Morphometric Analysis of Ken River Basin through Remote Sensing and GIS Techniques

**Ramesh Verma[1], Sumit Kumar[1*], Om Prakash Kumar[2], Gaurav Sharma[3]
and Pradeep Kumar Singh Bhadauria[4]**

[1]*Department of Farm Engineering, Institute of Agriculture Science, Banaras Hindu University,
Varanasi (UP) – 221005, India.*
[2]*G. B. Pant University of Agriculture and Technology, Pantnagar (UK), India.*
[3]*Regional Centre, National Institute of Hydrology, Bhopal-462016, India.*
[4]*Civil Engineering Department, B. R. Ambedkar College of Agriculture Engineering and Technology,
Etawah, India.*

Authors' contributions

*This work was carried out in collaboration among all authors. Author RV designed the study,
performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript.
Authors SK and OPK managed the analyses of the study. Author GS managed the literature
searches. All authors read and approved the final manuscript.*

Original Research Article

ABSTRACT

Management of water resources required assessment of morphometric parameters in order to
enhance the capability of understanding the factor which may help to render the impact caused due
to high flood due to inadequate water disposal management. In the present study computation of
linear, aerial and relief aspects viz., bifurcation ratio, mean bifurcation ratio (Rbm), mean stream
length (Lum), stream length ratio (Rl), form factor (Ff), circularity ratio (Rc), stream frequency (Fs),
drainage density (Dd), dissection index (Di), ruggedness index (Ri) has been carried out in order
evaluate watershed characteristics for soil conservation and watershed management. The basin
poses a high flood potential risk due to inadequate drainage and less channel development. The
Ken river basin is elongated in shape as indicated by the computation of form factor with

_____

*Corresponding author: E-mail: sumitkumardewaker59@gmail.com;

comparatively less value. Due to inadequate drainage patterns for safe disposal of surplus water, the vulnerability to water erosion can be considered as a major cause of concern in the Ken river basin. Evaluation of relief aspects suggested the existence of intense flood characteristics within the basin during period of heavy rainfall. Assessment using remote sensing and GIS approach can prove as an effective tool for analyzing properties of basin and for sustainable management of available water resources with exercise of suitable sites selection for development of structure to control runoff and adaptation of conventional methods for water conservation, thus increasing infiltration rate with decreased surface runoff and erosion.

Keywords: Morphometric parameters; remote sensing; GIS; watershed.

1. INTRODUCTION

In the present scenario climate change has resulted in unprecedented change to the natural cycles and thus affect the availability of water in different river basin. To render such uncertainty morphometric analysis of a river basin help to assess seasonal changes in drainage basin characteristics, understand the groundwater potential and address issues related to management of soil erosion due to flash floods during the high flows [1,2]. Analysis of morphometric parameters help to characterizing the hydrological response behaviour of the watershed [3]. Assessment of linear, aerial, relief and gradient of channel network and contributing ground slope of the basin helps to reveal morphometric characteristics of watershed [4]. The study of drainage morphometry is quiet significant as it influence the landform processes, soil physical properties and erosional characteristics of watershed.

Evaluation of morphometric characteristics of watershed help to reveal information regarding development of land surface processes that affects the hydrologic response of the watershed [5]. The extraction of river basin and its drainage networks help in basin management and other hydrological studies. Morphometric parameter can be used to estimate surface runoff and flow intensity of the drainage system using the geomorphic features of the watershed [6]. Assessment of Morphometric parameters using remote sensing and GIS approach help in understanding the influence of drainage morphometry on landforms and their characteristics. Various researcher has carried out morphometric studies for various river basins viz., Biswas et al. [7], Nag and Chakraborty [8], Narendra and Nageswara Rao, [9], John Wilson et al. (2012) and Magesh and Chandrasekar [10].

The spatial information assessed using remote sensing and GIS tool is vital for river basin management. Remote sensing data can be used in conjunction with conventional data for delineation of ridgelines, characterization, priority evaluation, problem identification, erosion-prone areas identification, for evolving water conservation strategies for constructing check dams and reservoirs, etc [11]. For determining, analysis, and interpreting spatial information related to river basins, remote sensing and GIS approach provides a suitable environment. Combination of both approach helps to investigate the geographic and geomorphic characteristics of a drainage basin as well as hydrological response for identification of groundwater potential, etc.

In the present study, an attempt was made to investigate the Morphometric characteristics, which include linear, aerial, and relief aspects of the Ken river basin.

1.1 Description of Study Area

Ken River is major tributary of River Yamuna which originates near Ahirgawan village in Jabalpur district, M.P. It is one of the major rivers in Bundelkhand region, central India. The basin lies between latitude of 23°20' and 25°20' N and longitude of 78°30' and 80°32' E. The river has a total length of 427 Km with total catchment area of 28,058 sq. Km, out of which 24,472 sq. km lies in Madhya Pradesh and rest in Uttar Pradesh.

2. METHODOLOGY

Effective management planning for utilization of water resources mainly depends on watershed characteristics evaluated using morphometric analysis. It helps to provide information about the hydrological response of the rock formation uncovered within the drainage basin. Information regarding permeability, storage within rocks formation, and yield from the basin can be effectively assessed and it involves the evaluation of drainage parameters such as

bifurcation ratio, drainage density, length ratio, drainage frequency, stream frequency and length of overland flow. The watershed boundary was delineated using DEM with the help of various geo-processing techniques viz. fill, flow direction, flow accumulation, and pour point identification in ArcGIS. Fig. 2 shows the digital elevation model (DEM) of Ken River Basin.

Drainage network was extracted using Strahler's formula in which segments with no tributaries identified as a first-order stream and when two first order stream segment joins, second order stream segment form and so on [12]. Morphometric analysis involves assessment of bifurcation ratio, mean bifurcation ratio (Rbm), mean stream length (Lum), stream length ratio (Rl), form factor (Ff), circularity ratio (Rc), stream frequency (Fs), drainage density (Dd), dissection index (Di), ruggedness index (Ri) through different formula as given in Table 1.

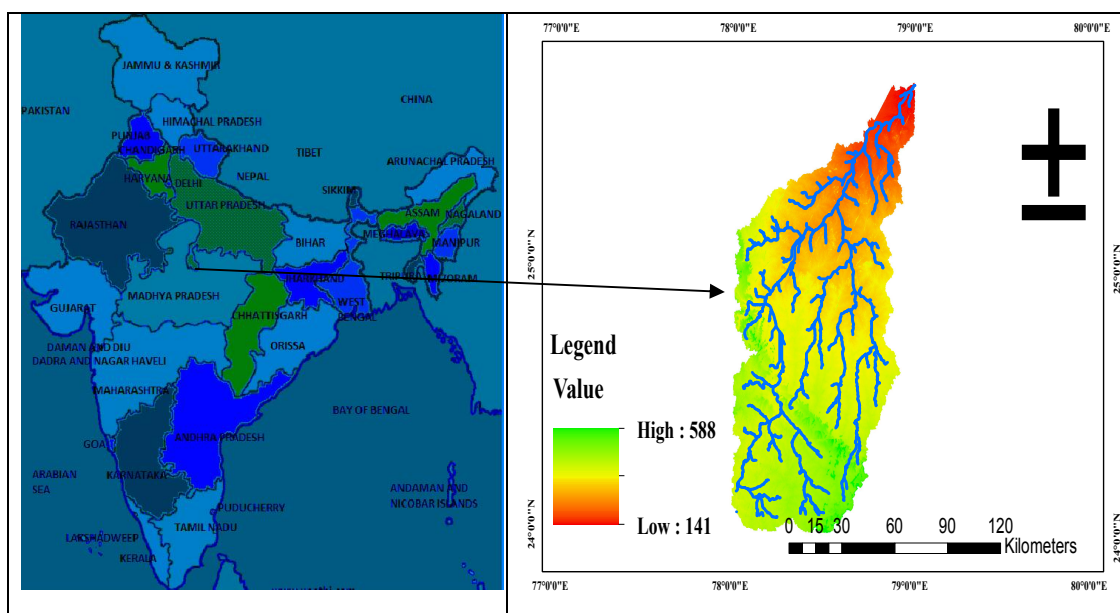**Fig. 1. Location map of study area**

Table 1. Standard formula for computing different morphometric parameters

Parameters	Formula	Nominate	Reference
Stream order (u)	Hierarchical rank	- - - - - - - - - -	Strahler [12]
Stream length (Lu)	Length of the basin	- - - - - - - - - -	Horton [13]
Bifurcation ratio(R_b)	R_b = Nu / Nu + 1	R_b = Bifurcation ratio Nu = Total no. of stream segments of order 'u' Nu+1 = No. of segments of the next higher order	Schumn (1956)
Mean bifurcation ratio (R_{bm})		R_{bm} = Average of bifurcation ratios of all orders	Strahler [14]
Drainage density (D_d)	D_d = Lu / A	D_d = Drainage density, Lu = Total stream length of all orders, A = Area of the basin (km2)	Horton (1932)
Stream Frequency (S_F)	S_F= Nu / A	S_F = Stream frequency Nu = Total no. of streams of all orders A = Area of the basin (km2)	Horton (1932)
Form factor (F_f)	A/L^2	Catchment area/(Catchment length)^2	Horton (1932)

124

| Parameters	Formula	Nominate	Reference
Compactness coefficient (C_c)	$0.2821*p/(\sqrt{A})$	Perimeter of the catchment/perimeter of the circle whose area is that of the basin	Nooka Ratnam et al. [15]
Circulatory Ratio (C_r)	$12.57*A/P^2$	Catchment area/Area if circle of catchment perimeter	Miller [16]
Elongation Ratio (E_r)	$1.128*\sqrt{A}/L$	Diameter of circle whose area is basin area/Catchment length	Schumn (1956)
Relief ratio (R_r)	$R_r = H/L_b$	H = Maximum watershed relief, L_b = Basin lenght	Schumm [17]
Ruggedness number (R_N)	$R_N = H*D_d$	H = Maximum watershed relief, D_d = Drainage density	Strahler (1958)
Basin relief (B_r)	$B_b = (HE - LE)$	HE = highest elevation LE = Lowest elevation	Schumm [17]
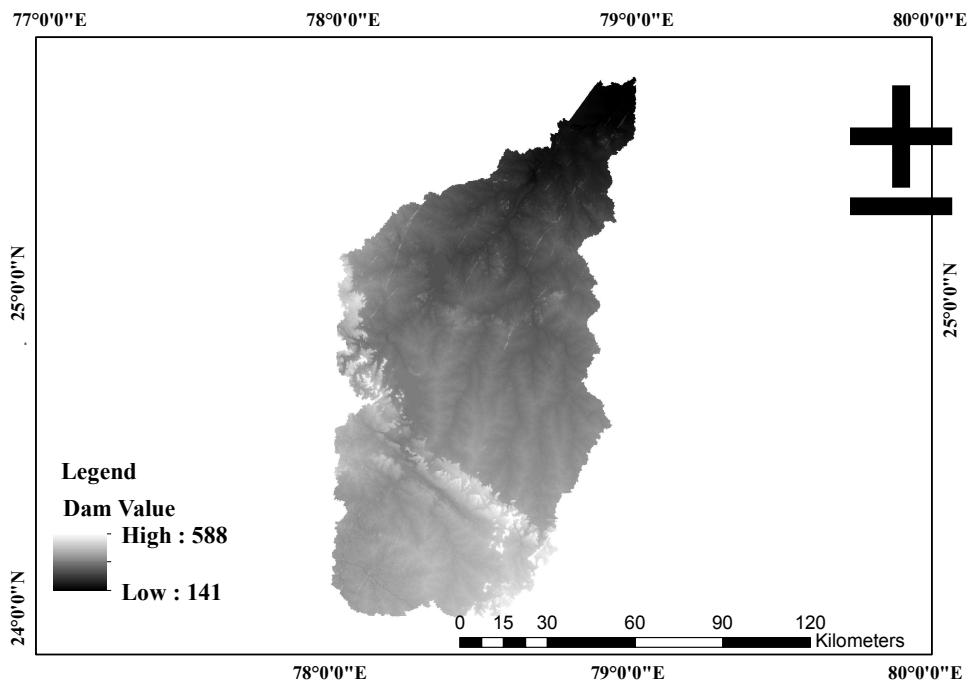
Fig. 2. Digital elevation model for Ken River Basin

3. RESULTS AND DISCUSSION

3.1 Linear Aspects

3.1.1 Stream order and stream number

The linear morphometric attributes of Ken River basin involves assessment of stream order, stream number, stream length, mean stream length, and bifurcation ratio. Stream order (U) is defined as a measure of the position of a stream, stream size and drainage area [14]. The Ken River basin identified as the fourth-order drainage basin. The stream number (Nu) is defined as a number of streams in each order

which is inversely proportional to stream order [13]. In the study area, total number of stream of different order is found to be 129. Table 2 enlists the number of stream of different order. Fig. 3 represent streams of different order in Ken river basin.

3.1.2 Bifurcation ratio (Rb)

The bifurcation ratio implies as the ratio of the number of stream segments of a given order to the number of segments of the next higher order and is a dimensionless property. In the present study, the bifurcation ratio varies between 3 to 6.67 and the mean bifurcation ratio was

125

observed to be 3.73, indicating drainage pattern not affected by the structural disturbances, and has less channel development with uniform geology.

3.1.3 Stream length

The stream lengths of each order were measured and are tabulated in Table 3. It helps to indicate the surface runoff characteristics which prevail in the river basin.

3.2 Areal Aspects of Drainage Basin

3.2.1 Form factor

Horton, 1932 defines form factor as the ratio of area (A) of a drainage basin to the square of its maximum length (Lb). In the study area, form factor value was found to be 0.17 which implies a more elongated basin having high sediment transport capacities, because streams flow into the mainstream at greater time intervals and
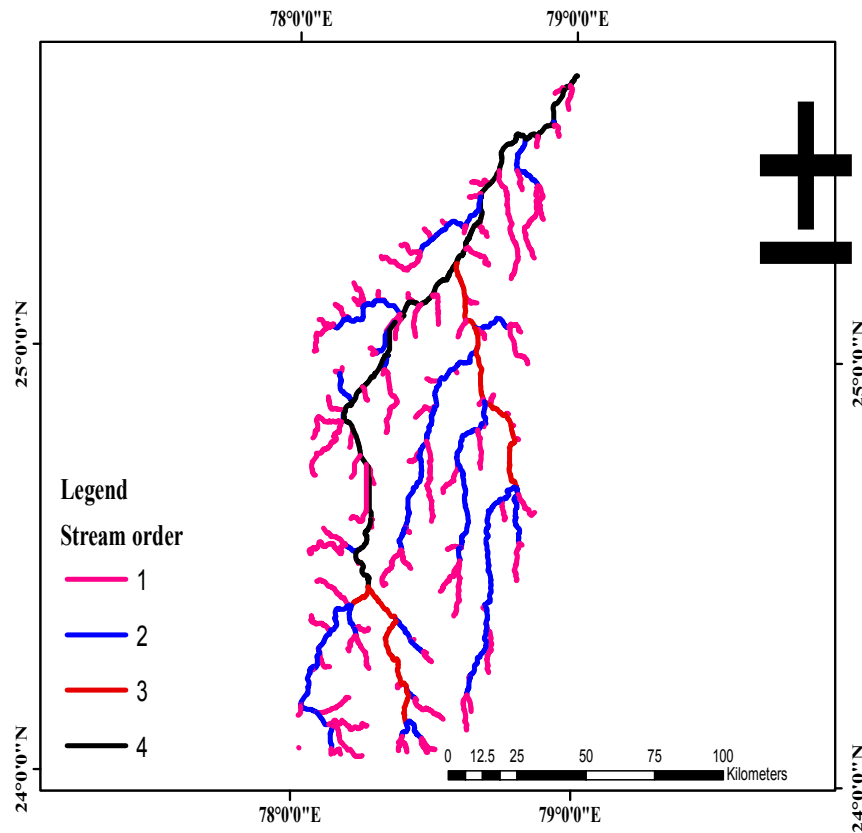

Fig. 3. Stream of different order in the study area

Table 2. Number of stream of different order

Parameter	Stream order				Total
	1ˢᵗ	2ⁿᵈ	3ʳᵈ	4ᵗʰ	
No. of streams	105	20	3	1	**129**

Table 3. Stream length of each order

Stream order	1ˢᵗ	2ⁿᵈ	3ʳᵈ	4ᵗʰ
Stream Number	105	20	3	1
Length of stream (km)	863	480	139	208

126

space which leads to groundwater percolation and creation of saturation zone. Thus water flows over the land surface with high velocity resulting in the generation of a flood-like situation.

3.2.2 Compactness coefficient

The compactness coefficient was found to be 2.46 and which is defined as the ratio of the perimeter of the catchment to the perimeter of the circle whose area is the same as that of the basin. The catchment has a higher value indicating vulnerability for erosion due to greater runoff.

3.2.3 Circulatory ratio

Miller (1935) used the term circulatory ratio, to indicate the basin shape, which is the ratio of catchment area to the area of the circle having same perimeter as the catchment. The computed circulatory ratio value, 0.16 indicates that the drainage basin is more elongated in shape with homogenous geologic formation and medium to low relief.

3.2.4 Elongation ratio

Elongation ratio used as an index that helps to reveal the shape of the drainage basin and is the ratio of the diameter of a circle of the same area as the basin to the maximum basin length [18]. Strahler [12] classified elongation ratio into different classes based on their shape: circular (0.9–1.0), oval (0.8–0.9), less elongated (0.7–0.8), elongated (0.5–0.7) and more elongated (<0.5). The value of the elongation ratio is 0.45 and thus it indicates a more elongated basin shape with a gentle slope.

3.2.5 Drainage density

Drainage density is the ratio of the total length of stream of all orders within a basin to its area. If drainage density is low it implies highly permeable subsoil material under dense vegetative cover. The drainage density of basin is computed as 0.1352 km/km2, which means the areas consist of permeable subsoil material, dense vegetation, and low relief [19].

3.2.6 Stream frequency

The Stream frequency is defined as the number of stream segments per unit basin area [13]. Generally, impermeable subsurface material related to high stream frequency sparse

vegetation, high relief and low infiltration capacity of the region and vice-versa. The lower value of stream frequency indicates poor drainage network. Stream frequency for the watershed is 0.0111/Km² which is very low, indicating lower permeability, poor drainage network, less relief and low slope.

3.2.7 Drainage texture

It is the total number of stream segments of all orders stream per perimeter of that area [13]. Horton analysis infiltration capacity as the single important factor variable which influences drainage texture, texture ratio and considered the drainage texture to include drainage density and stream frequency. Smith [20] has categorized drainage density into five several textures i.e. very coarse (<2), Coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). The Drainage texture for watershed is 0.31 indicating very coarse texture implies large basin lag time and thus peak runoff occurred after long duration.

3.3 Relief Aspects of Drainage Network

3.3.1 Basin relief

The basin relief aspect is an important terrain parameter which is defined as the elevation difference between basin outlet and the highest point located at the perimeter of the basin. The value of the basin relief is 346 m indicating mountainous areas with greater runoff velocity and erosion.

3.3.2 Relative relief

Melton [21] defined the relative relief as ratio of maximum basin relief (H) to basin perimeter (P). The relative relief for watersheds is 0.034 indicating high runoff potential and erosion.

3.3.3 Relief ratio

Relief ratio and relative relief is found to be 0.00128 and 0.034, respectively. There is an indication of erosion and thus watershed need to be rectified with soil and water conservation measures.

3.3.4 Ruggedness number

Ruggedness number is the product of drainage density and basin relief [21,14]. In the current study ruggedness value is 48.2. The highest value of ruggedness was observed in watershed.
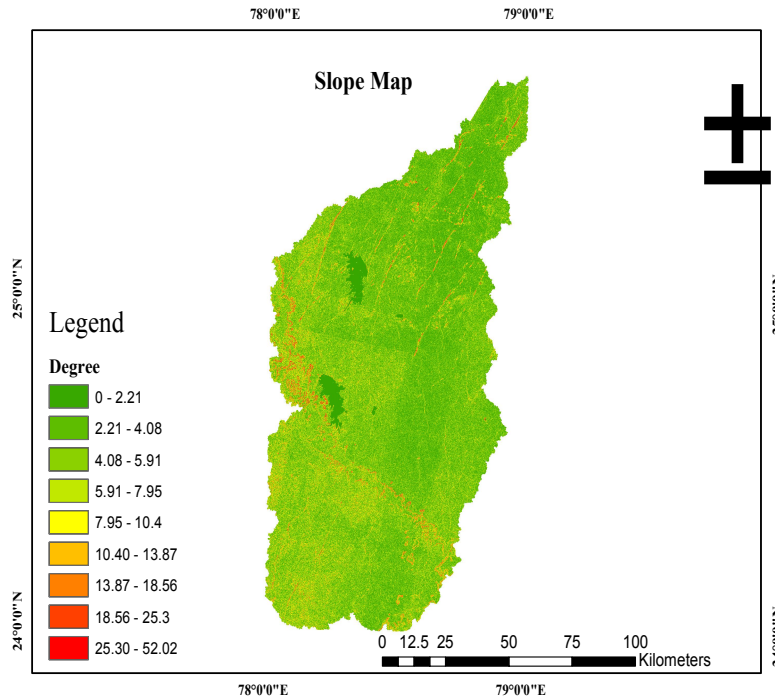
Fig. 4. Slope (in degree) which prevails in the Ken basin

3.3.5 Slope

Slope (Ѳ) is an important morphometric parameter controlled by morpho-climatic processes of any area underlain by varying resistance of rock surface. As slope determines the infiltration vs runoff relation, it is important to understand the nature of slope in any region. Infiltration capacity is inversely related to the slope. The very high slope (> 40°) dominated upper reaches of Ken basin thus, indicating low infiltration related high drainage density and frequency. It also indicates primary stages of geomorphic evolution. But slope dramatically decreases as Ken enters in foothill plain areas. This typical slope characteristic developed intense flood characteristics as well as specific geomorphic landforms like alluvial fan, etc. Fig. 4 reveals the slope characteristics which prevail in the region.

4. CONCLUSION

Morphometry plays an important role in basin level construction and flood control planning. The present study tries to unearth the morphological and hydrological characteristics of Ken river basin by assessing different morphometric parameters. The areas have high overland flow and discharges attributable to less permeable

rock formation associated with high slope configuration. Ken basin is more elongated in shape having high sediment transport capacities and thus indicates that the basin is highly susceptible to flooding. Drainage texture for watershed indicating very coarse texture implies large basin lag time and thus peak runoff occurred after long duration. Soil and water conservation structures are much needed to control the losses that occurred due to surface runoff and development of suitable structures helps in groundwater development and its management.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Arabameri A, Tiefenbacher JP, Blaschke T, Pradhan B, Tien Bui D. Morphometric analysis for soil erosion susceptibility mapping using novel GIS-based ensemble model. Remote Sensing. 2020;12(5):874.
2. Pophare AM, Balpande US. Morphometric analysis of Suketi River Basin, Himachal Himalaya, India. Journal of Earth System Science. 2014;123(7):1501-1515.

3. Rai PK, Mohan K, Mishra S, et al. A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. Appl Water Sci. 2017;7:217–232.

4. Sreedevi PD, Owais SHHK, Khan HH, Ahmed S. Morphometric analysis of a watershed of South India using SRTM data and GIS. Journal of the Geological Society of India. 2009;73(4):543-552.

5. Magesh NS, Jitheshlal KV, Chandrasekar N, et al. Geographical information system-based morphometric analysis of Bharathapuzha river basin, Kerala, India. Appl Water Sci. 2013;3:467–477.

6. Ozdemir H, Bird D. Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point floods. Environ Geol. 2009;56:1405–1415.

7. Biswas S, Sudhakar S, Desai VR. Prioritisation of sub-watersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach. J. Indian Soci. Remote Sensing. 1999;27(3):155-166.

8. Nag SK, Chakraborty S. Influence of rock types and structures in the development of drainage network in hard rock area. J Indian Soc Remote Sens. 2003;31(1):25–35.

9. Narendra K, Nageshwara Rao K. Morphometry of the Mehadrigedda watershed, Visakhapatnam district, Andhra Pradesh using GIS and resources at data. Jour. Indian Soc. Remote Sensing. 2006;3(4):101-110.

10. Magesh NS, Jitheshlal KV, Chandrasekar N, Jini KV. GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala, India. Earth Sci Inform. 2012b;5(2):111–121.

11. Paulinus UU, Ifedilichukwu NG, Ahamefula AC, Iheanyichukwu OA, Theophilus ET, Edet IG. Morphometric analysis of sub-watersheds in Oguta and Environs, Southeastern Nigeria using GIS and remote sensing data. Journal of Geosciences and Geomatics. 2016;4(2): 21-28.

12. Strahler AN. Quantitative geomorphology of drainage basins and channel networks. VT Chow (Ed), Handbook of Applied Hydrology. McGraw Hill Book Company, New York. 1964;4–11.

13. Horton RE. Erosional development of streams and their drainage basins: A hydrophysical approach to quantitative morphology. Geological Society of American Bulletin. 1945;56(3):275-370.

14. Strahler AN. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union. 1957;38:913-920.

15. NookaRatnam K, Srivastava YK, Venkateswara RV, Amminedu E, Murthy KSR. Check dam positioning by prioritization of microwater sheds using SYI model and morphometric analysis - remote sensing and GIS perspective. J. Indian Soc. Rem. Sens. 2005;33(1):25-38.

16. Miller VC. A quantitative geomorphic study of drainage basin characteristics on the Clinch Mountain Area, Virgina and Tennessee, Proj., NR 389-402, Tech Rep 3, Columbia University, Department of Geology, ONR, New York; 1953.

17. Schumm SA. Evolution of drainage systems and slopes in Badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin. 1956;67:597-646.

18. Kumar V. Elongation ratio. In: Singh V.P., Singh P., Haritashya U.K. (Eds) Encyclopedia of Snow, Ice and Glaciers. Encyclopedia of Earth Sciences Series. Springer, Dordrecht; 2011.

19. Raju NJ, Reddy TVK, Nayudu PT, Reddy GJ. Morphometric analysis of the Upper Gunjanaeru River Basin, Cuddapah District, Andhra Pradesh. Nat Geogr J India. 1995;41:145–153.

20. Smith KG. Standards for grading texture of erosional topography. Am J Sci. 1950;248:655–668.

21. Melton MA. Correlation structures of morphometric properties of drainage systems and their controlling agents. Journal of Geology. 1958;66:442-460.