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Analysis of geomorphological character of Machkula watershed (4D5B3) in Bhima lower Sub-basin

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Abstract
There has been an intensive search in recent years for suitable strategies to organize and classify the heterogeneous group of catchments that characterize landscape. The focus on testing the value of hydrological signatures is mostly derived from morphometric analysis of the watershed. The study of Machkula watershed (454.41 sq. km) involves its evaluation Interms of slope (0.28%), shape factor (11.04) and circulatory ratio (0.22) which influences the hydrological response. The steeper cross-slopes (0.27% to 3.04%) at its 3rd order network within flatter terrain as it appear at 6th order has greater impact on drainage pattern (2.93 to 4.83) at meso and micro scales of watersheds and derive proportional gravitational influences on runoff generation and sediment transportation. Its shape (11.04) at synoptic level under influence of topographic complexity Potray's the shapes at 3rd order network (2.31 to 10.34) indicating its varied influence on runoff and sedimentation transport process.

Keywords: Morphometric analysis, slope, hydrological, drainage pattern

Introduction

Morphological assessment of a river involves evaluation of geometry of the river basin and how they respond to a number of processes and environmental conditions over period of time would be pivotal on characterization of its watersheds ((Kuldeep and Upasana, 2011 and Kaliraj, 2015) [5, 4]. The factors such as diversion of flow line, storage of water in reservoirs and increased use of ground water have affected the distribution and timing of stream flow and transportation of sediments which affects channel geometry and consequently affect the hydrological balance. The river Bhima constituent of River Krishna basin (2,58,948 sq. km covering 8% of the geographical area of the country) is under going major changes in hydrologic regime and morphology as its water resources of the basin began to be developed for agricultural, municipal and industrial uses consistently. In this regard the analysis of morphometric characteristics at the watershed scale would be gathering important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed (Lama and Ramkrishna, 2019) [7]. The intensive study of the individual watershed is necessary for developing management for judicious use of all the resources also to increase our understanding on watershed geometry as it affects stream flow variability and availability. Hence, study was aimed at assessing the morphological (geometry) characteristics of Machkula watershed (4D5B3) of Bhima Lower sub-basin in Kriahna River Basin.

Description of Bhima lower sub-basin

Selected AoI, the Machkula Watershed (4D5B3) being part of Bhima Lower Sub-Basin (23652.70 sq. km) extends within the limits of North latitudes of 16°40’40.81 ″to 17°28’9.47 ″ and East longitudes of 75°25’44.48 ″to 77°15’56.90 ″(Fig. 1). The River Bhima, one of the major constituent of the Krishna basin originates near Bhimashankar Temple in the Bhimashankar hills of khed Taluk in Pune District of Maharashtra state and as a part of the Western Ghats system. The sub-basin stretches to a length of 861 km through Maharashtra, Karnataka and Telangana states which finally merges into Krishna River proper at about 24 km North of Raichur city along the inter states border of Karnataka and Telangana. Rainfall variation in sub basin ranges from a maximum of 1124 mm to minimum of 242 mm.

Location Machkula watershed (4D5B3)

Machkula watershed (454.41 sq. km) is a part of Bhima Lower Sub-Basin and subsiquently part of Lower Bhima catchment (4D5B) flows through Kalburgi taluk of Kalburgi District in Karnataka, extends from Northern latitudes of 17°15'33.47" to 17°25'38.38" and Eastern longitudes of 77°6'10.00" to 76°40'8.79" and stretches along the main valley length to a extent of 70.84 km (Fig. 1). During the course of its journey, the main valley which looses 200.00 m (500.00 m to 300.00 RL) of its elevation flows initially towards East (56.5 km), and then turns southward to join River Bhima within the Ivni village limits of Kalburgi taluk in Kalburgi District.

Description of Machkula watershed (4D5B3)

The main valley which flows with gradual decrease in the elevation (200 m) as lower order streams join at different junctions of the watershed. The watershed underlain by Deccan Traps and Intertrappean and Consolidated sediments (1 per cent of area). The morphology is composed by slightly dissected Plateau at outer ridge, Pedi plain (Weathered/ buried) and flood plains. The drainage area (454.41 sq. km) of the watershed forms nearly a semicircular shape with average land slope of 0.28 per cent constituted out of 9 No. of sub-watersheds and in turn they consist of 103 number of micro watersheds all together. The existing soils, which belong to the orders of Vertisols (276.01 sq. km), Inceptisols (143.19 sq. km) and Entisols (20.79 sq. km), classified under families of Montmorillonitic and Isohyperthermic and subsequently identified under the series namely, Binjalawadagi, Hudgi, Harnal, Rajapur. Texturally, soils are classified as clay, clay loam, loamy sand and loam which vary in depth from less than 25 cm to more than 150 cm with slow (0.05 cm hr^{-1}) to moderate (1.3 cm hr^{-1}) permeability.

Material and Methods

Data Aquisation and its nature

In order to interpretate and understand the complex physiography of the selected watershed under consideration, both existing and available data and detailed inventorisation were under taken to capture the essential and explicit characters diversified by virtue of morphology, physiography, soils, topography, land use, rainfall distribution (both spatial and temporal) and erosion status. The requisite data base has been obtained both from the primary data (measured directly) and as secondary data (received from various sources).

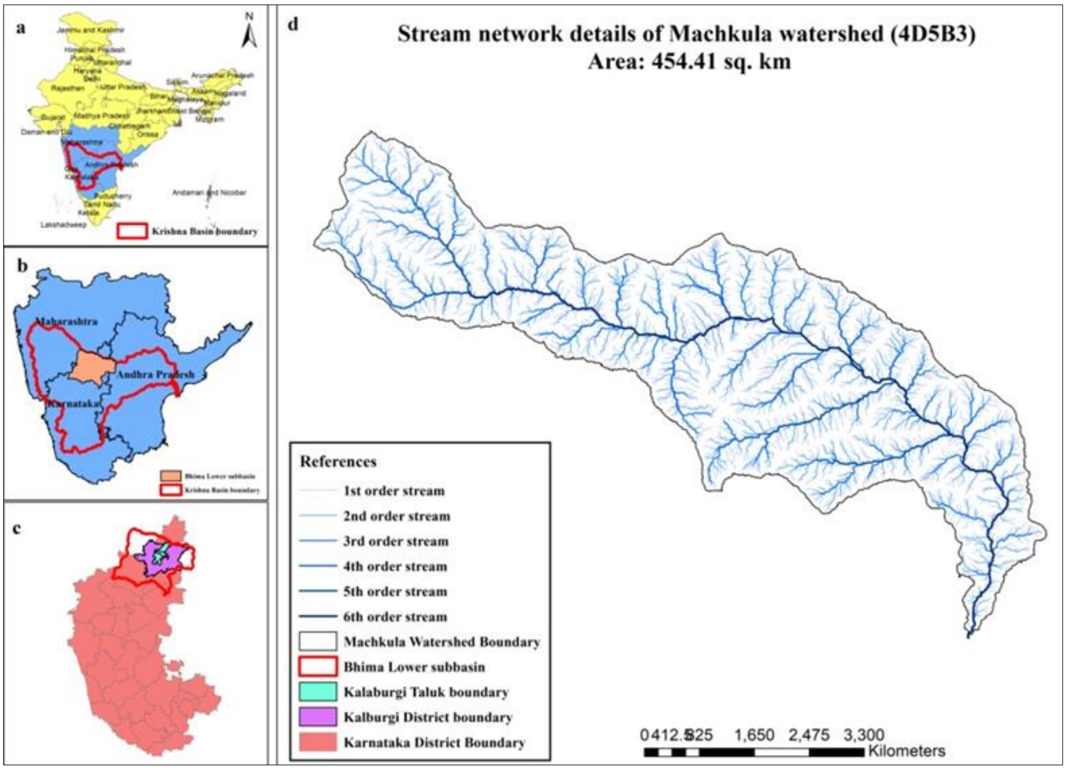

Fig 1: Location map of study area

The quantitative description of the drainage system of watershed can be studied by Morphometric analysis of the watershed (Strahler, 1964; Yangchan *et al.*, 2015; Waikar and Aditya, 2014 and Magesh *et al.*, 2011) [12, 16, 14, 8]. The traditional methods such as observations in the field and topographic maps or with advanced methods using remote sensing and GIS are used to study and identify the drainage networks within basins or sub basins. Field observations of Drainage network study will be difficult due undulated terrain and large area coverage. The necessity of morphometric parameters helps to study and analysis of various parameters of drainage namely, linear aspects, aerial aspects, relief aspects and shape aspects are derived on GIS platform using hydrological tools (Chopra *et al.*, 2005) [2]. These descriptive aspects help to characterize the watershed.

The Machkula watershed (4D5B3) as integral part of Lower Bhima sub basin characteristically runs from West to South direction and terminates into Krishna River Proper. The 6^{th} order watershed (45440.67 ha) has higher number of contributing streams (3758 No.). The main valley length (70.84 km) of watershed typically runs west to South direction getting contributed by six 5^{th} order streams at varied intervals (Table 1). Out of 28 No. of 4^{th} orders, 13 No. of them follow the hierarchy whereas 15 No. join 6^{th} order by passing 5th order. The tertiary 3rd order streams (130 No.) split in such way that 75 No. will join directly to 4th order whereas 17 No. join 5th order and remaining 38 No. directly join 6th order skipping their immediate hirarchieal order. Out of 2653 No. of 1st order streams, 1916 No. carry the overland flow to 692 No. of 2nd order streams directly, whereas remaining 737 No. would be carrying directly to higher order by skipping the 2nd order.

Results and Discussion

Linear aspects of watersheds

The whole system of 6th order stream network can be identified and distinguished into two distinctive characterisation. The parts of stream network wherein the over land flow passed to the main valley length (6th order) through the system of transfering heirarchially to their immediate higher order (5604.89 ha) where as others seek the paths of skipping the intermittent sequential orders which is the conspicuous character of the watershed carved in the plains of Krishna Basin. The main valley length (70.84 km) morphologically connects between the highest ridge point to the outlet and carries varied discharge and sediment load accrued through its network of system.

The bifurcation ratio (R_B) of 4.97 holds all streams in non-linear relationships (geometrical ratio) when transferred logarithmically (Fig. 2). The value of R_B depicts the requirement of streams of lower order to higher order sequentially present to absorb and get sediment transported through existing evolved relation between their numbers and account their lengths in response to changing rainfall charecteristics. When the 5th order stream network of watershed is looked, the each higher order needs be fed from the lower order streams in the wider range of 3.42 to 4.34 (Fig. 3) where as in case of 4th order and 3rd order streams, the range still widens between 2.42 to 6.12 and 2 to 8.25 respectively indicating varied changes in slope regime with sudden jerks or steepness (causing skips in the hirarchy while conveying flow from lower to higher order) both longitudinal and cross slopes domination of local changes in topography and the number of stream segments of any given order will be fewer than that of the next lower order but more than that of the next higher order (Fig. 4).

Table 1: Derived linear aspects of Machkula watershed (4D5B3) under Bhima Lower Sub-basin

Sl. No.	Serial of stream joining its higher hierarchy	Flow connectivity	Code	Number of stream order						Total streams (No.)	Main valley length (L_V), km	Mean stream length, km	Cumulative stream length, km	Bifurcation ratio (B_R)	Length ratio (R_L)
				1st	2nd	3rd	4th	5th	6th						
1	1		6.001K	2945	657	131	28	6	1	3758	70.84	0.44	1658.2	1.77	0.38
2	1	5th-6th	5.001K	324	66	16	3	1		410	14.15	0.41	167.55	1.20	0.10
3	2		5.002K	185	35	8	2	1		231	15.18	0.45	103.41	1.00	0.10
4	3		5.003K	99	24	4	2	1		130	7.10	0.41	52.76	0.86	-0.01
5	4		5.004K	92	22	4	2	1		121	8.00	0.46	56.24	0.84	-0.02
6	5		5.005K	232	59	11	2	1		305	17.77	0.47	142.69	1.10	0.14
7	6		5.006K	204	51	11	2	1		269	13.42	0.44	119.1	1.07	0.03
8	1	4th-5.001*	4.001K	193	36	9	1			239	9.77	0.40	96.58	1.20	0.05
9	2		4.002K	41	10	2	1			54	6.96	0.50	26.79	0.73	-0.03
10	3		4.003K	39	9	2	1			51	5.30	0.38	19.15	0.71	-0.19
11	4	4th-5.002	4.004K	108	18	4	1			131	12.22	0.43	56.77	0.97	0.04
12	5		4.005K	40	8	2	1			51	5.64	0.46	23.66	0.70	-0.08
13	6	4th-6th	4.006K	73	13	3	1			90	7.09	0.52	46.38	0.86	0.05
14	7		4.007K	28	7	2	1			38	4.26	0.36	13.80	0.65	-0.18
15	8		4.008K	40	10	2	1			53	5.97	0.43	22.66	0.73	-0.07
16	9		4.009K	50	14	2	1			67	6.04	0.41	27.75	0.79	-0.06
17	10		4.010K	47	10	2	1			60	6.14	0.36	21.37	0.74	-0.11
18	11		4.011K	109	22	4	1			136	8.69	0.44	59.44	1.00	0.04
19	12	4th-5.003	4.012K	57	15	2	1			75	5.16	0.38	28.64	0.81	-0.08
20	13		4.013K	36	7	2	1			46	5.07	0.43	19.90	0.68	-0.09
21	14	4th-6th	4.014K	63	15	2	1			81	7.58	0.45	36.84	0.82	-0.01
22	15		4.015K	17	5	2	1			25	3.13	0.33	8.22	0.56	-0.33
23	16		4.016K	105	24	5	1			135	8.67	0.46	62.40	1.03	0.04
24	17	4th-5.004	4.017K	46	9	2	1			58	6.18	0.47	27.51	0.73	-0.03
25	18		4.018K	35	9	2	1			47	4.34	0.46	21.41	0.70	-0.19
26	19	4th-6th	4.019K	40	11	2	1			54	5.06	0.49	26.39	0.74	-0.10
27	20	4th-5.005	4.020K	83	19	4	1			107	7.93	0.46	49.67	0.95	0.00
28	21		4.021K	27	8	2	1			38	4.07	0.41	15.54	0.66	-0.18
29	22	4th-6th	4.022K	35	8	2	1			46	4.74	0.45	20.54	0.69	-0.11
30	23	4th-5.006	4.023K	47	11	3	1			62	5.11	0.40	24.83	0.80	-0.17
31	24		4.024K	13	4	2	1			20	2.15	0.29	5.74	0.50	-0.67
32	25	4th-6th	4.025K	39	6	2	1			48	4.77	0.49	23.54	0.67	-0.08
33	26		4.026K	32	10	2	1			45	4.89	0.42	18.81	0.70	-0.21
34	27		4.027K	29	5	2	1			37	4.12	0.41	15.21	0.62	-0.20
35	28		4.028K	15	4	2	1			22	2.77	0.32	7.09	0.52	-0.38

Table 2: Derived areal aspects of Machkula watershed (4D5B3) under Bhima Lower Sub-basin

Sl. No.	Serial of stream joining its higher hierarchy	Flow connectivity	Code	Total area, ha	Perimeter, Km	Area ratio (R_A)
1	1		6.001K	45440.67	161.24	0.68
2	1	5th-6th	5.001K	4936.79	36.21	0.39
3	2		5.002K	2975.17	33.29	0.34

4	3		5.003K	1481.11	19.65	0.40
5	4		5.004K	1452.17	20.50	0.21
6	5		5.005K	3688.04	39.38	0.17
7	6		5.006K	3185.6	32.36	0.23
8	1	4^{th}-5.001	4.001K	2838.24	26.67	0.16
9	2		4.002K	797.45	16.95	0.04
10	3		4.003K	560.08	13.03	-0.06*
11	4	4^{th}-5.002	4.004K	1699.90	29.13	0.11
12	5		4.005K	653.11	14.36	0.01
13	6	4^{th}-6^{th}	4.006K	1272.73	19.16	0.13
14	7		4.007K	372.68	11.21	-0.19*
15	8		4.008K	618.69	14.78	-0.08*
16	9		4.009K	774.99	14.06	-0.01*
17	10		4.010K	678.40	14.72	-0.02*
18	11		4.011K	1660.56	21.56	-0.03*
19	12	4^{th}-5.003	4.012K	799.17	14.32	-0.01*
20	13		4.013K	561.52	12.61	-0.08*
21	14	4^{th} - 6^{th}	4.014K	992.65	18.11	0.02
22	15		4.015K	216.70	7.75	-0.31*
23	16		4.016K	1666.44	20.43	0.07
24	17	4^{th}-5.004	4.017K	754.96	15.82	0.00
25	18		4.018K	522.85	11.51	-0.10*
26	19	4^{th} - 6^{th}	4.019K	649.21	12.45	-0.03*
27	20	4^{th}-5.005	4.020K	1260.90	18.08	0.03
28	21		4.021K	387.30	9.92	-0.15*
29	22	4^{th} - 6^{th}	4.022K	546.47	12.57	-0.05*
30	23	4^{th}-5.006	4.023K	691.19	13.74	-0.03*
31	24		4.024K	143.98	5.91	-0.38*
32	25	4^{th}-6^{th}	4.025K	635.82	13.51	0.03
33	26		4.026K	522.91	11.19	-0.17*
34	27		4.027K	424.74	9.54	-0.11*
35	28		4.028K	221.39	7.25	-0.23*

* -0.06 – Indicates not adhering the positive exponential relation

Table 3: Derived relief aspects of Machkula watershed (4D5B3) under Bhima Lower Sub-basin

Sl. No.	Serial of stream joining its higher hierarchy	Flow connectivity	Code	Maximum Watershed relief (H), m	Relief ratio (R_r), per cent	Relative relief (R_R), per cent
1	1		6.001K	200	0.28	0.12
2	1	5^{th}-6^{th}	5.001K	81	0.57	0.22
3	2		5.002K	68	0.45	0.20
4	3		5.003K	52	0.73	0.26
5	4		5.004K	52	0.65	0.25
6	5		5.005K	136	0.77	0.35
7	6		5.006K	82	0.61	0.25
8	1	4^{th}-5.001	4.001K	69.00	0.71	0.26
9	2		4.002K	53.00	0.76	0.31
10	3		4.003K	48.00	0.91	0.37
11	4	4^{th}-5.002	4.004K	57.00	0.47	0.20
12	5		4.005K	38.00	0.67	0.26
13	6	4^{th}-6^{th}	4.006K	48.00	0.68	0.25
14	7		4.007K	43.00	1.01	0.38
15	8		4.008K	42.00	0.70	0.28
16	9		4.009K	65.00	1.08	0.46
17	10		4.010K	74.00	1.20	0.50
18	11		4.011K	47.00	0.54	0.22
19	12	4^{th}-5.003	4.012K	39.00	0.76	0.27
20	13		4.013K	68.00	1.34	0.54
21	14	4^{th} - 6^{th}	4.014K	55.00	0.73	0.30
22	15		4.015K	31.00	0.99	0.40
23	16		4.016K	54.00	0.62	0.26
24	17	4^{th}-5.004	4.017K	43.00	0.70	0.27
25	18		4.018K	37.00	0.85	0.32
26	19	4^{th} - 6^{th}	4.019K	41.00	0.81	0.33
27	20	4^{th}-5.005	4.020K	85.00	1.07	0.47
28	21		4.021K	94.00	2.31	0.95
29	22	4^{th} - 6^{th}	4.022K	38.00	0.80	0.30
30	23	4^{th}-5.006	4.023K	37.00	0.72	0.27
31	24		4.024K	19.00	0.88	0.32

32	25	4^{th}-6^{th}	4.025K	49.00	1.03	0.36
33	26		4.026K	38.00	0.78	0.34
34	27		4.027K	39.00	0.95	0.41
35	28		4.028K	24.00	0.87	0.33

Table 4: Shape aspects of Machkula watershed (4D5B3) under Bhima Lower Sub-basin

Sl. No.	Serial of stream joining its higher hierarchy	Flow connectivity	Code	Shape factor (S_b)	Elongation ratio (R_e)	Compactness coefficient (C_c)	Circulatory ratio (R_c)	Drainage density, (D_d) m km^{-1}	Stream density, (D_s) No. sq. km^{-1}
1	1	6th	6.001K	11.04	0.34	2.13	0.22	3.65	8.27
2	1	5^{th}-6^{th}	5.001K	4.05	0.56	1.45	0.47	3.39	8.30
3	2		5.002K	7.74	0.41	1.72	0.34	3.48	7.76
4	3		5.003K	3.40	0.61	1.44	0.48	3.56	8.78
5	4		5.004K	4.41	0.54	1.52	0.43	3.87	8.33
6	5		5.005K	8.56	0.39	1.83	0.30	3.87	8.27
7	6		5.006K	5.66	0.47	1.62	0.38	3.74	8.45
8	1	4^{th}-5.001	4.001K	3.36	0.62	1.41	0.50	3.40	8.42
9	2		4.002K	6.08	0.46	1.69	0.35	3.36	6.77
10	3		4.003K	5.02	0.50	1.55	0.41	3.42	9.11
11	4	4^{th}-5.002	4.004K	8.78	0.38	1.99	0.25	3.34	7.71
12	5		4.005K	4.86	0.51	1.59	0.40	3.62	7.81
13	6	4^{th}-6^{th}	4.006K	3.95	0.57	1.52	0.44	3.64	7.07
14	7		4.007K	4.88	0.51	1.64	0.37	3.70	10.20
15	8		4.008K	5.75	0.47	1.68	0.36	3.66	8.57
16	9		4.009K	4.70	0.52	1.43	0.49	3.58	8.65
17	10		4.010K	5.56	0.48	1.59	0.39	3.15	8.84
18	11		4.011K	4.55	0.53	1.49	0.45	3.58	8.19
19	12	4^{th}-5.003	4.012K	3.33	0.62	1.43	0.49	3.58	9.38
20	13		4.013K	4.57	0.53	1.50	0.44	3.54	8.19
21	14	4^{th} - 6^{th}	4.014K	5.78	0.47	1.62	0.38	3.71	8.16
22	15		4.015K	4.52	0.53	1.49	0.45	3.79	11.54
23	16		4.016K	4.51	0.53	1.41	0.50	3.74	8.10
24	17	4^{th}-5.004	4.017K	5.06	0.50	1.62	0.38	3.64	7.68
25	18		4.018K	3.60	0.59	1.42	0.50	4.10	8.99
26	19	4^{th} - 6^{th}	4.019K	3.94	0.57	1.38	0.53	4.07	8.32
27	20	4^{th}-5.005	4.020K	4.98	0.51	1.44	0.48	3.94	8.49
28	21		4.021K	4.28	0.55	1.42	0.49	4.01	9.81
29	22	4^{th} - 6^{th}	4.022K	4.10	0.56	1.52	0.43	3.76	8.42
30	23	4^{th}-5.006	4.023K	3.77	0.58	1.48	0.46	3.59	8.97
31	24		4.024K	3.21	0.63	1.39	0.52	3.98	13.89
32	25	4^{th}-6^{th}	4.025K	3.58	0.60	1.51	0.44	3.70	7.55
33	26		4.026K	4.57	0.53	1.38	0.52	3.60	8.61
34	27		4.027K	4.00	0.56	1.31	0.59	3.58	8.71
35	28		4.028K	3.46	0.61	1.37	0.53	3.20	9.94

The length of the 5^{th} order (6 No.), 4^{th} order (28 No.) and tertiary orders of 130 No. (meso scale) stretch to a distance in the range of 7.10 km to 17.77 km, 2.5 km to 12.22 km and 1.39 km to 6.76 km (Table 1). The finer elements of 1^{st} and 2^{nd} order streams (micro scale) concentrate the flow to a length in the range of 0.015 km to 2.65 km indicates the areas with larger slopes and finer texture. The stream length of 1^{st} order (0.015 km to 1.79 km) and respective higher 2^{nd} order (0.01 km to 2.65 km) vary marginally but distinctively. With respect to relation among stream length of each successive order in descending pattern, the 6^{th} order watershed proclaims stream average length at 2 times higher than their immediate lower order to transport water flow and sediment (Fig. 5). Then the subsequent lower 5^{th} order and 4^{th} order streams, there needs incremental increase in the mean length by 2.02 to 3.26 and 1.76 to 8.35 times respectively than their respective lower order (Fig. 6 and Fig. 7). The tertiary orders (micro scale) which are 130 numbers possess larger mean length than their lower order streams (1^{st} and 2^{nd}) in the range of 0.39 to 16.97 times.

The stream length ratio and bifurcation ratio help describe the evaluation of the stream network under which geological and topographical sequences and settings are carved in (Sethupathi *et al.*, 2011) [11]. The Machkula watershed derived out of Basltic region. The entire range of R_B ratio at 6^{th} order (4.97) level are in agreement within the typical range evolved else were in Indian Deccan plateau with a range of 3.5 to 5 (Satish Kumar *et al.*, 1999) [10]. The R_B of lower orders (2.42 to 6.12) indicate charecterisation of localised morphology that change abruptly as compared to synoptic level at 6^{th} order (4.97) through domination of plains and justify need for distinctive strategy in absorbing runoff as a part of conservation strategy (Kumar *et al.*, 2011) [6]. This means that their needs understanding of the watershed at 6^{th} order (synoptic level) and individually at the level of 3^{rd} order micro watershed concurrently before addressing the watershed treatment plan (UNESCO, 2011) [13].

Areal aspects of watersheds

In order to verify the affiliation of areas between two successive stream orders the log transformation necessitated to mask non linearity and it had shown an incremental increase (1.02) of the area of an order as compared to its immediate previous order area attributing non linearity at the levels of 5th and 6th order (Fig. 8 and Table 2). The 5th order has shown significant difference (0.99 to 1.68) in watershed (Fig. 9). On an average, 4th order stream networks possess the areal contribution with marginal changes in the range of 0.82 to 1.2 (Fig. 10). In a nutshell, the areal relation among the stream networks on an average remain with same ratio or slightly increase due to limitations passed by the constantly decreasing slope both longitudinally and transversely.

Relief aspects of watershed

The selected watershed by looking into the position with respect to the Krishna River basin, find itself in lower pediment with flatter watershed reliefs of 200 m (500 RL to 300 RL) with relative ratio (0.12 per cent) and relief ratio (0.28 per cent). Among the 5th order (6 No.), 4th order (20 No.) and 3rd order stream network the relief is ranged between 52 m to 136 m, 19 m to 94 m and 7 m to 88m respectively and corresponding relief ratio are 0.45 per cent to 0.77 per cent, 0.47 per cent to 2.31 per cent and 0.27 to 3.04 per cent respectively (Table 3). The analysis precipitates to the understanding that at synoptic level, which has ramification on generation runoff and erosion rates (Mahadevaswamy *et al.*, 2011) [9]. However, the strong variability of 5th,

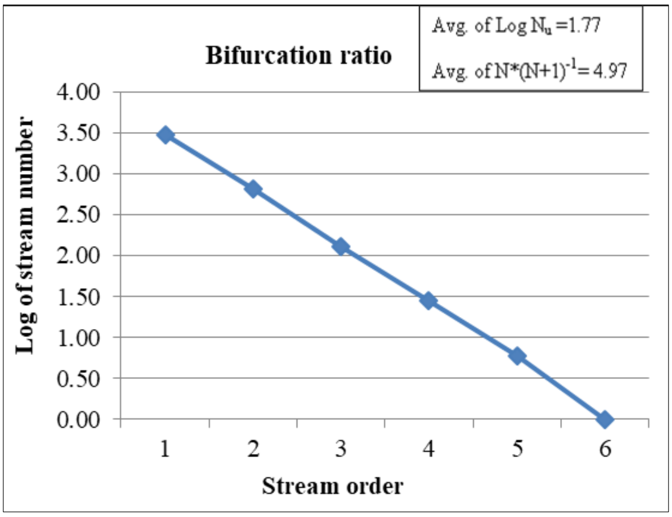

Fig 2: 6th order stream network

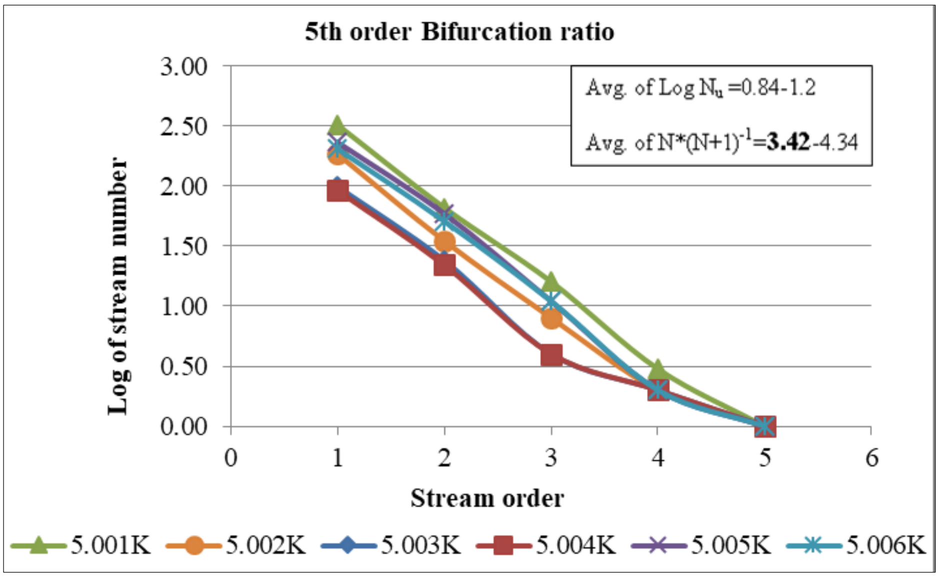

Fig 3: 5th order stream networks

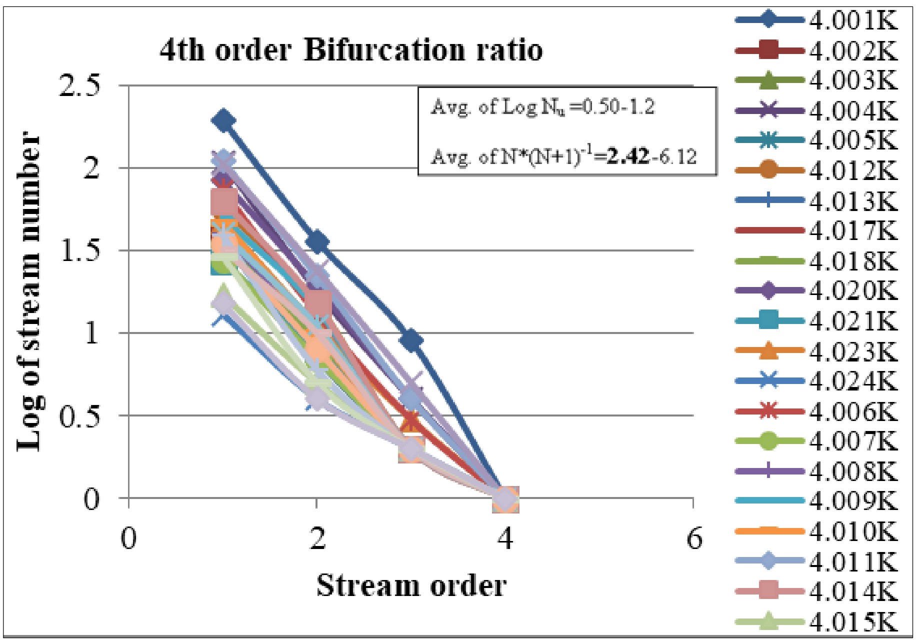

Figure 4: 4th order stream networks

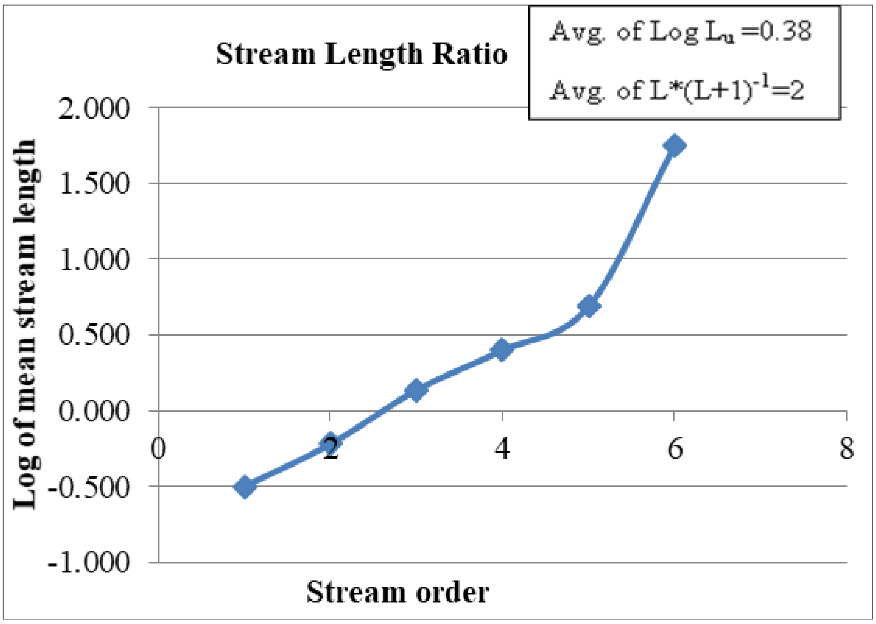

Fig 5: 6th order stream network

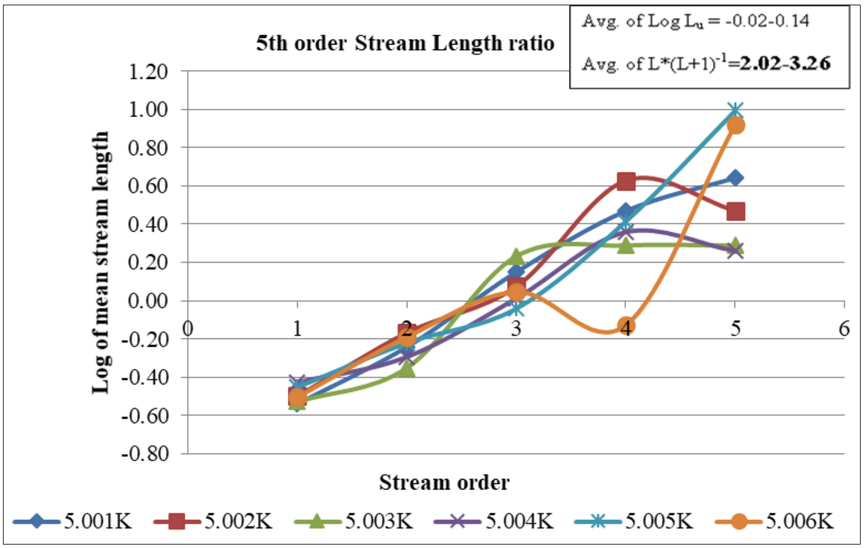

Fig 6: 5th order stream networks

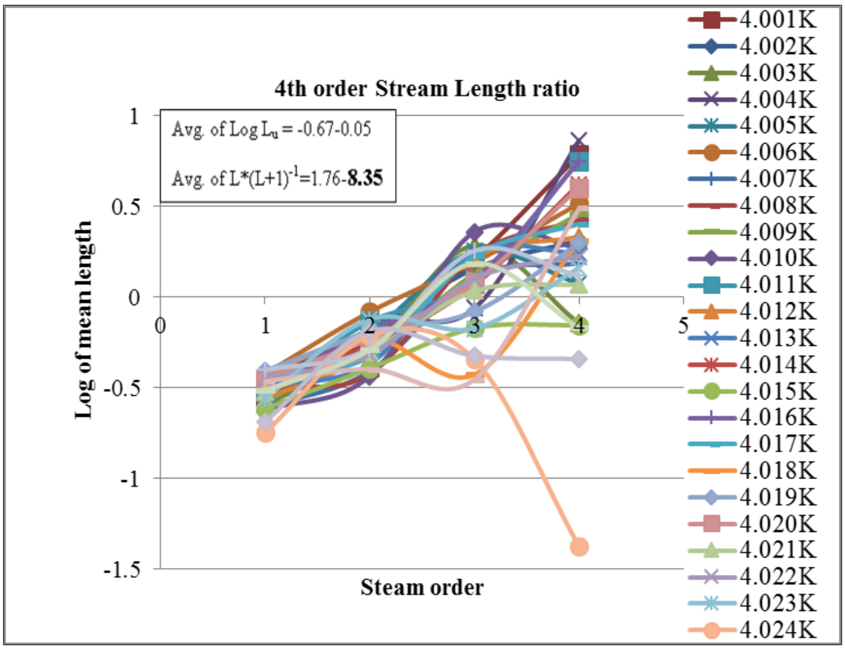

Fig 7: 4th order stream networks

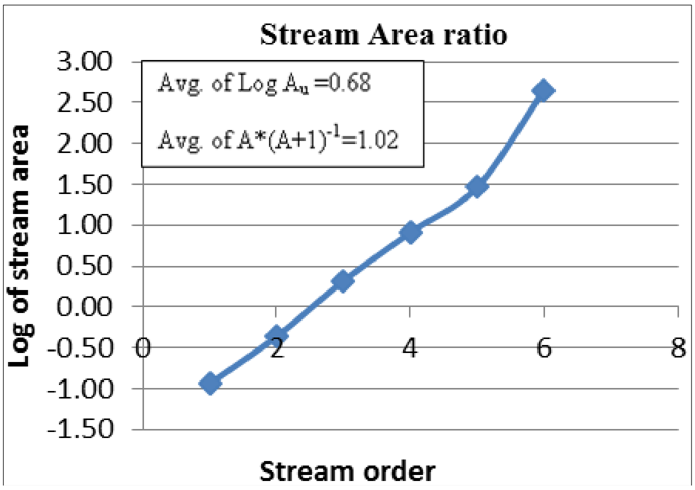

Fig 8: 6th order stream network

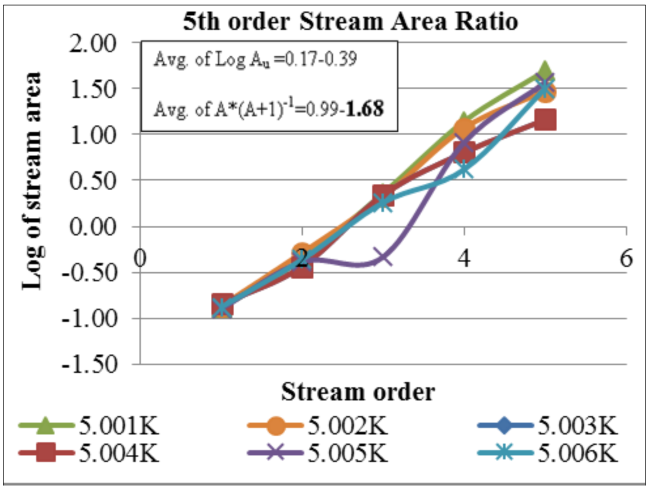

Fig 9: 5th order stream networks

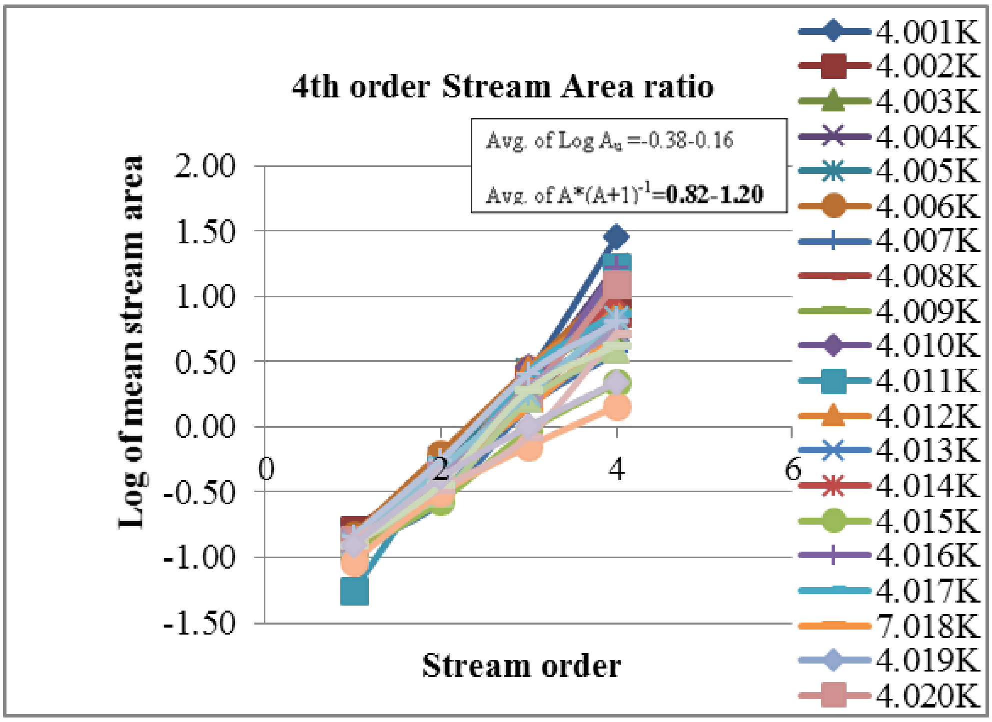

Fig 10: 4th order stream networks

4th and 3rd orders indicate sudden changes in the cross slopes across and along valley which in turn affects the enhanced peakedness of runoff concentration and erosion parameters.

Shape aspects of watershed

The shape of the watershed is also a conspicuous to each individual constituent starting from its synoptic order (6th order) to its constituent 1st order which measured through the parameters namely, shape factor, elongation ratio, compactness coefficient, circulatory ratio, drainage density and stream density to effectively define the degree of relative elongation stretchability (extent of irregularity of drainage area from geometrically defined circular shape), near to shape of circle or compactness (Yadav *et al.*, 2014 and Choudhari *et al.*, 2018) [15, 3]. The shape is constituted as a result of variability in topography both at meso and micro level (4th and 1st order) to their synoptic level (6th and 5th order network). Though the drainage areas under study form an irregular boundary on the map their complete size as a whole are accounted by defined shape parameters. In general, the shapes of drainage areas varied from pear ovoid to the extreme of fern shape.

The report of morphology as expressed by linear, areal and relief aspects at synoptic level also lead to similar shape evidenced by elongation ratio (0.34), compactness coefficient (2.13), circulatory ratio (0.22) which is less than 1.00 indicating far different from circular in shape (Table 4). In the similar lines, unbounded shape factor (11.04) indicates the watershed as long narrow drainage basin (Abdulkadir and Taofeeq, 2016) [1]. At 5th order stream network level, the range of variability as scrutinized by shape factor (3.40 to 8.56), elongation ratio (0.39 to 0.61), compactness coefficient (1.44 to 1.83) and circulatory ratio (0.30 to 0.48) strengthens the similar shape theory at of 6th order watershed. Whereas, the 4th order stream network when expressed their shape for watersheds through the lens of shape factor (3.21 to 8.78), elongation ratio (0.38 to 0.63), compactness coefficient (1.31 to 1.99) and circulatory ratio (0.25 to 0.59) shows the networks are moderately near to circular shape and not much elongated as that of 6th and 5th order stream networks. Thus, the shape parameters indicate undulations built on steady steepness in forward direction of watershed is representative characteristic of the middle of the Krishna river basin.

Summary and Conclusion

The geomorphological examination of a typical 6th watershed whose shape and size and its behaviors would be aggregation but with resultant effect of its constituent stream networks of lower order who exhibit deviations to each other and also with respect to their higher order conspicuously. Such a complex behavior has ramification on hydrological response with characteristic variations as the order moves from lower to higher order.

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