Morphological investigation on degrading minor irrigation tanks: a case study in Hunsur taluk of Mysore district- Karnataka, India

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Abstract: The objective of this morphological investigation is to ascertain and study the main reasons for the degradation of Minor Irrigation (MI) tanks and focusses its analysis and discussions on the Bilikere and Halebidu tanks and their combined catchment (BKHB) - a part of Hunsur taluk of Mysore district, Karnataka, India which were found completely deteriorated and degraded after 2004. In this regard it is relevant to mention here that analysis of the daily rainfall data from 1975 to 2014 reveals that the average annual rainfall has remained normal whereas the mean daily intensity has decreased and the number of rainy days has increased. Drainage morphometry in relation to hydrology of BKHB catchment is very useful in understanding the reasons behind degradation of these MI tanks. The study has made use of CARTOSAT data in generating Digital Elevation Model (DEM) of BKHB catchment covering 44.67 km^2 which is a part of Lakshman Theertha river basin which is a sub-basin of Cauvery river in the semi-arid region of Mysore district. A comprehensive study of linear aspects reveals that the basin is dominated by lower order streams, the mean bifurcation ratio (R_b) of the BKHB catchment is 4.17; that of 3rd order Micro Watersheds (MWS) is 3.9 shows that the drainage pattern is not influenced by geological structures and length of overland flow (L_g) indicates flat terrain with less surface run-off and more infiltration. Similarly, the study of areal aspects like form factor, Gravelius index, shape factor, circularity ratio and elongation ratio indicates that the 3rd order MWS are elongated. Other aspects like drainage density, texture etc., shows that the catchment is highly permeable and dominated by 1st order streams. Relief aspects indicates low degree slope of the land form and resistant bed rocks in the terrain. The dendritic drainage pattern shows uniform bedrock terrain with insignificant faults and joints. A sum total of all the indices lead to the fact that the BKHB catchment is more permeable with high infiltration and less runoff working as a contributory factor towards degradation of lakes.

Keywords: Morphometry, CARTOSAT, Bilikere and Halebidu, MI Tanks, BKHB Catchment.

1. Introduction

Drainage basins are the primary units for any hydrological study. Precipitation, floods and droughts are the primary atmospheric activities which alters the landforms. The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channels it to a single point. The fluvial activities leave imprints on the landforms or drainage basins. The number, the size and the shapes of the stream channels are the evidences of these imprints and are exhibited in the surficial topography. The formation of the channels depends on the type of soil, geology and vegetation. Characterization and evaluation of the basin hydrology is an important factor in the study of surface runoff, ground water potential and management of environment. In this investigation, Bilikere and Halebidu (BKHB) catchment is delineated using SOI topomaps. GIS analysis is carried out using CARTOSAT DEM and Hydrology tool in Arc-GIS software. The combined catchment is further divided into 2 Sub-watersheds (SBW) namely Bilikere and Halebidu taking into consideration their proximity, interdependency being a cascade system and comprising of 13 micro watersheds (MWS). Prioritization of 3rd order MWS is considered because of the domination of lower order streams.

The importance of surface drainage networks and its development has been given attention from past several years using conventional methods (Horton, 1945; Strahler, 1952; Strahler, 1956; Strahler, 1965). ASTER data integrated with GIS was used for the characterization of 3rd order watersheds where the lower order streams dominated the basin (Rama, 2014). GIS based methodology for the assessment of drainage morphometric parameters combined with Remote Sensing (RS) data is more suitable than the conventional methods (Pareta and Pareta, 2012). Morphometric analysis carried out in Najanagud taluk of Mysore district revealed that the elongated shape of the basin is due to the guiding effect of thrusting and faulting (Subhan and Rao, 2011). Landsat imageries and topographical maps were used to illustrate the hydrological behavior of a subtropical Andean basin in Argentina (Mesa, 2006). RS and GIS has been demonstrated to be an effective tool in the process of delineating drainage and morphometric study (Lone et.al, 2012). LISS-III +PAN merged image and SOI topomaps were used to study and analyze the sub-watersheds in the district of Tumkur, Karnataka, India and demonstrated that RS techniques are capable tool in morphometric analysis (Srinivasa et al., 2004). Bio-physical and hydrological features like population, rainfall etc., and land use/land cover of various watersheds can be comprehended by RS and GIS techniques (Ramachandra et al., 2014). The inter-relationships between landforms and land resources can be better realized for planning and management at a micro watershed level (Boobalan et.al., 2014). Disaster due to floods and other natural calamities could be properly managed using advanced satellite images and technologies (Altaf et.al., 2013). A correlation between drainage density and stream frequency was calculated for different watersheds and found to be positive (Malik et.al., 2011). The work reported in this paper is intended to find out the hydrological behavior of the BKHB catchment using the morphometric parameters and consequently establish the reason behind the degradation of the water bodies in the study area.

2. Study area

Hunsur Taluk of Mysore district has seven Minor Irrigation (MI) tanks with overall Culturable Command Area (CCA) of 740 Hectares. Among seven lakes two major lakes; Bilikere lake and Halebidu lake have dried up completely since 2004. These lakes are situated between 12°21'10.163"N & 12°17'37.353"N latitude and 76°25'46.296"E & 76°31'4.167"E longitude as shown in figure 1 & 2. Both the tanks are rain fed waterbodies at an altitude of 695 m and 680 m Mean Sea Level (MSL) respectively located west of Mysore, Karnataka, India in a suburban area. The water was used for agriculture, horticulture, fish culture and domestic purposes. The combined catchment BKHB has an area of 44.67 km^2 with a highest elevation of 774 m and lowest elevation of 680 m above MSL. Geologically, the area comprises of granites, gneisses and charnockite rock stratum. The catchment is primarily dominated by agricultural land and major part of the land is cropland, sparse vegetation and poor soil cover. The soil types are red sandy soil, red loamy soil and deep black soil of varying thickness upto 6 m (Basavarajappa et al., 2014). Variation in rainfall leads to recurring drought and over usage of ground water which characterizes the study area.

3. Details of tanks

There are about 27 water bodies including ponds and lakes; ranging from 0.7 Hectare to 62 Hectare in the BKHB catchment. This catchment is a part of Lakshman Theertha River which is a sub-basin of Cauvery river. The Bilikere lake has a catchment area of 22.87 km^2, live capacity of 21 MCft (Million Cubic feet) with water spread area of 36.8 Hectares and a total physiographical area of 62.12 Hectares. The Halebidu lake has a catchment area of 21.80 km^2, live capacity of 18 MCft with a water spread area of 30 Hectares and a total physiographical area of 58.33 Hectares.

4. Data used and methodology

Open series Survey of India topographical maps D43W7 & D43W11 (2005 edition) on 1:50, 000 scale are used as the base maps. Morphometric analysis is carried using CARTOSAT-DEM; Version 1.1, R1, developed by ISRO, India, derived from the CARTOSAT-1, stereo payload launched in 2005, vertical accuracy is 8 m at 90% confidence and horizontal resolution of one arc second (approximately 30m). Landsat-5 TM and ETM images (Table 1) with spatial resolution of 30 m and 8-bit radiometric resolution downloaded from USGS were utilized to find the temporal changes in the waterbodies. The morphometric parameters were analyzed in three aspects; linear, areal and relief. Various parameters are derived using GIS tools and other empirical formulae (Ven, 1964) as presented in table 2.

5. Results and discussion

5.1 Linear aspects

Stream network is generated using Cartosat DEM for the BKHB catchment. Stream links and junctions characterize linear aspects of the catchment. Stream definition is calculated for a grid cell size of 50 pixels covering 4.67 Hectares of land (0.1% of catchment area) because of the small size of BKHB catchment; so that small streams (30 m length) can be identified. The linear aspects include stream order, stream length, mean stream length, stream length ratio, bifurcation ratio, length of the basin, length of overland flow and rho coefficient as listed in the tables 3 & 4.

5.1.1 Stream order (S_u)

According Strahler (1952, 1957 and 1964) and Horton (1945), Stream order is a measure of the relative size of streams. In the study area 5th order stream is the highest order. There are 357 streams identified in the catchment out of which 283 - 1st order (79.3%), 57 – 2nd order (16%), 13 – 3rd order (3.6%), 3 – 4th order (0.8%) and 1 - 5th order (0.3%). It is also observed that overall 35% of 1st order streams directly contribute to the higher order streams.

Table 1: Details of satellite data

Sl.No	Name of the Satellite	Sensor	Date of acquisition	Path	Row
1	Landsat -5	MSS	05/12/1994	144	052
2	Landsat -5	MSS	06/11/1996	144	052
3	Landsat -5	MSS	11/09/1999	144	052
4	Landsat -5	MSS	16/12/2004	144	052
5	Landsat -5	MSS	31/12/2006	144	052
6	IRS-P6	LISS-III	03/11/2009	099	065

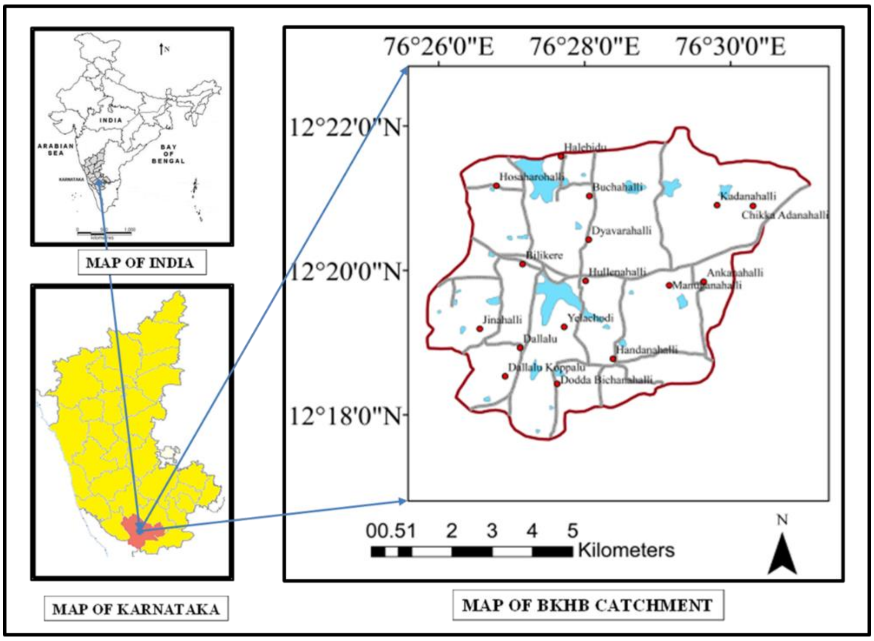

Figure 1: Location map of the study area

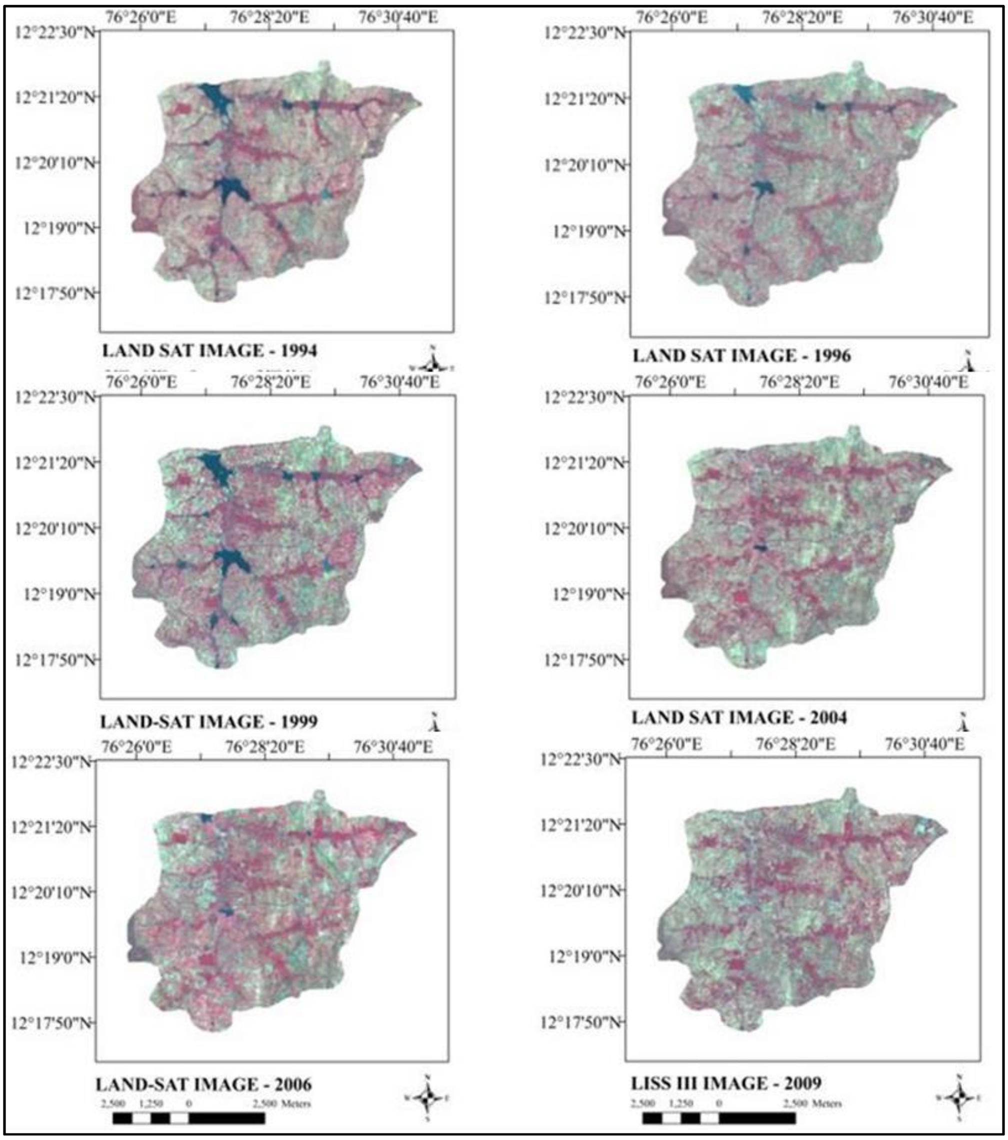

Figure 2: Temporal satellite images of the study area

Table 2 : Determination of morphological parameters

Sl. No	Particulars	Formulae	References
LINEAR PARAMETERS			
1	Stream Order (S_u)	Hierarchical ranking system	Strahler (1964)
2	Stream Length (L_u)	Law of stream lengths	Horton (1945)
3	Stream Number (N_u)	Law of stream Number	Horton (1945)
4	Mean Stream Length (L_{um})	$\mathbf{L_{um}} = \mathbf{L_u}/\mathbf{N_u}$	Strahler (1964)
5	Stream Length ratio (L_{ur})	$\mathbf{L_{ur}} = \mathbf{L_u}/\mathbf{L_{u-1}}$	Horton (1945)
6	Length of overland flow (L_g)	$\mathbf{L_g} = \mathbf{1}/\mathbf{2D_d}$	Horton (1932)
7	Bifurcation Ratio (R_b)	$\mathbf{R_b} = \mathbf{N_u}/\mathbf{N_{u+1}}$	Strahler (1964)
8	RHO Coefficient (R_{ho})	$\mathbf{R_{ho}} = \mathbf{L_{ur}}/\mathbf{R_b}$	Mesa (2006)
AREAL PARAMETERS			
9	Area (A)	Area calculated from GIS Tools	GIS
10	Perimeter (P)	Calculated using GIS Tools	GIS
11	Basin Length (L_b)	Calculated using GIS Tools	GIS
12	Form Factor (F_f)	$\mathbf{F_r} = \mathbf{A}/L_b^2$	Horton (1945)
13	Gravelius Index (G_i)	$\mathbf{G_i} = \mathbf{0.284P}/\sqrt{\mathbf{A}}$	Gravelius (1914)
14	Shape Factor (S_f)	$\mathbf{S_f} = L_b^2/\mathbf{A}$	Horton (1932)
15	Circularity Ratio (R_c)	$\mathbf{R_c} = \mathbf{12.57A}/\mathbf{P^2}$	Miller (1957)
16	Elongation Ratio (R_e)	$\mathbf{R_e} = D/L_b = \mathbf{1.128}\sqrt{A}/L_b$	Schumm (1956)
17	Drainage Density (D_d)	$\mathbf{D_d} = \sum \mathbf{L_u}/\mathbf{A}$	Horton (1945)
18	Drainage Texture (D_t)	$\mathbf{D_t} = \sum \mathbf{N_u}/\mathbf{P}$	Smith (1950)
19	Texture Ratio (T_r)	$\mathbf{T_r} = \sum \mathbf{N_1}/\mathbf{P}$	Schumm (1965)
20	Stream Frequency (F_s)	$\mathbf{F_s} = \sum \mathbf{N_u}/\mathbf{A}$	Horton (1945)
21	Infiltration Number (I_f)	$\mathbf{I_f} = F_s D_d$	Faniran (1968)
22	Constant of channel maintenance (C_m)	$\mathbf{C_m} = \mathbf{1}/D_d$	Schumm(1956)
23	Lemniscate's ratio (K)	$\mathbf{K} = \mathbf{3.14}L_b^2/\mathbf{4A}$	Chorley (1957)
RELIEF PARAMETERS			
24	Watershed Relief (R)	$\mathbf{R} = \mathbf{H} - \mathbf{h}$	Strahler (1952)
25	Relief ratio (R_f)	$\mathbf{R_f} = R/L_b$	Schumm(1956)
26	Relative relief ratio (R_r)	$\mathbf{R_r} = \mathbf{R}/\mathbf{P}$	Schumm(1956)
27	Slope gradient (S_g)	$\mathbf{S_g} = \mathbf{R}/\mathbf{L_b^2}$	Gravelius (1914)
28	Ruggedness number (R_n)	$\mathbf{R_n} = \mathbf{HD_d}$	Strahler (1964)

5.1.2 Stream number (N_u)

The number of streams, of different orders in a given drainage basin tends closely to approximate an inverse geometric series in which first term is unity and the ratio is the bifurcation ratio (Horton 1945), (Figure 3).

5.1.3 Stream length (L_u)

Stream length is one of the most important hydrological features of the basin as it reveals the surface runoff behaviors. The length of the stream is a clue of the gradient of the catchment and of the degree of the basin. In general, streams are smaller in number, greater in length; in more permeable strata whereas larger in number, smaller in length in a steep well drained basin. The number of streams of various orders in a sub-watershed is counted and their lengths from mouth to drainage divide are measured. The stream length 'L_u' has been computed based on the law proposed by Horton (1945). The stream length of MWS & SWS is calculated using GIS tools and it is observed that the sum of stream length is minimum (1.23 km) in BK-ManuganaHalli MWS and maximum (14.84 km) in HB-ChikkaKadanahalli MWS.

5.1.4 Mean stream length (L_{um})

Mean Stream length is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces (Strahler A N, 1964). It is obtained by dividing the total length of stream of an order by total number of segments in the order; mean stream length found to vary from 0.12 km to 0.34 km for I order; 0.09 km-1.02 km for II order; 0.26 km-3.16 km for III order streams. The results indicate no structural disturbance in the formation of streams in all the MWS of 3rd order.

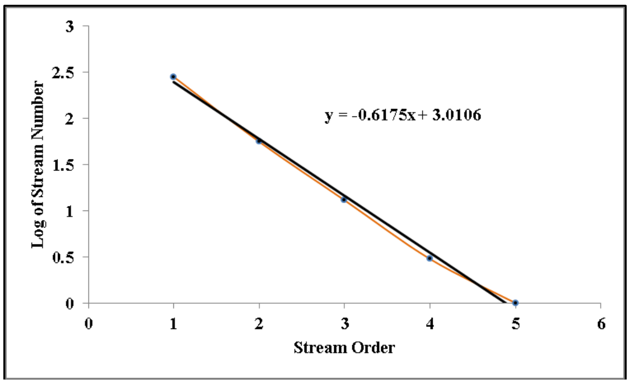

Figure 3: Relationship of Stream Numbers and Stream Order

5.1.5 Stream length ratio (L_{ur})

Horton (1945) states the ratio of the mean (L_{um}) of segments of order (S_u) to mean length of segments of the next lower order (L_{um-1}), which tends to be constant throughout the successive orders of a basin. His law of stream lengths refers that the mean stream lengths of stream segments of each of the successive orders of a watershed tend to approximate a direct geometric sequence in which the first term is the average length of segments of the first order. Changes of stream length ratio from one order to another order indicating their late youth stage of geomorphic development (Singh and Singh, 1997). The variation in the values of 'L_{ur}' for different order streams within a basin indicates the permeability of the surface contributing to the stream network of the basin. It is apparent from the values of the BKHB catchment that the 'L_{ur}' for the III order stream is higher (2.72) than the 'L_{ur}' for the streams of the other orders. It is followed by the II order stream (2.24). This shows the absorbent nature of the region through which the 2[nd] and 3[rd] order streams flow.

A graphical plot (Figure 4) between the order of the stream (x-axis) and log of mean stream lengths (y-axis) illustrates a direct relationship upto the 5[th] order of BKHB catchment. The equation for the trend line is given by

$$\log Y = -0.0861X + 0.5208 \qquad 1$$

Where Y, is the mean stream length and X, is the order of the stream. The regression coefficient – 'R' squared value of 0.57 shows the statistical significance of linear regression fit and confirms the law of stream length ratio proposed by Horton.

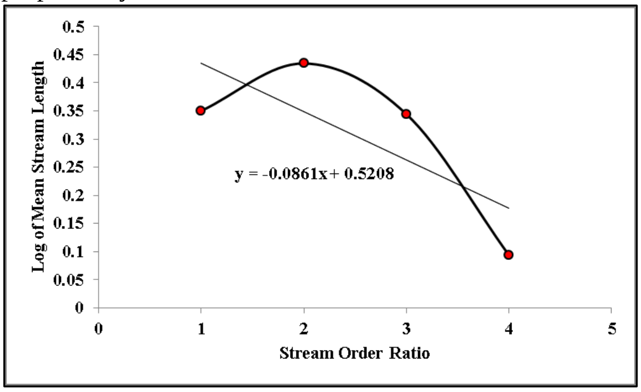

Figure 4: Relationship of stream length and stream order ratio

Table 3: Linear aspects of Sub-Watersheds

SBWS	**Stream Number-N_u**						**Bifurcation Ratio-R_b**				
	I	II	III	IV	V	Total	R_{b1}	R_{b2}	R_{b3}	R_{b4}	Mean
Bilikere	151	31	8	2	0	192	4.87	3.88	4.00		4.25
Halebidu	126	24	6	2	1	159	5.25	4.00	3.00	2.00	3.56
Combined-BKHB	283	57	13	3	1	357	4.96	4.38	4.33	3.00	4.17
Average	**186.67**	**37.33**	**9.00**	**2.33**	**1.00**	**236.00**	**5.03**	**4.09**	**3.78**	**2.50**	**3.99**

SBWS	**Stream Length-L_u**						**Mean Stream Length-L_{um}**				
	I	II	III	IV	V	Total	I	II	III	IV	V
Bilikere	37.67	17.10	9.47	7.54	0.00	71.78	0.25	0.55	1.18	3.77	
Halebidu	32.40	15.13	10.15	5.42	1.20	64.30	0.26	0.63	1.69	2.71	1.20
Combined-BKHB	71.40	32.20	19.98	10.18	4.22	137.98	0.25	0.56	1.54	3.39	4.22
Average	**47.16**	**21.48**	**13.20**	**7.71**	**1.81**	**91.35**	**0.25**	**0.58**	**1.47**	**3.29**	**2.71**

SBWS	**Stream Length Ratio-L_{ur}**				**RHO-Coefficient-RHO**					**L_g**
	L_{u2}/L_{u1}	L_{u3}/L_{u2}	L_{u4}/L_{u3}	L_{u5}/L_{u4}	Mean	R_{ho1}	R_{ho2}	R_{ho3}	R_{ho4}	Mean	
Bilikere	2.21	2.15	3.18	-	2.51	0.45	0.55	0.80		0.60	0.16
Halebidu	2.45	2.68	1.60	0.44	1.79	0.47	0.67	0.53	0.22	0.47	0.16
Combined-BKHB	2.24	2.72	2.21	1.24	2.10	0.45	0.62	0.51	0.41	0.50	0.16
Average	**2.30**	**2.52**	**2.33**	**0.84**	**2.14**	**0.46**	**0.62**	**0.61**	**0.32**	**0.52**	**0.16**

Table 4: Linear aspects of BKHB 3rd order MWS

MWS-No	MWS-Name	Stream Number-N_u				Bifurcation Ratio-R_b		
		I	II	III	Total	R_{b1}	R_{b2}	Mean
1	HB_Chikka Kadanahalli	28.00	6.00	1.00	35.00	4.67	6.00	5.33
2	HB_Hosa Harohalli	9.00	3.00	1.00	13.00	3.00	3.00	3.00
3	HB_Kadanahalli	12.00	2.00	1.00	15.00	6.00	2.00	4.00
4	HB_BiliKere	15.00	2.00	1.00	18.00	7.50	2.00	4.75
5	HB_DyavaraHalli	17.00	3.00	1.00	21.00	5.67	3.00	4.33
6	BK_AnkanaHalli	9.00	3.00	1.00	13.00	3.00	3.00	3.00
7	BK_HullenaHalli	6.00	2.00	1.00	9.00	3.00	2.00	2.50
8	BK_ManuganaHalli	5.00	2.00	1.00	8.00	2.50	2.00	2.25
9	BK_JinaHalli	30.00	6.00	1.00	37.00	5.00	6.00	5.50
10	BK_Dallalu	4.00	2.00	1.00	7.00	2.00	2.00	2.00
11	BK_Dallalu Kappalu	28.00	4.00	1.00	33.00	7.00	4.00	5.50
12	BK_Dodda BichanaHalli	15.00	4.00	1.00	20.00	3.75	4.00	3.88
13	BK_HandanaHalli	22.00	5.00	1.00	28.00	4.40	5.00	4.70
	Average	**15.38**	**3.38**	**1.00**	**19.77**	**4.42**	**3.38**	**3.90**

MWS-No	MWS-Name	Stream Length-L_u				Mean stream Length-L_{um}			
		I	II	III	Total	I	II	III	Total
1	HB_Chikka Kadanahalli	7.76	4.79	2.29	14.84	0.28	0.80	2.29	3.37
2	HB_Hosa Harohalli	2.69	1.39	1.74	5.82	0.30	0.46	1.74	2.50
3	HB_Kadanahalli	2.82	1.23	1.42	5.47	0.24	0.62	1.42	2.27
4	HB_BiliKere	2.31	1.07	1.79	5.17	0.15	0.54	1.79	2.48
5	HB_DyavaraHalli	3.84	1.06	2.55	7.45	0.23	0.35	2.55	3.13
6	BK_AnkanaHalli	3.07	1.14	0.93	5.14	0.34	0.38	0.93	1.65
7	BK_HullenaHalli	1.61	1.14	0.26	3.01	0.27	0.57	0.26	1.10
8	BK_ManuganaHalli	0.58	0.28	0.37	1.23	0.12	0.14	0.37	0.63
9	BK_JinaHalli	7.60	3.63	3.16	14.39	0.25	0.61	3.16	4.02
10	BK_Dallalu	1.16	0.73	0.50	2.39	0.29	0.37	0.50	1.16
11	BK_Dallalu Kappalu	6.90	4.08	1.00	11.98	0.25	1.02	1.00	2.27
12	BK_Dodda BichanaHalli	3.53	0.35	1.32	5.20	0.24	0.09	1.32	1.64
13	BK_HandanaHalli	6.53	2.60	2.66	11.79	0.30	0.52	2.66	3.48
	Average	**3.88**	**1.81**	**1.54**	**7.22**	**0.25**	**0.50**	**1.54**	**2.28**

MWS-No	MWS-Name	Stream Length Ratio-L_{ur}			RHO-Coefficient-RHO			L_g
		Lu2/Lu1	Lu3/Lu2	Mean	R_{ho1}	R_{ho2}	Mean	
1	HB_Chikka Kadanahalli	0.62	0.48	0.55	0.13	0.08	0.11	0.17
2	HB_Hosa Harohalli	0.52	1.25	0.88	0.17	0.42	0.29	0.17
3	HB_Kadanahalli	0.44	1.15	0.80	0.07	0.58	0.32	0.18
4	HB_BiliKere	0.46	1.67	1.07	0.06	0.84	0.45	0.18
5	HB_DyavaraHalli	0.28	2.41	1.34	0.05	0.80	0.43	0.18
6	BK_AnkanaHalli	0.37	0.82	0.59	0.12	0.27	0.20	0.18
7	BK_HullenaHalli	0.71	0.23	0.47	0.24	0.11	0.18	0.15
8	BK_ManuganaHalli	0.48	1.32	0.90	0.19	0.66	0.43	0.15
9	BK_JinaHalli	0.48	0.87	0.67	0.10	0.15	0.12	0.16
10	BK_Dallalu	0.63	0.68	0.66	0.31	0.34	0.33	0.17
11	BK_Dallalu Kappalu	0.59	0.25	0.42	0.08	0.06	0.07	0.17
12	BK_Dodda BichanaHalli	0.10	3.77	1.94	0.03	0.94	0.48	0.16
13	BK_HandanaHalli	0.40	1.02	0.71	0.09	0.20	0.15	0.16
	Average	**0.47**	**1.22**	**0.85**	**0.13**	**0.42**	**0.27**	**0.17**

5.1.6 Bifurcation ratio (R_b)

It is a dimensionless number denoting the ratio between the number of streams of one order 'N_u' and those of the next higher order 'N_{u+1}' in a drainage network. According to Horton (1945), bifurcation ratio indicates the relief and dissertation. Strahler (1957) demonstrates that bifurcation ratio shows a small range of variation for different regions except where the powerful geological control dominates. It is observed that the bifurcation ratio characteristically ranges between 3.0 and 5.0, for the basin in which geology is reasonably homogeneous and with no structural disturbances. The lower values of 'R_b' indicate less structural disturbances. 'R_b' is a measure of proneness to flooding. Higher the bifurcation ratio greater the probability of flooding. The observed mean value of 'R_b' (3.38) of 3rd order MWS is less than 5 signifying that there is no structural disturbance on the drainage network. Out of thirteen, 3rd order MWS, only two 3rd order watersheds have a value more than 5 indicating structural control over the development of drainage network in these MWS. 'R_b' value for the 2nd order streams vary from 2.0 to 7.5, four MWS among thirteen show the value of 'R_b' greater than 5 indicating that the drainage network is influenced by the structural disturbances.

Figure 3 shows a graphical presentation between stream order as abscissa and log of stream number as ordinate. The best fitting regression equation for the linear relationship is given by

$$\log Y = -0.6175X + 3.0106 \qquad 2$$

Where 'Y' is the number of streams and 'X' is the order of the stream. The regression coefficient – 'R' squared value of 0.99 shows the statistical significance of linear regression fit and confirms the law of stream order proposed by Horton.

Overall the mean value of 'R_b' for 2nd order stream is 4.42, for 3rd order it is 3.38, for BKHB catchment it is 4.17 suggesting that there is no structural disturbances in the formation of drainage network and there are about 4.2 times as many numbers of streams of any given order to that of the next higher order.

5.1.7 Length of overland flow (L_g)

(Horton R E, 1932) describes overland flow as the tendency of water to flow horizontally across soil surfaces when rainfall exceeds the capacity of infiltration. Length of overland flow is the length of the run of the surface water on the land surface before it is assigned into definite channels. Horton has taken L_g as the length equal to half the reciprocal of the drainage density. Higher the values of 'L_g' lower the permeability and lower the value higher the permeability. The observed value of 3rd order streams of all MWS vary between 0.15-0.18 km/km^2 with a mean value of 0.17 km/km^2, BKHB catchment has a value of 0.16 km/km^2 indicating that the catchment is having a low slope, smaller flow paths, Less surface runoff and more infiltration.

5.1.8 Length of the basin (L_b)

Schumm defines the basin length as the longest dimension of the basin parallel to the principal drainage line (S. Schumm, 1956). The length of the basin for MWS varies from 0.8 km to 3.36 km, with a mean length of 2.28 km. The length of the BKHB Catchment found to be 7.2 km.

5.1.9 RHO coefficient

It defines the relationship between the drainage density and the development of the earth's features in the basin. It evaluates the storage capacity of the drainage network (Horton 1945). Higher values of RHO exhibit higher water storage during floods and essentially weaken the erosion effect during elevated discharge. The average R_{HO} coefficient of BKHB catchment is 0.5; that of MWS is 0.27 indicating less storage capacity of the channel network. **Areal aspects**

The physical characteristics of a catchment rely upon the size, shape, and gradient, drainage density of the watershed; size and length of the contributing streams. Areal aspects of a catchment of a particular order is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment of that particular order including all branches of lower order. The size and shape of the catchment has an important relation to the drainage discharge characteristics. For instance, a circular catchment with a low bifurcation ratio can have a peak discharge compared to an elongated catchment with high bifurcation ratio may have a fluctuated flood discharge. Runoff, sediment processes and rate of discharge also depend heavily on the shape of the catchment. Parameters like form factor, circularity ratio, drainage density, compaction coefficient, elongation ratio etc., define the characteristics of a catchment. Table 5 shows the areal parameters for the MWS and BKHB catchment.

5.2.1 Form factor (F_f)

According to Horton (1932), Form Factor is the ratio of basin area to square of the basin length. It is a dimensionless number. The value of form factor would always be greater than 0.754 for a perfectly circular watershed. Smaller the value of form factor, more elongated will be the watershed. The mean value of the all 3rd order MWS found to be 0.44 indicating, elongated MWS.

5.2.2 Gravelius index (G_i)

Gravelius Index also known as compactness co-efficient (Gravelius, 1914), of a watershed is the ratio of perimeter of a watershed to circumference of circular area, which equals the area of the watershed. A circular catchment yields the shortest time of concentration before peak flow occurs in the basin. G_i=1 indicates that the catchment behaves like a circular catchment. G_i>1 shows that the basin deviates from circular to elongated and hence the time of concentration also increases. 'G_i' of 3rd order MWS found to vary from1.23-1.79; with a mean of 1.44, which indicates most of the MWS are elongated.

5.2.3 Shape factor (S_f)

It is the ratio of square of the basin length to the basin area (Horton R E, 1932) It is used to measure the degree of similarity of catchment shapes. The value of S_f=1 for a perfect square catchment, If S_f>1 then the catchment is elongated and If S_f<1 then the catchment is a circular one. The shape factor for all MWS varies from 1.43 to 3.65, indicating elongated shape of the MWS, 'S_f' for BKHB catchment is 1.16 which suggests that the total catchment is slightly elongated.

5.2.4 Circularity ratio (R_c)

Circularity ratio is defined as the ratio of the basin area to the area of a circle having the same perimeter as the perimeter of the basin (Miller, 1957). It signifies the dissection stages of the study area with low, medium and high values, which represent youth, mature and old stages of the cycle of the tributary watershed of the region. According to Miller, If the value ranges between 0.4-0.5, It implies that the basin area is elongated, highly permeable and having a homogeneous lithology. The average 'R_c' for MWS is 0.49 and that of BKHB is 0.38, which means the basin area is elongated, more infiltration, low discharge and the subsoil is highly absorbent.

5.2.5 Elongation ratio (R_e)

Schumm (1956) defines it as the ratio of the diameter of the circle having the same area of the basin to the maximum length of the basin. Mean 'R_e' value of MWS in the study area is 0.74 indicating elongated shape with low relief. 'R_e' for BKHB is 1.05; reveals that the basin area is typically low relief area.

5.2.6 Drainage density (D_d)

It is defined as the ratio of the total length of all the streams to the total area of the drainage basin and is a measure of catchment characteristics like infiltration, runoff and land use. Higher values of drainage densities indicate more runoff and lower value indicates more infiltration or vegetation. The mean value of 'D_d' for the MWS is found to be 3 which indicate that the basin is medium textured. It also shows that the basin is highly permeable with low relief.

5.2.7 Drainage texture (D_t)

Horton (1945) defined drainage texture as the total number of stream segments of all order per perimeter of the basin. Drainage texture depends on the underlying lithology, infiltration capacity and relief aspect of the terrain. (Smith, 1950) has classified drainage texture into 5 different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). The drainage texture for the MWS in the study area lies from 1.52 to 3.58 with a mean of 2.52 indicating very coarse to coarse texture; BKHB catchment has a value of 9.3 signifying that the 1st order streams dominate the basin.

5.2.8 Texture ratio (T_r)

According to (Schumm, 1965), it is expressed as the ratio between the first order streams and perimeter of the basin and it depends on the underlying rocks, infiltration capacity and relief aspects of the terrain. It ranges between 0.89-2.86 for MWS with an average of 1.91, for BKHB it is 7.34; which reveals that the basin is controlled by first order streams.

5.2.9 Stream frequency (F_s)

According to Horton (1945) Stream frequency is referred to as number of streams per unit area of the catchment. It shows the relation of the lithology with the catchment. For 3rd order MWS it ranges from 6.63 to 21.05 per km^2; with a mean value of 9.35 /km^2 suggesting that the catchment is moderately drained.

5.2.10 Infiltration number (I_f)

It is defined the infiltration number as the product of drainage density and stream frequency, Lower value of 'I_f', higher the rate of infiltration and higher the value of 'I_f' lower the infiltration rate (Faniran, 1968). The mean value of the 'I_f' is found to be 28.39 for MWS; with a minimum of 29.69 and maximum of 68.14. The entire catchment has a value of 24.69 suggesting a moderate infiltration rate in the study area.

5.2.11 Constant of channel maintenance (C_m)

It has been characterized as the inverse of the drainage density by Schumm (1956). This constant provides an approximation of the extent of catchment required to maintain a unit length of the channel. The mean value of 'C_m' for all MWS is 0.334 km^2/km which indicates that about 0.334 km^2 of area is required to support one kilometer of the channel.

5.2.12 Lemniscate's ratio (K)

Lemniscate or pear shape, which defines the shape of the basin; it is more consistent with empirical reality than an ideal circular shape of a basin (Chorley, 1967). Chorley suggested that if the K value<0.6, then the shape of the basin is circular; if it is between 0.6-0.9 then it is oval; if K>0.9 elongated; Accordingly, the values of 'K' for MWS varies between 1.12 to 2.87 with a mean of 1.90 indicating that the 3rd order basins are elongated. The 'K' for the BKHB catchment is 0.91 which implies it is less elongated.

5.2.13 Drainage pattern

In morphological analysis, the flow pattern formed by the streams is called as drainage pattern. The pattern is controlled by geology of the area like dominating hard and soft rocks, slope of the terrain and topography of the catchment or land. In the present study, the pattern is identified as dendritic (Figures 5 & 6) which occurs in horizontal sedimentary or in intrusive igneous rocks with homogeneity of rock mass. This pattern is the most common form of drainage system. There are many twigs of streams which are then joined into the tributaries of the main stream or lakes. Dendritic pattern develops in a terrain which has uniform bedrock and where faulting and jointing are insignificant.

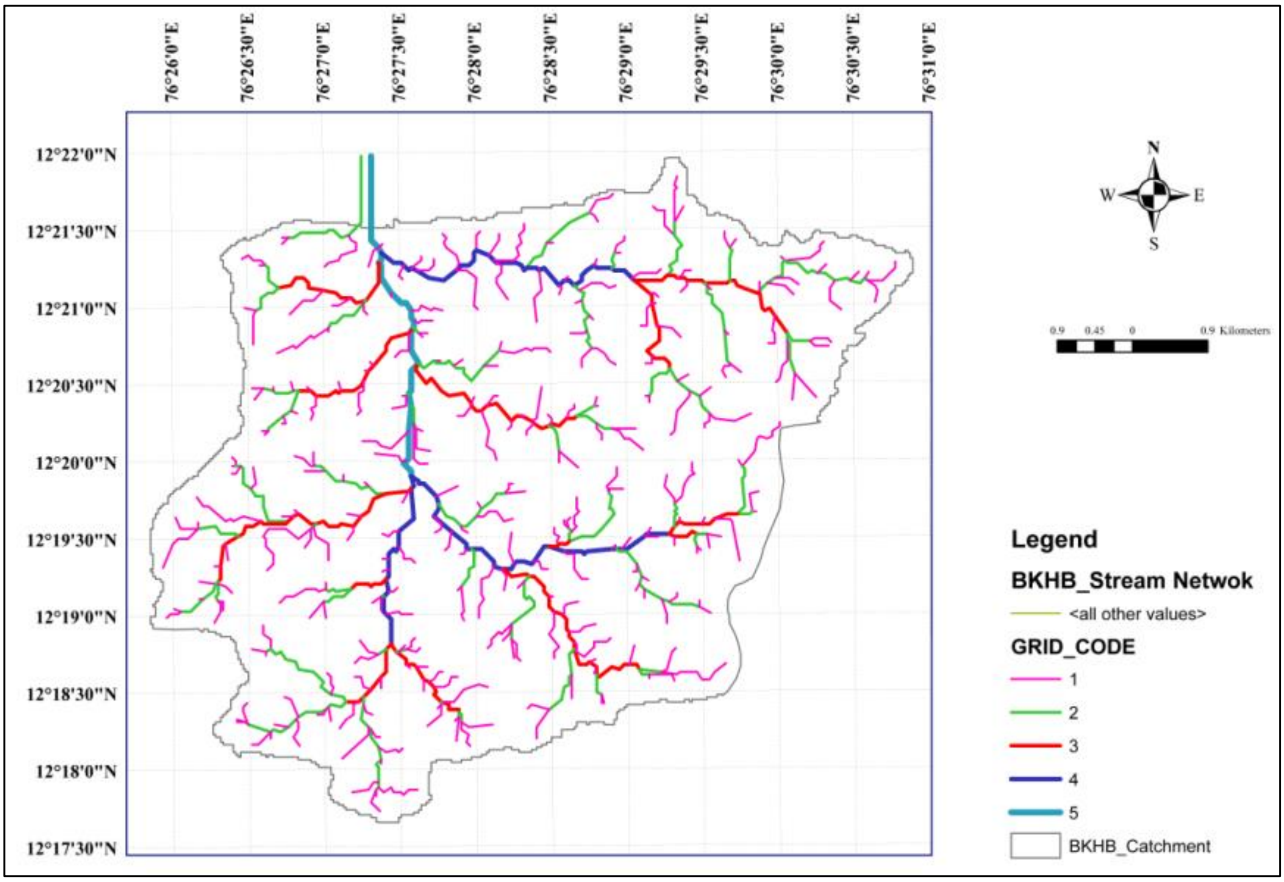

Figure 5: Drainage map of BKHB Catchment.

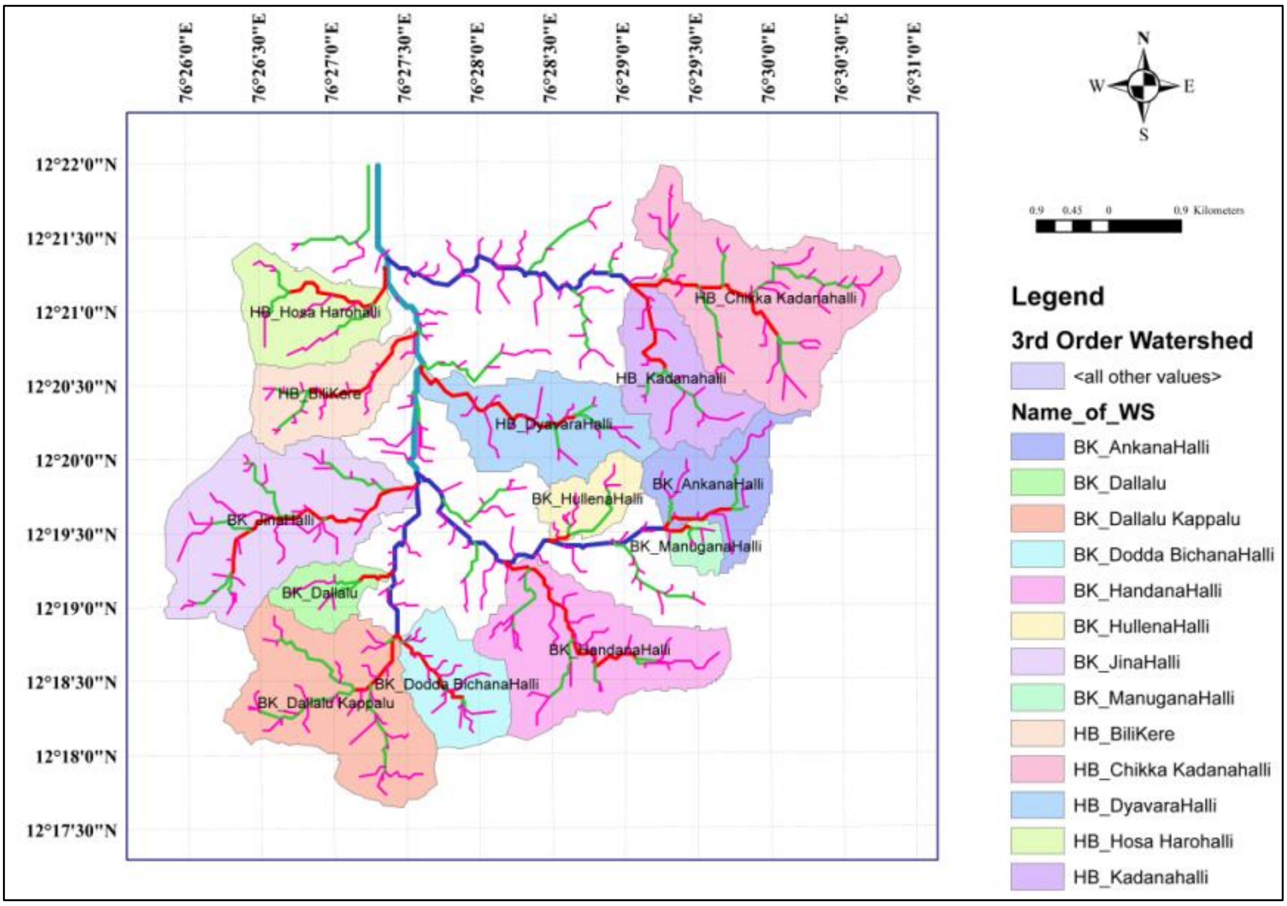

Figure 6: 3rd Order Micro watershed with Streams

Table 5: Areal parameters of BKHB- MWS & SBW

MWS-No	Name of MWS	A	P	L_b	F_f	G_i	S_f	R_c	R_e
1	HB_Chikka Kadanahalli	4.94	12.45	3.36	0.44	1.58	2.29	0.40	0.75
2	HB_Hosa Harohalli	1.96	6.85	1.90	0.54	1.38	1.84	0.52	0.83
3	HB_Kadanahalli	2.02	7.48	2.31	0.38	1.49	2.64	0.45	0.69
4	HB_BiliKere	1.83	6.67	2.33	0.34	1.39	2.97	0.52	0.65
5	HB_DyavaraHalli	2.63	9.10	3.10	0.27	1.58	3.65	0.40	0.59
6	BK_AnkanaHalli	1.82	8.57	1.95	0.48	1.79	2.09	0.31	0.78
7	BK_HullenaHalli	0.91	4.63	1.50	0.40	1.37	2.47	0.53	0.72
8	BK_ManuganaHalli	0.38	2.73	0.80	0.59	1.25	1.68	0.64	0.87
9	BK_JinaHalli	4.58	10.48	3.50	0.37	1.38	2.67	0.52	0.69
10	BK_Dallalu	0.80	4.51	1.60	0.31	1.42	3.20	0.49	0.63
11	BK_Dallalu Kappalu	4.03	10.03	2.40	0.70	1.41	1.43	0.50	0.94
12	BK_Dodda BichanaHalli	1.65	5.59	1.85	0.48	1.23	2.07	0.66	0.78
13	BK_HandanaHalli	3.83	10.28	3.03	0.42	1.48	2.40	0.46	0.73
	Mean	**2.41**	**7.64**	**2.28**	**0.44**	**1.44**	**2.42**	**0.49**	**0.74**
SWS	Name of SWS	Data of the sub-watershed							
BK	BK_Bilikere	22.87	32.10	4.30	1.21	1.91	0.83	0.27	1.24
HB	HB_Halebidu	21.80	29.16	6.50	0.49	1.80	2.03	0.31	0.79
BKHB	Combined Catchment	44.67	38.56	7.20	0.86	1.63	1.16	0.38	1.05

MWS-No	Name of MWS	Dd	Dt	T_r	F_s	I_f	C_m	K
1	HB_Chikka Kadanahalli	3.00	2.81	2.25	7.09	21.28	0.333	1.79
2	HB_Hosa Harohalli	2.97	1.90	1.31	6.63	19.69	0.337	1.45
3	HB_Kadanahalli	2.71	2.01	1.60	7.43	20.11	0.369	2.07
4	HB_BiliKere	2.83	2.70	2.25	9.84	27.79	0.354	2.33
5	HB_DyavaraHalli	2.83	2.31	1.87	7.98	22.62	0.353	2.87
6	BK_AnkanaHalli	2.82	1.52	1.05	7.14	20.17	0.354	1.64
7	BK_HullenaHalli	3.31	1.95	1.30	9.89	32.71	0.302	1.94
8	BK_ManuganaHalli	3.24	2.93	1.83	21.05	68.14	0.309	1.32
9	BK_JinaHalli	3.14	3.53	2.86	8.08	25.38	0.318	2.10
10	BK_Dallalu	2.99	1.55	0.89	8.75	26.14	0.335	2.51
11	BK_Dallalu Kappalu	2.97	3.29	2.79	8.19	24.34	0.336	1.12
12	BK_Dodda BichanaHalli	3.15	3.58	2.68	12.12	38.20	0.317	1.63
13	BK_HandanaHalli	3.08	2.72	2.14	7.31	22.50	0.325	1.88
	Mean	**3.00**	**2.52**	**1.91**	**9.35**	**28.39**	**0.334**	**1.90**
SWS	Name of SWS	Data of the sub-watershed						
BK	BK_Bilikere	3.20	5.98	4.70	8.57	27.47	0.312	0.65
HB	HB_Halebidu	3.08	5.45	4.32	7.62	23.50	0.324	1.59
BKHB	Combined Catchment	3.09	9.26	7.34	7.99	24.69	0.324	0.91

5.2 Relief aspects

It is the signature of the direction of flow. It helps in determining the degree of erosion in the catchment. It consists of watershed relief, relief ratio, relative relief, slope, slope gradient and ruggedness number. Figure 7 shows the DEM of 3rd order MWS and figure 8 shows the slope map of the BKHB catchment. The results are shown in table 6.

5.3.1 Watershed relief (R)

It is the difference in elevation between the highest point on the ridge line of the catchment to the mouth of the watershed. In the combined BKHB catchment; the highest elevation point is 774m and lowest point is 680m above MSL, it is extracted from Cartosat DEM.

5.3.2 Relief ratio (R_f)

Relief ratio is defined as the ratio of total relief to the basin length (Schumm 1956). Schumm correlated the relation between the hydrological characteristics of the basin to the relief ratio. He observed that areas with low to moderate relief and slope are characterized by moderate value of relief ratios. Low value of relief ratios are mainly due to the resistant bed rocks of the basin and low degree of slope. The value of 'R_f' ranges from 0.018 to 0.049 with an average value of 0.025; 0.013 for BKHB indicating the terrain is of low relief for all MWS

5.3.3 Relative relief (R_r)

Relative relief is the ratio of total relief to the perimeter of the basin in percentage (Melton, 1958). R_{hp} for 3rd order MWS ranges between 0.47%-1.43%; with an average value of 0.76%, for BKHB catchment it is found to be 0.24%.

5.3.4 Slope

Slope analysis is a valuable criterion in geomorphic studies. The slope aspects are controlled by the terrain features and lithological elements like underlying bed rocks of different resistance. For the management of the watershed and waterbodies; it is essential to analyze the gradient of the terrain.

5.3.5 Slope gradient (S_g)

Slope gradient is one of the factors which influence the drainage density.

5.3.6 Ruggedness Number (R_n)

Strahler's ruggedness number is defined as the product of the basin relief and the stream density and usually combines slope with its length. Accordingly it is calculated for all the MWS and BKHB catchment.

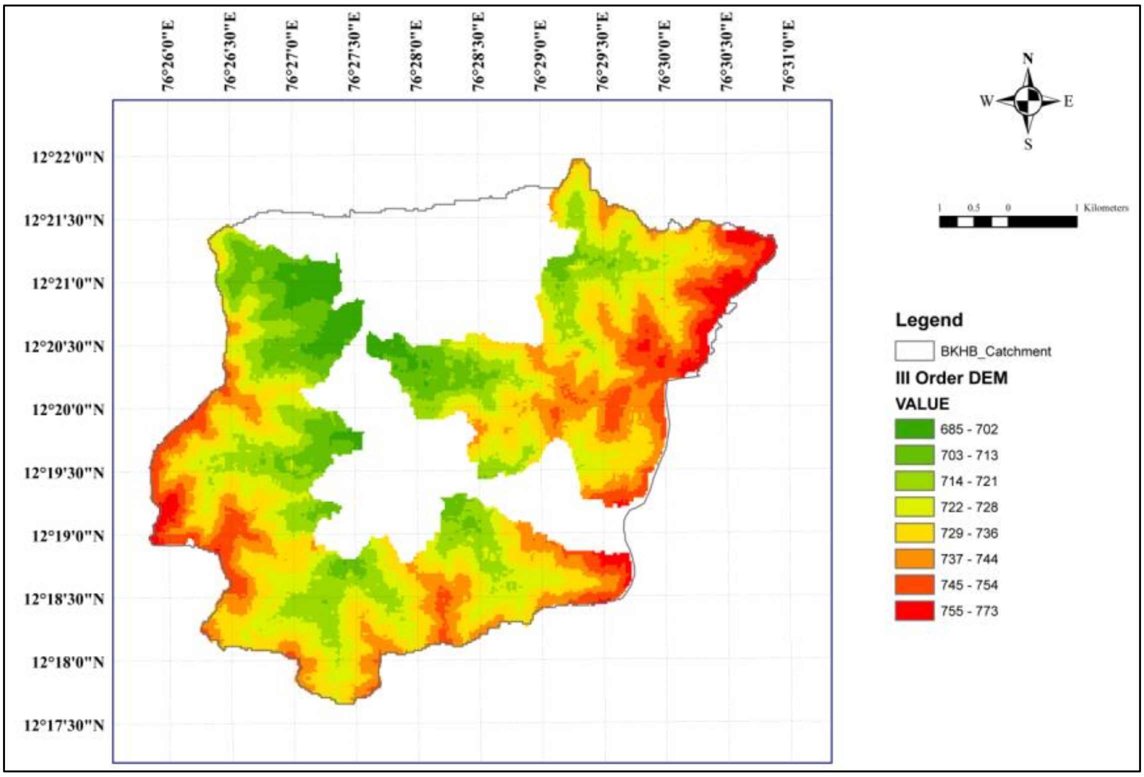

Figure 7: DEM of 3rd Order MWS of BKHB Catchment

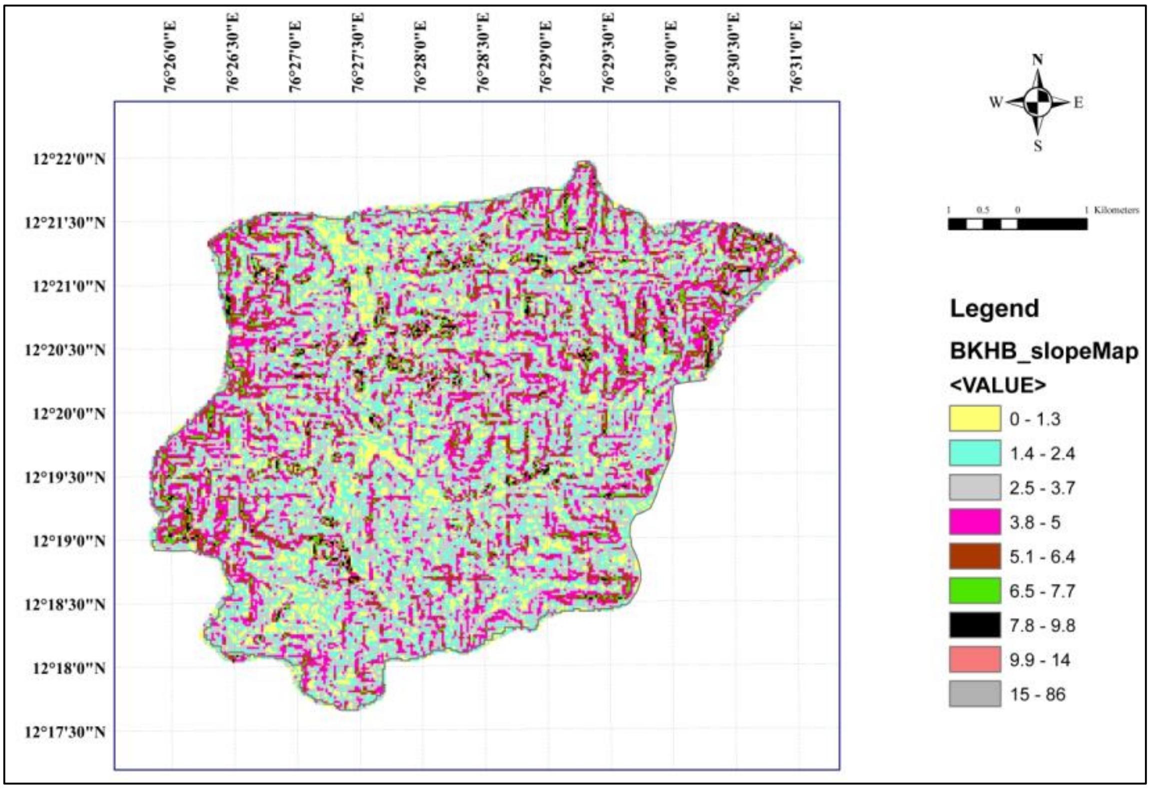

Figure 8: Slope map of BKHB Catchment

Table 6: Relief parameters of BKHB MWS & SBW

MWS-No	Name of MWS	H(m)	H(m)	R(m)	R_f	R_r(%)	Sg	Rn
1	HB_Chikka Kadanahalli	773	708	65	0.019	0.52	5.76	0.195
2	HB_Hosa Harohalli	742	685	57	0.030	0.83	15.79	0.169
3	HB_Kadanahalli	757	708	49	0.021	0.66	9.18	0.133
4	HB_BiliKere	749	689	60	0.026	0.90	11.05	0.170
5	HB_DyavaraHalli	748	691	57	0.018	0.63	5.93	0.161
6	BK_AnkanaHalli	767	707	60	0.031	0.70	15.78	0.169
7	BK_HullenaHalli	746	712	34	0.023	0.73	15.11	0.112
8	BK_ManuganaHalli	760	721	39	0.049	1.43	60.94	0.126
9	BK_JinaHalli	766	698	68	0.019	0.65	5.55	0.214
10	BK_Dallalu	754	704	50	0.031	1.11	19.53	0.149
11	BK_Dallalu Kappalu	756	709	47	0.020	0.47	8.16	0.140
12	BK_Dodda BichanaHalli	748	709	39	0.021	0.70	11.40	0.123
13	BK_HandanaHalli	761	707	54	0.018	0.53	5.88	0.166
	Mean				0.025	0.76	14.62	0.156
SWS	**Name of SWS**	**Data of the sub-watershed**						
BK	BK_Bilikere	767	695	72	0.017	0.22	3.89	0.231
HB	HB_Halebidu	774	680	94	0.014	0.32	2.22	0.290
BKHB	Combined Catchment	774	680	94	0.013	0.24	1.81	0.290

6 Conclusions

From the morphometric analysis of linear, areal and relief aspects; few major geomorphological conclusions are that the Stream order analysis shows that 79.3% of the catchment is dominated by first order streams. Further linear aspects like mean stream length, stream length ratio, bifurcation ratio, length of overland flow, length of the basin and Rho coefficient, as a subset of the major set of linear aspect reveals that no structural disturbance in the formation of streams of 3rd order, the catchment is absorbent in nature, low slope, smaller flow paths, less runoff and more infiltration with less storage capacity of channels. Areal parameters like form Factor, Gravelius index, Shape factor, Circularity index, Elongation ratio, Stream frequency, Drainage density and texture show that all MWS are elongated in shape with high permeability. MWS with Elongated shape and high permeability enhances time of concentration. Constant of channel maintenance result suggest that a minimum of 33 Hectares of catchment is required to maintain a channel of 1 km in the study area. The relief parameters reveal that the catchment is having a very low slope, less runoff and more infiltration. These conclusions may be used to supplement the rainfall-runoff analysis as a contributing factor for the degradation of lakes.

References

Altaf, F., G. Meraj and S. A. Romshoo (2013). Morphometric analysis to infer hydrological behavior of Lidderwatershed, Western Himalaya, India. Geography Journal, 2013, 14.

Basavarajappa, H. T., T. Parviz., M. C. Manjunatha and A. Balasubramanian (2014). Integration of geology, drainage and lineament on suitable landfill sites selection and environmental appraisal around Mysore city, Karnataka, India through remote sensing and. Journal of Geomatics, 8(1), 119–124.

Boobalan, C., B. Gurugnanam and M. Mahesh (2014). Drainage morphometry and its influence on landform in a crystalline terrain, Sarabanga Sub-basin, Cauvery River, South India – a remote sensing and GIS approach. International Journal of Advanced Geosciences and Technical Research, 4, 765–781.

Chorley, R. J., Donald, E. G., Malm and H. A. Pogorzelski (1957), A new standard for estimating drainage basin shape, American Journal of Science, 255, 138-141

Faniran, A. (1968). The index of drainage intensity - A Provisional New Drainage Factor. Australian Journal of Science, 31, 328–330.

Gravelius, H. (1914). Grundrifi der gesamten Gewcisserkunde Band I: Flufikunde Compendium of Hydrology, 1, Goschen, Berlin.

Horton, R. E. (1932). Drainage basin characteristics. American Geophysical Union, 13, 350–361.

Horton, R. E. (1945). Erosional development of streams and their Drainage Basins. Bulletin of the Geological Society of America, 56, 275–370.

Lone, M., D. Nagaraju., G. Mahadeva swamy., Lakshmamma and S. Siddalingamurthy (2012). Morphometric Analysis of HeggadadevanaKote(H D Kote) Taluk, Mysore District, Karnataka, India, 5(2), 288–293.

Malik, M. I., M. S. Bhat and N. A. Kuchay (2011). Watershed based drainage morphometric analysis of Lidder catchment in Kashmir valley using geographical information system. Recent Research in Science and Technology, 3(4), 118–126.

Melton, M. A. (1958). Geometric properties of mature drainage systems and their representation in an E4 phase space. The Journal of Geology, 66(1), 35–54.

Mesa, L. M. (2006). Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina). Environmental Geology, 50, 1235–1242.

Miller, V. C. (1957). A quantitative geomorphic study of drainage basin characteristic s in the clinch mountain area, Virginia and Tennessee. The Journal of Geology., 65(1), 112–113.

Pareta, K. and U. Pareta (2012). Quantitative geomorphological analysis of a watershed of Ravi River basin, H.P. India. International Journal of Remote Sensing and GIS, 1(1), 41–56.

Rama, V. A. (2014). Drainage basin analysis for characterization of 3rdorder watersheds using Geographic Information System (GIS) and ASTER data. Journal of Geomatics, 8(2), 200–210.

Ramachandra, T. V., N. Nagar, S. Vinay and B. H. Aithal (2014). Modelling hydrologic regime of Lakshmanatirtha watershed, Cauvery river. 2014 IEEE Global Humanitarian Technology Conference - South Asia Satellite, GHTC-SAS 2014, 64–71.

Schumm, S. (1956). Evolution of drainage systems and slopes in badland at Perth Amboy, New Jersey. Geological Society of America Bulletin, 67(5), 597–646.

Schumm, S. A. (1965). Geomorphic research: Applications to erosion control in New Zealand: Soil and Water Soil Conserve. and Rivers Control Council, 1, 21–24.

Smith, K. G. (1950). Standards for grading texture of Erosional Topography. American Journal of Science, 248, 655–668.

Singh, S. and M. C. Singh (1997). Morphometric analysis of Kanhar river basin. National Geographical Journal of India.

Srinivasa V. S., S.Govindaiah and H. H. Gowda (2004). Morphometric analysis of sub-watersheds in the Pavagada area of Tumkur district, South India using remote sensing and GIS techniques. Journal of the Indian Society of Remote Sensing, 32(4), 351–362.

Strahler, A. N. (1952). Hypsometric Analysis of erosional topography. Bulletin of the Geological Society of America, 63, 1117–1142.

Strahler, A. N. (1956). Quantitative slope analysis. Bulletin of the Geological Society of America, 67, 571–596.

Strahler, A. N. (1964). Quantitative geomorphology of drainage basin and channel network. In Hand Book of Applied Hydrology, (39–76).

Strahler, A, N, (1965). Quantitative geomorphology of drainage basin and channel Networks. Hand book of applied Hydrology.

Subhan, L. M and K. Rao (2011). Morphometric analysis of Nanjangud taluk, Mysore District, Karnataka, India, using GIS Techniques. International Journal of Geomatics and Geosciences, 1(4), 721–734.

Ven, T.C (1964). Handbook of applied hydrology. USA: McGraw-Hill.