87	20.60				
WS20	1322.41	1.99	4.64	9.61	23.25	79.92		
WS21	109.03	1.92	5.03	20.57				
WS22	287.15	2.10	4.22	7.89	38.33			
WS23	883.07	2.01	5.59	10.70	7.08	58.94		
WS24	177.54	2.06	3.40	8.80	19.53			
WS25	239.42	1.69	5.26	13.48	17.48			
WS26	153.49	1.68	5.60	36.53				
Bhima lower	13544.81	1.94	4.56	9.87	15.45	50.68	85.67	333.74

A higher Rb value suggests an elongated basin and vice versa [28]. The mean bifurcation ratio ranges from 2.75 to 8.63 and for the basin it is 5.39 which is moderate. Higher the Rb higher is the possibility of flooding, accordingly, WS 11b, WS11c, WS14, WS16, WS19, WS21, and WS26 are at higher risk of flooding (Table V).

f) Rho coefficient (ρ)

When the stream length ratio (Rl) is divided by the bifurcation ratio (Rb), the Rho coefficient is obtained [29], which is a measure of the drainage network's storage capacity [28], [30], [31]. For the watersheds, it ranges from 0.09 to 0.30 and for the basin it is 0.08. The low value indicates lower hydrologic storage during floods [28], [32].

TABLE IV. STREAM LENGTH RATIO (RI) OF ALL THE WATERSHEDS IN BHIMA LOWER SUB-BASIN

Watershed	Stream Length Ratio (RI)					
	2/1	3/2	4/3	5/4	6/5	7/6
WS01	1.63	1.93	0.37			
WS02	2.24	5.52				
WS03	1.33	2.46				
WS04	2.13	2.17	1.52	0.38		
WS05	2.99	2.57				
WS06	1.57	3.23				
WS07	4.05	0.28				
WS08	2.53	2.22	1.88			
WS09	2.25	1.72	0.41			
WS10	2.58	3.96	0.57			
WS11	2.09	2.15	1.70	3.51	1.58	
WS11a	2.31	6.15				
WS11b	2.85	2.11				
WS11c	1.59	15.52				
WS11d	2.63	1.38	0.08			
WS11e	2.69	2.68				
WS11f	2.03	2.12	1.76	8.16		
WS11g	1.92	0.42				
WS11h	1.93	0.96	3.27	1.12		
WS11i	1.56	6.45				
WS11j	3.27	0.81	4.55			
WS11k	2.20	2.45	1.51	2.14		
WS11l	1.26	2.00	2.19	2.25		
WS12	2.40	2.31	0.50			
WS13	1.84	2.10	2.43			
WS14	2.65	5.48				
WS15	1.13	4.02				
WS16	1.97	4.54				
WS17	2.45	2.04	2.39	1.53		
WS18	3.06	1.98	0.99	5.86		
WS19	3.10	3.51				
WS20	2.33	2.07	2.42	3.44		
WS21	2.63	4.08				
WS22	2.01	1.87	4.86			
WS23	2.78	1.91	0.66	8.32		
WS24	1.65	2.59	2.22			
WS25	3.11	2.56	1.30			
WS26	3.33	6.53				
Bhima lower	0.49	0.48	0.39	0.72	0.19	3.90

C. Aerial aspects

a) Drainage density (Dd)

The drainage density is the number of streams per unit area [23] . It is a mathematical connection determined as the ratio of the total length of all stream orders in a drainage basin to the drainage basin's total area [33]. . The Dd indicates how close the streams are spaced, and it is controlled by the permeability of the subsurface lithology, flora and topography. The Dd value for each of the micro-watersheds and the basin was calculated using the equation,

$$Drainage\ Density = Total\ stream\ length / Area$$

The watershed with the maximum drainage density is WS 09 (0.68) and the one with the lowest Dd value is WS 2

(0.498) (Table 6a). The Bhima lower sub-basin has a drainage density of 0.551 (Fig. 5).

TABLE V. BIFURCATION RATIO OF EACH OF THE STREAM ORDERS (SO) FOR ALL WATERSHEDS IN THE BHIMA LOWER SUB-BASIN.

Watershed	Bifurcation ratio (Rb)						
	1/2	2/3	3/4	4/5	5/6	6/7	Mean (Rb)
WS01	5.17	3.0	2				3.39
WS02	4.67	3.0					3.83
WS03	3.33	3.0					3.17
WS04	4.88	3.2	2.5	2			3.14
WS05	4.00	4.0					4.00
WS06	3.75	4.0					3.88
WS07	6.50	2.0					4.25
WS08	4.33	6.0	2				4.11
WS09	3.83	3.0	2				2.94
WS10	4.09	5.5	2				3.86
WS11	4.62	4.1	4.41	4.25	4		4.27
WS11a	4.50	6.0					5.25
WS11b	4.67	3.0					3.83
WS11c	5.25	12.					8.63
WS11d	3.29	3.5	2				2.93
WS11e	6.67	3.0					4.83
WS11f	5.15	4.0	4.4	5			4.64
WS11g	3.50	2.0					2.75
WS11h	3.94	2.6	3.5	2			3.00
WS11i	5.25	4.0					4.63
WS11j	4.15	3.3	4				3.80
WS11k	4.31	4.5	3.75	4			4.13
WS11l	4.26	3.9	4.5	4			4.16
WS12	4.86	3.5	2				3.45
WS13	4.11	4.5	2				3.54
WS14	4.75	8.0					6.38
WS15	3.20	5.0					4.10
WS16	4.83	6.0					5.42
WS17	5.13	5.0	3	3			4.03
WS18	5.09	4.0	5.5	2			4.15
WS19	4.43	7.0					5.71
WS20	4.62	5.7	3.25	4			4.39
WS21	6.60	5.0					5.80
WS22	5.13	5.0	3				4.38
WS23	5.72	3.3	3	4			3.99
WS24	3.67	4.0	3				3.56
WS25	6.64	3.7	3				4.43
WS26	5.38	8.0					6.69
Bhima lower	4.83	4.5	4.02	4.56	9	1	5.39

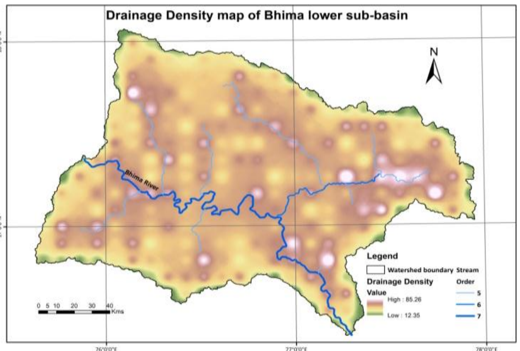

Fig. 5. Drainage density map of the Bhima Lower sub-basin per $10km^2$ area.

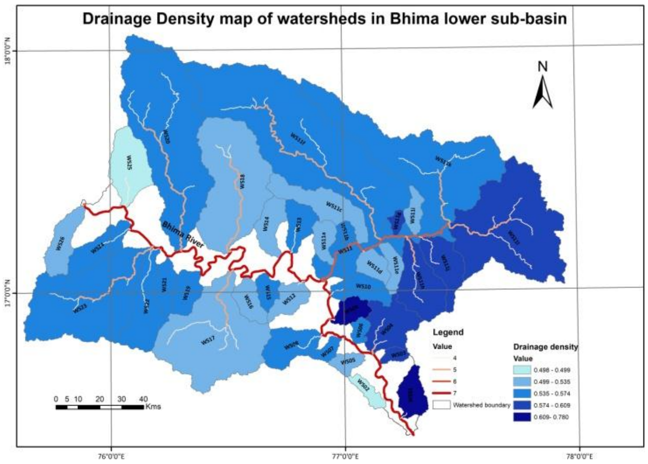

Fig. 6. Drainage density map for each of the watersheds in Bhima lower sub-basin

The drainage density (Dd) map was created using the interpolation tool in ArcGIS 10.3 software [28], by dividing the watershed area into 10km x 10km grids and the drainage density was calculated per $10km^2$ area. Accordingly, the basin shows more Dd near the eastern and southeastern parts (Fig. 6). The drainage density reflects the effects of topography and soil on the water movement on the surface as well as its penetration power [34]. High density of streams reflects the presence of impermeable formations below whereas low density ensures permeable subsurface. This was found true for the area as the parts showing low drainage density are underlain by the Deccan basalts whereas those with low density were seen to concentrate around the other formations.

b) Stream frequency (Fs)

Stream frequency, also known as channel frequency, is the total number of stream segments per unit area for all stream orders [18], [20], [31], [33], [35]. The watershed with maximum stream frequency is the WS6 (0.257), while the lowest stream frequency was observed in the micro-watershed 11b (0.156) (Table VI). The frequency of streams was calculated using the formula,

$$Stream\ frequency = \frac{Total\ no.\,of\ streams}{Area}$$

The stream frequency value of the basin was found to be 0.186. The basin has an overall low stream frequency indicating lowrunoff and high infiltration [36].

c) Infiltration number (If)

The product of drainage density and stream frequency is the infiltration number [20], [37]. For the present study, an overall infiltration ratio of 0.102 was achieved, the value for the watersheds range from 0.16 WS11c to 0.26 WS06 (Table 6a). A higher infiltration number suggests low infiltration owing to hard and impermeable strata here basalts and vice versa [38].

d) Drainage texture (Rt)

"Texture ratio is the ratio between the total stream number to the total perimeter of the basin" [14] [17]. The equation is as follows,

$$Texture\ ratio = \frac{Total\ stream\ number}{Perimeter}$$

The drainage texture is related to the amount of precipitation, vegetation type, lithology, and stage of river development [39]. It has been categorised into five textures, according to Smith [26] : very coarse (less than 2), coarse (2–4), intermediate (4–6), fine (6–8), and very fine (more than 8)[18] (Table VI). For the present study, an overall very coarse drainage texture was identified.

e) Length of overland flow (Lg)

The length of overland flow is the distance the water travels over the ground before [14] joining a specific stream channel[17]. It has an inverse relationship with the drainage density of the river basin and is calculated using the equation,

$$Length\ of\ Overland\ flow = 1\ /\ (Drainage\ \text{density})$$

The Lg for the basin was found to be 0.907 whereas for the watersheds it ranges from 0.64 (WS01) to 1 (WS 2, 11c, 11e, 12, 14, 16, 18, 25 and 26) (Table VI). Low Lg values indicate high relief, short flow paths, greater runoff, and reduced infiltration [40], all of which contribute to the danger of flash flooding. In the meantime, a high Lg value indicates moderate slopes and extended flow routes, as well as more infiltration and reduced runoff.

f) Constant of channel maintenance (C)

The constant of channel maintenance is the reciprocal of an area's drainage density [15], [24]. It's the amount of basin surface area required to support a unit length of stream channel [15]. The value here ranges from 1.28 km^2 WS01 to 2.01 km2 WS02, and for the sub-basin it was computed to be 1.8.4 km^2 (Table VI). The value was found to be lower near the eastern and southern part of the sub-basin indicating steep terrain and impermeable formation (fig. 7). For most parts of the basin, the value was found to be high suggesting relatively permeable formation [41]

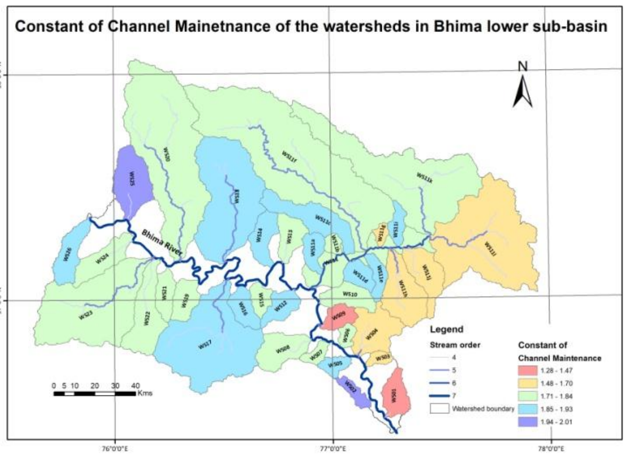

Fig. 7. Map showing the constant of channel maintenance in the Bhima lower sub-basin

g) Shape aspects

1) Shape factor (Bs)

The shape factor is the ratio of the square of the basin length to the basin area[17]. It is inversely related to the form factor and is calculated as,

$$Shape\ factor = Basin\ length^2\ /Area$$

The shape factor for the Basin was found to be 1.4, the watershed with the smallest Bs is basin 11 (1.318) and the highest value of the Bs was found to be for WS11c (5.117) (Table VII).

2) Form factor (Rf)

As per Schumm 1956, Rf is the ratio between the area of the basin and the square of the length of the basin[14], [24]. The low Rf is indicative of an elongated basin with a flatter peak flow of precipitation of low duration [41]. The basin WS11c was observed to have a very low Rf (elongated basin) whereas the basin WS11 showed the highest Rf (0.76) indicating a near circular basin shape (Table VII). The basin as a whole had a Rf of 0.72.

3) Circulatory ratio (Rc)

The circularity ratio is the ratio of the basin area to the area of a circle with the same perimeter as the basin (Re) [42], [43]. The circularity ratio is studied in relation to the length of stream and frequency of streams, lithology, land use and land cover (LULC), climatic condition, relief of the area, and slope of the basin [44]. The ratio was calculated using the formula,

$$(Circulatory\ Ratio\ = 4\pi Area\ /\ (Perimeter^2\ )$$

The Rc value near 1 indicates a more or less circular basin whereas one near 0 indicates a non-circular or elongated basin. The circulatory ratio of the watersheds in the Bhima lower sub-basin range in value from 0.17 to 0.58 indicating roughly elongated to elongated basin (Table VII). The sub-watershed has a very low circulatory ratio of 0.15 reflecting the non-circulatory shape of the basin which is evident from the drainage map (Fig. 4).

4) Elongation ratio (Re)

Elongation ratio is defined as the ratio between the diameter of the circle of equal area as that of the basin to the basin length [18], [24], [35]. It is calculated using the equation,

$$Elongation\ Ratio = 1.129\frac{\sqrt{Area}}{Basin\ length}$$

The Re value ranges from 0.6 to 1.0 depending on the climatic and geological condition, which can be categorised as: <0.7 indicates less elongated; 0.8-0.9 indicates oval basin shape and >0.9 [35] indicates circular basin shape [18]. Low relief is defined as a value larger than 1.0, whereas high relief and steep ground slope are defined as 0.6 to 0.9 [18], [19]. The elongation ratio of the sub-basin indicates a near circular basin (0.954) while that for the watersheds range from 0.983 at WS 11, min 0.5 at MS 11c (Table VII). The greater the Re value, the higher the infiltration rate and the lower the runoff, and vice versa [18].

5) Gravellus Index or compactness coefficient (GI or Cc)

Compactness coefficient also known as Gravellus Index (GI) is calculated as the ratio of the basin perimeter to the circumference of the circle of the subwatershed's area [15], [18]. When the compactness coefficient is equal to 1, the basin is regarded as circular; when it is more than 1, the basin is deemed elongated. Here, the GI was found to be 2.556 for the basin whereas for the micro-watersheds it ranges from 1.314 (WS11b) to 2.413 (WS11k) (Table VII). The watersheds show variation in shape from low to high elongated.

TABLE VI. AERIAL ASPECTS OF DRAINAGE MORPHOMETRY FOR BHIMA LOWER SUB-BASIN AND WATERSHEDS

Watershed	Dd Km^{-1}	Fs Km^{-2}	If	Rt Km^{-1}	Lg Km	C Km
WS01	0.780	0.178	0.14	0.475	0.6	1.28
WS02	0.498	0.168	0.08	0.262	1.0	2.01
WS03	0.604	0.199	0.12	0.306	0.8	1.66
WS04	0.606	0.234	0.14	0.770	0.8	1.65
WS05	0.528	0.191	0.10	0.354	0.9	1.90
WS06	0.574	0.257	0.15	0.422	0.9	1.74
WS07	0.545	0.179	0.10	0.303	0.9	1.83
WS08	0.565	0.193	0.11	0.697	0.9	1.77
WS09	0.681	0.205	0.14	0.464	0.7	1.47
WS10	0.554	0.230	0.13	0.634	0.9	1.81
WS11	0.561	0.189	0.11	2.521	0.9	1.78
WS11a	0.528	0.210	0.11	0.492	0.9	1.89
WS11b	0.559	0.251	0.14	0.457	0.9	1.79
WS11c	0.523	0.156	0.08	0.470	1.0	1.91
WS11d	0.529	0.204	0.11	0.524	0.9	1.89
WS11e	0.518	0.171	0.09	0.317	1.0	1.93
WS11f	0.544	0.182	0.10	1.440	0.9	1.84
WS11g	0.588	0.173	0.10	0.251	0.9	1.70
WS11h	0.602	0.185	0.11	0.779	0.8	1.66
WS11i	0.535	0.208	0.11	0.388	0.9	1.87
WS11j	0.606	0.198	0.12	0.614	0.8	1.65
WS11k	0.543	0.196	0.11	1.002	0.9	1.84
WS11l	0.609	0.205	0.12	1.358	0.8	1.64
WS12	0.523	0.216	0.11	0.555	1.0	1.91
WS13	0.551	0.208	0.11	0.581	0.9	1.81
WS14	0.517	0.186	0.10	0.527	1.0	1.93
WS15	0.561	0.168	0.09	0.380	0.9	1.78
WS16	0.526	0.177	0.09	0.512	1.0	1.90
WS17	0.535	0.178	0.10	1.254	0.9	1.87
WS18	0.521	0.186	0.10	1.306	1.0	1.92
WS19	0.550	0.178	0.10	0.516	0.9	1.82
WS20	0.559	0.183	0.10	1.394	0.9	1.79
WS21	0.571	0.204	0.12	0.488	0.9	1.75
WS22	0.551	0.184	0.10	0.642	0.9	1.82
WS23	0.554	0.175	0.10	1.208	0.9	1.81
WS24	0.554	0.187	0.10	0.550	0.9	1.80
WS25	0.499	0.183	0.09	0.784	1.0	2.00
WS26	0.518	0.175	0.09	0.501	1.0	1.93
WS21	0.571	0.204	0.12	0.488	0.9	1.75
Bhima lower	0.551	0.816	0.102	3.216	0.9	1.814

D. Relief aspects

a) Basin relief (H)

Basin relief can be said to be the vertical difference between the highest and the lowest elevation of an area [15], [18]. For the watersheds, the relief ranges from 93m (WS11b) to 353m (WS11), whereas for the whole of the basin it is 397m (Table VIII, Fig. 8).

b) Relief ratio (Rhl)

Relief ratio is the ratio between the relief of the basin and the length of the basin [14], [21]. In general, a low relief ratio indicates a low slope and low relief, while a high value indicates a steep slope and high relief. The lower the relief, the more resistant the basement rocks are to soil erosion in the watershed, and the steeper the slope, the more extensive the soil erosion in the watershed [18].

TABLE VII. SHAPE ASPECTS OF BASIN AND WATERSHEDS

Watershed	Bs	Rf	Rc	Re	Cc
WS01	2.927	0.342	0.398	0.660	1.586
WS02	4.102	0.244	0.286	0.557	1.871
WS03	3.037	0.329	0.421	0.648	1.542
WS04	1.983	0.504	0.312	0.802	1.790
WS05	1.764	0.567	0.392	0.850	1.598
WS06	2.054	0.487	0.436	0.788	1.515
WS07	3.110	0.322	0.401	0.640	1.579
WS08	2.496	0.401	0.472	0.715	1.456
WS09	2.573	0.389	0.412	0.704	1.558
WS10	2.457	0.407	0.371	0.720	1.642
WS11	1.318	0.759	0.233	0.983	2.072
WS11a	2.949	0.339	0.428	0.657	1.529
WS11b	1.614	0.619	0.580	0.889	1.314
WS11c	5.117	0.195	0.234	0.499	2.069
WS11d	2.130	0.469	0.514	0.773	1.395
WS11e	3.974	0.252	0.308	0.566	1.804
WS11f	4.676	0.214	0.251	0.522	1.995
WS11g	2.694	0.371	0.458	0.688	1.479
WS11h	3.048	0.328	0.417	0.647	1.548
WS11i	4.181	0.239	0.350	0.552	1.690
WS11j	3.853	0.260	0.333	0.575	1.733
WS11k	4.596	0.218	0.172	0.527	2.413
WS11l	1.511	0.662	0.289	0.918	1.860
WS12	3.210	0.312	0.407	0.630	1.567
WS13	2.571	0.389	0.416	0.704	1.551
WS14	2.951	0.339	0.400	0.657	1.581
WS15	2.379	0.420	0.492	0.732	1.426
WS16	2.455	0.407	0.516	0.721	1.393
WS17	2.127	0.470	0.383	0.774	1.616
WS18	2.531	0.395	0.408	0.710	1.566
WS19	1.914	0.522	0.482	0.816	1.440
WS20	4.308	0.232	0.307	0.544	1.805
WS21	3.964	0.252	0.376	0.567	1.631
WS22	4.440	0.225	0.293	0.536	1.847
WS23	3.248	0.308	0.376	0.626	1.631
WS24	4.163	0.240	0.339	0.553	1.719
WS25	2.926	0.342	0.479	0.660	1.445
WS26	4.205	0.238	0.346	0.551	1.701
Bhima lower	1.4	0.714	0.513	0.954	2.556

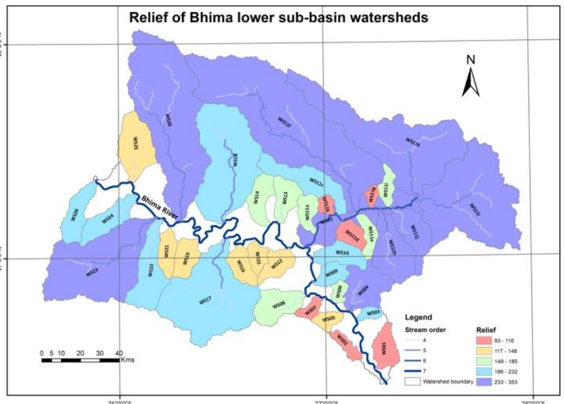

Fig. 8. Relief map of Bhima lower sub-basin watersheds

The relief ratio for the present study ranges from 2.34 WS11f to 13.83 WS03 where the one with lower values are concentrated mostly in the deccan terrain, the Rhl for the basin is 2.141 (Table VIII).

c) Relative relief ratio (Rhp)

The difference between the highest and lowest elevation of a watershed divided by the perimeter (P) of the basin gives the relative relief ratio, which is equated as[2],

$$Relative\ relief\ ratio = (Relief * 100)/P$$

The maximum Rhp was observed in WS3 (440.93) whereas the least was seen in WS11 (49), the overall rhp for the basin is 27.96 (Table VIII). The low values are characteristic features of less resistant rocks[38], [45].

d) Ruggedness number (Rn)

Ruggedness number refers to the product of the relief of the basin and the drainage density of the basin [22]. For the present study the Rn was found to be least for WS02 (0.05) and highest for WS04 (0.20). For the basin, it was found to be 0.22 (Table VIII, fig 9). When both variables, D and H, are large and the slope is not only steep but also lengthy, the roughness number reaches an exceptionally high value [21], [38].

e) Melton Ruggedness ratio (MRn)

The Melton ruggedness number is a slope index that provides specialised representation of relief ruggedness within the watershed[42], [46].

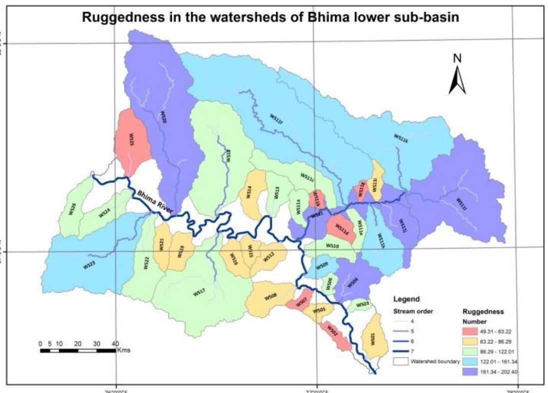

Fig. 9. Ruggedness in the Bhima lower sub-basin watershed

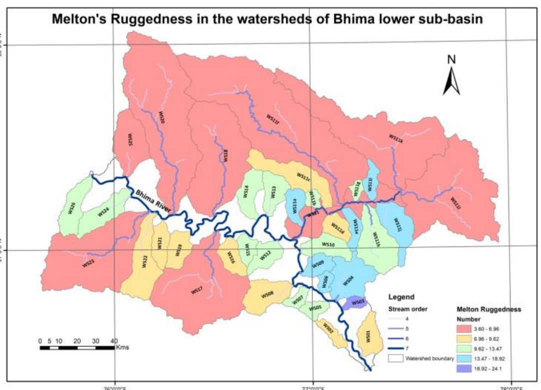

Fig. 10. Melton Ruggedness number for each of the watersheds in Bhima lower sub-basin.

It is a simple flow accumulation related index which is calculated as the ratio between the relief in the catchment area and the square root of the area of the catchment [47]. The MRn in the watersheds varies from 3.60 (WS11) to 24.10 (WS03) and for the basin is 2.53 (Table VIII). The watersheds near the mouth of the river have a higher ruggedness compared to the rest (Fig. 10).

TABLE VIII. THE RELIEF ASPECTS OF THE BHIMA LOWER SUB-BASIN WATERSHEDS

Water-shed	H (m)	Rhl	Rn	Mrn	Gr
WS01	108	4.21	0.08	7.21	3.08
WS02	99	4.72	0.05	9.57	2.34
WS03	202	13.83	0.12	24.10	4.59
WS04	334	11.36	0.20	15.99	6.05
WS05	133	9.55	0.07	12.69	2.37
WS06	167	13.20	0.10	18.92	4.58
WS07	116	6.97	0.06	12.29	3.84
WS08	153	5.20	0.09	8.21	3.57
WS09	215	10.73	0.15	17.22	7.59
WS10	215	8.57	0.12	13.44	4.78
WS11	353	3.13	0.20	3.60	2.58
WS11a	181	8.28	0.10	14.21	4.48
WS11b	93	8.65	0.05	10.99	4.09
WS11c	194	3.89	0.10	8.79	3.19
WS11d	105	5.65	0.06	8.25	4.52
WS11e	185	7.84	0.10	15.63	5.34
WS11f	290	2.40	0.16	5.19	1.99
WS11g	98	7.87	0.06	12.91	4.33
WS11h	268	6.63	0.16	11.58	4.93
WS11i	161	7.04	0.09	14.39	5.07
WS11j	306	8.17	0.19	16.03	6.14
WS11k	269	2.86	0.15	6.13	2.55
WS11l	304	5.66	0.19	6.96	4.28
WS12	148	5.79	0.08	10.38	4.81
WS13	170	6.91	0.09	11.08	3.94
WS14	165	6.04	0.09	10.38	3.99
WS15	129	7.30	0.07	11.27	5.55
WS16	137	6.14	0.07	9.62	4.57
WS17	199	3.39	0.11	4.94	2.71
WS18	210	3.39	0.11	5.40	3.02
WS19	126	6.16	0.07	8.52	4.50
WS20	316	3.13	0.18	6.50	2.56
WS21	131	4.76	0.07	9.48	3.53
WS22	193	4.01	0.11	8.45	2.83
WS23	266	3.70	0.15	6.66	3.20
WS24	215	5.89	0.12	12.01	3.86
WS25	125	3.34	0.06	5.71	2.59
WS26	232	6.57	0.12	13.47	4.81
Bhima lower	397	2.14	0.22	2.53	0.45

f) Gradient ratio

It is the ratio between the difference in the elevation of the basin from mouth to source and the basin length [25]. It is equated as,

$$Gradient\ ratio = \frac{Source\ elevation - Mouth\ elevation}{Basin\ Length}$$

Here it ranges from 1.99 WS 11f to 7.59 WS 9 and for the basin the value was found to be 0.45.

V. DISCUSSION

The Bhima lower sub-basin has an area of 24571 km^2 with WS11 covering 39% of the sub-basin. The basin length was found to be 221.52km, while the longest watershed is the WS11f (120.87Km). The sub-basin has an aggregate of 4567 streams with the first-order stream contributing to 79% of the total. These streams were found to have a total stream length of 13544.81 Km. With respect to the stream orders, the Lu decreases progressively with an increase in stream order. The mean stream length of the watershed increases for the whole of the basin but in some watersheds, it increased and then decreased reflecting a great influence of slope and topography on the drainage system. The stream length ratio showed a similar trend as the mean stream length. Higher the Rb higher is the possibility of flooding, Accordingly, WS 11b, WS11c, WS14, WS16, WS19, WS21, and WS26 were found to be at a higher risk of flooding. The lower rho coefficient value indicates lower hydrologic storage during a flood. The drainage density was found to be higher in the eastern and southeastern part of the basin, indicating impermeable formations underneath and the opposite was found true for the constant of channel maintenance. The basin has low stream frequency indicating high infiltration resulting in low runoff. The infiltration ratio supports the same. The length of overland flow for the watersheds ranges from 0.64 to 1 indicating long flow routes, reduced runoff and moderate slope. Except for the whole of the basin (3.2) and for WS11 (2.5), a very coarse drainage texture was identified. The low circulatory ratio of the basin as well as for the watersheds indicate a non-circular basin. The form factor of 0.72 along with the elongation ratio of 0.954 suggests a near circular basin. The shape aspects of the watersheds verify that the watersheds differ in shape from low circular to highly elongated. The relief aspects show more than the majority of the watersheds to have higher relief than the rest. The WS11 and WS20 were seen to have more Ruggedness, but the Melton Ruggedness number shows most of the terrain to have high ruggedness value.

VI. CONCLUSION

The study demonstrates the efficient use of CartoDEM along with ArcGIS to understand the morphometry of the Bhima lower sub-basin along with its watersheds and micro-watersheds. The basin is classified as a 7th order watershed which was found to be controlled mostly by the geology of the area. The watersheds underlain by the Deccan basalts were seen to have greater aerial extent as well as were more elongated than others. The bifurcation ratio suggests flooding in some watersheds [48] and the lower rho coefficient value indicate lower hydrologic storage during flooding. These watersheds were found to be in the basaltic terrain. Here, the drainage density was seen to be lower with low stream frequency suggesting low runoff and high infiltration showing the permeable nature of these Basaltic rocks suggesting a fractured hard rock formation. The morphometry was found to be very much controlled by the difference in the lithology of the area as suggested by the length of overland flow, constant of channel maintenance. The relief of the watersheds were found to be lower in the Deccan reflecting the resistant nature of the lithology, which was found true by the relative relief ratio and ruggedness number study of the basin. The presence of meanders indicates a mature stage for the Bhima lower sub-basin. The study forms a basis for further basin management, land use planning and other sustainable development works.

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REFERENCES

[1] U. Kedar, V. Rathod, and N. Jadhav, “Quantitative Morphometric Analysis of a Manganga Basin, Maharashtra, India using Cartosat (DEM) and GIS,” vol. 06, no. 4, p. 17, 2019.

[2] A. Bharath, “Drainage morphometry based sub-watershed prioritization of Kalinadi basin using geospatial technology | Elsevier Enhanced Reader.” https://reader.elsevier.com/reader/sd/pii/S2667010021002560?token=D5BA26685539F4ACF681563D1076C75E8C00215399A365283CB471DBAD94D5D34801A89ED92679D78F2BE1C43ADE9C9F&originRegion=eu-west-1&originCreation=20211229150452 (accessed Dec. 29, 2021).

[3] P. K. Rai, K. Mohan, S. Mishra, A. Ahmad, and V. N. Mishra, “A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India,” Appl. Water Sci., vol. 7, no. 1, pp. 217–232, Mar. 2017, doi: 10.1007/s13201-014-0238-y.

[4] V. M. Devappa, “MANAGING DROUGHT: SHORT TERM STRATEGIES IN SEMI ARID REGIONS -A CASE STUDY,” Int. J. Res. Eng. Technol., vol. 02, no. 13, pp. 410–416, Nov. 2013, doi: 10.15623/ijret.2013.0213077.

[5] V. M. Devappa, P. Khageshan, and S. R. Mise, “Long term assessment of southwest monsoon drought events at Taluka levels in Gulbarga District of Karnataka,” Mausam, vol. 62, no. 3, pp. 449–456, 2011.

[6] G. R. Singh, M. K. Jain, and V. Gupta, “Spatiotemporal assessment of drought hazard, vulnerability and risk in the Krishna River basin, India,” Nat. Hazards, vol. 99, no. 2, pp. 611–635, Nov. 2019, doi: 10.1007/s11069-019-03762-6.

[7] N. Patki, V. R. Ghodke, and N. J. Sathe, “Delineation Of Recharging Zones For Groundwater In Bhima River Basin, Pandharpur, Maharashtra,” p. 5.

[8] A. D. Pawar, J. Sarup, and S. K. Mittal, “Application of GIS and RS for Morphometric Analysis of Upper Bhima Basin: A Case Study,” J. Inst. Eng. India Ser. A, vol. 95, no. 4, pp. 249–257, Dec. 2014, doi: 10.1007/s40030-014-0097-4.

[9] D. R. Samal and S. Gedam, “Assessing the impacts of land use and land cover change on water resources in the Upper Bhima river basin, India,” Environ. Chall., vol. 5, p. 100251, Dec. 2021, doi: 10.1016/j.envc.2021.100251.

[10] N. D. Zagade and B. N. Umrikar, “Drought severity modeling of upper Bhima river basin, western India, using GIS–AHP tools for effective mitigation and resource management,” Nat. Hazards, vol. 105, no. 2, pp. 1165–1188, Jan. 2021, doi: 10.1007/s11069-020-04350-9.

[11] M. Rudraiah, S. Govindaiah, and S. S. Vittala, “Morphometry using remote sensing and GIS techniques in the sub-basins of Kagna river basin, Gulburga district, Karnataka, India,” J. Indian Soc. Remote Sens., vol. 36, no. 4, pp. 351–360, Dec. 2008, doi: 10.1007/s12524-008-0035-x.

[12] NRSC, Krishna Basin. CWC, 2014. [Online]. Available: http://www.india-wris.nrsc.gov.in

[13] M. S. Sofi, K. S. Rautela, S. U. Bhat, I. Rashid, and J. C. Kuniyal, “Application of Geomorphometric Approach for the Estimation of Hydro-sedimentological Flows and Cation Weathering Rate: Towards Understanding the Sustainable Land Use Policy for the Sindh Basin, Kashmir Himalaya,” Water. Air. Soil Pollut., vol. 232, no. 7, p. 280, Jul. 2021, doi: 10.1007/s11270-021-05217-w.

[14] A. Abdelkarim, S. S. Al-Alola, H. M. Alogayell, S. A. Mohamed, I. I. Alkadi, and I. Y. Youssef, “Mapping of GIS-Flood Hazard Using the Geomorphometric-Hazard Model: Case Study of the Al-Shamal Train Pathway in the City of Qurayyat, Kingdom of Saudi Arabia,” Geosciences, vol. 10, no. 9, p. 333, Aug. 2020, doi: 10.3390/geosciences10090333.

[15] A. N. Asode, A. Sreenivasa, and T. K. Lakkundi, “Quantitative morphometric analysis in the hard rock Hirehalla sub-basin, Bellary and Davanagere Districts, Karnataka, India using RS and GIS,” Arab. J. Geosci., vol. 9, no. 5, p. 381, May 2016, doi: 10.1007/s12517-016-2414-x.

[16] D. Sarkar, P. Mondal, S. Sutradhar, and P. Sarkar, “Morphometric Analysis Using SRTM-DEM and GIS of Nagar River Basin, Indo-Bangladesh Barind Tract,” J. Indian Soc. Remote Sens., vol. 48, no. 4, pp. 597–614, Apr. 2020, doi: 10.1007/s12524-020-01106-7.

[17] R. E. Horton, “EROSIONAL DEVELOPMENT OF STREAMS AND THEIR DRAINAGE BASINS; HYDROPHYSICAL

APPROACH TO QUANTITATIVE MORPHOLOGY," Geol. Soc. Am. Bull., vol. 56, no. 3, p. 275, 1945, doi: 10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2.

[18] A. Balasubramanian, K. Duraisamy, S. Thirumalaisamy, S. Krishnaraj, and R. K. Yatheendradasan, "Prioritization of subwatersheds based on quantitative morphometric analysis in lower Bhavani basin, Tamil Nadu, India using DEM and GIS techniques," Arab. J. Geosci., vol. 10, no. 24, p. 552, Dec. 2017, doi: 10.1007/s12517-017-3312-6.

[19] A. N. STRAHLER, "Quantitative geomorphology of drainage basin and channel network. In: V.T. Chow (Ed.)," Handb. Appl. Hydrol. McGraw Hill N. Y., p. 4.39-4.76, 1964.

[20] N. J. Raj, A. Prabhakaran, and A. Muthukrishnan, "Quantitative stream network analysis for assessing form and hydrological processes of the watersheds of Kolli hills, Tamil Nadu, India," Arab. J. Geosci., vol. 14, no. 23, p. 2646, Dec. 2021, doi: 10.1007/s12517-021-08882-7.

[21] A. N. STRAHLER, "Quantitative analysis of watershed geomorphology," Trans Amer Geophys Union, vol. 38, p. .913-920, 1957.

[22] P. Arulbalaji and D. Padmalal, "Sub-watershed Prioritization Based on Drainage Morphometric Analysis: A Case Study of Cauvery River Basin in South India," J. Geol. Soc. India, vol. 95, no. 1, pp. 25–35, Jan. 2020, doi: 10.1007/s12594-020-1383-6.

[23] Department, of Geography Vivekananda Mahavidyalaya, Burdwan, West Bengal, India. and Dr. S. N. S. Mura*, "A Geospatial Morphometric Analysis of Kulbera and Daurighara River Basins in Western Part of Purulia District of West Bengal, India," Int. J. Eng. Adv. Technol., vol. 10, no. 3, pp. 143–154, Feb. 2021, doi: 10.35940/ijeat.C2247.0210321.

[24] S. A. Schumn, "Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey," Geol Soc Am Bull, vol. 67, pp. 597–646, 1956.

[25] P. K. Ghosh, R. Mukhopadhyay, and N. C. Jana, "Quantitative Analysis of Drainage Basin Parameters towards better Management of Damodar River, Eastern India," J. Geol. Soc. India, vol. 97, no. 7, pp. 711–734, Jul. 2021, doi: 10.1007/s12594-021-1753-8.

[26] K. J. Babu, S. Sreekumar, and A. Aslam, "Implication of drainage basin parameters of a tropical river basin of South India.," Appl. Water Sci., vol. 6, no. 1, pp. 67–75, 2016.

[27] S. Kaliraj, N. Chandrasekar, and N. S. Magesh, "Morphometric analysis of the River Thamirabarani sub-basin in Kanyakumari District, South west coast of Tamil Nadu, India, using remote sensing and GIS," Environ. Earth Sci., vol. 73, no. 11, pp. 7375–7401, Jun. 2015, doi: 10.1007/s12665-014-3914-1.

[28] S. Soni, "Assessment of morphometric characteristics of Chakrar watershed in Madhya Pradesh India using geospatial technique," Appl. Water Sci., vol. 7, no. 5, pp. 2089–2102, Sep. 2017, doi: 10.1007/s13201-016-0395-2.

[29] V. Mandale and R. Bansod, "Quantitative Morphometric Analysis of the Adula Watershed, in Ahmednagar Maharashtra Using the ESRI-ArcGIS Tool," Curr. J. Appl. Sci. Technol., vol. 36, no. 5, pp. 1–10, 2019.

[30] S. Deshmukh and A. Wayal, "Morphometric Analysis of Upper Karha Watershed In Semi-Arid Area, Western Maharashtra, India. Journal of Advances and Scholarly Researches in Allied Education.," vol. 15, pp. 308–313, 2018.

[31] Lal. Kumar, G. Joshi, and K. K. Agarwal, "Morphometry and Morphostructural Studies of the Parts of Gola River and Kalsa River Basins, Chanphi-Okhalkanda Region, Kumaun Lesser Himalaya, India," Geotectonics, vol. 54, no. 3, pp. 410–427, May 2020, doi: 10.1134/S0016852120030048.

[32] K. Prakash, T. Mohanty, and J. K. Pati, "Morphotectonics of the Jamini River basin, Bundelkhand Craton, Central India; using remote sensing and GIS technique," Appl Water Sci, vol. 7, pp. 3767–3782, 2017.

[33] R. E. Horton, "Drainage- basin characteristics," Eos Trans. Am. Geophys. Union, vol. 13, no. 1, pp. 350–361, 1932.

[34] V. Ansan and N. Mangold, "New observations of Warrego Valles, Mars: Evidence for precipitation and surface runoff," Planet. Space Sci., vol. 54, no. 3, pp. 219–242, Mar. 2006, doi: 10.1016/j.pss.2005.12.009.

[35] B. Das, S. Singh, S. K. Jain, and P. K. Thakur, "Prioritization of Sub-Basins of Gomti River for Soil and Water Conservation Through Morphometric and LULC Analysis Using Remote Sensing and GIS," J. Indian Soc. Remote Sens., vol. 49, no. 10, pp. 2503–2522, Oct. 2021, doi: 10.1007/s12524-021-01410-w.

[36] N. Mundetia, D. Sharma, and S. K. Dubey, "Morphometric assessment and sub-watershed prioritization of Khari River basin in semi-arid region of Rajasthan, India," Arab. J. Geosci., vol. 11, no. 18, p. 530, Sep. 2018, doi: 10.1007/s12517-018-3819-5.

[37] A. Faniran, "The index of drainage intensity: a provisional new drainage factor.," Aust J Sci, vol. 31, no. 9, pp. 326–330, 1968.

[38] Z. R. Ansari, L. A. K. Rao, and A. Yusuf, "GIS based morphometric analysis of Yamuna drainage network in parts of Fatehabad area of Agra district, Uttar Pradesh," J. Geol. Soc. India, vol. 79, no. 5, pp. 505–514, May 2012, doi: 10.1007/s12594-012-0075-2.

[39] K. Smith, "Standards for grading texture of erosional topography," Am J Sci, vol. 248, pp. 655–668, 1950.

[40] S. Sukristiyanti, R. Maria, and H. Lestiana, "Watershed-based Morphometric Analysis: A Review," IOP Conf. Ser. Earth Environ. Sci., vol. 118, p. 012028, Feb. 2018, doi: 10.1088/1755-1315/118/1/012028.

[41] P. Pisal and A. Yadav, "Morphometric Analysis Of Bhogavati River Basin, Kolhapur District, Maharashtra, India.," IOSR J. Mech. Civ. Eng. IOSR-JMCE, pp. 01–08, Feb. 2013.

[42] S. Kanhaiya, B. P. Singh, S. Singh, P. Mittal, and V. K. Srivastava, "Morphometric analysis, bedload sediments, and weathering intensity in the Khurar River Basin, central India," Geol. J., vol. 54, no. 1, pp. 466–481, Jan. 2019, doi: 10.1002/gj.3194.

[43] V. C. Miller, "A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Varginia and Tennessee," Columbia University, Department of Geology, ONR, Geography Branch, New York., New York, Tech. Rept. 3, 1953.

[44] M. Waikar and A. Nilawar, "Morphometric Analysis of a Drainage Basin Using Geographical Information System: A Case study," vol. 2, Feb. 2014.

[45] P. D. SREEDEVI, "Assessment and management of groundwater resources of Pageru River basin, Cuddapah District, Andhra Pradesh, India," Unpublished Ph.D. Thesis, Sri Venkateswara Univ., Tirupati., 1999.

[46] M. Melton, "The geomorphic and paleoclimatic significance of alluvial deposits in Southern Arizona," J Geo, vol. 73, pp. 1–38, 1965.

[47] V. R. Suji, R. V. Sheeja, and S. Karuppasamy, "Prioritization using Morphometric Analysis and Land Use/Land Cover Parameters for Vazhichal Watershed using Remote Sensing and GIS Techniques," vol. 2, no. 1, p. 9.

[48] DDMA, "Kalaburagi District -Disaster Management Plan 2019-2020." [Online]. Available: https://ksdma.karnataka.gov.in/storage/pdf-files/KalaburagiDDMPplan2019-20.pdf

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