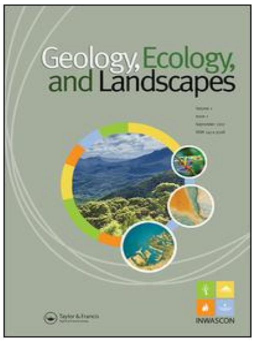

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Morphometric analysis of landforms on basalt, granite gneiss and schist geological formations in north Karnataka, India – a comparison

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RESEARCH ARTICLE

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Morphometric analysis of landforms on basalt, granite gneiss and schist geological formations in north Karnataka, India – a comparison

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ABSTRACT
Morphometric analysis reveals the development of land surface processes and provides an insight into hydrologic behaviour of watershed. A morphometric analysis of landforms on basalt, granite gneiss and schist in north Karnataka was conducted with the objective of comparing various morphometric parameters among them. A sub-watershed each was selected to represent landform on basalt, granite gneiss and schist. The stream length was highest in sub-watershed on basalt and was least on schist with one on granite gneiss being intermediate. The stream number was highest in basalt and its values were similar in granite gneiss and schist. Total relief, relief ratio and ruggedness number were distinctly high in sub-watershed on schist compared to the other two. The low mean bifurcation ratios in all three sub-watersheds suggested stability of the landforms. Drainage density was relatively coarser in the sub-watershed on granite-gneiss compared to the other two. The drainage network was dendritic in the sub-watershed on basalt, sub-dendritic on granite gneiss and sub-trelis on schist. The drainage texture and texture ratio were slightly higher, overland flow values were lower in sub-watersheds on basalt and schist compared to that on granite-gneiss. All three sub-watersheds exhibited similar elongation ratio, form factor and circularity ratio.

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Comparative morphometry; DEM; drainage pattern; geological formations; sub-watersheds

Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy, Maji, & Gajbhiye, 2002). Hydrologic and geomorphic processes occur within a watershed. Therefore, morphometric characterization at the watershed level brings out the information on development of land surface processes and provides an insight into the hydrologic behaviour of a watershed (Altaf, Meraj, & Ramshoo, 2013; Singh, 1992). Morphometric analysis also helps to understand initial slope or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler, 1964). These studies are made for a range of objectives including prioritization of watersheds (Biswas, Sudhakar, & Desai, 1999), to understand ground water hydrology (Nag & Chakraborty 2003), to study the drainage network as influenced by bedrock geology (Nag & Chakraborty 2003; Sameena, Krishnamurthy, & Jayaraman, 2009) and others. Extensive use of GIS techniques for assessing various terrain and morphometric parameters of the drainage basins and watersheds has been the hallmark of these studies, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information. Karnataka is known for its geologic diversity with formations ranging from the Archean granites, granite gneisses, and schists through Holocene basalts to Pre-Cambrian sedimentary rocks to recent alluvium. Granite gneiss occupies dominant area in the state of Karnataka with considerable area of basalts, especially in the northern and north western part and schist scattered all around (Radhakrishna & Vaidynadhan 2011). Karnataka state is a pioneer in watershed development works in India. Presently, it is implementing Sujala-3 Watershed Development project with World Bank funding in 11 districts of the state including Vijayapur, Koppal and Gadag. Basalt is the predominant geological formation in Vijayapur district and granite gneiss is the dominant geology in both Koppal and Gadag districts, with considerable area under chlorite schist in both the districts. Therefore, it was of interest to see the land surface processes on these three important geological formations under similar overhead climate. Vittala, Govindaiah, and Honnegowda (2004) studied morphometry of a watershed in granite gneiss terrain in southern Karnataka and Yasmin, Sateeshkumar, Ayyangoudar, and Narayanrao (2013) in Raichur district in northern Karnataka. There are many other studies on morphometry on granitic landscapes of south India (Sreedevi, Owais, Khan, & Ahmed, 2009; Wilson, Chandrasekar, & Magesh, 2012). Similarly, Sahu et al. (2010) made a morphometric analysis of basaltic terrain in sub-humid central India. Altaf et al.

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(2013) studied the morphometry of Lidder river valley in Kashmir on sedimentary formations. However, a comparative study of morphometry under a similar climate on different geological formations are few (Krishnamurthy, Srinivas, Jayaram, & Chandrasekhar, 1996; Nag & Chakraborty 2003) and none for northern Karnataka. Therefore, this study was made to compare the morphometric properties among the three landforms on the three major geological formations under a similar overhead semi-arid climatic condition in north Karnataka.

Study area

Location

For this study, three sub-watersheds occurring on three different geological formations were selected. These three sub-watersheds include Dadamatti on basalt in Vijyapura district, Belageri on granite-gneiss in Koppal district and Dindur sub-watershed on chlorite-schist in Gadag district. The location of these sub-watersheds, their constituent micro-watersheds and the drainage network is shown in Figure 1. Dadamatti sub-watershed comprises of seven micro-watersheds, Belageri of 11 and Dindur sub-watershed of eight micro-watersheds. The area of the former two is similar whereas that of Dindur is less than both.

Climate

All the three sub-watersheds are located in the semi-arid area of north Karnataka described as Northern Dry zone (zone-3) agro-climatically. Dindur sub-watershed is somewhat more humid than the other two. The climatic and other ancillary data is furnished in Table 1.

Geology, geomorphology and slope

The Dadamatti sub-watershed is occupied by the basaltic flows of Deccan traps, which belong to the sequence of Middle Deccan Traps of Upper Cretaceous to Lower Eocene Age. The basalts are generally dark grey to black in colour, fine grained, highly vesicular and zeolitic in nature. The sub-watershed has predominantly pediments, pediplains and floodplain along the river Doni.

The granite gneiss landscape is moderately plain with shallow troughs and mounds of granites hills at scattered places in rugged topography with highest peaks. The hard granite-gneissic rocks do not have any primary porosity; however, weathering, fracturing, joints and tectonic features like folds and faults have secondary porosity and permeability (Central Ground Water Board (CGWB), 2008). Weathered thickness is reported to vary from a minimum of one metre to a maximum of 20 m nearer to streams. In general, ground water is available in the weathered zone under phreatic

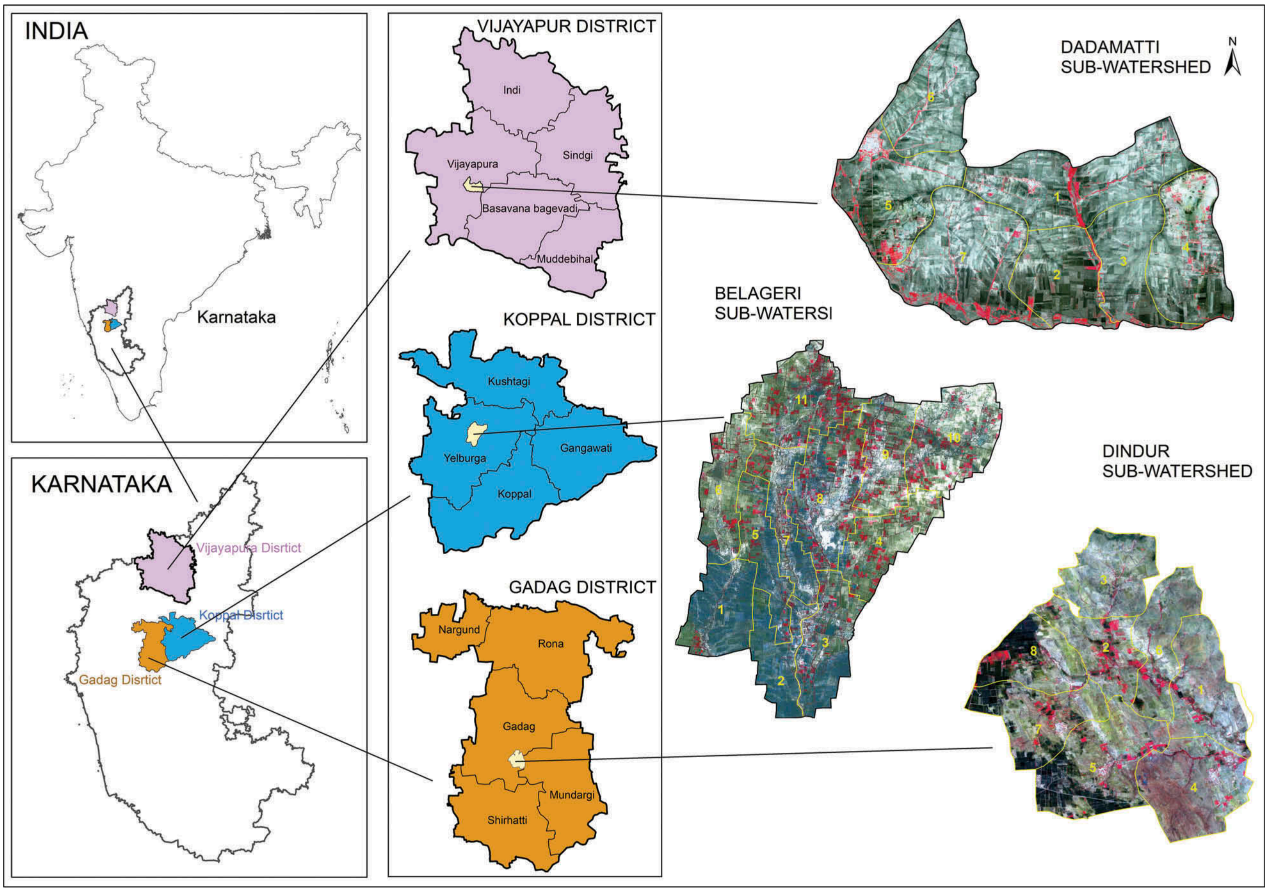

Figure 1. Location map of sub-watersheds studied.

Table 1. Salient features of the sub-watersheds selected.

Sub-watershed	Geology	Rain fall mm	Temperature °C		Slope	No. of wells	Predominant soils
			Max	Min			
Dadamatti	Basalt	565.0	33.6	19.6	Nearly all the area has 1–3%	165	70% area calcareous Vertisols and 20% Lithic Ustorthents,
Belageri	Granite gneiss	559.6	36.5	20.4	1/3rd area 0–1% and remaining 1–3%	922	Lithic and Typic Haplustalfs, Ustepts and Vertisols
Dindur	Schist	628.0	32.1	19.2	Area distributed equally among 1–3%, 3–5% and >5%	160	Lithic Ustorthents and Lithic Haplustepts

condition and under confined to semi-confined conditions in the jointed and fractured formation.

The Gadag schist belt consists of a 2000 m thick pile of meta-volcanics and meta-sediments. The structural deposition of the belt is the result of an overall E–W compressional regime with uplift and diaperism of the sialic basement. These rocks have no primary porosity or permeability; ground water occurs under a phreatic condition in weathered zone of these formations.

Nearly, all of the sub-watershed area on both basalt and granite gneiss is nearly level to very gently sloping lands except for 1% area with slopes 3–5%. In sharp contrast to these two, the sub-watershed on schist has considerable area (35%) under gently sloping lands with slope class of 3–5%, followed by 19% area under moderately sloping lands with slope range of 5–10% and strongly sloping area (8%) with a slope of 10–15% range.

Soils and erosion

Very deep black soils (Vertisols) predominate in Dadamatti sub-watershed with appreciable portion of shallow and very shallow black soils occupying higher elements of topography. The soils of Beligeri sub-watershed comprise of moderately deep (75–100 cm) and deep (100–150 cm) red soils (Haplustalfs) and associated black soils (Haplusterts). Dindur sub-watershed comprises mainly very shallow (<25 cm) and shallow (25–50 cm) and to some extent moderately shallow fine textured red soils in 75% area and black soils (Vertisols and vertic Inceptisols) in the remaining area.

Both Dadamati and Belegeri sub-watersheds are predominantly moderately to slightly eroded. The Dindur stands out with 42% area affected by severely and very severely eroded class compared to 4% area in Beligeri and under 1% in Dadamatti.

Methodology

The sub-watershed maps were prepared by geo-referencing and merger of high resolution Liss IV and CARTOSAT data at a scale of 1:7920. The drainage network layer has been converted to digital format through on-screen digitization using Arc GIS ver. 10.4 software from the image employing Survey of India toposheets (1:50,000) as reference. Various entities were measured, computed and outputs generated using Arc GIS 10.4. The formulae employed for computation of various morphometric parameters are presented in Table 2. The DEM of the three sub-watersheds was generated by using SRTM data of 90 m resolution to highlight the relief features (Figure 2).

Results and discussion

Linear aspects

Linear aspects such as stream order, stream number for various orders, bifurcation ratio, stream lengths for various stream orders and stream length ratio are described below.

Stream number

The sub-watersheds on basalt and granite-gneiss had fifth order streams and the one on schist had fourth order stream (Table 3), This is perhaps due to the smaller area of the sub-watershed on schist compared to the other two as basin area is known to increase exponentially with stream order as per law of areas (Schumm, 1956). The number of streams decreased as the stream order increased in all the three sub-watersheds. In all of them, first order stream numbers constitute nearly 50% and second order 25% of the total as observed elsewhere (Magesh, Jiteshlal, Chandrashekar, & Jini, 2013). At first, second and third order, the number of streams in sub-watershed on basalt was roughly one and a half times more than that observed in other two sub-watersheds. There was similarity between sub-watersheds on granite gneiss and schist with respect to number of streams at different orders. The total number of streams was highest in the sub-watershed on basalt followed by a similar number in those on granite gneiss and schist. Similar trend was observed in the component micro-watersheds as well.

Whereas the first and second order streams were observed in all the sub-watersheds, the third order streams were present in all the micro-watersheds of Dadamatti, five in Beligeri and four in Dindur. The fourth order streams were present in three micro-watersheds of Dadamatti, in two of Belageri but none of Dindur.

Table 2. Computation methods used to derive various morphometric parameters described in the study.

Sl. No	Morphometric Parameter	Formula	Reference
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length (Lu)	Length of the stream	Horton (1945)
3	Mean stream length (Lsm)	Lsm = Lu/Nu; where Lu = total stream length of order "u" and Nu = Total no. of stream segments of order "u"	Strahler (1964)
4	Stream length ratio (RL)	RL = Lu/Lu-1 where, Lu = total stream length of order (u), and Lu-1 = the total stream length of its next lower order	Horton (1945)
5	Bifurcation ratio (Rb)	Rb = Nu/Nu+1; where, Nu = Total number of stream segment of given order, Nu+1 = Total number of segments of next of given order	Schumm (1956)
6	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
7	Total relief (H)	Total relief is difference between maximum and minimum elevation in the sub-watershed	
8	Relief ratio (Rr)	Rh = H/Lb; Where, H = total relief and Lb = basin length	Schumm (1956)
9	Ruggedness number (Rn)	Rn = H*D where H = total relief (Km) and D = drainage density (Km/Km^2)	Strahler (1964)
9	Elongation ratio (Re)	Re = {2×Sqrt(A/π)}/Lb where, A = Area of the basin and Lb = Basin length	Schumm (1956)
8	Drainage density (D)	D = Lu/A; where Lu = total stream length of all orders (Km) and A = area of the basin (Km^2)	Horton (1932)
9	Drainage texture (Dt)	Rt = Nu/P; where, Nu = total number of streams of all orders and P = perimeter of basin (Km)	Horton (1945)
10	Texture ratio (Rt)	T = N1/P; where, N1 = total number of first order streams and P = perimeter of basin (Km)	Horton (1932)
13	Stream frequency (Fs)	Fs = Nu/A; where, Nu = total number of streams of all orders and A = basin area	Horton (1932)
14	Form factor (Rf)	Rf = A/(Lb)^2; where, A = Area of basin and Lb = basin length	Horton (1932)
15	Circularity ratio (Rc)	Rc = (4π × A)/P^2, where A = area of basin (Km^2) and P^2 = perimeter of basin (Km)	Miller (1953)
16	Length of overland flow	Lg = 1/2×D; where D = drainage density	Horton (1945)

Stream length

The difference among the three sub-watersheds is more clearly brought out in length of the stream. The total length of all streams and that of first order stream is highest in the sub-watershed on basalt followed by that on granite gneiss and was least in the sub-watershed on schist. The length of second, fourth and fifth order streams were similar in sub-watershed on basalt and granite gneiss, and were lesser than both in that on schist. The length of third order streams in sub-watersheds on granite gneiss and schist were similar but distinctly less than in basalt.

Mean stream length reflects the size of component drainage network and its contributing surface and is directly proportional to the size and topography of the drainage basin. It is observed that the mean stream length values for any stream order are greater than that of the lower order. The mean stream length increased from 0.83 in first order to 4.24 km in fourth order in the sub-watershed on basalt (Table 3). Whereas the difference between the first and the second order was not much, it was more than twice between second and third and between third and fourth. In the sub-watershed on granite gneiss terrain, however, the mean stream length in first order was comparable to that of basalt but unlike in basalt the difference was twice as much between first and second and increased by a smaller magnitude in subsequent orders with maximum in fourth order like in basalt. The mean stream length in the sub-watershed on schist followed similar trend as in basalt but in absolute terms it was lowest compared to the other two ranging from 0.42 to 3.08. Wilson et al. (2012) also observed an increase in mean stream length with increase in order in sub-watersheds on granitic terrain in Tamil Nadu with some exceptions as observed in this study.

A plot of log stream number against stream order (Figure 3(a)) conforms to the law of stream numbers (Horton, 1945) which states that the number of streams of different orders in a given drainage basin tends to approximate an inverse geometric ratio in respect of all the three sub-watersheds. Similarly a plot of log mean stream length against stream order (Figure 3(b)) conforms to law of stream length (Horton, 1932) which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio. This suggests that the basin evolution followed the erosion laws acting on geologic material with homogenous weathering-erosion characteristics (Sameena et al., 2009) with no upliftment of the basins (Altaf et al., 2013).

Stream length ratio

Stream length ratio varied in a rather narrow range among the sub-watersheds but varied widely in respect of component micro-watersheds of all the three sub-watersheds. For example, the stream length ratio varied from 0.34 to 0.57 in the sub-watershed on basalt, from 0.36 to 0.86 in that on granite-gneiss and from 0.52 to

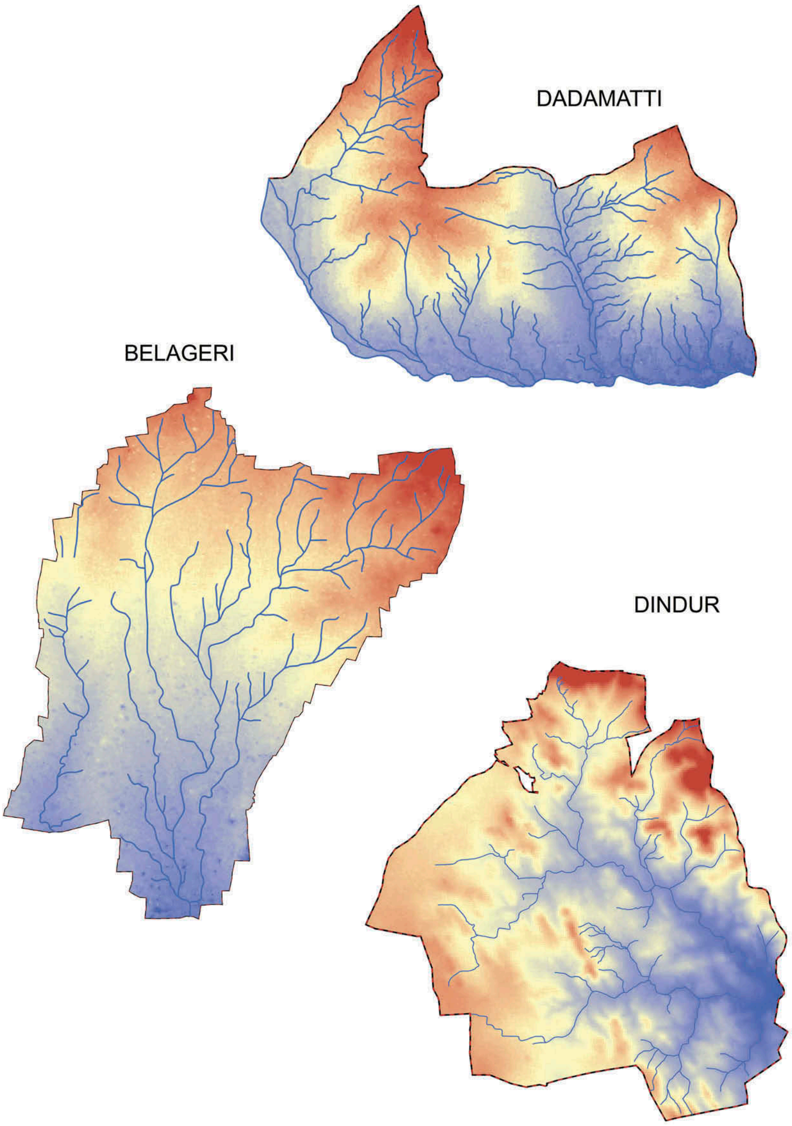

Figure 2. Digital elevation models of the three sub-watersheds.

0.70 in the sub-watershed on schist. However, the range presented by the constituent micro-watersheds varied considerably from 0.02 to 1.75 for the sub-watershed on basalt, from 0.18 to 2.28 in that on granite-gneiss and from 0.14 to 3.48 in the sub-watershed on schist; a trend of increasing upper limit was observed going from basalt to schist. The stream length ratio increased steadily from lower order to higher order in the sub-watersheds on both basalt and schist suggesting their mature geomorphic stage of development (Vittala et al., 2004). An inconsistent trend was observed in the sub-watershed on granite gneiss.

Bifurcation ratio

Bifurcation ratio may be defined as the number of stream segments of given order to the number of segments of the next higher order (Schumm, 1956). It is considered as an index of relief and dissection (Horton, 1945). Bifurcation ratio varied from 2.0 to 4.5 in sub-watershed on basalt, 2.0–4.75 in granite gneiss and in a narrow range of 3.00–3.33 in schist. Further, the highest Br was observed in III/II in all the three sub-watersheds. According to Horton (1945) bifurcation ratio of 2–3 indicate flat region. In the present study the mean Br values are in a narrow range of 3.07–3.23, which fall under normal basin category according to Strahler (1957). He demonstrated that the bifurcation ratio shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. The variation in respect of both Br and mean Br was more among the component micro-watersheds in all the three sub-watersheds with highest in granite gneiss sub-watershed. The mean bifurcation ratios of the sub-watersheds and their component micro-watersheds are within the range 3.0–5.0 suggesting that the influence of geological structures on the drainage network is negligible. Therefore, all the sub-watersheds have suffered least structural disturbances.

Drainage pattern

The drainage pattern is dendritic in sub-watersheds on basalt and sub-dendritic in granite gneiss but sub-

Table 3. Linear properties of the sub-watersheds and their component micro-watersheds studied.

Micro-watershed	Area (Km^2)	Length (Km)	Perimeter (Km)	Stream order	No. of streams in different orders						Order wise Stream Length (Km)					
					I	II	III	IV	V	Total	I	II	III	IV	V	Total
BASALT (DADAMATTI SUB-WATERSHED)																
MWS-1	9.37	6.59	16.47	4	19	7	2	1		29	13.37	5.84	2.84	0.40		22.45
MWS-2	5.55	3.60	10.22	3	10	3	1			14	8.33	6.99	0.27			15.59
MWS-3	5.30	4.15	12.64	3	13	4	1			18	11.70	2.90	5.07			19.67
MWS-4	7.22	4.27	11.62	3	11	2	1			14	10.60	3.80	0.99			15.39
MWS-5	7.71	4.12	12.92	3	11	2	1			14	9.85	5.20	0.57			15.62
MWS-6	5.89	4.06	10.40	3	16	3	1			20	11.24	1.88	1.76			14.88
MWS-7	10.03	4.95	15.25	4	18	6	2	1		27	14.77	7.64	5.62	0.11		28.14
Sub-watershed	51.07	11.59	36.89	5	92	27	6	2	1	128	75.92	25.93	14.98	8.48	3.60	128.91
GRANITE GNEISS (BELIGERI SUB-WATERSHED)																
MWS-1	4.73	3.35	9.73	2	4	1				5	2.32	3.08				5.40
MWS-2	3.76	4.01	14.51	2	7	1				8	4.26	0.32				4.58
MWS-3	5.08	4.34	11.90	2	7	1				8	6.57	3.14				9.71
MWS-4	4.55	3.91	11.67	2	8	1				9	5.51	2.67				8.18
MWS-5	3.94	5.15	13.53	1	3					3	6.29					6.29
MWS-6	4.48	4.54	12.09	2	8	1				9	4.76	1.91				6.67
MWS-7	4.00	5.09	14.50	2	3	1				4	1.96	4.46				6.42
MWS-8	7.07	4.85	15.17	3	9	2	1			12	10.11	1.83	2.18			14.42
MWS-9	4.52	3.61	10.72	3	10	3	1			14	5.17	3.96	1.22			10.35
MWS-10	6.69	4.04	11.50	3	13	4	1			18	8.22	3.82	1.57			13.61
MWS-11	6.48	3.73	13.92	4	12	5	2	1		20	7.28	3.05	2.16	0.39		12.88
Sub-watershed	55.31	11.93	41.04	5	67	19	4	2	1	93	51.63	25.88	9.20	7.89	3.65	98.25
SCHIST (DINDUR SUB-WATERSHED)																
MWS-1	3.90	3.57	9.44	3	8	3	1			12	2.09	2.57	3.29			7.94
MWS-2	2.82	3.13	8.85	2	4	1				5	2.97	1.32				4.29
MWS-3	3.76	2.64	9.24	3	13	3	1			17	4.71	0.64	2.23			7.58
MWS-4	4.52	2.72	8.56	3	13	4	1			18	5.17	3.01	2.50			10.68
MWS-5	5.09	3.59	10.42	3	13	4	1			18	5.76	2.72	1.32			9.80
MWS-6	3.14	3.69	9.71	3	12	3	1			16	4.28	1.93	2.10			8.31
MWS-7	3.62	3.32	9.39	2	2	1				3	1.08	1.40				2.48
MWS-8	2.93	2.64	7.27	2	5	2				7	1.88	0.64				2.52
Sub-watershed	29.77	7.52	28.44	4	63	20	6	2		91	26.29	13.74	8.85	6.15		55.03

Micro-Watershed	Mean Stream Length in Km (Lsm)					Stream Length Ratio (RL)				Bifurcation Ratio (Rb)				Mean Bifurcation Ratio (Rbm)
	I	II	III	IV	V	II/I	III/II	IV/III	V/IV	I/II	II/III	III/IV	IV/V	
BASALT (DADAMATTI SUB-WATERSHED)														
MWS-1	0.70	0.83	1.42	0.40		0.44	0.49	0.14	0.00	2.71	3.5	2.0		2.74
MWS-2	0.83	2.33	0.27			0.84	0.04	0.00		3.33	3.0			3.17
MWS-3	0.90	0.73	5.07			0.25	1.75	0.00		3.25	4.0			3.63
MWS-4	0.96	1.90	0.99			0.36	0.26	0.00		5.50	2.0			3.75
MWS-5	0.90	2.60	0.57			0.53	0.11	0.00		5.50	2.0			3.75
MWS-6	0.70	0.63	1.76			0.17	0.94	0.00		5.33	3.0			4.17
MWS-7	0.82	1.27	2.81	0.11		0.52	0.74	0.02	0.00	3.00	3.0	2.0		2.67
Sub-watershed	0.83	0.96	2.50	4.24	3.60	0.34	0.58	0.57	0.42	3.41	4.5	3.0	2.0	3.23
GRANITE GNEISS (BELIGERI SUB-WATERSHED)														
MWS-1	0.58	3.08	0.00	0.00	0.00	1.33	0.00	0.00	0.00	4.00	0.00	0.00	0.00	4.00
MWS-2	0.61	0.32	0.00	0.00	0.00	0.08	0.00	0.00	0.00	7.00	0.00	0.00	0.00	7.00
MWS-3	0.94	3.14	0.00	0.00	0.00	0.48	0.00	0.00	0.00	7.00	0.00	0.00	0.00	7.00
MWS-4	0.69	2.67	0.00	0.00	0.00	0.48	0.00	0.00	0.00	8.00	0.00	0.00	0.00	8.00
MWS-5	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MWS-6	0.60	1.91	0.00	0.00	0.00	0.40	0.00	0.00	0.00	8.00	0.00	0.00	0.00	8.00
MWS-7	0.65	4.46	0.00	0.00	0.00	2.28	0.00	0.00	0.00	3.00	0.00	0.00	0.00	3.00
MWS-8	1.12	0.92	2.18	0.00	0.00	0.18	1.19	0.00	0.00	4.50	2.00	0.00	0.00	3.25
MWS-9	0.52	1.32	1.22	0.00	0.00	0.77	0.31	0.00	0.00	3.33	3.00	0.00	0.00	3.17
MWS-10	0.63	0.96	1.57	0.00	0.00	0.46	0.41	0.00	0.00	3.25	4.00	0.00	0.00	3.63
MWS-11	0.61	0.61	1.08	0.39	0.00	0.42	0.71	0.18	0.00	2.40	2.50	2.00	0.00	2.30
Sub-watershed	0.77	1.36	2.30	3.95	3.65	0.50	0.36	0.86	0.46	3.53	4.75	2.00	2.00	3.07
SCHIST (DINDUR SUB-WATERSHED)														
MWS-1	0.26	0.86	3.29	0.00		1.23	1.28	0.00		2.67	3.00			2.83
MWS-2	0.74	1.32	0.00	0.00		0.44	0.00	0.00		4.00	0.00			4.00
MWS-3	0.36	0.21	2.23	0.00		0.14	3.48	0.00		4.33	3.00			3.67
MWS-4	0.40	0.75	2.50	0.00		0.58	0.83	0.00		3.25	4.00			3.63
MWS-5	0.44	0.68	1.32	0.00		0.47	0.49	0.00		3.25	4.00			3.63
MWS-6	0.36	0.64	2.10	0.00		0.45	1.09	0.00		4.00	3.00			3.50
MWS-7	0.54	1.40	0.00	0.00		1.30	0.00	0.00		2.00	0.00			2.00
MWS-8	0.38	0.32	0.00	0.00		0.34	0.00	0.00		2.50	0.00			2.50
Sub-watershed	0.42	0.69	1.48	3.08		0.52	0.64	0.70		3.15	3.33	3.0		3.16

trelis on schist, thus pointing the effect of lithology (Figure 2). A dendritic to sub-dentritic drainage pattern on Peninsular gneiss and trellis to sub-trellis drainage pattern on schistose formations in semi-arid climatic regions of southern Karnataka (Krishnamurthy et al., 1996) and in much humidor climate of West Bengal (Nag & Chakraborty, 2003) was documented.

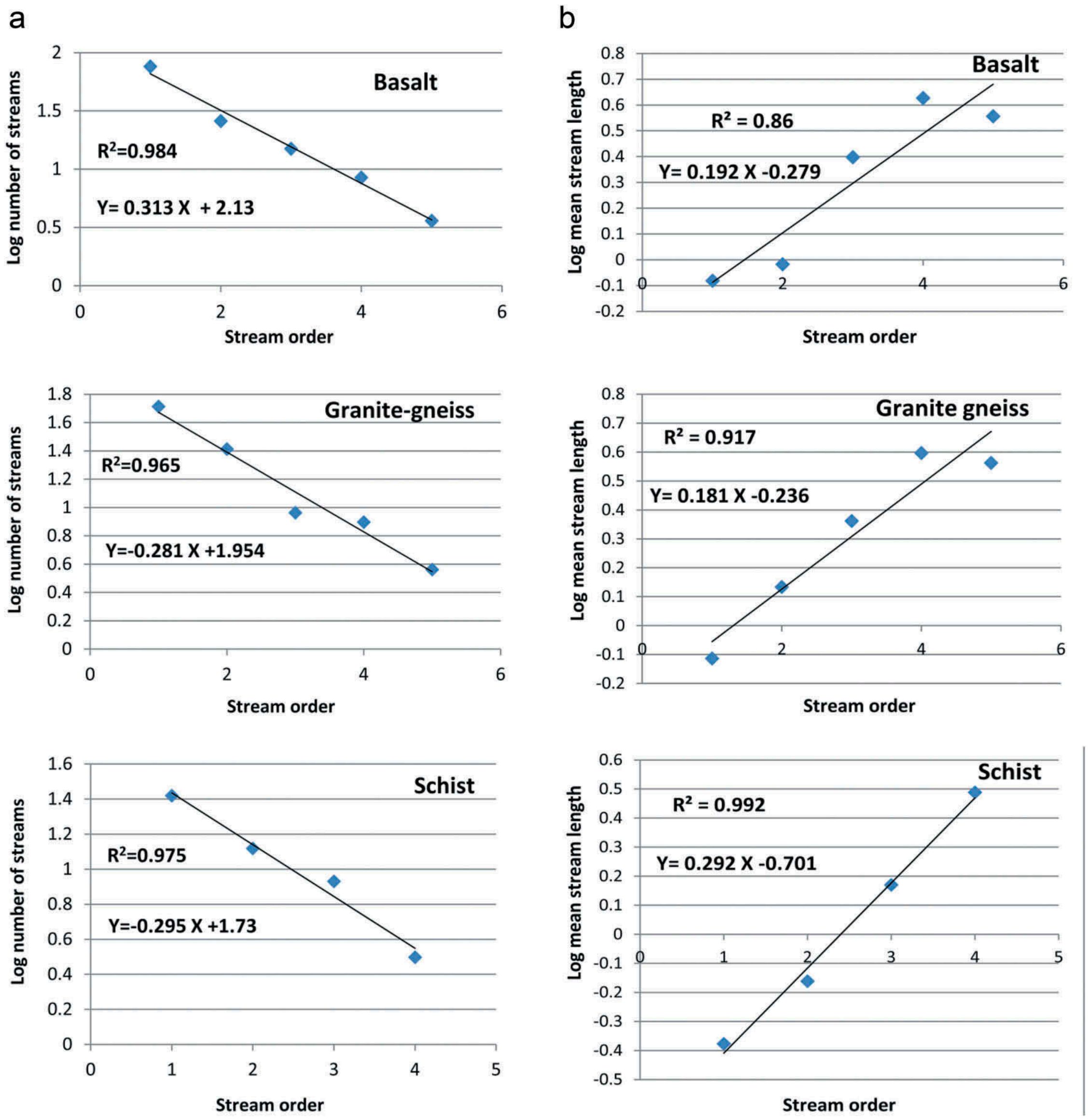

Figure 3. (a) Plot of number of streams vs stream order. (b) Plot of mean stream length vs stream order.

Relief characteristics

The relief properties bring out the influence of aspect and height over a basin area. Total relief ratio and ruggedness number were studied. Total relief was highest in sub-watershed on schist followed by granite gneiss and basalt (Table 4). The constituent micro-watersheds on schist presented a wide variation in relief compared to granite gneiss and basalt. According to relative relief classification by Melton (1957) sub-watersheds on both basalt and granite gneiss exhibit low relative relief (<100 m) and that on schist a medium relative relief (100–300 m). Both the relief ratio and ruggedness numbers were highest in sub-watershed on schist and both these parameters were considerably less in the case of sub-watersheds on granite gneiss and basalt (Table 4). The relief ratio and ruggedness number of the constituent micro-watersheds on schist exhibited wide variability compared to the micro-watersheds of the other two sub-watersheds. The high values are associated with hilly areas and mounds and the low values with valleys and pediments (Sreedevi et al., 2009).

Drainage texture analysis

Drainage texture analysis includes drainage density, stream frequency and length of overland flow. Drainage density is a measure of landscape dissection and runoff potential, infiltration capacity of the land and vegetation cover of the catchment and it is known to influence the output of water and sediment from the catchment area and erosion susceptibility (Soni, 2016). Drainage density was least in the sub-watershed on granite-gneiss followed by basalt and schist. Krishnamurthy et al. (1996) also recorded similar values for the watershed on Peninsular gneiss in southern Karnataka. The drainage texture was coarse in all the three sub-watersheds as the values were in the range of 2–4 (Smith, 1950). However, the value was distinctly less in the watershed on granite gneiss

Table 4. Relief and gradient parameters of the sub-watersheds and their component micro-watersheds studied.

Watershed Name	Total relief (m)	Relief ratio (Rr)	Ruggedness no. (Rn)	Drainage texture (Dt)	Texture ratio (Rt)	Drainage density (D) (km/km^2)	Stream frequency (Fs) (km/Km	Form factor (Rf)	Circu larity ratio (Rc)	Elongation ratio (Re)	Length of overland flow (Lg)
BASALT (DADAMATTI SUB-WATERSHED)											
MWS-1	36	0.005	0.11	1.76	1.15	3.09	2.40	0.22	0.43	0.52	0.16
MWS-2	23	0.006	0.06	1.37	0.98	2.52	2.81	0.43	0.67	0.74	0.20
MWS-3	30	0.007	0.10	1.42	1.03	3.39	3.71	0.31	0.42	0.63	0.15
MWS-4	40	0.009	0.08	1.20	0.95	1.94	2.13	0.40	0.67	0.71	0.26
MWS-5	29	0.007	0.05	1.08	0.85	1.82	2.03	0.46	0.58	0.76	0.27
MWS-6	35	0.009	0.12	1.92	1.54	3.40	2.53	0.36	0.68	0.67	0.15
MWS-7	35	0.007	0.09	1.77	1.18	2.69	2.81	0.41	0.54	0.72	0.19
Sub-watershed	53	0.005	0.13	3.47	2.49	2.51	2.52	0.38	0.47	0.70	0.20
GRANITE GNEISS (BELIGERI SUB-WATERSHED)											
MWS-1	33	0.010	0.03	0.51	0.41	1.06	1.14	0.42	0.63	0.73	0.47
MWS-2	40	0.010	0.09	0.55	0.48	2.13	1.22	0.23	0.22	0.55	0.24
MWS-3	37	0.009	0.06	0.67	0.59	1.57	1.91	0.27	0.45	0.59	0.32
MWS-4	50	0.013	0.10	0.77	0.69	1.98	1.80	0.30	0.42	0.62	0.25
MWS-5	47	0.009	0.04	0.22	0.22	0.76	1.60	0.15	0.27	0.43	0.66
MWS-6	35	0.008	0.07	0.74	0.66	2.01	1.49	0.22	0.39	0.53	0.25
MWS-7	39	0.008	0.04	0.28	0.21	1.00	1.61	0.15	0.24	0.44	0.50
MWS-8	34	0.007	0.06	0.79	0.59	1.70	2.00	0.30	0.39	0.62	0.29
MWS-9	32	0.009	0.10	1.31.	0.93	3.09	2.29	0.35	0.49	0.66	0.16
MWS-10	47	0.012	0.13	1.57	1.13	2.69	2.03	0.41	0.64	0.72	0.19
MWS-11	30	0.008	0.09	1.44	0.86	3.09	1.99	0.47	0.42	0.77	0.16
Sub-watershed	89	0.007	0.15	2.27	1.63	1.68	1.78	0.39	0.41	0.70	0.30
SCHIST (DINDUR SUB-WATERSHED)											
MWS-1	151	0.042	0.47	1.27	0.85	3.08	2.04	0.31	0.46	0.62	0.16
MWS-2	69	0.022	0.12	0.56	0.45	1.77	0.52	0.29	0.45	0.61	0.28
MWS-3	172	0.065	0.78	1.84	1.41	4.52	2.01	0.54	0.55	0.83	0.11
MWS-4	106	0.039	0.42	2.10	1.52	3.98	2.36	0.61	0.78	0.88	0.13
MWS-5	87	0.024	0.31	1.73	1.25	3.54	1.93	0.39	0.59	0.71	0.14
MWS-6	163	0.044	0.83	1.65	1.24	5.10	2.65	0.23	0.42	0.54	0.10
MWS-7	58	0.017	0.05	0.32	0.21	0.83	0.69	0.33	0.52	0.65	0.60
MWS-8	56	0.021	0.13	0.96	0.69	2.39	0.86	0.42	0.70	0.73	0.21
Sub-watershed	218	0.043	0.67	3.20	2.21	3.06	1.85	0.53	0.55	0.82	0.16

than the other two and a majority of component micro-watersheds had values of less than 1. A relatively lower drainage density and drainage texture in the sub-watersheds on granite gneiss underpins the relatively higher permeability of the weathered rock and of the predominantly red soils they have in this sub-watersheds. Large number of wells (Table 1) in this sub-watershed holds testimony to this. Relative spacing of channels in a drainage basin is expressed by texture ratio (Rt) and drainage texture (Dt). Relatively higher values of Rt and Dt were observed in MWS 9, 10 and 11 of granite gneiss and, MWS 3 and 5 of schist situated in the upper reaches (Figure 2). High values are generally found in the upper reaches and low values near the mouth (Biswas, Majumdar, & Banerjee, 2014).

The texture ratio and stream frequency values of sub-watershed on basalt were distinctly different from those on granite-gneiss and schist (Table 4). Fs values of all the sub-watersheds have close relation with Dd indicating the increase in stream population with increase in drainage density. The stream frequency was more in basalt compared to granite gneiss and schist. However, the component micro-watersheds on schist presented a wider range than those on granite gneiss. The length of overland flow was distinctly greater in the sub-watershed on granite gneiss compared to those on basalt and schist suggesting that the surface runoff in the former will travel faster compared to that on basalt and schist (Krishnamurthy et al. 1996).

Basin geometry

The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9 ~ 0.10), oval (0.8 ~ 0.9), less elongated (0.7 ~ 0.8), elongated (0.5 ~ 0.7) and more elongated (less than 0.5). The three sub-watersheds can be termed as less elongated as they exhibited elongation ratio of 0.70–-0.82 and conform to the observation by Strahler (1957) that elongation ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. Elongated basins are known to have low Rb values and circular basins have high Rb values (Verstappen, 1983). The form factor was remarkably similar in the sub-watersheds on basalt and granite gneiss with that on schist exhibiting slightly higher value. However, the component micro-watersheds exhibited considerable variability. Smaller the value of form factor, more elongated will be the watershed and these watersheds would experience low peak flows for longer duration.

The circularity ratio is the ratio of basin area to the area of a circle having the same perimeter as the basin (Strahler, 1964). The ratio approaching one indicates that the basin is circular. The circularity ratios varied from 0.41 in the sub-watershed on granite gneiss to

0.55 in that on schist with sub-watershed on basalt lying in between, suggesting all are far from being circular. However, the component micro-watersheds exhibited some variability with the highest observed in the sub-watershed on granite gneiss with a circulatory ratio ranging from 0.22 to 0.64.

Conclusions

A morphometric analysis of landforms on basalt, granite gneiss and schist in north Karnataka was conducted with the objective of comparing various morphometric parameters among them. The total number of streams as well as length of first order stream was highest in the sub-watershed on basalt compared to those on granite gneiss and schist. The stream number values were similar in granite gneiss and schist. The stream length was highest in sub-watershed on basalt and was least on schist with one on granite gneiss being intermediate. The drainage network was dendritic in the sub-watershed on basalt, sub-dendritic on granite gneiss and sub-trelis on schist. Total relief, relief ratio and ruggedness number were distinctly high in sub-watershed on schist compared to the other two. Drainage density was relatively coarser in the sub-watershed on granite-gneiss compared to the other two. The drainage texture and texture ratio were slightly higher, overland flow values were lower in sub-watersheds on basalt and schist compared to that on granite-gneiss. There was uniformity among the three sub-watersheds with respect to basin geometry. All three sub-watersheds belonged to less-elongated category exhibiting similar elongation ratio, form factor and circularity ratio. Low mean bifurcation ratio suggested stability of the landforms in all the three sub-watersheds. A larger study area, say a watershed within a similar agro-climatic zone, would perhaps bring out the differences more clearly than a sub-watershed. It would also be of interest to study the variations in morphometric parameters induced due to variation in climate on similar geological formations as such diversities are presented in India.

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No potential conflict of interest was reported by the authors.

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References

Agarwal, C. S. (1998). Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P. *Journal of the Indian Society of Remote Sensing*, *26*, 169–175.

Altaf, F., Meraj, G., & Ramshoo, S. A. (2013). Morphometric analysis to infer hydrological behaviour of Lidder watershed, Western Himalayas, India. *Geography Journal*, 14. Article ID 178021. doi:10.1155/2013/178021.

Biswas, A., Majumdar, D. D., & Banerjee, S. (2014). Morphometry governs the dynamics of a drainage basin: Analysis and implications. *Geography Journal*, 14. Article ID 927176. doi:10.1155/2014/927176.

Biswas, S., Sudhakar, S., & Desai, V. R. (1999). Prioritization of sub-watersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach. *Journal of the Indian Society of Remote Sensing*, *27*, 155–166.

Central Ground Water Board (CGWB). (2008). *Groundwater information booklet of Koppal district, Karnataka* (pp. 19). Bangalore: CGWB South Western Region.

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

Horton, R. E. (1945). Erosional development of streams and their drainage basins: Hydrophysicalapproach to quantitative morphology. *Geological Society of America Bulletin*, *56*, 275–370.

Krishnamurthy, J., Srinivas, G., Jayaram, V. M., & Chandrasekhar, G. (1996). Influence of rock type and structure in the development of drainage networks in typical hard rock terrain. *ITC Journal*, *3*(4), 252–259.

Magesh, N. S., Jiteshlal, K. V., Chandrashekar, N., & Jini, K. V. (2013). Geographic-system based morphometric analysis of Bharatpuzha river basin, Kerala, India. *Applied Water Science*, *3*, 467–477.

Melton, M. A. (1957). An analysis of the relations among the elements of climate, surface properties and geomorphology. Technical Report 11, New York: Department of Geology, Columbia University.

Miller, V. C. (1953). A quantitative geometric study of drainage basin characteristics in the clinch mountain area, Virginia and Tennessee, Proj. NR 389-402, Tech. Rep 3, New York: Columbia University, Department of Geology, ONR.

Nag, S. K., & Chakraborty, S. (2003). Influence of rock types and structures in the development of drainage network in hardrock area. *Journal of the Indian Society of Remote Sensing*, *31*, 25–35.

Obi Reddy, G. E., Maji, A. K., & Gajbhiye, K. S. (2002). GIS for morphometric analysis of drainage basins. *GIS India*, *11*, 9–14.

Radhakrishna, B. P., & Vaidynadhan, R. (2011). *Geology of Karnataka* (pp. 298). Geological Society of India, Bangalore, India.

Sahu, N., Obi Reddy, G. P., Kumar, N., Nagaraju, M. S. S., Srivastava, R., & Singh, S. K. (2010). Morphometric analysis in basaltic terrain of Central India using GIS techniques: A case study. *Applied Water Science*, *6*, 1–7.

Sameena, M., Krishnamurthy, J., & Jayaraman, V. (2009). Evaluation of drainage networks developed in hard rock terrain. *Geocarto International*, *24*, 397–420.

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

Singh, S. (1992). Quantitative geomorphology of the drainage basin. In T. S. Chouhan & K. N. Joshi (Eds.), *Readings on remote sensing applications*. Jodhpur: Scientific Publishers. pp. 176-183

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

Soni, S. (2016). Assessment of morphologic characteristics of Chakrar watershed in Madhya Pradesh India using geospatial technique. *Applied Water Science*. doi:10.1007/s13201-016-0395-2

Sreedevi, P. D., Owais, S., Khan, H. H., & Ahmed, S. (2009). Morphometric study of a watershed of South India using SRTM data and GIS. *Journal of Geological Society of India*, *73*, 543–552.

Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology. *Transactions American Geophysical Union*, *38*, 913–920.

Strahler, A. N. (1964). *Quantitative geomorphology of basins and channel networks*. New York: Handbook of Applied Hydrology (ed: Ven Ta Chow) McGraw Hill Book Company.

Verstappen, H. (1983). *The applied geomorphology*. Enschede: International Institute for Aerial Survey and Earth Science (ITC).

Vittala, S., Govindaiah, S., & Honnegowda, H. (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*, 351–363.

Wilson, J. S. J., Chandrasekar, N., & Magesh, N. S. (2012). Morphometric analysis of major sub-watersheds in Aiyar and Karai Pottanar basin, Central Tamil Nadu, India using remote sensing and GIS techniques. *Bonfring International Journal of Industrial Engineering and Management Science*, *2*, 8–15.

Yasmin, P., Sateeshkumar, B. S., Ayyangoudar M.S., U., & Narayanrao, K. (2013). Morphometric analysis of milli watershed of Raichur district using GIS techniques. *Karnataka Journal of Agricultural Sciences*, *26*, 92–96.