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Morphometric Analysis of Markandeya River Sub Basin (MRSB), Belgaum District, Karnataka using Remote Sensing and Geographical Information System

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Abstract:- In this present study, Remote Sensing (RS) and Geographical Information System (GIS) techniques are used to update drainage and surface water bodies to evaluate linear, relief and aerial morphometric parameters and to prioritize the watersheds of the Markandeya River Sub-Basin (MRSB), located in Belgaum district of Karnataka state,India. The Markandeya River Sub-Basin has sub-dendritic to dendritic drainage pattern. The highest bifurcation ratio among all the watersheds is 5.14 which indicates a weak structural control on the drainage. The maximum value of circularity ratio is 0.5198 for the watershed MW-3, which also has highest elongation ratio (0.64). The form factor values are in the range of 0.25 to 0.32 which indicates that the Markandeya River Sub-Basin has moderately high peak flow for shorter duration. The compound parameter values are calculated and prioritization rating of four watersheds in Markandeya River Sub-Basin is carried out. The watershed with the lowest compound parameter value is given the highest priority. The watershed MW-1 having a minimum compound parameter (Cp) value of 1.625 is likely to be subjected to maximum soil erosion and hence, it should be provided with immediate soil conservation measures.

Keywords:- Markandeya River Sub-Basin, Morphometric analysis, RS, GIS, Watershed prioritization,

I. INTRODUCTION

Topography, geology, and climate are the three determinants controlling drainage pattern, density and geometry of the fluvial system (Frissel et al. 1986). Among these, the relative influence of each factor may vary from place to place and subsequently displayed in the drainage characteristics. The quantitative analysis of drainage networks and catchment shapes is a subject of interest to both geomorphologists and hydrologists worldwide. Further robust, quantitative descriptions of drainage basins are one of the essential components for the interpretation of basin evolution.

II. STUDY AREA

The present study area, Markandeya River sub-basin (MRSB) falls in the survey of India toposheets 47 L/12, 47 L/16, 48 I/5 and 48 I/9, lies between the latitudes15^{0}45' and 16^{0}15' N and longitudes 74^{0}15' and 74^{0}50' E. Markandeya River, one of the tributaries of River Ghataprabha, originates at Bailur village and flow at a length of 66 km before it joins the Ghataprabha river near Gokak. MRSB forms the part of a semi-arid belt and agro-climatically it is a part of Belgaum district, a northern dry region of Karnataka State (Fig.1). Physiographically, the area exhibit relatively flat with gentle slopes covering major portion of the area with moderately undulating central and hilly northern part. Geologically the area comprises of Proterozoic and Phanerozoic rocks mainly basalts, sandstones, dolomite covering major portions of the study area with the minor patches of laterite and gneiss (Fig.1).

III. MATERIALS AND METHODOLOGY

Survey of India topographic (SOI) map no 48L/16 of 1:50,000 scale was registered to UTM projection (WGS 84 North, Zone 43) and the drainage network was created manually by digitizing drainage lines in GIS. SRTM images were downloaded from GLCF website (http://glcf.umiacs.umd.edu). The drainage network from SRTM was extracted, using the Arc Hydro toolset in ArcGIS 10.2.1 adopting the standard procedures (Band, 1986; Morris and Heerdegen, 1988; Tarboton et al., 1991; Gurnell and Montgomery, 1999; Maidment, 2002).
The drainage network of the basin and the stream ordering was analysed as per Horton (1945), Strahler (1964), Verstappen (1983), Reddy et al. (2004b), Sreedevi et al. (2004), Vittala et al. 2006), Mesa (2006) and Ozdemir and Bird (2009).

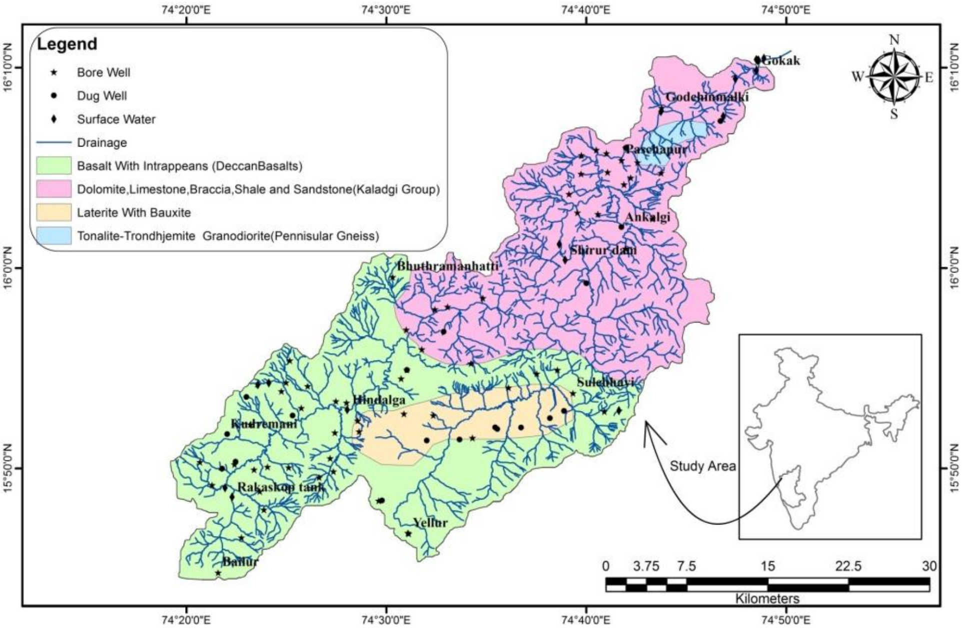

Fig.1: Location Map

IV. RESULTS AND DISCUSSION

A. Morphometric Analysis

The designation of stream order is the first step in morphometric analysis of a drainage basin, based on hierarchy marking of streams proposed by Strahler (1964). The Markandeya river sub-basin demarcated into 4 miniwatersheds (Fig.2) for which stream order analysis is given in Table 1. The morphometric analysis (Table 2) is discussed under linear and shape parameters.

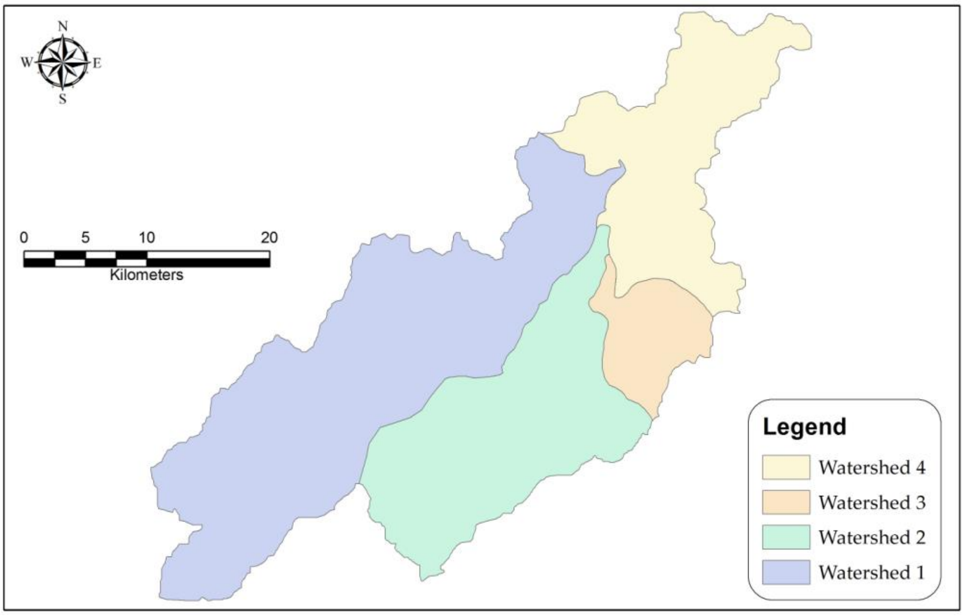

Fig.2: Miniwatersheds of Markandeya River Sub-Basin

B. Linear Parameters

Drainage parameters such as bifurcation ratio, drainage density, stream frequency and drainage texture are grouped under linear parameters and are discussed below:

B.1 *Area (A)*

The total drainage area of Markandeya river sub-basin is 1052 km2, and the areas of each watershed are shown in table.1. The area of watersheds is MW1 is 481 km^2, MW2 is 276 km^2, MW3 is 73 km^2 and MW4 is 222 km^2**.**

B.2 *Perimeter (P)*

The perimeter is the total length of the drainage basin boundary. The perimeter values of each watershed are MW1, MW2, MW3 and MW4 are 146km, 90km, 42km and 104km respectively, presented in Table.2.

B.3 *Basin Length (L)*

The basin length corresponds to the maximum length of the basin and sub-basins measured parallel to the main drainage line. The basin length is 69.56 km^2 for the entire basin. The length of each watershed is presented in Table.1.

B.4 *Stream number and order*

The first and most important parameter in the drainage basin analysis is ordering, where by the hierarchal position of the streams is designated following strahler's scheme, it has been found that in MRSB the total number of streams is 1242 out of which 876 belongs to first order, 276 are of second order, 70 are of third order, 16 are of fourth order, 3 of fifth order and one of sixth order. The watershed wise number and order is given in the Table.1and depicted in fig.2. It reveals that the highest number of streams is in MW1 followed by MW4 and MW2, whereas the smallest number of streams is found in MW3. It is also reveals that the first order streams are highest in number in all MW, which decreases as the order increases and highest order has the lowest number of streams. Drainage patterns of work stream network from watersheds were mainly dendritic type which indicates the homogeneity in texture and lack of structural control. The pattern is characterized by a tree like or fernlike pattern with branches that intersect primarily at acute angles.

Horton's First Law, i.e. Law of stream Numbers states that "The number of stream segments of each order forms an inverse geometric sequence with order number" Nu = Rbk-u where 'Nu' is the number of stream segments of 'u'; 'Rb' is the Bifurcation Ratio and 'K' is the order of the trunk segment. The logarithm of streams is plotted against order, the most drainage networks show a linear relationship, with small deviation from a straight line (Chow, 1964).This hold good for the all the miniwatersheds (Fig.3).

B.5 *Stream Length (Lu)*

Horton's low of stream length states that the mean lengths of stream segments of each of the successive orders of a basin tend to approximate a direct geometric sequence in which the first order term is the average length of segments of the first order (Horton, 1945). Table.1 shows that in MSRB length of stream generally decreases with increase in order of segments except watershed 1 and watershed 4, the variation may be due to high relief, or moderately steep slopes underlain by varying lithology (Singh and Singh, 1997). Mean stream length is dimensional, revealing the characteristic size of the components of a drainage network and it contributes basin surfaces (Strahler, 1964).In general mean stream length increases as the order of segment increases.

B.6 *Mean stream length (Lsm)*

The mean stream length is calculated as the ratio of total stream length of particular order with number of stream of segment of that order Table.1. In the study area, in watershed 1 Lsm varies from 0.75 to 64.87, in watershed 2 Lsm varies from 0.82 to 16.62, in watershed 3 Lsm varies from 0.78 to 6.14 and in the watershed 4 Lsm varies from 0.79 to 46.41. Lsm of any given order is greater than that of the lower order and less than that of its next higher order in the watershed 2 and 3 but for the fifth and sixth order in the watershed 1 and 2 respectively the value is than the lower order streams.

Hortons Law of Stream Lengths which states that "The mean length of stream segments of each of the successive orders of a basin tend to approximate a direct geometric sequence" in this average length of segments of first order is the first term. If this law of stream lengths is valid, a plot of logarithm of stream length as a function of order should yield a set of points lying essentially along the straight line. According to the Krishnamurthy et al (1996) and Sameena et al (2009), this linear relationship indicates that basin evolution follows erosion laws acting on geologic material with homogeneous weathering-erosion characteristics and any deviation of points from the linearity may be due to structural control of the streams. It is clear from the (Fig.4) that all the points of the all the Miniwatersheds show a linear relation, there are well defined deviations from the straight line indicating structural control.

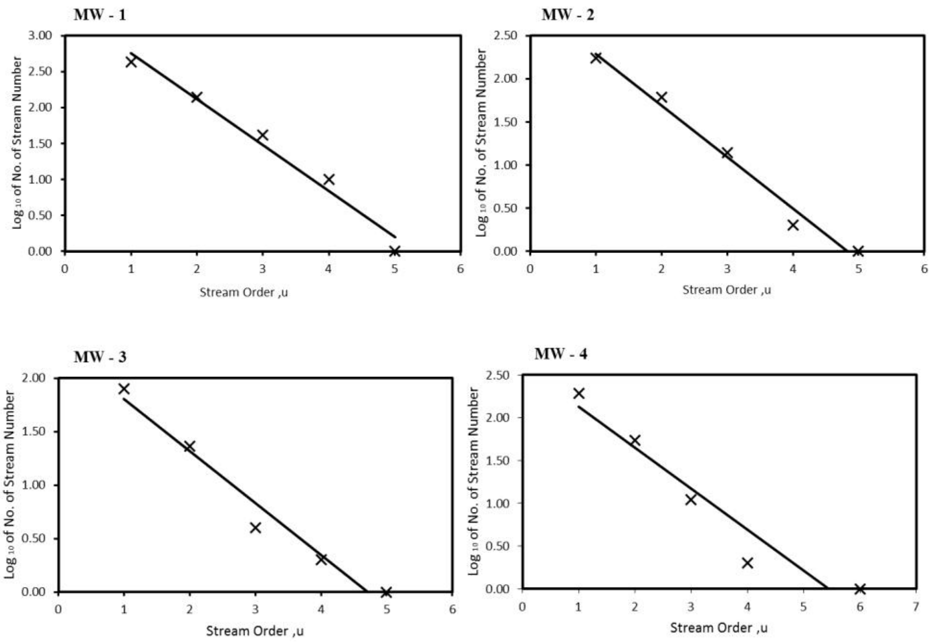

Fig.3: Regression of logarithm of number of stream segments on Stream order for The Miniwatersheds of the Markandeya river sub-basin.

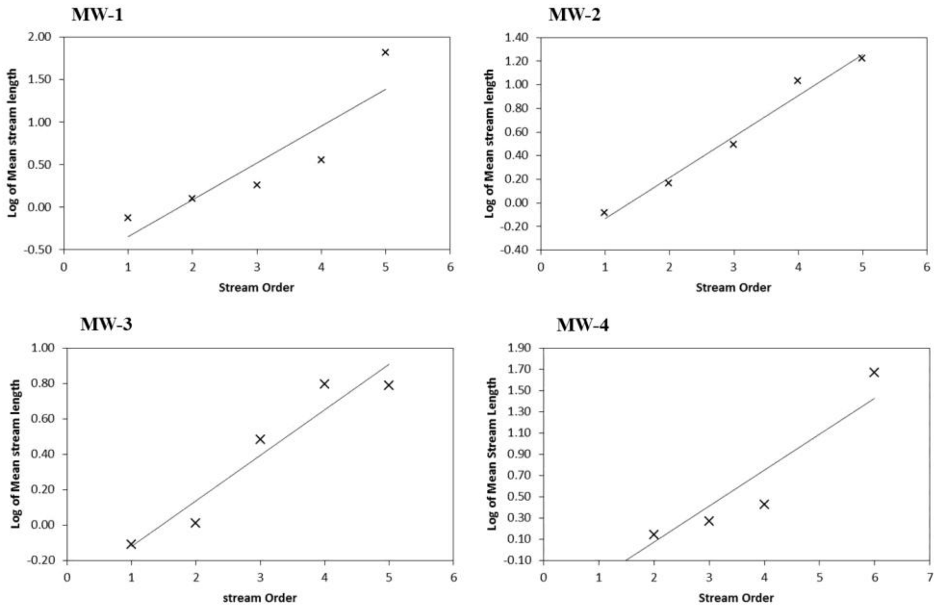

Fig.4: Regression of logarithm of Mean stream length on stream order for the Miniwatersheds of the Markandeya river sub-basin

B.7 *Bifurcation Ratio (Rbm)*

Bifurcation ratio (Rbm) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumm, 1956). The bifurcation ratio is an index of relief and dissection (Horton, 1945). The bifurcation shows a small range of variation for different environment except where the powerful geological control dominates (Strahler, 1957). The irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). The lower values of Rb are characteristics of the basin that has suffered less structural disturbances (Strahler, 1964) and the drainage patterns that has not been distorted because of the structural disturbances (Nag, 1998). Higher values of Rb indicate strong structural control on drainage pattern. In the study area mean bifurcation ratio (Rbm) varies from 3.30 to 5.14, lower values in MW-3 suggests less structural disturbance, whereas higher value in MW-1 indicates that it has structurally controlled drainage pattern.

B.8 *Drainage Density (D)*

Langbein (1947) recognized the significance of drainage density as a factor determining the time of travel by water and suggested that drainage density values between 0.55 and 2.09 km/km^2 correspond to humid regions, with an average of 1.03 km/km^2 (Langbein, 1947). It has been observed from drainage density measurements made over a wide range of geological and climatic types that low drainage density is more likely to occur in regions of high resistant and high permeable sub soil material under dense vegetative cover, and where relief is low, whereas high drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief (Nag, 1998). Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahler, 1964). In the present study the drainage density ranges from 1.12 to 1.60 km/km^2, which suggests that the watershed is underlain by highly permeable material like gravelly soil/highly weathered zone with shallow depth of weathering and represents low relief. However, there are local variations and imbalances observed across the miniwatersheds resulting from the on-farm developmental activity, which has induced local drainage congestion and development of water logging and soil salinity in patches. Karl pearson's coefficient of correlation between drainage density and area tested for the all miniwatersheds of order 2 is found to be negative (i.e. r = -0.5363) (Fig.5).

B.9 *Drainage Texture (Rt)*

Drainage texture ratio (Rt) is one of the important concepts of geomorphology which indicates the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. Smith (1954) classified drainage density into five different classes of drainage textures, i.e. <2 indicates very coarse, between 2 and 4 is coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. Drainage texture values of the miniwatersheds lie between 2.50 (MW-4), 2.78 (MW-2), 2.61 (MW-3) and 4.24 (MW-1). All the miniwatersheds of the Markandeya River watershed indicates coarse drainage texture but except the MW-4 is moderate drainage texture.

B.10 *Stream Frequency (Fs)*

Reddy et al (2004b) stated that low values of stream frequency (Fs) indicate presence of permeable subsurface material and low relief. Stream frequency values of the miniwatersheds vary from 0.90 (MW-2) to 1.50 (MW-3), suggests miniwatersheds having lower Stream frequency values represents low relief and permeable sub-surface material whereas, miniwatersheds with higher Fs values show resistant/low conducting sub-surface material, sparse vegetation and high relief. In general Stream frequency values indicate positive correlation with the drainage density in all miniwatersheds suggesting an increase in stream population with respect to increase in drainage density. The plot between Stream frequency and drainage density for all the miniwatersheds as well as for the study area as a whole shows remarkably small scatter and correlation coefficient is strongly positive at 0.99(Fig.6).

C. Shape Parameters

Drainage parameters such as form factor, circularity ratio, elongation ratio and compactness coefficient are grouped under shape parameters and are discussed below:

C.1 *Form Factor (Rf)*

The value of Form Factor varies form 0 (highly elongated shape) to 0.78 (perfect circular shape) (Horton, 1932). If the Form Factor (Rf) is multiplied by the multiplier 1.27, the index would have a value of 1, corresponding to a circular shape, with values ranging down to zero, with distortions away from a circle. Therefore, higher the value of the Rf the more circular the shape of the basin and vice-versa (Senthilvelan et al., 2012). The basins with higher Rf have high peak flows for shorter duration, whereas elongated basins with lower values of Rf have low peak flows for longer duration. Flood flows of elongated basins are easier to manage than those of the circular basins (Nautiyal, 1994). In the study area, the Rf values of the miniwatersheds vary from 0.25 to 0.32 suggesting moderately elongated shape with moderately high peak flow for shorter duration.

C.2 *Circularity Ratio (Rc)*

Miller (1953) defined that the basin of the circularity ratio (Rc) ranging between 0.4 and 0.5, indicates strongly elongated and highly permeable homogenous geological materials, land use/land cover, climate and relief and the slope of the basin. It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate and slope of the basin. The circularity ratios of miniwatersheds vary from 0.25 to 0.51; indicating miniwatersheds are moderately elongated in shape.

C.3 *Elongation Ratio (Re)*

According to Schumm (1956) the shape of any drainage basin is expressed by the elongation ratio (Re), which is the ratio between the diameter of a circle with the same area as the basin and maximum length of the basin. Similar to the elongation ratio Miller (1953) used a measure which is the ratio of circumference of a circle with same area as the basin to the basin perimeter. The value of elongation ratio generally varies from 0.6 to 0.1 associated with a wide variety of climate and geology (Strahler, 1964). Values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are associated with high relief and steep ground slope (Dar et al., 2013). These values can be grouped into four categories, viz., circular (>0.9), oval (0.9-0.8), less elongated (0.8-0.7) and elongated (<0.7) (Sentivelan et al., 2012). In the study area, the value of Re ranges between 0.56 to 0.64, indicating that the miniwatersheds are moderately elongated with moderately high relief and steep slope.

C.4 *Compactness Coefficient (Cc)*

The compactness coefficient is equal to unity when the basin shape is a perfect circle, increasing to 1.128 in the case of a square, and may exceed 3 for very elongated basin (Zavoianu, 1978). Cc of the studied miniwatersheds is found to be higher than unity (1.386 to 1.969), which suggests that the shape of the basin is moderately elongated. If Cc is greater than unity, basin shape is deviated from circular nature of the basin (Altaf et al., 2013). In the present study, the miniwatersheds have the moderate deviation from circular nature and moderately long time of concentration before peak flow occurs.

The compound parameter values of four miniwatersheds of Markandeya river sub-basin watershed are calculated and prioritization rating is shown in Table 3. MW-3, MW-2 and MW-1 with the lowest compound parameter value of 1.386,1.528 and 1.877 , receives the highest priority (one) and MW-4 with the highest compound parameter value of 1.96 receives the lowest priority (four). Highest priority indicates the greater degree of erosion in the particular miniwatershed (Thakkar and Dhiman, 2007) and it becomes potential candidate for applying soil conservative measure. The final prioritized map of the study area is shown in Fig.3. Thus soil conservation measures can first be applied to miniwatersheds MW-1, MW-2 and MW-3, and then to the other miniwatersheds depending upon their priority.

C.5 *Length of overland flow (Lg)*

Horton (1945) defined length of overland flow L0 as the length of flow path, projected to the horizontal, nonchannel flow from a point on the drainage divide to a point on the adjacent stream channel. He noted that length of overland flow is one of the most important independent variables affecting both the hydrologic and physiographic development of drainage basins. During the evolution of the drainage system, L0 is adjusted to a magnitude appropriate to the scale of the first order drainage basins and is approximately equal to one half the reciprocal of the drainage density. The shorter the length of overland flow, the quicker the surface runoff from the streams. For a present study the values of MW1, MW2, MW 3 &MW4 respectively given in Table.2.

C.6 *Constant of Stream Maintenance (C)*

Schumm (1956) used the inverse of drainage density as a property termed constant of stream maintenance “C” thus C=1/D .This constant in units of square feet per foot, has the dimension of length and therefor increase in magnitude as the scale of the land form units increases. Specifically the Constant “C” provides information of the number of square feet of watershed surface required to sustain one linear foot of stream. The values of “C” MSRB, MW1, MW2, MW3 &MW4 is in Table.2. It means that on an average 0.8 square feet surface is needed in MSRB.MW2 for creation of one linear foot of the stream channel.

V. CONCLUSION

Remote sensing and GIS have proved to be efficient tool in drainage delineation and Updation in the present study and this updated drainage have been used for the Morphometric analysis. The Markandeya River Sub-Basin has sub-dendritic to dendritic drainage pattern. The highest bifurcation ratio among all the watersheds is 5.2 which indicates a weak structural control on the drainage. The maximum value of circularity ratio is 0.5198 for the watershed MW-3, which also has highest elongation ratio (0.64). The form factor values are in the range of 0.25 to 0.32 which indicates that the Markandeya River Sub-Basin has moderately high peak flow for shorter duration. The variation in the stream length ratio might be due to change in slope and topography. The stream frequencies for all mini watersheds of the study exhibit positive correlation with the drainage density values indicating the increase in stream population with respect to increase in Drainage density. The logarithm of streams is plotted against order, the most drainage networks show a linear relationship, with small deviation from a straight line. The logarithm of mean stream length is plotted against order from this plot it is clear that all the points of all the Miniwatersheds show a linear relation; there are well defined deviations from the straight line indicating structural control. The compound parameter values are calculated and prioritization rating of four watersheds in Markandeya River Sub-Basin is carried out. The watershed with the lowest compound parameter value is given the highest priority. The watershed MW-1 having a minimum compound parameter (Cp) value of

1.625 is likely to be subjected to maximum soil erosion and hence, it should be provided with immediate soil conservation measures.

Table 1: Stream Analysis

SW	Stream Order						
		I	II	III	IV	V	VI
MW-1	No. of Streams	430	138	41	10	1	
	Stream Length (km)	320.46	174.19	74.48	35.79	64.87	
	Cumulative Stream Length (km)	320.46	494.65	569.13	604.92	669.79	
	Mean Stream Length (km)	0.75	1.26	1.82	3.58	64.87	
MW-2	No. of Streams	173	61	14	2	1	
	Stream Length (km)	141.69	88.6	43.05	21.37	16.62	
	Cumulative Stream Length (km)	141.69	230.29	273.34	294.71	311.33	
	Mean Stream Length (km)	0.82	1.45	3.08	10.69	16.62	
MW-3	No. of Streams	80	23	4	2	1	
	Stream Length (km)	62.57	23.70	12.11	12.45	6.14	
	Cumulative Stream Length (km)	62.57	86.27	98.38	110.83	116.97	
	Mean Stream Length (km)	0.78	1.03	3.03	6.23	6.14	
MW-4	No. of Streams	193	54	11	2		1
	Stream Length (km)	152.38	74.55	20.48	5.33		46.41
	Cumulative Stream Length (km)	152.38	226.93	247.41	252.74		299.15
	Mean Stream Length (km)	0.79	1.38	1.86	2.67		46.41

Table 2: Morphometric Analysis

SW	A (sq.km)	P (km)	Lb (km)	Rbm	D	Rt	Fs	Rc	Rf	Cc	Re	Lg	C
MW-1	481.00	146.00	43.79	5.1454	1.3925	4.2466	1.2890	0.2834	0.2508	1.8779	0.5653	0.3590	0.7181
MW-2	276.00	90.00	31.94	4.0483	1.1280	2.7889	0.9094	0.4279	0.2705	1.5282	0.5871	0.4432	0.8865
MW-3	73.00	42.00	15.01	3.3071	1.6023	2.6191	1.5068	0.5197	0.3240	1.3867	0.6425	0.3120	0.6241
MW-4	222.00	104.00	28.23	3.4958	1.3475	2.5096	1.1757	0.2578	0.2785	1.9691	0.5957	0.3710	0.7421

Table 3: Prioritization results of Morphometric Analysis

MW	Rbm	D	Fs	Rt	Rf	Rc	Re	Cc	Cp	Priority
1	1	2	2	1	1	2	1	3	1.625	1
2	2	4	4	2	2	3	2	2	2.625	2
3	4	1	1	3	4	4	4	1	2.750	3
4	3	3	3	4	3	1	3	4	3.000	4

REFERENCES

[1]. Altaf F., Meraj G. and Romshoo S. A. 2013: "Morphometric analysis to infer hydrological behaviour of lidder watershed, Western Himalaya, India" Geography Journal 2013, 1-14.
[2]. Band LE (1986) Topographic partition of watersheds with digital elevation models. *Water Resour Res* 22: 15–24
[3]. Chow, V.T. (Ed.) (1964) Handbook of Applied Hydrology – A compendium of water-resourses technology. McGraw – Hill Book Company.
[4]. Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10: 199-214.
[5]. Gurnell AM and Montgomery AR (1999) Hydrological applications of GIS. Wiley, Chichester, pp 176
[6]. Horton, R.E. (1932) Drainage Basin Characteristics. Transactions of the American Geophysical Union, Vol.13, pp.350-361.
[7]. Horton,R.E.(1945) Erosional Development of Streams and their Drainage Basins: Hydrophysical Approach to Quantitative Morphology. Bulletin of Geological Society of America, Vol.56, pp.275-370.
[8]. K. G. Smith, "Standards for Grading Texture of Erosional Topography," American Journal of Science, Vol. 248, 1954, pp. 655-668. doi:10.2475/ajs.248.9.655.
[9]. Krishnamurthy, J., Srinivas, G., Jayaram, V. and Chandrasekhar, M.G.(1996) Influence of Rock Types and Structures in the development of Drainage Networks in Typical Hard Rock Terrain. ITC Journal, Vol.3, No. 4, pp. 252-259.
[10]. Langbein, W.B. and others (1947) Topographic characteristics of drainage basins. U.S.Geological survey water supply paper 968-C, 1947.
[11]. M. Sameena, J. Krishnamurthy, V. Jayaraman, and G. Ranganna, "Evaluation of drainage networks developed in hard rock terrain," Geocarto International, vol. 24, no. 5, pp. 397–420, 2009.
[12]. Maidment DR (2002) ArcHydro GIS for water resources. Esri Press, California Mesa, L.M. (2006) Morphometric analysis of a subtropical Andean basin (Tucuman, argentina). Environmetal Geology (Springer – Verlag), Vol. 50, pp. 1235 – 1242.
[13]. Miller VC (1953) A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Technical report, 3, Office of Naval Research. Department of Geology, Columbia University, New York.
[14]. Morris DG and Heerdegen RG (1988) Automatically derived catchment boundaries and channel networks and their hydrological applications. *Geomorphology* 1:131–141
[15]. Nag, S.K. (1998). Morphometric analysis Using Remote Sensing Techniques in the Chaka Sub-Basin. Puruha District, West Bengal. J. Indian Soe. Remote Sensing. 26(1&2): pp. 69-76.
[16]. Nautiyal, M. D (1994), Morphometric Analysis of a Drainage Basin using Aerial photographs: A case study of Khairakulli Basin, District Dehradun, Uttar Pradesh.
[17]. *Journal* of the Indian Society of Remote Sensing, 22(4), pp 251261.
[18]. Ozdemir, H. and Bird, D. (2009) "Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point of floods" Environ Geol 56:1405–1415.
[19]. Ravikumar. P and Somashekar. R. K. (2011). Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purpose in the Markandeya River basin, Belgaum District, Karnataka. Environ Monit Assess. 173; 459-487.
[20]. Reddy, O.G.P., Maji, A.K. and Gajbhiye, S.K. (2004b), Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India – A remote sensing and GIS approach, Jour. Applied Earth Observation and Geoinformatics,6,1-6
[21]. Schumm, S.A. (1956) The Evoluation of Drainage systems and slopes in Badlands at perth Amboy, New Jersey. Bulletin of Geological Society of America, Vol.67,pp.597-646.
[22]. Senthilvelan, Ganesh and Banukumar.(2012) . Linear And Areal Morphometric Aspects Of Porandalar Watershed, Amaravathi Sub Basin, Tamil Nadu. Int. Journal of Advances in Remote Sensing and GIS, Vol. 1, No. 2, 2012.
[23]. Singh,S and Singh, M.C.(1997). Morphometric Analysis of Kanhar River Basin. National Geographical. Journal of India, 43(1): pp. 31-43.
[24]. Sreedevi PD, Subrahmanyam K, Ahmed S (2004) The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environ Geol 47:412–420.
[25]. Strahler,A.N.(1964) Quantative geomorphology of drainage basin and channel networks. In: Chow VT (ed) Handbook of applied hydrology. McGraw Hill, New York, pp 4–76
[26]. Strahler,A.N.(1957) Quantative Analysis of Watershed Geomorphology. Transactions of American Geophysicists Union, Vol.38, pp.913-920.
[27]. Tarboton DG, Bras RL, Rodriguez-Iturbe I (1991) Onthe extraction of channel networks from digital elevation data. TT Hydrol Process 5:81–100.

[28]. Thakkar, A.K. and Dhiman, S.D., (2007), Morphometric Analysis and Prioritization of miniwatersheds in Mohr Watershed, Gujarat Using Remote Sensing and GIS technique, Journal of the Indian society of Remote Sensing, 35(4), 313-321.
[29]. Verstappen H (1983) The applied geomorphology.International Institute for Aerial Survey and Earth Science (I.T.C), Enschede, The Netherlands,Amsterdam, Oxford, New York.
[30]. Vittala SS, Govindaiah S and Honne Gowda H (2006) Digital Elevation Model (DEM) for identification of groundwater prospective zones. *J. Indian Soc. Remote Sensing* 34, 305 310
[31]. Zavoianu. (1978) - Morfometria bazinelor hidrografice. Academiei, Bucurerti, 176 pp.