

# GIS based quantitative morphometric analysis and its consequences: a case study from Shanur River Basin, Maharashtra India

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**Abstract** A morphometric analysis of Shanur basin has been carried out using geoprocessing techniques in GIS. These techniques are found relevant for the extraction of river basin and its drainage networks. The extracted drainage network was classified according to Strahler's system of classification and it reveals that the terrain exhibits dendritic to sub-dendritic drainage pattern. Hence, from the study, it is concluded that remote sensing data (SRTM–DEM data of 30 m resolution) coupled with geoprocessing techniques prove to be a competent tool used in morphometric analysis and evaluation of linear, slope, areal and relief aspects of morphometric parameters. The combined outcomes have established the topographical and even recent developmental situations in basin. It will also change the setup of the region. It therefore needs to analyze high level parameters of drainage and environment for suitable planning and management of water resource developmental plan and land resource development plan. The Shanur drainage basin is sprawled over an area of 281.33 km<sup>2</sup>. The slope of the basin varies from 1 to 10 %, and the slope variation is chiefly controlled by the local geology and erosion cycles. The main stream length ratio of the basin is 14.92 indicating that the study area is elongated with moderate relief and steep slopes. The morphometric parameters of the stream have been analyzed and calculated by applying standard methods and techniques viz. Horton (Trans Am Geophys Union 13:350–361, 1945), Miller (A quantitative geomorphologic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee Columbia University, Department of Geology, Technical Report, No. 3, Contract N6 ONR 271–300, 1953),

and Strahler (Handbook of applied hydrology, McGraw Hill Book Company, New York, 1964). GIS based on analysis of all morphometric parameters and the erosional development of the area by the streams has been progressed well beyond maturity and lithology is an influence in the drainage development. These studies are very useful for planning of rain-water harvesting and watershed management.

**Keywords** Morphometric analysis · Digital elevation model · Slope map · Geographical information system · Geoprocessing

## Introduction

Morphometry is defined as the measurement and mathematical analysis of the configuration of the Earth's surface, and the shape and dimensions of its landforms. The development of a drainage system over space and time is influenced by several variables such as geology, structural components, geomorphology, soil and vegetation of an area through which it flows. Morphometric analysis of river basin provides a quantitative description of the drainage system, which is an important aspect of the characterization of basins (Strahler 1964). It is important in any hydrological investigation like assessment of groundwater potential, groundwater management, basin management and environmental assessment.

Various hydrological phenomena is correlated with the physiographic characteristics of a drainage basin such as size, shape, slope of the drainage area, drainage density, size and length of the tributaries, etc. (Rastogi and Sharma 1976; Magesh et al. 2012). The dynamic nature of runoff is controlled by the geomorphologic structure of the catchment area and the induced runoff is very sensitive towards the

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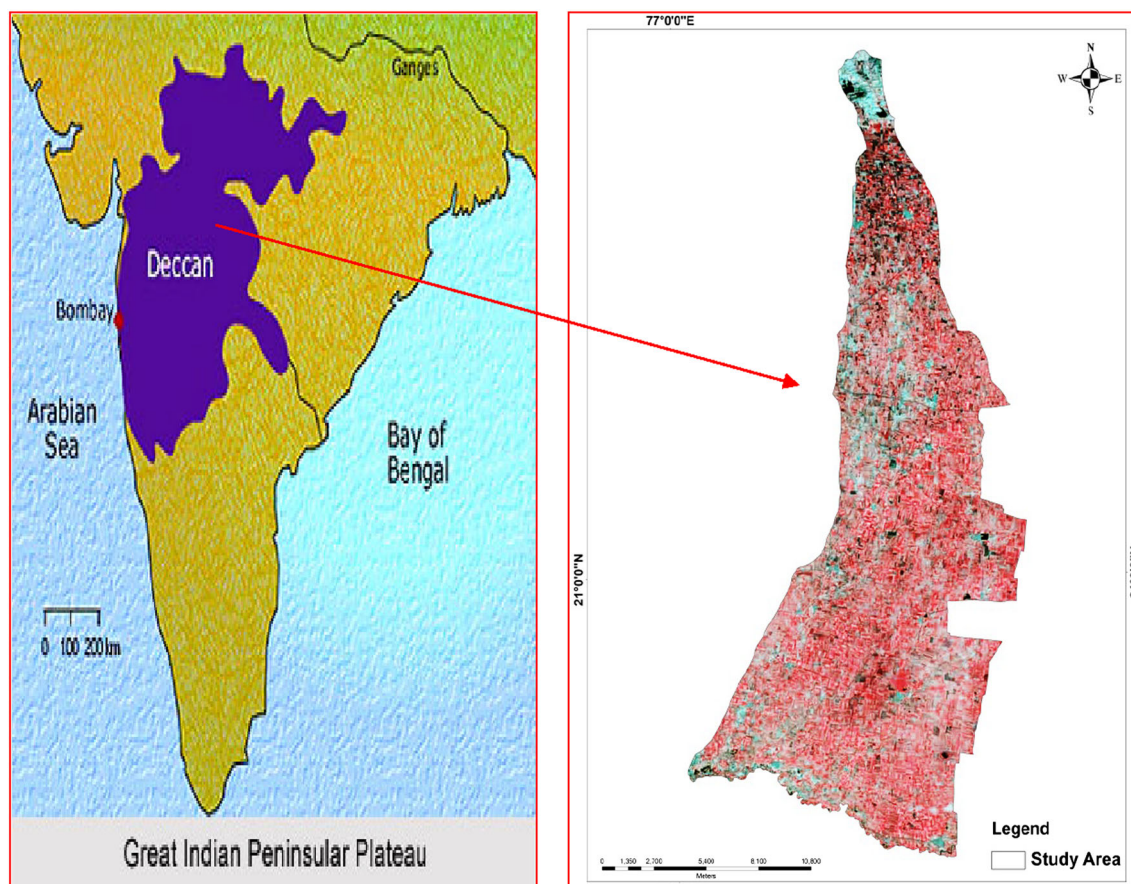
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morphometric characteristics of the contributing area (Rudraiah et al. 2008). The morphometric analysis is performed through measurement of linear, aerial, relief, gradient of channel network and contributing ground slope of the basin (Nautiyal 1994; Nag and Chakraborty 2003; Magesh et al. 2012). In India, National Institute of Hydrology (1993) hydro-geomorphological studies of various basins has been carried out and their analyses are based on linear, aerial and relief aspects using different mathematical equations. Various morphometric parameters such as drainage pattern, stream order, bifurcation ratio, drainage density and other linear aspects are studied using remote sensing technique and topographical map (Mesa 2006; Zwnnitz 1932). The surface runoff and flow intensity of the drainage system is estimated using the geomorphic features associated with morphometric parameters (Ozdemir and Bird 2009). Pioneer work on basin morphometry has been carried out by Horton (1932, 1945), Miller (1953), Smith (1950), and Strahler (1964). Application of remote sensing provides a reliable source for the preparation of various thematic layers for morphometric analysis. The digital elevation data is used for generating the elevation model of a landscape to any extent. The resolution of the image may vary with respect to the satellite sensors. The

processed DEM is used for generating the stream network and other supporting layers (Magesh et al. 2011; Moharir and Pande 2014). Geographical information systems (GIS) have been used for assessing various basin parameters, providing flexible environment and powerful tool for determination, interpretation and analysis of spatial information related to river basins. Geology, relief and climate are the primary determinants of a running water ecosystem functioning at the basin scale (John Wilson et al. 2012). Thus, detailed study of morphometric analysis of a basin is great help in understanding the influence of drainage morphometry on landforms and their characteristics. The present study area describes the process to calculate the various morphometric parameters of Shanur River Basin in Akola and Amravati districts using remote sensing and GIS techniques.

### Study area

The Shanur River Basin is situated in Akola and Amravati Districts of Maharashtra, India. It lies between  $20^{\circ}40'36''$ N latitude and  $76^{\circ}46'11''$ E longitude covered by survey of India toposheets no. 55 H/5 and 55 H/9 on 1:50,000 Scale



**Fig. 1** Location map of study area

in (Fig. 1). The study area is covers 281.33 km<sup>2</sup>. It has continental type climate classified as sub-tropical and sub-humid with average annual rainfall of 1200 mm.

The study area is delineated river basin boundary and stream network of basin from SRTM data. The extracted basin and stream network are projected to the regional projection (WGS 1984 UTM Zone 43N).

### Methodology

The present work is based on morphometric analysis of Shanur River Basin for development of water and soil conservation measures. The morphometric conditions has were study with the help of DEM data (30 m resolution) and SOI topographical maps (1:50,000). The drainage map (Fig. 2) of the study area is prepared using Geocoded FCC of bands 2, 3 and 4 of IRS- LISS-III satellite images in March, 2014 and SOI toposheets on 1:50,000 scale with sufficient ground truth. The Shanur River Basin is

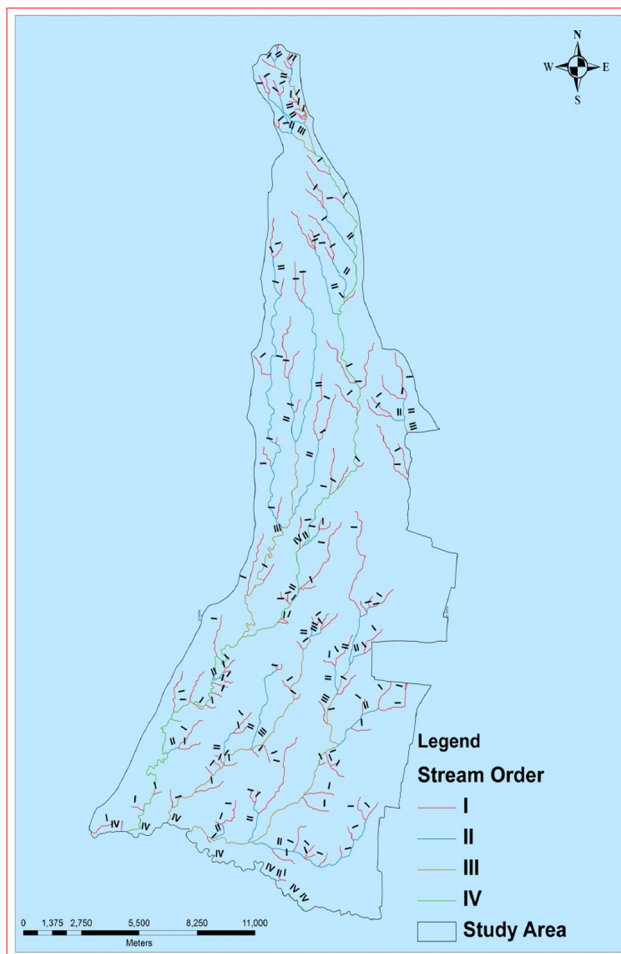


Fig. 2 Stream order map of study area

delineated with the help of Arc GIS 10 software. Direct measurements of geometric characteristics (e.g., area and perimeter of the basin, length and number of streams) are automatically obtained from GIS software. The various morphometric parameters such as area, perimeter, stream order, stream length, stream number, bifurcation ratio, drainage density, stream frequency, drainage texture, length of basin, form factor, circulatory ratio and elongation ratio, etc., is computed based on the formula suggested by (Horton 1945; Miller 1953; Schumm 1956; Strahler 1964) given in Tables 1, 2 and 3. Each morphometric characteristic is considered as a single parameter and knowledge based weightage has been assigned by considering its role in soil erosion. Each parameter has been given a rank as per morphometric result. For linear aspect, high weightage has been given for high values, and aerial aspect is assigned low weightage for high values. The drainage basin characteristics help in interpreting and understanding the interrelated relief and slope properties. The compound parameter values are calculated and the basin with lowest compound weight has been given highest priority. The final priority classification has been specified into three major classes, i.e., high priority, moderate priority and poor priority. The high priority indicates need of reclamation

**Table 1** Stream order, streams number, and bifurcation ratios of Shanur River Basin

$S_u$	$N_u$	$R_b$	$N_{u-r}$	$R_b \times N_{u-r}$	$R_{bwm}$
I	144	–	–	–	4.39
II	33	4.36	177	771.72	
III	7	4.71	40	188.4	
IV	2	3.5	9	31.5	
Total	186	12.57	226	991.62	
Mean		3.14 <sup>a</sup>			

$S_u$  stream order,  $N_u$  number of streams,  $R_b$  bifurcation ratios,  $N_{u-r}$  number of stream used in the ratio,  $R_{bwm}$  weighted mean bifurcation ratio

<sup>a</sup>  $R_{bm}$  Mean bifurcation ratio

**Table 2** Stream length and stream length ratio in Shanur River Basin

$S_u$	$L_u$	$L_u/S_u$	$L_{ur}$	$L_{ur-r}$	$L_{ur} \times L_{ur-r}$	$L_{uwm}$
I	151.71	1.03	–	–	–	1.94
II	71.93	2.18	0.17	223.64	38.02	
III	47.38	6.77	3.1	119.31	369.86	
IV	58.81	29.4	4.34	106.91	463.99	
Total	329.83	39.38	7.61	449.86	871.87	
Mean			1.90 <sup>a</sup>			

$S_u$  stream order,  $L_u$  stream length,  $L_{ur}$  stream length ratio,  $L_{ur-r}$  stream length used in the ratio,  $L_{uwm}$  weighted mean stream length ratio

<sup>a</sup>  $L_{urm}$  Mean stream length ratio

**Table 3** Result of morphometric analysis of Shanur River Basin

1	Stream order ( $S_u$ )	Hierarchical rank	Strahler (1952)	1–4
2	1st order stream ( $S_{uf}$ )	$S_{uf} = N1$	Strahler (1952)	144
3	Stream number ( $N_u$ )	$N_u = N_1 + N_2 + \dots N_n$	Horton (1945)	186
4	Stream length ( $L_u$ ) Kms	$L_u = L_1 + L_2 \dots L_n$	Strahler (1964)	329.83
5	Stream length ratio ( $L_{ur}$ )	–	Strahler (1964)	0.17–4.34
6	Mean stream length ratio ( $L_{urm}$ )	–	Horton (1945)	1.90
7	Weighted mean stream length ratio ( $L_{uwm}$ )	–	Horton (1945)	1.94
8	Bifurcation ratio ( $R_b$ )	–	Strahler (1964)	3.5–4.71
9	Mean bifurcation ratio ( $R_{bm}$ )	–	Strahler (1964)	3.14
10	Weighted mean bifurcation ratio ( $R_b$ )	–	Strahler (1953)	1.94
11	Main channel length ( $C_1$ ) km.	GIS software analysis		14.92
12	Valley length ( $V_l$ ) Kms	GIS software analysis		43.88
13	Minimum aerial distance ( $A_{dm}$ ) Kms	GIS software analysis		38.42
14	Channel index ( $C_i$ )	$C_i = C_l/A_{dm}$ (H and TS)	Miller (1968)	0.38
15	Valley index ( $V_i$ )	$V_i = V_l/A_{dm}$ ( $T_S$ )	Miller (1968)	1.14
16	Rho coefficient ( $\rho$ )	$\rho = L_{ur}/R_b$	Horton (1945)	0.31
17	Basin area (A) $S_q$ Kms	GIS software analysis	Schumm(1956)	281.33
18	Basin length ( $L_b$ ) Kms	GIS software analysis	Schumm(1956)	43.88
19	Drainage density (Dd)	$Dd = L_{u-A}$	Horton (1945)	1.17

process and action plan for soil and water conservations and flood management.

### Morphometric analysis

The present study integrated the use of remote sensing and GIS techniques in morphometric analysis, and the results of morphometric parameters determined are briefly described and discussed. The study of basin morphometry attempts to relate basin and stream network geometries to the transmission of water and sediment through the basin. The size of a drainage basin acts upon the amount of water yield, the length, shape and relief, affect the rate at which water is discharged from the basin. The morphometric analysis is carried out with respect to the parameters like stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, and relief ratio using mathematical formulae given in Tables 1, 2 and the results given in Table 3.

### Results and discussion

The morphometric parameters of Shanur River Basin have been examined and the results are given below. The total study area is 281.33 km<sup>2</sup>. The drainage pattern is dendritic

in nature and it is inclined by the general topography of the area.

### Drainage network

#### Stream order ( $S_u$ )

The concept of stream order was introduced by Horton in 1932. Stream ordering is a widely applied method for stream classification in a river basin. Stream ordering is defined as a measure of the position of a stream in the hierarchy of tributaries (Leopold et al. 1964) and the streams of Shanur River Basin have been demarcated according to the Strahler's system of stream ordering. The stream order and the total number of stream segments in each order for the basin are shown in Table 1. Based on the Strahler (1964) system of stream ordering, the basin has been designated as a fourth-order basin in Fig. 2. In the present investigation, maximum frequency is observed in the first-order streams (Table 1). More number of first-order streams is observed in the hilly region of the study area, which point towards terrain density and compacted nature of the bedrock lithology. Moreover, the presence of large number of streams in the basin indicates that the topography is still undergoing erosion, and at the same time, less number of streams indicates mature topography. The calculated result matched with Strahler (1964), which described that the total number of streams gradually decreases as the stream order increases.



### Bifurcation ratio ( $R_b$ )

The term bifurcation ratio ( $R_b$ ) was introduced by Horton in (1932).  $R_b$  is related to the branching pattern of a drainage network and is defined as the ratio of the number of streams of any given order to the number of streams in the next higher order in a drainage basin (Schumm 1956). It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin.  $R_b$  shows a small range of variation for different regions or for different environments except those where the powerful geological control dominates. The  $R_b$  for the Shanur River Basin varies from 3.5 to 4.71 (Table 1) with a mean  $R_b$  of 3.14. The mean bifurcation ratio ( $R_{bm}$ ) characteristically ranges between 3.0 and 5.0 for a basin when the influence of geological structures on the drainage network is negligible (Verstappen 1983). The analysis showed that the  $R_b$  is not same for all orders. Geological and lithological development of the drainage basin may be the reason for these variations (Strahler 1964). Low  $R_b$  value indicates poor structural disturbance and the drainage patterns have not been distorted (Strahler 1964), whereas the high  $R_b$  value indicates value of  $R_b$  is also indicative of the shape of the basin. An elongated basin is likely to have high  $R_b$ , whereas a circular basin is likely to have a low  $R_b$ . In the present study area, total bifurcation ratio is 12.57 and mean is 3.14.

### Weighted mean bifurcation ratio ( $R_{bwm}$ )

To arrive at a more representative bifurcation number, Strahler (1953) used a weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values. Schumm (1956) has used this method to determine the weighted mean bifurcation ratio of the value of 4.39 of the drainage (Table 1).

### Stream number ( $N_u$ )

With the help of GIS, the five streams of different orders and the total numbers of streams in the basin are counted independently (Table 1). Generally, the number of streams gradually decreases as the stream order increases, the variation in order and size of tributary basins largely depends on physiographic and structural condition of the region. The 186 stream segments are recognized in Shanur River Basin (Table 1). That is very large runoff drainage pattern identify in the study area. All of this morphometric parameters use in developed watershed management and also identify runoff zone, ground water recharge zone and storage. High values of first-order streams indicate that

there is a possibility of unexpected flash flood after heavy rainfall in the down streams (Chitra et al. 2011).

### Stream length ( $L_u$ )

Generally, the total length of stream segments is the maximum in first-order streams and decreases with an increase in the stream order. Streams with relatively short lengths are representative of areas with steep slopes and finer texture, whereas longer lengths of stream are generally indicative of low gradients (Strahler 1964). Stream length is calculated from mouth of a river to drainage with help of Arc GIS-10 software. This has been computed based on the law proposed by Horton's law for all the river basin of the study area. The total stream length of the Shanur River Basin is 329.83. Usually, the total length of stream segments in first-order streams is maximum and it increases as the stream order increases. The study computed the stream length based on the law proposed by Horton (1945) in Table 2.

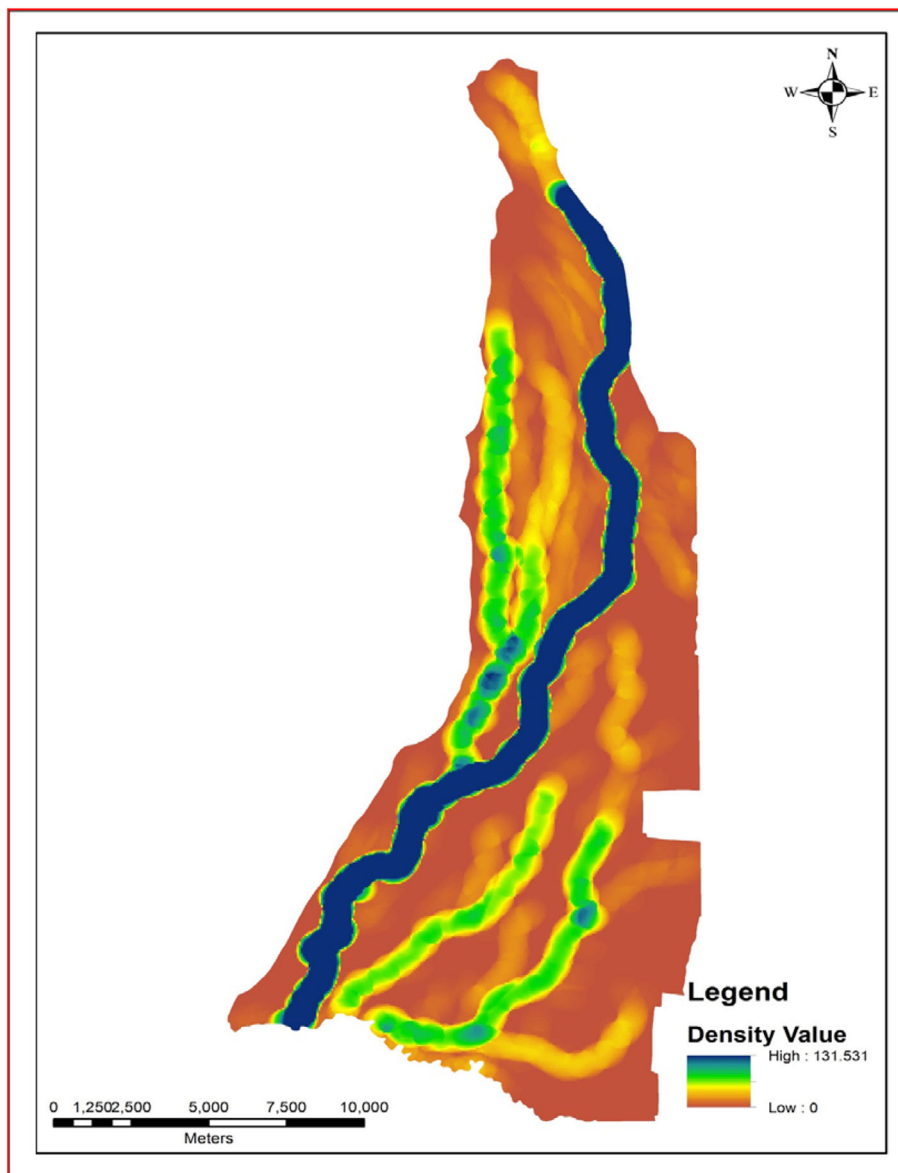
### Mean stream length ( $L_{um}$ )

Mean stream length is characteristic property related to the drainage network components of a drainage network and its contributing Mahesh basin area surfaces (Strahler 1964). It is obtained by dividing the total length of stream of an order by total number of segments. The  $L_{sm}$  values differ with respect to different basins, basins, as they are directly proportional to the size and topography of the basin. Strahler (1964) indicated that the  $L_{sm}$  is a characteristic property related to the size of drainage network and its associated surfaces.

### Stream length ratio ( $L_{urm}$ )

Stream length ratio is the ratio of the mean length of one order to the next lower order of the stream segments. The stream length ratio between the streams of different orders of the study area shows changes in basin. This change might be attributed to variation in slope and topography, indicating the late, youth stage of geomorphic development in the streams of the study area. Horton (1945) states that the length ratio is the ratio of the mean ( $L_{ur}$ ) of segments of order ( $S_o$ ) to mean length of segments of the next lower order ( $L_{u-1}$ ), which tends to be constant throughout the successive orders of a basin. His law of stream lengths states that the mean stream lengths of stream segments of each of the successive orders of a watershed tend to approximate a direct geometric sequence in which the first term (stream length) is the average length of segments of the first order. Changes of stream length ratio from one order to another order indicate their late youth stage of geomorphic development.

**Fig. 3** Drainage density map of study area



#### *Basin length ( $L_b$ )*

The basin length ( $L_b$ ) is the longest length of the basin from the head waters to the point of confluence (Gregory and Walling 1973). The Shanur River Basin originates from the Western Ghats at an altitude of about 785 m above mean sea level and drains into the Arabian Sea. The basin length determines the shape of the basin. High basin length indicates elongated basin. The  $L_b$  of the basin is 43.88 km (Table 3).

#### *Channel index ( $C_i$ ) and valley index ( $V_i$ )*

The river channel is divided into number of segments for determination of sinuosity parameter. The measurement of channel length, valley length, and shortest distance between the source, and mouth of the river ( $A_{dm}$ ), i.e., air

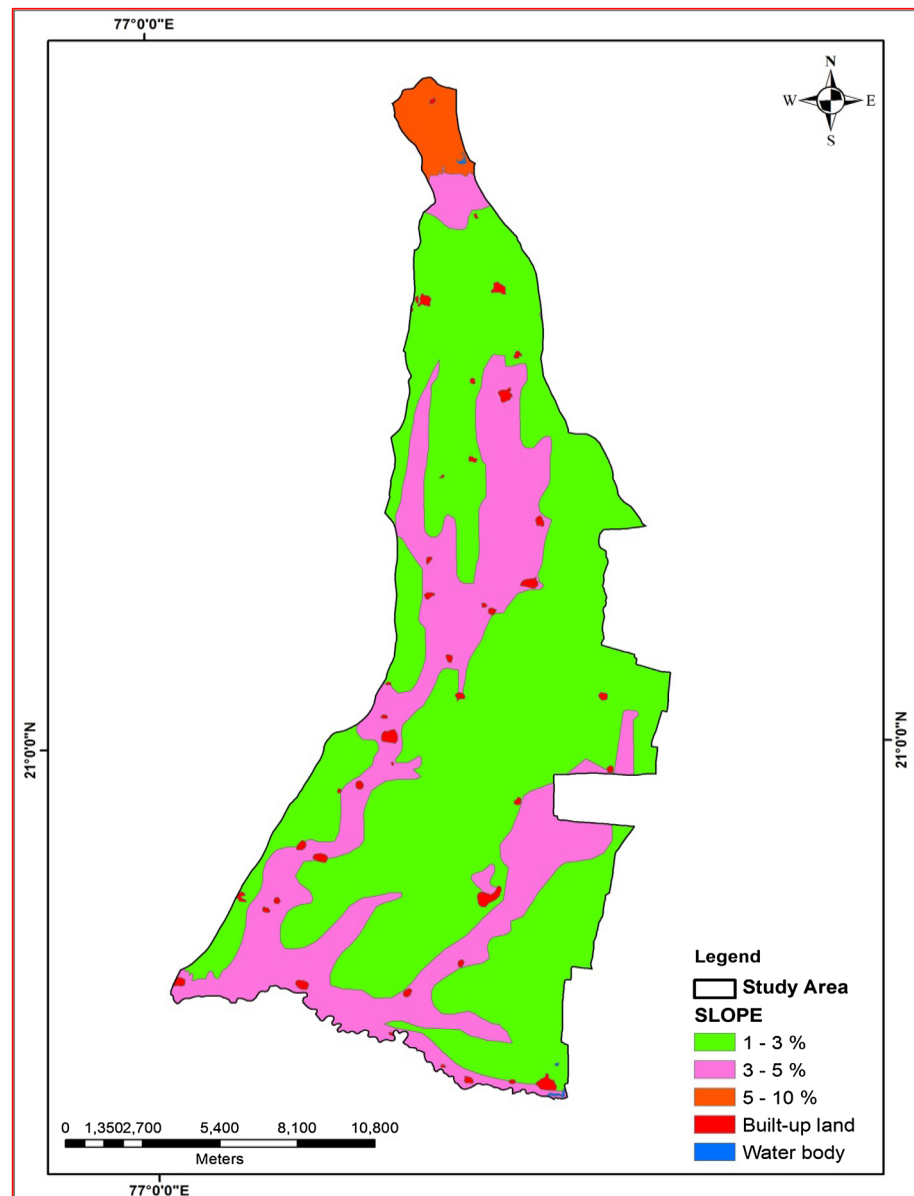
lengths are used for calculation of Channel index and valley index in (Table 3).

#### *Basin area ( $A$ )*

The area of the river basin is another important parameter like the length of the stream drainage. Schumm (1956) established an interesting relation between the total basin areas and the total stream lengths, which are supported by the contributing areas. The basin area is computed 281.33 km<sup>2</sup> with the help of Arc GIS-10 software in Table 3.

#### *Rho coefficient ( $\rho$ )*

The Rho coefficient is an important parameter relating drainage density to physiographic development of a

**Fig. 4** Slope map of study area

watershed which facilitate evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed Horton (1945). The climatic, geologic, biologic, geomorphologic, and anthropogenic factors determine the changes in this parameter. Rho value of the Shanur River basin is 0.31 as shown in Table 3. This suggests higher hydrologic storage during decrease of effects of erosion during elevated discharge.

#### *Drainage density (Dd)*

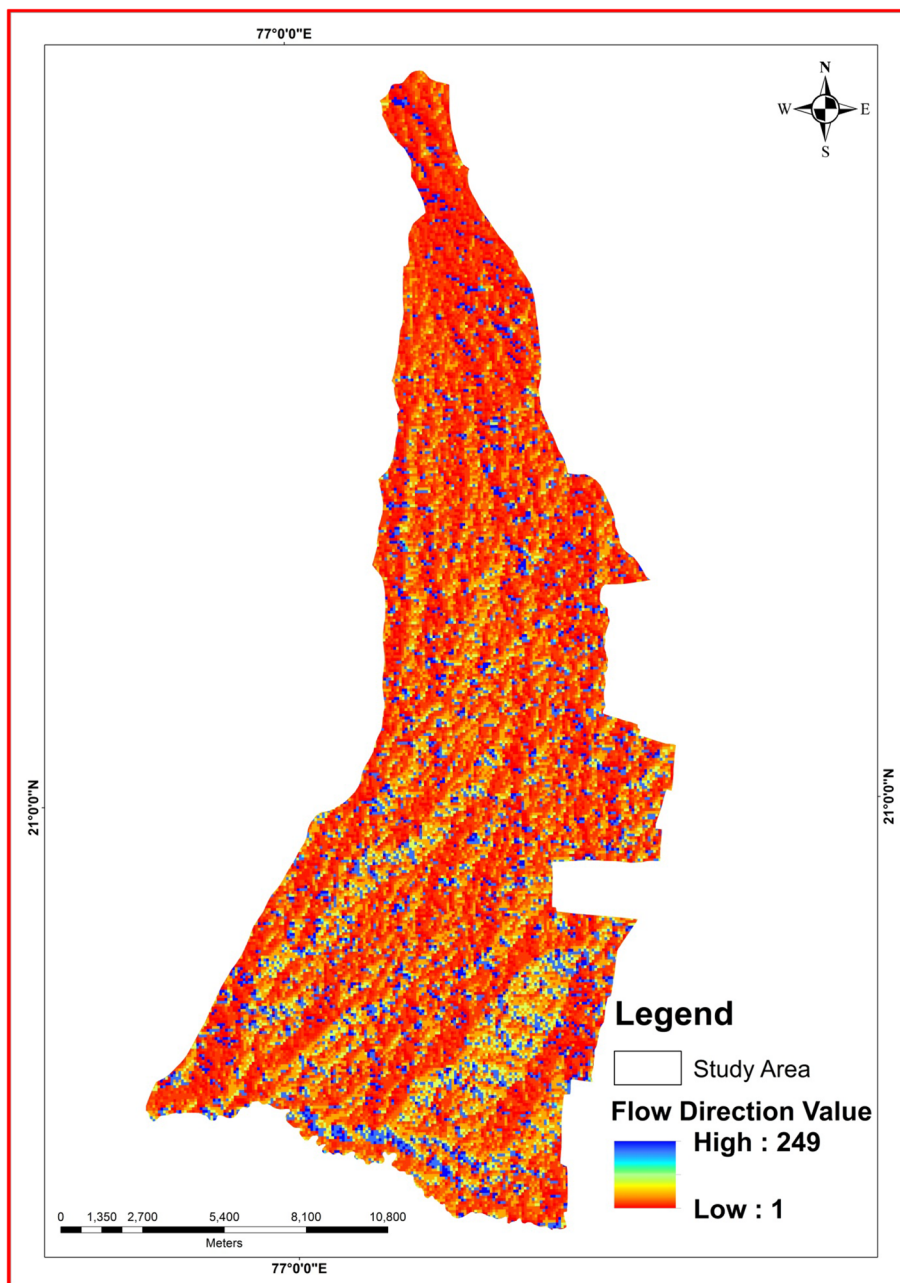
Drainage density (Dd) is one of the important indicators of the landform element and provides a numerical measurement of landscape dissection and runoff potential (Chorley

1969). Dd is defined as the total stream length in a given basin to the total area of the basin (Strahler 1964) (Fig. 3).

#### *Slope*

The slope of a terrain to the amount of inclination of physical feature, landform is the horizontal surface. Slope analysis is an important parameter in morphometric studies. The slope elements, in turn are controlled by climate-morphogenic processes in areas having rock of varying resistance. According to Burrough (1986), it is the maximum rate of change in value from each cell to its neighbors is identified as slope grid. The present of slope exhibited by Shanur River Basin varies from 1 to 10 %. The slope map of the Shanur Basin is shown in Fig. 4. The higher slope

**Fig. 5** Flow direction map of study area



gradient in the study area is contributed by the hilly Western Ghats. Higher slope gradient results in rapid runoff with potential soil loss or erosion in Fig. 4.

#### *Flow direction*

Flow direction map of Shanur River Basin is prepared by using the DEM dataset. Water flows in the direction of the steepest downhill gradient. In DEM dataset, every pixel is potentially surrounded by eight neighboring pixels. The slope in each of these eight neighboring locations and the value at the pixels are being examined. The present study area flow direction value is 1–249 calculated by DEM data.

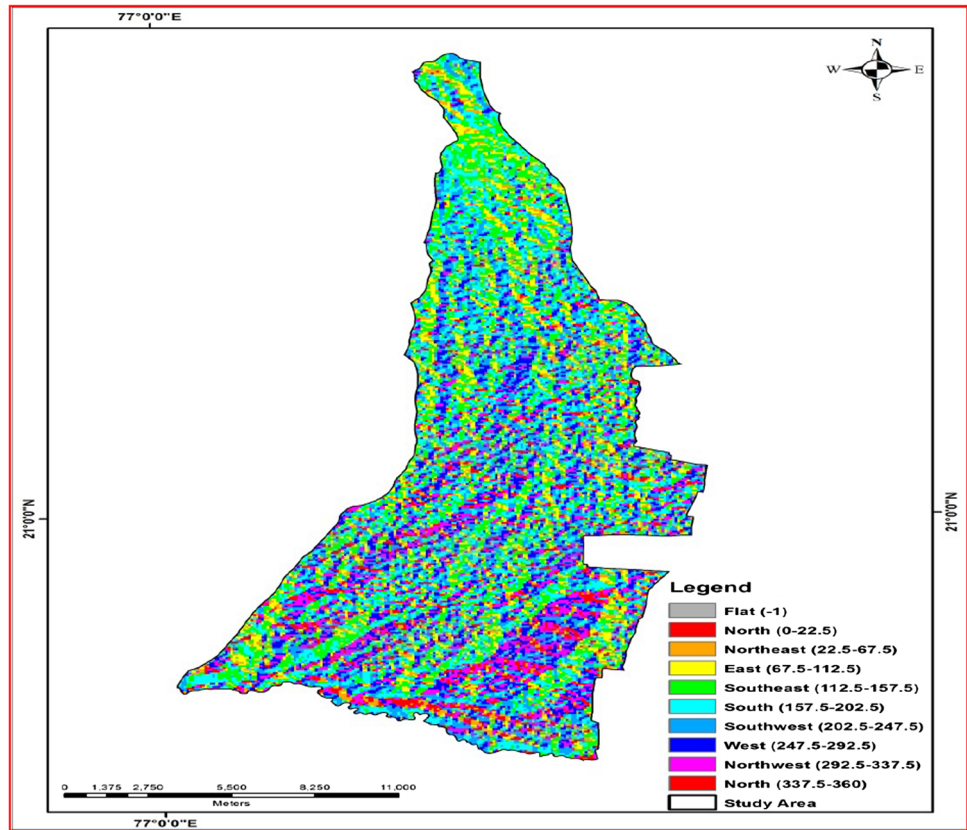
This difference in elevation is then divided by the center to center distance between directions of water flow. The flow direction at every point throughout delineating watersheds was determined. The analysis reveals that the flow direction is mostly towards eastern side as seen in Fig. 5 (Figs. 6, 7).

#### *Final prioritization*

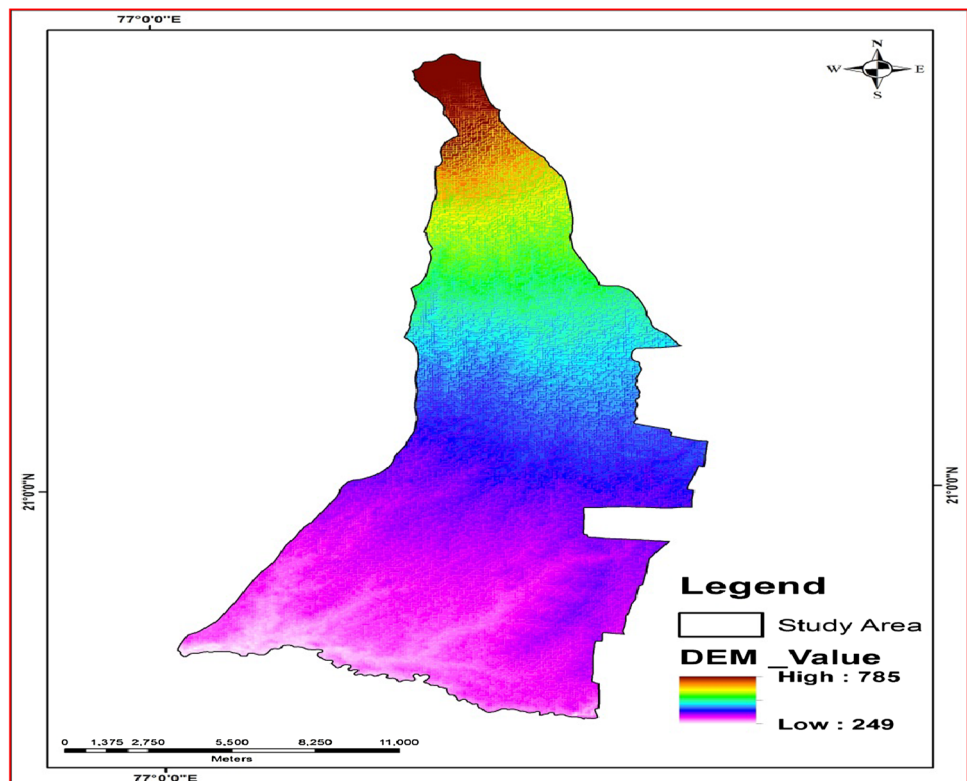
The Stream order wise prioritization of river basin total values are calculated individual and then cumulative values often by using total values of morphometric parameter. After that, weighted value is assigned to each of the stream



**Fig. 6** Aspect map of study area



**Fig. 7** Topographic model of study area



**Table 4** Morphometric parameters using prioritization of the stream

Stream number	Bifurcation ratio ( $R_b$ )	Stream length	$L_u/S_u$	Rank
1	10	8	1	I
2	6	4	7	II
3	5	5	6	III
4	9	3	7	IV

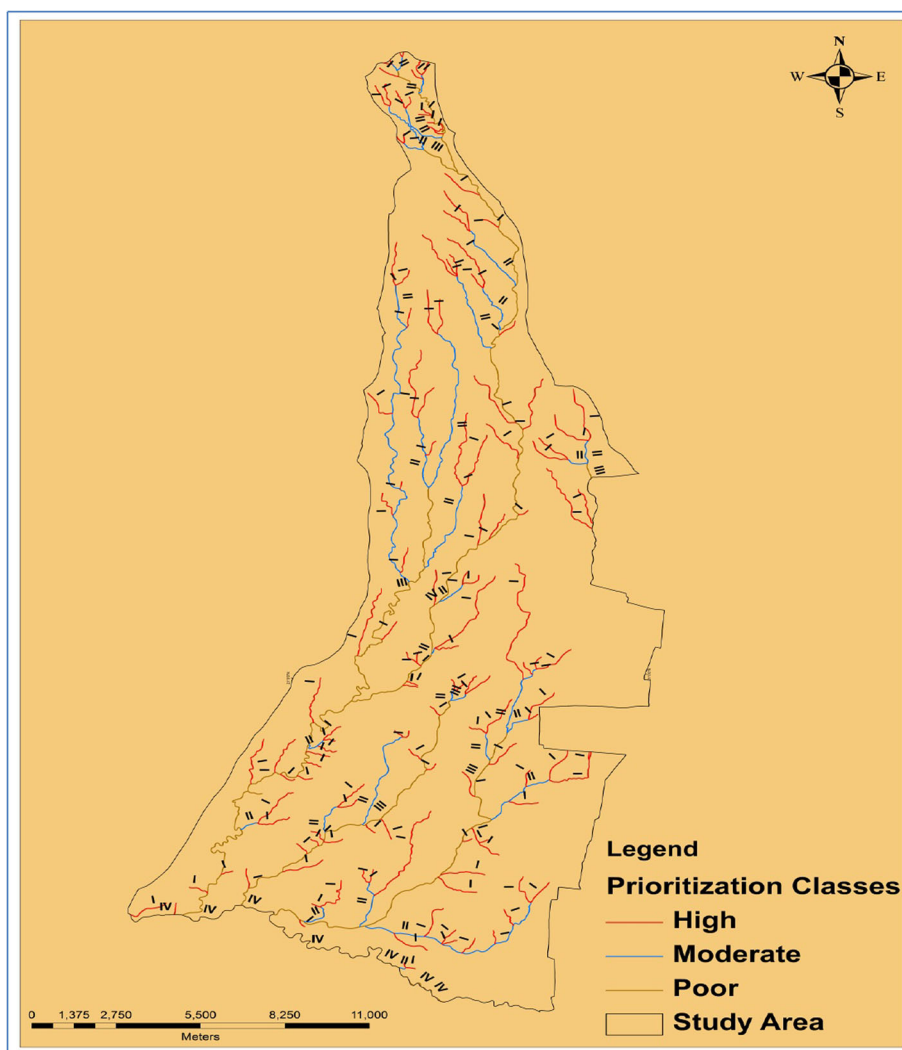
according to the deferent morphometric aspects. Then total weighted values of each streams order wise have been calculated and then stream first priority and final prioritization class is made Table 4 class was made (Fig. 8).

## Conclusion

The present study area proved that the GIS and RS technique used for computation and analysis of various morphometric parameters of the basin and helps to understand various terrain parameters such as nature of the bedrock,

infiltration capacity, surface runoff, etc. The Shanur River is well drained in nature with the stream order varying from 1 to 4. The basin is dominated by lower order streams and the total length of stream segments. Stream frequency and drainage density is the prime criterion for the morphometric classification of drainage basins, which certainly control the runoff pattern, sediment yield, and other hydrological parameters of the drainage basin. The detailed study shows 19 morphometric parameters that have been calculated with the help of Arc GIS-10 software. The bifurcation ratio ranges is 3.5–4.71 and the total bifurcation ratio is 12.57. The quantitative analysis of linear, relief and aerial parameters using GIS and RS techniques is found to be of immense utility in river basin evaluation, basin prioritization for soil and water conservation and natural resource management. The bifurcation ratio in the basin indicates normal basin category and the presence of moderate drainage density suggesting that, it is moderate permeable subsoil and coarse drainage texture. The morphometric analysis of the drainage network of the basin

**Fig. 8** Prioritization classes map of study area



show dendritic to sub-dendritic drainage patterns with moderate drainage texture. The variation in stream length ratio might be due to change in slope and topography. The morphometric analysis is carried out in 4 stream order of Shanur River Basin using GIS and RS techniques for determining the linear aspects such as stream order, bifurcation ratio, stream length and  $L_u/S_u$ . The difference in stream length ratio might be due to changes in slope and topography. The basin is having moderate to high relief of the terrain and elongated in shape. The higher drainage density indicates that the sub-basin is impermeable subsoil and sparse vegetation cover. The Channel index ( $C_i$ ), Valley index ( $V_i$ ), Rho coefficient ( $\rho$ ) and minimum aerial distance ( $A_{dm}$ ) Kms values are 0.38, 1.14, 0.31, and 38.42, respectively, indicating that the Shanur River Basin is elongated in shape, with high discharge of runoff and impermeable subsoil condition. Remote sensing and GIS techniques have best efficient tool in drainage delineation. The conventional methods of morphometric analysis are time-consuming and error prone, while use of GIS method allows for more reliable and accurate estimation of similar parameters of Shanur River Basin. The first and second stream order is a high priority stream and is prone to comparatively higher erosion and soil loss. Geological field verification also agrees with the present morphological-based prioritization. Hence, appropriate soil erosion control measures are required in this basin to conserve the land from further erosion.

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## References

- Burrough PA (1986) Principles of geographical information systems for land resources assessment. Oxford University Press, New York, p 50
- Chitra C, Alaguraja P, Ganeshkumari K, Yuvaraj D, Manivel M (2011) Watershed characteristics of Kundah sub-basin using remote sensing and GIS techniques. *Int. J Geomatics Geosci*: 311–335
- Chorley RJ (1969) Introduction to physical hydrology. Methuen and Co., Ltd., Suffolk, p p 211
- Gregory KJ, Walling DE (1973) Drainage basin form and process ageo-morphological approach. Edward Arnold, London
- Horton RE (1932) Drainage basin characteristics. *Trans Am Geophys Union* 13:350–361
- Horton RE (1945) Erosional development of streams and their drainage basins Hydro-physical approach to quantitative morphology. *Bull Geol Soc America* 56:275–370
- John Wilson JS, Chandrasekar N, Magesh NS (2012) Morphometric analysis of major sub-watersheds in Aiyar and Karai Pottanar
- Leopold LB, Wolman MG, Miller JP (1964) Fluvial processes in geomorphology. WH Freeman and Company, San Francisco
- Magesh NS, Chandrasekar N, Soundranayagam JP (2011) Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. *Environ Earth Sci* 64(2):373–381
- Mesa LM (2006) Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina). *Environ Geol* 50(8):1235–1242
- Miller VC (1953) A quantitative geomorphologic study of drainage basin characteristics in the Clinch mountain area, Virginia and Tennessee Columbia University, Department of Geology, Technical Report, No. 3, Contract N6 ONR 271–300
- Moharir KN, Pande CB (2014) Analysis of morphometric parameters using Remote-sensing and GIS techniques in the lonar nala in Akola district Maharashtra India. *Int J Tech Res Eng* 1(10)
- Nag SK, Chakraborty S (2003) Influence of rock types and structures in the development of drainage network in hard rock area. *J Indian Soc Remote Sensing* 31(1):25–35
- National Institute of Hydrology (1993) Geomorphological characteristics of Narmada basin up to Manot, CS (AR)—128 NIH Roorkee Technical report
- Nautiyal MD (1994) Morphometric analysis of a drainage basin, district Dehradun Uttar Pradesh. *J Indian Soc Remote Sens* 22(4):251–261
- Ozdemir H, Bird D (2009) Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point floods. *Environ Geol* 56:1405–1415
- Rastogi RA, Sharma TC (1976) Quantitative analysis of drainage basin characteristics. *J Soil Water Conserv India* 26(1–4):18–25
- Rudraiah M, Govindaiah S, Srinivas VS (2008) Morphometry using remote sensing and GIS techniques in the sub-basins of Kagna river basin Gulbarga district Karnataka India. *J Indian Soc. Remote Sens.* 36:351–360
- Schumm SA (1956) Evolution of drainage systems and slopes in bed lands at Perth Amboy, New Jersey, *Bull Geol. Soc Am* 67:597–646
- Smith KG (1950a) Standards for grading texture of erosional topography. *Am J Sci* 248:655–668
- Smith KG (1950b) Erosional processes and landforms in bad lands national monument, South Dakota. *Geol Soc Am Bull* 69:975–1008
- Strahler AN (1953) Hypsometric analysis of erosional topography. *Bull Geol Soc Am* 63:1117–1142
- Strahler AN (1957) Quantitative analysis of watershed geomorphology. *Trans Am Geophys Union* 38:913–920
- Strahler AN (1964) Quantitative geomorphology of drainage basins and channel networks. In: Chow VT (ed) Handbook of applied hydrology. McGraw Hill Book Company, New York
- Verstappen H (1983) The applied geomorphology, International Institute for Aerial Survey and Earth Science (ITC). Enschede
- Zwinnitz ER (1932) Drainage Pattern and their Significance. *J Geol* 6:498–521