Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2015, Volume 4, Issue 1, pp. 895-910, Article ID Tech-342
ISSN 2320 - 0243

Research Article **Open Access**

GIS Based Morphometric Analysis of the Kochara Sub-Watershed of Greater Periyar Plateau (GPP) of South Western Ghats, India

C.K. Baiju[1, 2], B. Ajay Kumar[2], Girish Gopinath[3], M.S. Shylesh Chandran[4] and T. Ramkumar[1]

[1]Deapartment of Earth Sciences, Annamalai University, Annamalai Nagar, Tamil Nadu, India
[2]Department of Mining and Geology, Govt. of Kerala, India
[3]Centre for Water Resources Development and Management, Kozhikode, Kerala, India
[4]School of Environmental Sciences, Mahatma Gandhi University, Kerala, India

Correspondence should be addressed to B. Ajay Kumar, jemnair@gmail.com

Publication Date: 30 March 2015

Article Link: http://technical.cloud-journals.com/index.php/IJARSG/article/view/Tech-342

Abstract The Munnar Plateau and the Greater Periyar Plateau (GPP is composed of Periyar and Pirmed plateaus) of the South Western Ghats of India had their origin during the Late Palaeocene and it has been assessed that the deduced age of these plateaus coincides with that of the Biligirangan surface. Ever since their formation, both the plateaus have been subjected to substantial geological modifications during the subsequent years, especially the Periyar plateau of the GPP, which was acted as Holocene depocentre. The distribution of palaeodeposit of sand in the Kochara sub-watershed occupying the Periyar Plateau of the South Western Ghats has led to interpret the quantitative geomorphology of the river basin for elucidating the relationship between mathematical expressions and filed observations. 163.07km^2 basin area of the Kochara stream was subjected to morphometric analysis. The drainage networks were delineated using remote sensing data – Geocoded False Colour Composite (FCC) of IRS 1D (LISS III) coupled with the Survey of India toposheets (1:50,000) and the morphometric analysis was carried out using ArcGIS software. Linear aspects, relief aspect and aerial aspects of the basin were analysed and the relationships among the different aspects were interpreted. The study depicts the remarkable relationship between theoretical data sets with field observations, especially the role of geology, geomorphology and tectonism in influencing the basin morphometry and identity. Hence, the analysis of the inter-relationships among the basin parameters helps in understanding the terrain characteristics, slope, landforms, soils, soil erosion and ground water potential for watershed development and management.
Keywords *Greater Periyar Plateau; Kochara Sub-Watershed; Morphometry; Geographical Information System*

1. Introduction

The latitudinal profile of the South Western Ghats shows two major planation surfaces, involving (i) the Greater Periyar plateau at 800–1000m altitude and (ii) the Munnar plateau at 1500m elevation. The

Greater Periyar plateau is composed of Periyar plateau at the north and Pirmed plateau at the south. As the highest surface is generally oldest, if structurally undisturbed, the age of the Munnar plateau can be deduced as late Palaeocene by linking it up with the coastal sedimentary formations and unconformities (Soman, 2002). Longitudinal profiles of the Western Ghats indicate that the Munnar plateau, lying to the north of the extensive Periyar plateau, shows an abrupt decline in elevation close to the Bodinayakkannur pass and it can be summarized that the higher elevation of the Munnar plateau has resulted from the uplift of the northern flank of the Bodinayakkannur pass (Soman, 2002) and the deduced age of the Munnar and Periyar plateaus coincides with that of the Biligirangan surface (Radhakrishna and Vaidyanadhan, 1997). The Periyar plateau, northern linear surface of the Greater Periyar Plateau (GPP), has well preserved Holocene terrigenous proxy records and hence it is assumed that the plateau was acted as depocentre of the Holocene sediments (Baiju, et al., 2013). It is evident from the above that the fluvial geomorphology of the plateau has significant relations with the surface modifications during the Holocene. The prominent tectonism reported from the Southern Granulite Terrain during 4000YBP (Radhakrishna and Vaidyanathan, 1997; Soman, 2002) also has a significant role. Hence, the analysis of the quantitative fluvial geomorphology using mathematical expressions definitely brings its relationship with the surface configurations.

The channel patterns are the surface expressions of the variables influencing river dynamics (Zwnnitz, 1932; Lahiri, 1996; Casteltort and Simpson, 2006; Raj, 2007). The behaviour of a river is changed, when the character of one or more dependent variables is altered and hence the fluvial geomorphology intrinsically related with the geometry of a basin and its channel network (Matsuda, 2004). Morphometry is the measurement and mathematical analysis of the earth's surface, shape and dimension of its landforms and this analysis could be achieved through measurement of linear, aerial and relief aspects of basin and slope contributions (Agarwal, 1998; Reddy, et al., 2002; Nag and Chakraborty, 2003; Putty, 2007). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behaviour of surface drainage networks (Horton, 1945). Since, the development of drainage system and flowing pattern of a river over space and time are influenced by several variables of geology, geomorphology, structural components, soil and vegetation of the area through which it flows, the morphometric elements have become the integral components of evaluation under quantitative geomorphology (Calef, 1950; Chorley, 1957; Dade, 2001).

The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed (Mahtab, et al., 2003; Pareta and Pareta, 2012; Romshoo, et al., 2012; Vandana, 2013). Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds (Strahler, 1964; Faniran, 1968; Saud, 2009; Rao, et al., 2010; Panhalkar, et al., 2012; Magesh, et al., 2013). In recent years, the Remote Sensing coupled with GIS technique has been emerged as a tool in river morphometric analysis (Srivastava and Mitra, 1995; Nag, 1998; Agarwal, 1998; Moussa, 2003; Vittala, et al., 2004; Kouli, et al., 2007; Geena and Ballukraya, 2011; Chavan and Gadge, 2013). All these studies have portrayed only the individual significance of the morphometric parameters, while the present study depicts the interrelationship among the various morphometric parameters as well the theoretical explanation for the surface configuration in a GIS environment. Besides, the present makes a comparison of the morphometric properties of different watersheds of India enjoying different sets of geology and climatology.

2. Materials and Methods

2.1. Study Area and Its Regional Settings

The present study covers 163.07km^2 of the Kochara sub-watershed, which forms part of the Periyar river basin of the Western Ghats (KSLUB, 1996) (Figure 1). The study area lies in the Periyar Plateau, which is the northern part of the extensive and elongated Greater Periyar plateau at an elevation range of 700-1000m. The eastern edge of the plateau is a straight-line scarp falling off to the Tamil Nadu plains. NW-SE trending elongated ridges and intervening broad valleys and transverse gorges give the plateau an aspect of both maturity and indication of later rejuvenation. All the river courses within the plateau are remarkably straight and the streams have perfect trellis pattern. Superposed east-west profiles show escarpments at the western and eastern margins. The Kochara sub-watershed has a north-westerly slope and is composed of charnockite, hornblende biotite gneiss and granite (Figure 2). Evidences of intense migmatisation and granitisation are seen in many parts of the plateau (Soman, 2002). The hydrological units encountered in the Kochara sub-watershed area are laterites, weathered crystallines and fractures crystallines. Laterite is extensive aquifer in the study area, which is generally underlain by lithomargic clay. Due to the porous nature of the laterites in the plateau region, the dug well tapping laterite get recharged fast, but the recharged water escapes as sub surface flow and the water level falls quite fast. The average depth to the pre-monsoon water table is 3-5m bgl (below ground level); while during the post monsoon period the water table is at 1-2m bgl.

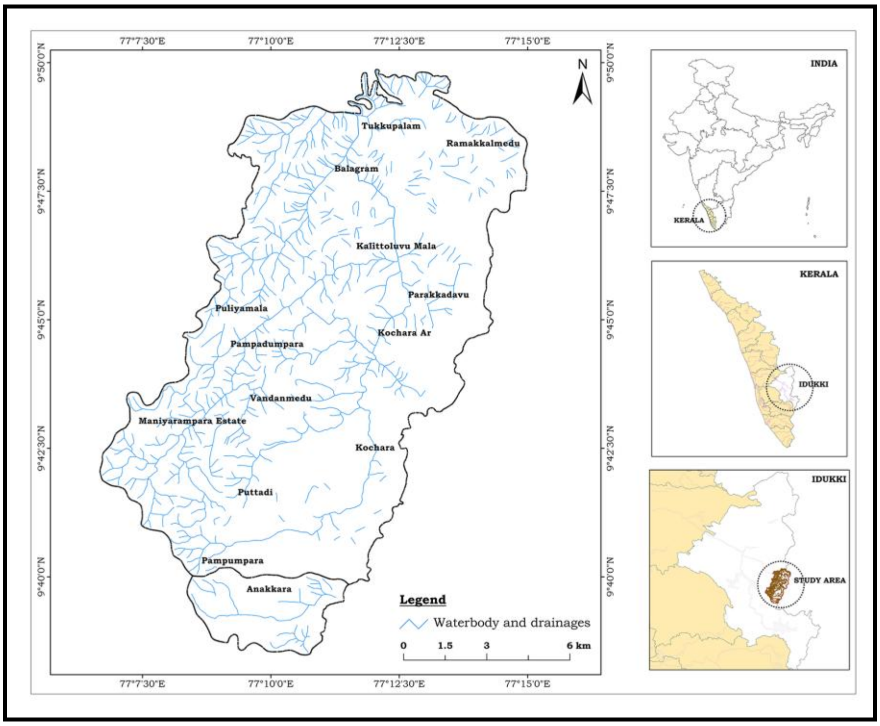

Figure 1: *Location map with drainage network of Kochara watershed*

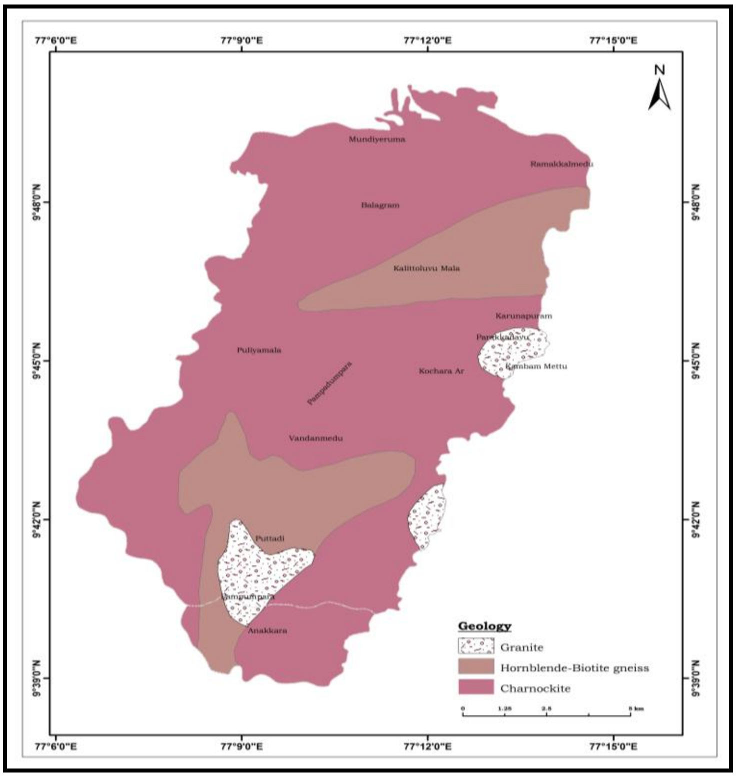

Figure 2: *Geology of Kochara Watershed*

2.2. Data Source

IRS – ID LISS –III geocoded False Colour Composite data on 1:50,000 scale corresponding to Survey of India toposheets (58G/1 & 58G/2) of the area was used for the study. Base map showing drainage details was prepared from the toposheets and the satellite imagery. Due to non-availability of high resolution stereo-imaging data for generating the Digital Elevation Model (DEM), the present study preferred the 1:50,000 scale topographic maps with 20 m contours to generate DEM. DEM at 20 m resolution was generated from the digitized contours at watershed level using Inverse Distance Weighted (IDW) interpolation technique. Quantitative analysis of the drainage pattern derived from both satellite data and toposheet was done in GIS environment using Arc GIS.

2.3. Morphometric Analysis

The geomorphological map of the Kochara sub-watershed derived from the satellite imagery suggests that most of Kochara sub-watershed area falls in the geomorphological category of dissected middle plateau, while the valleys occupy in rather elongated shape with denudational hills at the south western and northern margins (Figure 3). Besides, the Digital Elevation Model (DEM) (Figure 4) and slope map (Figure 5) of the sub-watershed were also derived to delineate relationship of the morphometric parameters with surface configuration. Altogether thirty parameters were morphometrically analysed in GIS environment using the mathematical formulae given in Table 1. The morphometric parameters analysed were divided into 3 categories related to their orientation in space. They are linear aspects, aerial aspects and relief aspects. The linear aspects were studied using the methods of Horton (1945), Schumm (1956), Melton (1958) and Strahler (1957, 1964), the areal aspects using those of Gravelius (1914), Horton (1932, 1945), Miller (1953), Schumm (1956), Chorley (1957), Faniran (1968) and Strahler (1964, 1968), and the relief aspects employing the techniques of Horton (1945), Schumm (1954), Strahler (1964).

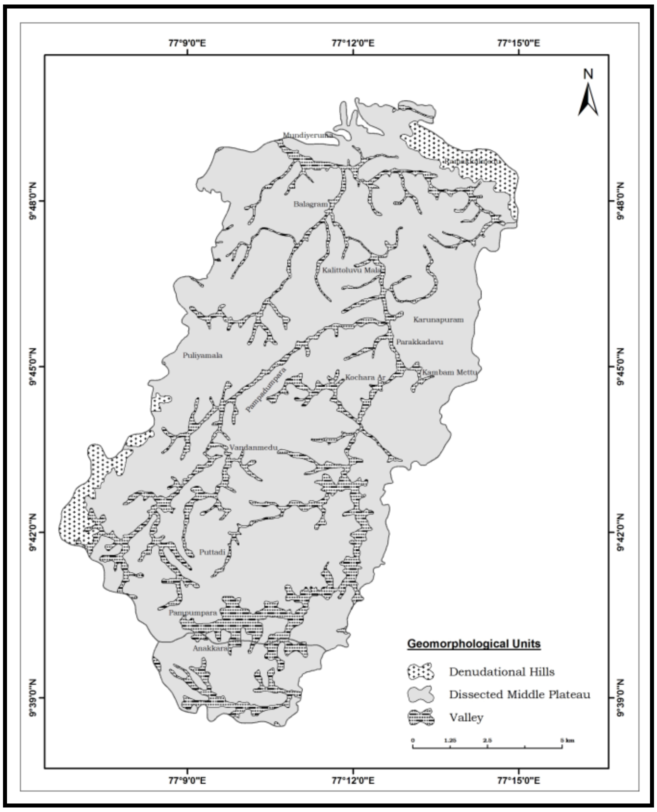

Figure 3: *Geomorphology of Kochara watershed*

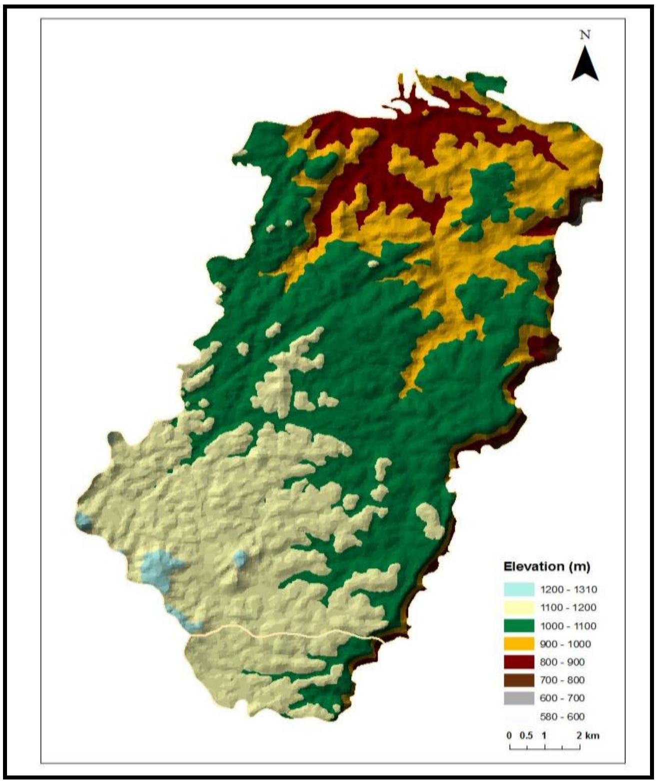

Figure 4: *Digital Elevation Model of Kochara Watershed*

Table1: *Parameters and Methods Included in Morphometric Analysis*

Sl. No.	Morphometric Parameters	Formula	Reference
A. Linear Aspects			
1.	Stream Order	Hierarchical rank – GIS analysis	Strahler (1964)
2.	Basin perimeter (P)	Outer boundary of the drainage basin – GIS analysis	Schumm (1956)
3.	Basin Length (Lb)	GIS analysis	Schumm (1956)
4.	Stream length (Lu)	Total stream length of the order 'u' – GIS analysis	Horton (1945)
5.	Length of main channel (Cl)	Longest channel of the basin - GIS analysis	Horton (1945)
6.	Mean Stream Length (Lsm)	Lsm = Lu/ Nu, Where, Lu = Total stream length of the order 'u' Nu = Total no. of stream segments of order 'u'	Strahler (1964)
7.	Stream Length Ratio (RL)	RL = Lu / Lu – 1, Where Lu = Total stream length of the order 'u' Lu-1= Total stream length of its next lower order	Horton (1945)
8.	Bifurcation Ratio (Rb)	Rb = Nu / Nu + 1, Where Nu = Total no. of stream segments of order 'u' Nu+1= Number of segments of the next higher order	Schumm (1956)
9.	Mean stream length ratio (RLm)	RLm = Average of stream length ratios of all orders	Strahler (1964)
10.	Mean Bifurcation Ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
11.	Drainage Texture (Rt)	Rt = Nu / P, Where Nu = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
12.	Rho Coefficient (ρ)	ρ = RLm/Rbm, Where RLm = Average of stream length ratio of all orders Rbm = Average of bifurcation ratios of all orders	Horton (1945)
13.	Fitness Ratio (Rf)	Rf = Cl/P, Where Cl = Length of the main channel P = Perimeter of the basin	Melton (1958)
B. Aerial Aspects			
14.	Basin Area (A)	GIS analysis	Schumm (1956)
15.	Mean basin width (Wb)	Wb = A/Lb, Where A = Area of the basin Lb = Basin length	Schumm (1956)
16.	Drainage Density (Dd)	Dd = Lu / A, Where Lu = Total stream length of all orders A = Basin area (km^2)	Horton (1932)
17.	Stream Frequency (Fs)	Fs = Nu / A, Where Nu = Total no. of streams of all orders A = Basin area (km^2)	Horton (1932)
18.	Form Factor Ratio (RF)	RF = A / Lb^2, Where A = Basin area (km^2) Lb^2 = Square of basin length	Horton (1932)
19.	Circularity Ratio (Rc)	Rc = $4\pi A / P^2$, Where $\pi = 3.14$ A = Basin area P^2 = Square of the basin perimeter	Miller (1953)

20.	Elongation Ratio (Re)	Re = 2* √ (A / π) / Lb, Where π = 3.14 A = Basin area Lb = Basin length	Schumm (1956)
21.	Length of Overland Flow (Lg)	Lg = 1/2Dd, Where Dd = Drainage Density	Horton (1945)
22.	Lemniscate's Value (k)	k = $\pi Lb^2/4A$, Where, π = 3.14 Lb^2 = Square of the basin length A = Basin area	Chorley (1957)
23.	Compactness Coefficient (Cc)	Cc = 0.2841* P/ √A, Where P = Basin perimeter A = Basin area	Gravelius (1914)
24.	Constant Channel Maintenance (Cm)	Cm = 1/Dd, Where Dd = Drainage density	Schumm (1956)
25.	Drainage Intensity (Di)	Di = Fs/Dd, Where Fs = Stream frequency Dd = Drainage density	Faniran (1968)
26.	Infiltration Number (If)	If = Fs*Dd, Where Fs = Stream frequency Dd = Drainage density	Faniran (1968)
	C. Relief Aspects		
27.	Relief of the basin (H)	$Height_{maximum} - Height_{minimum}$	Horton (1945)
28.	Relief Ratio (Rh)	Rh = H / Lb, Where H = Relief of the basin in kilometers Lb = Basin length	Schumm (1956)
29.	Ruggedness Index (Ir)	Ir = Dd*H, Where Dd = Drainage density H = Relief of the basin in kilometer	Strahler (1964)
30.	Dissection Index (Id)	Id = $H/Height_{maximum}$, Where H = Relief of the basin $Height_{maximum}$ = Maximum height recorded in the basin	Schumm (1956)

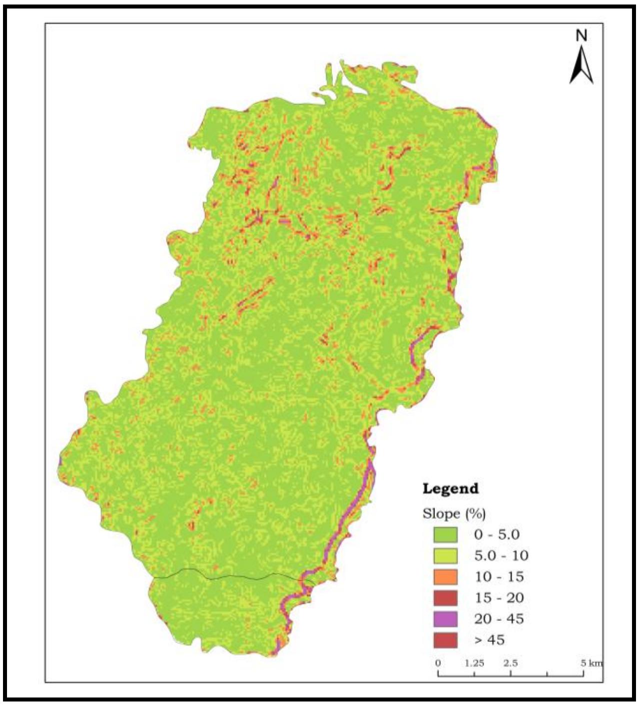

Figure 5: *Slope Map of Kochara Watershed*

3. Results and Discussion

3.1. Linear Aspects

It is observed from the analysis that the watersheds have the maximum frequency in the case of first order streams and its frequency decreases as the stream order increases (Table 2). There has been almost uniformity in bifurcation ratios for the streams of lower order streams, but the bifurcation ratio has been increased widely between third and fourth order streams. The Bifurcation Ratio (Rb) is an index of relief and dissections. It is generally observed that the Rb value varies between 3 and 5 and irregularities in the values of Rb are attributed to geological and lithological control over the drainage development. The high values of Rb indicate strong structural control on the drainage pattern, while the lower values project the watersheds which suffered less/no structural disturbances. The high value of Rb (7.40) of the Kochara stream is attributed to the characteristics of structural disturbances, which in turn, have distorted the drainage pattern (Table 2) and it clearly indicates the factor of geological control on the drainage pattern. The observations of Gieusti and Schneider (1965) that the bifurcation ratio within a basin decreases with increasing order and that bifurcation ratio increases with the catchment area initially and then tends to become a constant, do not hold well here.

Generally the total length of stream segments is maximum in first order streams and decreases as the stream order increases and the Kochara stream watershed agrees with this general observation. According to the Horton's (1945) law of stream length, the plot of logarithm of stream length (ordinate) as a function of stream order (abscissa) should yield a set of points lying essentially along a straight line and it results when basin evolution follows the erosion laws acting on geological material with homogeneous weathering–erosion characteristics. The law is seen almost merited in the case of Kochara stream (Figure 6). Similarly, the plot of logarithm of stream number (ordinate) as a function of stream order (abscissa) should yield a set of points lying essentially along a straight line and the same is also merited (Figure 7). The mean stream length (Lsm) varies from 0.49 km to 6.86 km. It is generally observed that the Lsm of any given order is greater than that of the lower order and less than that of its higher order. This general observation fails in the case of second order streams and this deviation in the value of Lsm is due to the slope and topographical variations. It is generally observed that, there is an increasing trend in the Length Ratio (RL) from lower order to higher order indicating their mature geomorphic stages and if there is a change from one order to another order, it indicates their late youth stage of geomorphic development (Singh and Singh, 1997). Abnormal low value (0.28) of the stream length ratio between third and fourth streams in the present study revealed that the river basin was subjected to neo-tectonic adjustments, as suggested by Lahiri (1996), resulting in late youth stage of geomorphic development (Table 2). Drainage texture (Rt) of a watershed is influenced by a single important factor – the infiltration capacity (Horton, 1945) and according to the classification proposed by Smith (1950); the Kochara river basin has coarse texture (3.58 km^{-1}). Rho coefficient (ρ) of a watershed is an important parameter relating drainage density to physiographic development of a hydrographic basin which facilitate evaluation of water storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed (Horton, 1945). Low values of Rho indicate low capacity for storage of water, while high values of Rho indicate high capacity of storage of water and the climatic, geologic, geomorphologic, and anthropogenic factors determine the changes in this parameter (Melton, 1958). Kochara sub-watershed has a very low value (0.10) indicating sub-surface draining of ground water due to the peculiar nature of geologic formations. Fitness ratio (Rf) is measure of topographic fitness and the fitness ratio value (0.15) for the Kochara sub-watershed indicates that the basin is more elongated with better possibility for ground water recharge as suggested by Pareta and Pareta (2012).

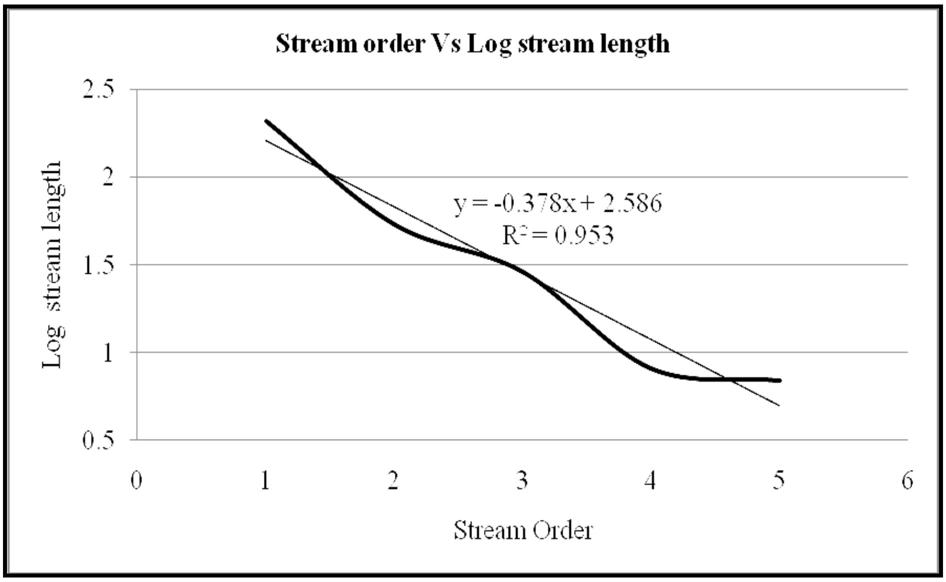

Figure 6: *Stream Order vs. Log Stream Length (Narrow Line is the Trend Line)*

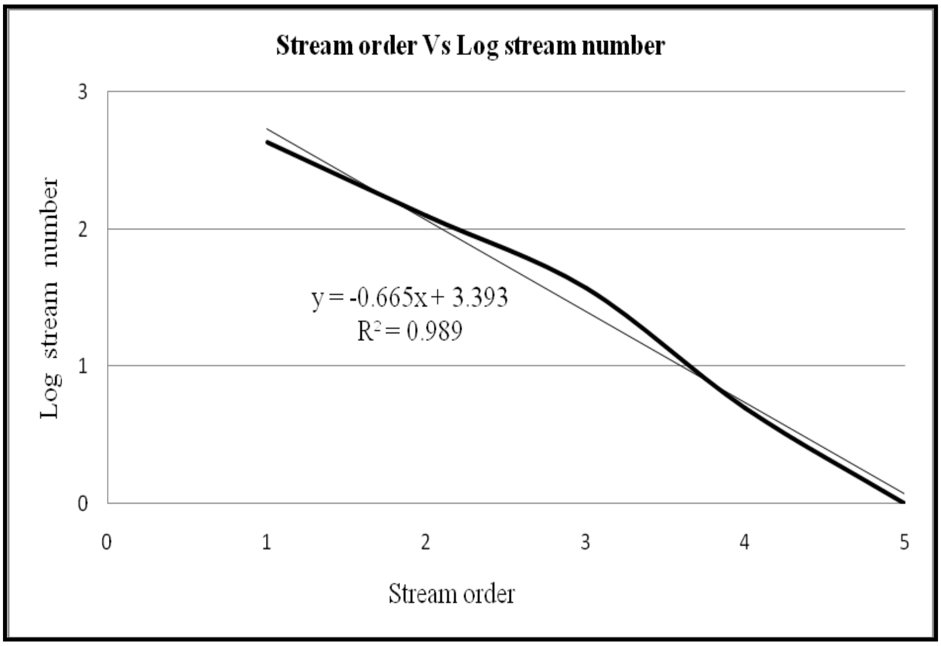

Figure 7: *Stream Order vs. Log Stream Number (Narrow Line is the Trend Line)*

3.2. Aerial Aspects

The factor of drainage density (Dd) is related with climate, petrology, rate of infiltration, surface configuration, land-use and vegetation of the area. The analysis showed the drainage density (Dd) is 1.88 km^{-1} (Table 2) and the very low Dd value is attributed due to the presence of permeable sub-surface formation, dense vegetation and low relief (Langbein, 1947; Nag, 1998). The stream frequency (Fs) of Kochara sub-watershed is 3.64 km^{-2} which in turn indicates the increase of stream population. The analysis showed that the form factor (RF) value is 0.46, which suggest an elongated shape for the drainage basin. The value of elongation ratio (Re) of the basin (0.76) indicated that it has more or less elongated appearance. The circularity ratio (Rc) correlates not only with the basin shape, but with the stage of topographical evolution as well and the river basin of Kochara stream (0.075) shows the immature stage of the basin (Horton, 1932; Vittala, et al., 2004). The value of the length of the overland flow (Lg) is 0.248 km. It implies the length of run-off of the rain water on the ground surface before it gets localized into definite channels (Kokkal, 1998). The value of Lg for the Kochara stream indicates more length of sheet flow and less influence of the factor of hydraulic gradient. The Lemniscate's value (k) is one of the parameters which describe the shape and slope of the basin. The ideal Lemniscate's value of elongated basins varies from 0.50 to 1.80 and for Kochara sub-watershed; the value is 1.74 and which reveals that the basin is less prone to erosion hazard due to the longer time of concentration of runoff water to reach the outlet from the remotest point of the basin in elongated ones. The results tally with the findings of Srivastava and Mitra (1995) and Moussa (2003). The Compactness coefficient (Cc) is independent of the size watershed and dependent only on the slope. For study area, the value is 3.66 which points towards the surface undulations with gentle slopes and the value agrees with surface expression portrayed by Figure 5. The constant channel maintenance value of the sub-watershed in 0.53 km and the drainage intensity is 1.94/km. Low value of drainage intensity implies that the drainage density and drainage frequency have little effect on the extent to which the surface has been lowered by the agents of denudation as suggested by Geena and Ballukraya (2011) as well as Chavan and Gadge (2013). This clearly suggests the role of neo-tectonic events in shaping the surface configuration of the plateau and is quite evident from the undeveloped drainage channels distributed at the north eastern part of the study area (Figure 1). The moderate value (6.84) for the Infiltration index is attributed to low runoff.

Table 2: *Morphometric Parameters of Kochara Sub-Watershed*

A. Linear Aspects						
1.	Maximum stream order attained	V				
2.	Basin perimeter (P) (km)	165.68				
3.	Basin Length (Lb) (km)	18.99				
4.	Length of main channel (Cl) (km)	24.94				
5.	Stream length (Lu) (km)	I	II	III	IV	V
		209.02	53.61	29.02	8.08	6.86
6.	Number of stream segments	I	II	III	IV	V
		426	124	37	5	1
7.	Mean Stream Length (Lsm) (km)	I	II	III	IV	V
		0.49	0.43	0.78	1.62	6.86
8.	Stream Length Ratio (RL)	II/I	III/II	IV/III	V/IV	
		0.26	0.54	0.28	0.85	
9.	Bifurcation Ratio (Rb)	I/II	II/III	III/IV	IV/V	
		3.44	3.35	7.40	5.00	
10.	Mean stream length ratio (RLm)	0.48				
11.	Mean Bifurcation Ratio (Rbm)	4.80				
12.	Drainage Texture (Rt) (km^{-1})	3.58				
13.	Rho Coefficient (ρ)	0.10				
14.	Fitness Ratio (Rf)	0.15				
B. Aerial Aspects						
15.	Basin Area (A) (km2)	163.07				
16.	Mean basin width (Wb)	8.59				
17.	Drainage Density (Dd) (km^{-1})	1.88				
18.	Stream Frequency (Fs) (km^{-2})	3.64				
19.	Form Factor Ratio (RF)	0.46				
20.	Circularity Ratio (Rc)	0.08				
21.	Elongation Ratio (Re)	0.76				
22.	Length of Overland Flow (Lg) (km)	0.25				
23.	Lemniscate's Value (k)	1.74				
24.	Compactness Coefficient (Cc)	3.66				
25.	Constant Channel Maintenance (Cm) (km)	0.53				

26.	Drainage Intensity (Di) (km^{-1})	1.94
27.	Infiltration Number (If)	6.84
	C. Relief Aspects	
28.	$Height_{maximum}$ of the basin (km)	1.310
29.	$Height_{minimum}$ of the basin (km)	0.854
30.	Relief of the basin (H) (km)	0.456
31.	Relief Ratio (Rh)	0.024
32.	Ruggedness Index (Ir)	0.857
33.	Dissection Index (Id)	0.348

3.3. Relief Aspects

There is a correlation between hydrological characteristics and the relief ratio (Rh) of a drainage basin. The low value of Rh for the Kochara river basin (0.024) indicates moderate relief and the presence of basement rocks that are exposed in the form of small ridges and mounds with moderate to lower degree slopes (Table 2) (Figure 5). Kochara sub-watershed has the Ruggedness index (Ir) of 0.857 and this low value implies that the drainage basin has intrinsic structural complexity in association with relief and drainage density. Dissection index (Id) is an important morphometric indicator of the nature and magnitude of dissection of terrain. The value of Id varies from zero (complete absence of dissection) to one (vertical cliff). Generally, low Id corresponds with the subdued relief or old stage, and with low relative relief. Conversely, the areas with high Id indicate high relative relief where slope of the land is steep (Schumm, 1956). Based on the Id value obtained by the analysis, Kochara sub-watershed has medium to low dissection index (0.348) which suggests that the topography of the region favours the deposition of lean sediment that ensures thin layer of soil. Furthermore, it does not favour active mobilization of the weathered material and such topography assures relaxed irrigation because of low gradient. The workings of fields such as tillage, spading, hoeing, sowing and harvesting are not a difficult task.

The total number of streams and cumulative length of streams at Kochara basin revealed that the number of streams exceeds the cumulative stream length, except for the fourth and fifth order streams. It reflects that the watershed is favourable for longer flow and good infiltration once the river reaches its lowland areas. The first, second and third order streams with number of streams exceeds the cumulative stream length, it represents that the river basin at elevated areas has low permeability, low infiltration rate, existence of shallow soils under excessive drainage or they are influenced by structural disturbances. Analysis of the cumulative length of streams and drainage density of the basin revealed that it has favourable factors for infiltration and low surface runoff and development of moderately deep soils at its lower reaches. The present result is agreeable with the findings of Sreedevi, et al., (2005) as far as a structurally influenced region is concerned. Generally high form factor value with low cumulative length values indicates that total volume of water runs into few channels in a shorter duration. Analysis of form factor and cumulative stream length with respect to Kochara stream revealed that the basin has almost level slopes, low soil erosion, favourability for the formation of alluvial deposits as revealed by the Figure 3.

3.4. Comparison with Other Watersheds

The morphometric analysis of drainage basins revealed that the distribution of surface water in different landforms is controlled by the combined effect of the quantitative geomorphic characteristics of drainage basins. Table 3 compares some of the selected morphometric parameters of the present study with those of some relevant previous studies carried out in India. The comparison shows that the quantitative geomorphic characteristics of each drainage basin are depended on the set of geo-environmental conditions enjoyed by that basin. The river basin like Pennar (Vittala, et al., 2004), which receives less than 600 mm of rainfall, is able to develop a comparable drainage network with that of Kuttiyadi river basin (James and Padmini, 1983) receiving 4000 mm rainfall. Similarly, the Karso basin receiving 1300 mm rainfall (Pandey, et al., 2004) has developed more established stream network than those of Kaveri river basin receiving 3775 mm rainfall (Putty, 2007), even though the former has a very less basin area. It is well established that the drainage network development in a particular area is in accordance with the climate, surface configuration, geology, geomorphology, structural disturbances, etc.

Table 3: *Comparison of Certain Morphometric Parameters of Different Watersheds of India*

Basin	Area studied (km^2)	Mean bifurcation ratio		Circularity Ratio		Drainage Density		Drainage Frequency		Rain fall (mm)	Remarks
		From	To	From	To	From	To	From	To		
Chaka basin, West Bengal	137.5	1.95	2.07	0.27	---	0.52	---	*ND	*ND	118	Nag 1998
Karso, Jharkhand	23.0	2.10	5.20	0.32	0.56	2.80	4.80	3.70	7.00	1300	Pandey et al. 2004
Kaveri basin, Western Ghats	1070.0	3.35	4.70	0.42	0.64	1.90	2.68	2.35	3.79	3775	Putty 2007
Khairkuli basin, Uttar Pradesh	28.0	2.80	8.30	0.43	0.82	1.80	2.85	3.50	7.63	*ND	Nautiyal 1994
Kuttiyadi basin, Kerala	646.0	*ND	*ND	0.37	0.56	1.40	2.60	1.10	2.40	4000	James and Padmini 1983
Meenachil basin, Kerala	846.0	3.33	5.30	0.12	0.47	1.65	2.87	1.78	4.41	3120	Ajaykumar et al. 2011
Mirzapur upland, Uttar Pradesh	4172.0	4.00	6.70	0.28	0.88	1.70	3.10	2.20	5.80	120	Singh 1992
Naugarh block, Uttar Pradesh	806.0	2.68	4.07	0.31	0.67	1.47	2.46	1.24	1.84	*ND	Agarwal 1998
Pennar basin, Pavagada	570.0	3.21	4.88	0.32	0.53	1.55	2.16	1.70	2.91	560	Vittala et al. 2004
Purulia district, West Bengal	156.0	1.46	2.10	0.10	0.18	0.40	2.98	*ND	*ND	*ND	Nag and Chakraborty 2003
Tarafeni basin, West Bengal	600.0	1.00	10.00	0.25	0.76	0.40	2.78	*ND	*ND	*ND	Nookaratnam et al. 2005
Tawi, Jammu and Kashmir	1885.0	3.50	11.00	*ND	*ND	2.50	---	3.90	---	135	NIH 1993
Kochara stream, Kerala	**163.1**	**4.80**	**--**	**0.08**	**--**	**1.88**	**--**	**3.64**	**--**	**2809**	**Present study**

* ND – Not detected in the study

4. Conclusion

The drainage morphometry of a river basin reflects the hydro-geologic maturity of that river. The analysis helped to reveal the relationships between the drainage basin and hydro-geologic parameters. It is observed that the Kochara stream has established predominantly with the trellis drainage pattern, followed by semi-dendritic pattern at the higher reaches with drainage development up to a V order stream. It also revealed that the stream channel development is irrelevantly related with the areal extent of the drainage basin and their frequency decreases as their stream order increases. The high Bifurcation ratio between the III and IV order streams of Kochara stream is attributed to the characteristics of structural disturbances, which in turn have influenced the drainage pattern. The varying trend in the stream length Ratio from lower order to higher order indicated that the basin has attained late youth stage of geomorphologic development. The low relief ratio low value indicates the presence of small ridges and mounds in the case of Kochara stream and the low Drainage Density value is attributed to the presence of permeable sub-surface formation and low relief. The mathematical expression of the surface configuration of the Kochara stream could explain why this plateau region has remarkable presence of palaeodeposit of sand as observed by Baiju et al. (2013). Since the drainage basin is elongated in shape, it will have a flatter peak of flow for longer duration. Flood flows of these elongated basins are easily manageable than that of circular basins.

One of the important observations made, during the comparative study between different watersheds with different climatic regimes in India, is that the channel development is irrelevantly related with the areal extent of a drainage basin. It is well established that the drainage network development in a particular area is in accordance with the climate, surface configuration, geology, geomorphology, structural disturbances, etc. Hence, the analysis of the inter-relationships helps in understanding the terrain characteristics, slope, landforms, soils, soil erosion and ground water potential for watershed development and management. Apart from the earlier studies on morphometric analysis, which had considered only the individual morphometric parameters and its possible meaning, the present study incorporated geomorphological character of the river basin along with the mathematical expressions for the surface configuration in a GIS environment. Since the study could draw the remarkable relationship between theoretical data sets with field observations on surface configuration, geology, structural components, it is concluded that the GIS is an excellent competent tool for interpreting the quantitative geomorphology of a river basin.

Acknowledgement

Mr. C.K. Baiju and Dr. B. Ajaykumar express their words of gratitude to the Director of Mining and Geology, Govt. of Kerala for the constant encouragement. Dr. Girish Gopinath extends his sincere thanks to the Executive Director, CWRDM for providing the centralised Remote Sensing facility for the analysis. Mr. M.S. Shylesh Chandran is thankful to the Director of School of Environmental Sciences for the support.

References

Agarwal, C.S. *Study of Drainage Pattern Through Aerial Data in Naugarh Area of Varanasi District, U. P.* Journal of the Indian Society of Remote Sensing. 1998. 26 (4) 169-175.

Ajaykumar, B., Rakesh, P.S., Mahesh Mohan, Unni, K.S. and Thomas, A.P. *Interpretation of the Quantitative Geomorphology of the Meenachil River Basin, Kerala, South India using Remote Sensing and Geographical Information System.* Ecology, Environment and Conservation. 2011. 17 (2) 129-143.

Baiju, C.K., Ajaykumar, B., Ramkumar, T. and Girish Gopinath, 2013: Holocene Climate Changes Over the Indian Subcontinent – A Review. In: Daniel, J.A. (ed.) Advances in Environmental Research. Vol. 28. New York: Nova Science Publishers, Inc. 245-256.

Calef, W.C., 1950: *Form and Process.* London: Cambridge University Press. 473.

Casteltort, S. and Simpson, G. *River Spacing and Drainage Network Growth in Widening Mountain Ranges*. Basin Research. 2006. 18 (3) 267-276.

Chavan, V.T. and Gadge, P.S. *Morphometric Analysis of Junana Mini Watershed Nandgoan (Kh.), Dist. Amravati, Maharashtra Using GIS.* International Journal of Science, Environment and Technology. 2013. 2 (5) 1072-1079.

Chopra, R., Dhiman, R.D. and Sharma, P.K. *Morphometric Analysis of Sub Watersheds in Gurdaspur District, Punjab Using Remote Sensing and GIS Techniques*. Journal of the Indian Society of Remote Sensing. 2005. 33 (4) 531-539.

Chorley, R.J. *Illustrating the Laws of Morphometry*. Geological Magazine. 1957. 94; 140-150.

Dade, W.B. *Multiple Scales in River Basin Morphology.* American Journal of Science. 2001. 301; 60-73.

Faniran, A. *The Index of Drainage Intensity-A Provisional New Drainage Factor*. Australian Journal of Science. 1968. 31; 328-330.

Geena, G.B. and Ballukraya, P.N. *Morphometric Analysis of Korattalaiyar River Basin, Tamil Nadu, India: A GIS Approach*. International Journal of Geomatics and Geosciences. 2011. 2 (2) 383-391.

Gieusti, E.V. and Schneider, W.J., 1965: *The Distribution of Branches in River Networks.* United States Geological Survey. 422.

Gravelius, H., 1914: *Flusskunde.* Berlin: Goschen'sche Verlagshandlung.

Horton, R.E. *Drainage Basin Characteristics*. Transactions of American Geophysical Union. 1932. 13; 350-361.

Horton, R.E. *Erosional Development of Streams and Their Drainage Basins; Hydrophysical Approach to Quantitative Morphology.* Bulletin of Geological Society of America. 1945. 56; 275-370.

James, E.J. and Padmini, V. *Quantitative Geomorphological Studies of the Kuttiyadi River Basin on the Malabar Coast.* Journal of the Institution of Engineers (India). 1983. 63; 266.

Kokkal, K., 1998: *Hydrogeomorphometric Study of the Kariangotte River Basin, Kasaragod District, Kerala.* Proceedings of the Tenth Kerala Science Congress. 22-24.

Kouli, M., Vallianatos, F., Soupios, P. and Alexakis, D. *GIS-Based Morphometric Analysis of Two Major Watersheds, Western Crete, Greece*. Journal of Environmental Hydrology. 2007. 15 (1) 1-17.

KSLUB, 1996: *Watershed Atlas.* Publication of Kerala State Land Use Board, Govt. of Kerala, India.

Lahiri, S. *Channel Pattern as Signature of Neotectonic Movements – A Case Study from Brahmaputra Valley in Assam*. Journal of the Indian Society of Remote Sensing. 1996. 24 (4) 265-272.

Langbein, W.B. *Topographic Characteristics of Drainage Basins.* United States Geological Survey Water – Supply Paper. 1947. 986 (C) 157-159.

Magesh, N.S., Jitheshlal, K.V., Chandrasekar, N. and Jini, K.V. *Geographical Information System-Based Morphometric Analysis of Bharathapuzha River Basin, Kerala, India*. Applied Water Science. 2013. 3; 467-477.

Mahtab, A., Narender, B. and Ajai. *Satellite Derived Digital Elevation Model and Terrain Parameters–Generation, Accuracy Assessment and Validation.* Journal of the Indian Society of Remote Sensing. 2003. 31 (1) 19-24.

Matsuda, I., 2004: *River Morphology and Channel Processes.* In: Dooge, J.C.I. (ed.) Fresh Water. Encyclopedia of Life Support Systems (EOLSS). Oxford: UNESCO, EOLSS Publishers.

Melton, M.A. *Correlation Structure of Morphometric Properties of Drainage System and Their Controlling Agents.* The Journal of Geology. 1958. 66; 442-460.

Miller, V.C., 1953: *A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area.* Virginia and Tennessee, Project Number 389–402. Technical Report-3, Dept. of Geology, Columbia University, New York.

Moussa, R. *On Morphometric Properties of Basins, Scale Effects and Hydrological Response*. Hydrological Processes. 2003. 17; 33-58.

Nag, S.K. *Morphometric Analysis using Remote Sensing Techniques in the Chaka Sub-Basin, Purulia District, West Bengal*. Journal of the Indian Society of Remote Sensing. 1998. 26 (1&2) 69-76.

Nag, S.K. and Chakraborty, S. *Influence of Rock Types and Structures in the Development of Drainage Network in Hard Rock Area.* Journal of the Indian Society of Remote Sensing. 2003. 31 (1) 25-35.

Nautiyal, M.D. *Morphometric Analysis of a Drainage Basing Using Aerial Photographs: A Case Study of Khairkuli Basin, District Dehradun, U.P.* Journal of the Indian Society of Remote Sensing. 1994. 22 (4) 251-261.

NIH, 1993: *Hydrogeomorphological Studies of Tawi basin in Jammu and Kashmir.* Report, National Institute of Hydrology, CS. 114.

Nookaratnam, K., Srivastava, Y.K., Rao, V.V., Amminedu, E. and Murthy, K.S.R. C*heck Dam Positioning by Prioritization of Micro-Watersheds Using SYI Model and Morphometric Analysis – Remote Sensing and GIS Perspective*. Journal of the Indian Society of Remote Sensing. 2005. 33 (1) 25-38.

Pandey, A., Chowdry, V.M. and Mal, B.C. *Morphological Analysis and Watershed Management Using GIS.* Hydrology Journal of IAH. 2004. 27 (3&4) 71.

Panhalkar, S.S., Mali, S.P. and Pawar, C.T. *Morphometric Analysis and Watershed Development Prioritization of Hiranyakeshi basin, Maharashtra, India.* International Journal of Environmental Sciences. 2012. 3 (1) 525-534.

Pareta, K. and Pareta, U. *Quantitative Geomorphological Analysis of a Watershed of a Ravi River Basin, H.P. India.* International Journal of Remote sensing and GIS. 2012. 1 (1) 41-56.

Putty, M.R.Y. *Quantitative Geomorphology of the Upper Kaveri Basin in Western Ghats, in Karnataka.* Journal of the Institution of Engineers (India)–CV. 2007. 88; 44-49.

Radhakrishna, B.P. and Vaidyanadhan, R., 1997: *Geology of Karnataka*. Geological Society of India, Bangalore. 298.

Raj, R. *Strike Slip Faulting Inferred from Off-Setting of Drainages: Lower Narmada Basin, Western India*. Journal of Earth System Sciences. 2007. 116 (5) 413-421.

Rao, K.N., Latha, P.S., Kumar, P.A. and Krishna, M.H. *Morphometric Analysis of Gostani River Basin in Andhra Pradesh State, India, using Spatial Information Technology.* International Journal of Geomatics and Geosciences. 2010. 1 (2) 179-187.

Reddy, G.P.O., Maji, A.K. and Gajbhiye, K.S. *GIS for Morphometric Analysis of River Basins*. GIS India. 2002. 11 (9) 9-14.

Romshoo, S.A., Bhat, S.A. and Rashid, I. *Geoinformatics for Assessing the Morphometric Control on Hydrological Response at Watershed Scale in the Upper Indus Basin.* Journal of Earth System Science. 2012. 12 (3) 659-686.

Saud, M.A. *Morphometric Analysis of Wadi Aurnah Drainage System, Western Arabian Peninsula.* The Open Hydrology Journal. 2009. 3; 1-10.

Schumm, S.A. *The relation of Drainage Basin Relief to Sediment Loss.* International Association of Scientific Hydrology. 1954. 36; 216-219.

Schumm, S.A. *Evolution of Drainage Systems & Slopes in Badlands at Perth Amboy, New Jersey.* Bulletin of the Geological Society of America. 1954. 67; 597-646.

Singh, C.P. *Some Selected Drainage Basins of South Mirzapur Upland, U.P.: Morphometric Evaluation.* National Geographical Journal of India. 1992. 41 (3) 247.

Singh, S. and Singh, M.C. *Morphometric Analysis of Kanhar River Basin.* National Geographical Journal of India. 1997. 43 (1) 31-43.

Smith, K.G. *Standards for Grading Textures of Erosional Topography.* American Journal of Sciences. 1950. 248; 655-668.

Soman, K., 2002: *Geology of Kerala.* 2nd Edn. Geological Society of India, Bangalore. 117-138.

Sreedevi, P.D, Subrahmanyam, K. and Ahmed, S. *The Significance of Morphometric Analysis for Obtaining Groundwater Potential Zones in a Structurally Controlled Terrain.* Environmental Geology. 2005. 47 (3) 142-420.

Srivastava, V.K. and Mitra, D. *Study of Drainage Pattern of Raniganj Coalfield (Burdwan District) as Observed on Landsat-TM/IRS LISS II Imagery.* Journal of the Indian Society of Remote Sensing. 1995. 23 (4) 225-235.

Strahler, A.N. *Quantitative Analysis of Watershed Geomorphology.* Transactions of American Geophysical Union. 1957. 38; 913-920.

Strahler, A.N., 1964: *Quantitative Geomorphology of Drainage Basins and Channels Networks.* In: Chow, V.T. (ed.). Handbook of Applied Hydrology. New York: McGraw Hill Book Company.

Strahler, A.N., 1968: *Quantitative Geomorphology* In: Fairbridge, R.W. (ed.). The Encyclopedia of Geomorphology. New York: Reinhold Book Crop.

Vandana, M. *Morphometric Analysis and Watershed Prioritization: A Case Study of Kabani River Basin, Wayanad District, Kerala, India.* Indian Journal of Geo-Marine Sciences. 2013. 42 (2) 211-222.

Vittala, S.S, Govindaiah, S. and Gowda, H. *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. 2004. 32 (4) 351-362.

Zwnnitz, E.R. *Drainage Pattern and their Significance.* Journal of Geology XL. 1932. 6; 498-521.