Eco. Env. & Cons. 29 (4) : 2023; pp. (1940-1948)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i04.082

A Quantitative Analysis of Morphometric Parameters Using Remote Sensing and GIS Techniques in the Geil River Basin of Darjeeling Himalaya

Bishal Chhetri

Department of Geography, Southfield College, Darjeeling, India

(Received 20 August, 2023; Accepted 6 September, 2023)

ABSTRACT

The morphometric analysis of the Geil river basin has been carried out with the help of geographic information system (GIS). The drainage network has been classified using Strahler's scheme for ranking the streams, it has been found that the river basin exhibits dendritic drainage pattern and is a fifth order river basin which is entirely dominated by the lower order streams. The predominance of first order streams that run over a very short length over the steep slopes of the study area has produced a rugged terrain and deeply dissected valleys. The drainage basin has high degree of surface runoff due to the steepness of the topography, impermeable subsurface material and sparse vegetation which in turn makes the area more prone to soil erosion and landslides. The linear morphometric parameters were used for developing the prioritization of the streams; this exercise has helped in the identification of the streams/ stream orders where soil and water conservation measures can be concentrated for an efficient management of the watershed.

Key words: *Darjeeling Himalaya, Flow Direction, Geil River, GIS, Morphometric.*

Introduction

Morphometry refers to the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimension of its landforms (Clarke, 1966; Agarwal, 1998; Rai *et al*., 2014; Pande and Moharir, 2015). A river basin is generally analyzed using morphometric techniques to determine a quantitative description of the drainage system which becomes an important aspect for the characterization of basins (Strahler, 1964; Pande and Moharir, 2015). The morphometric analysis is usually carried out through measurement of linear, aerial, relief, gradient of channel network and the contributing ground slope of the basin (Nautiyal, 1994; Nag and Chakraborty, 2003; Magesh *et al.*, 2012; Rai *et al.,* 2014). It helps to understand hydrological and geomorphological responses of surface runoff, soil erosion, floods, droughts, sedimentations, etc. within a basin and helps in prioritization of the watershed for soil and water conservation at a micro level (Arabameri *et al.,* 2020; Frissel *et al.,* 1986). Remote sensing and GIS has been increasingly used in this field in the recent years than the conventional methods as it provides accurate, fast and reliable source of data for preparing many thematic layers that can be used for morphometric analysis (Pande and Moharir, 2015). The Shuttle Radar Topographic Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radi-

Orcid id: 0000- 0003-2722-3872

ometer (ASTER) data when analyzed by GIS software can give a precise, fast, and an inexpensive way for analyzing hydrological systems (Smith and Sandwell, 2003; Grohmann, 2004; Rai *et al.,* 2014). The delineation of river basin, stream networks and evaluation of various morphometric parameters like drainage density, order, relief, etc can all be achieved by using DEM data in a GIS environment (Mesa 2006; Magesh *et al.,* 2011; Rai *et al*., 2014). Thus, the detailed study of basin morphometry using remote sensing and GIS, helps in prioritization of watersheds for conservation of soil and water at a micro level in a very accurate, reliable and fast manner.

Study Area

The Giel River basin is situated in the District of Darjeeling, West Bengal, India. It lies between 27^o 00′ 0" N to 27^o 3′ 0" N and 88^o 20′ 0" E to 88^o 26′0" E. It descends from Takdah spur and flows eastward to join Teesta (Desai, 2014). It is fed with numerous small tributaries that descend from the steep slopes to join the main river. The tributaries on the left bank are far more numerous than on the right bank. The Geil river basin has very high surface run-off due to its smooth surfaced segment and scanty vegetative cover. The erosional potential of this river basin is very high (Desai, 2014) and thereby makes the area more prone to landslides.

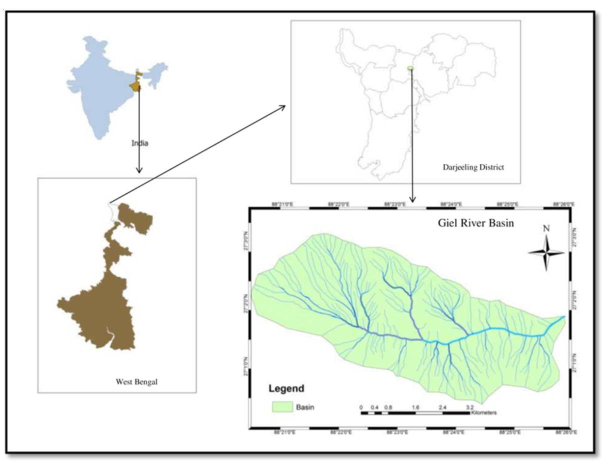

Fig. 1. Study Area

Methodology

The present study is based on morphometric analysis of Geil river basin. Delineation of the river basin was done with the help of SOI (1:50000) and the morphometric study was conducted by using DEM (30 m resolution). IRS- LISS- III satellite image obtained in January 2019 and SOI (1:50000) was used to prepare the drainage map of the study area with the help of Arc GIS 10.2.1 software. Various geometric characteristics like area, perimeter, length and number of streams were directly obtained from the GIS software, whereas, the other morphometric parameters of the river basin pertaining to the Linear, Areal and Relief like the stream order, stream length, mean stream length, bifurcation ratio, drainage density, stream frequency elongation ratio etc. are software based and have been computed by using the formula suggested by (Smith, 1935; Horton, 1945; Schumm, 1956; Strahler, 1964) given in Table 1. Each linear aspect has been considered as a single parameter and weightages have been assigned considering its role in soil erosion. High weightage has been assigned to the high values and weighted index values have been obtained to identify the prioritization of classes. Three classes have been obtained, i.e. high priority, moderate priority and low priority. The high priority class is that class where soil conservation, water conservation and flood management measures should be concentrated.

Results and Discussion

The various morphometric parameters of Geil River basin have been calculated and the study tries to relate basin geometry and stream networks with the flow of water and sediments through the basin. The size of the drainage basin is said have an effect upon the amount of water yield, the length, shape and relief, affect the rate at which water is discharged from the basin (Pande and Moharir, 2015). The total basin area is 25 Km^2 and the drainage pattern is dendrictic in nature, which is influenced by the topography, geology and the rainfall.

Linear Aspects

The analysis of linear aspects like stream order, stream number, Stream Length (Lµ), Mean Stream Length (Lsm), Length Ratio (Rl) and Bifurcation Ratio (Rb) has been conducted and has been discussed in detail in the following paragraphs.

Stream Order (S_u)

The present study uses Strahler's scheme for ranking the streams. Stream order (S_u) has been defined as a measure of the position of a stream in the hierarchy of tributaries (Leopold *et al*., 1964). According to Strahler's scheme the smallest, unbranched fingertip streams are the first order streams. When two first order streams meet, the lower segment of the meeting point is identified as second order stream. When two second order stream meets the third order stream is created, i.e. whenever the streams of same order meet they create a stream of higher order. The stream order and total number of steams in each order segment has been shown in Table 2. It was observed that number of stream gradually decrease with the increase in the stream order, the first order streams are found in the steep hill slopes of the basin area which is due to the compact nature of the bed lithology. The presence of large number of streams in the basin area also indicates that the topography is still young with the high rates of erosion, as the mature topography has less number of streams (Pande and Moharir, 2015). The study area is a fifth order basin (Fig. 2a) and has a total of 209 streams among which 154 are 1st order streams, 40 are 2nd order streams, 10 are 3rd order streams, 4 are 4th order streams and 1 is of the 5th order stream (Table 2).

Table 1. Methods of Analysing the Morphometric Parameters of Drainage Basin

Aspects	Parameters	Formula	References
Linear	Stream Order	Hierarchical Rank	Strahler, 1964
	Stream Length (Lμ)	Length of the Stream	Horton, 1945
	Mean Stream Length (Lsm)	Lsm = (Lμ/Nμ) Nμ = Number of stream	Strahler, 1964
	Length Ratio (L_{ur})	Rl= Lμ/ Lμ- 1 Lμ = The total stream length of order μ; Lμ- 1 = Length in next lower order	Horton, 1945
	Mean Length Ratio (L_{urm})	$\Sigma L_{ur}/N\mu$ Nμ = Number of stream	Horton, 1945
	Bifurcation Ratio (Rb)	$Rb = \frac{N\mu}{N\mu+1}$ Nμ = Number of stream; Nμ+1 = Number of stream in next higher order	Schumm, 1956
	Form Factor (F)	$F = \frac{A}{L^2}$ A= Basin area; L= Basin length	Horton, 1932
	Elongation ratio (Re)	$Re = \frac{2}{L_b} * \left(\frac{A}{\pi}\right)^{0.5}$ L_b= Basin length; A= Basin area	Schumm, 1956
Areal	Law of basin area	$A\mu = A_{1\,R}Ra(\mu-1)$	Strahler, 1969
	Drainage Density (Dd)	$Dd = \frac{\sum L}{A}$ L = Length of the rivers; A= Area	Horton, 1932
	Stream Frequency (Df)	$Df = \frac{\sum N}{A}$ N = Number of river segments, A= Area.	Horton, 1945
	Drainage Texture (Dt)	Dt = Nμ/P Nμ = Total number of stream in all segments; P = Basin perimeter	Horton, 1945
Relief	Relative relief	Rr = (Rma–Rmi) Rma= Maximum Relief, Rmi= Minimum relief	Smith (1935)
	Dissection index	$DI = \frac{Rr}{Hx} \times 100$ Hx =Maximum relief; Rx = Relative relief	Dov Nir (1957)/ Miller (1954)
	Ruggedness Index	Rn= Bh X Dd, Bh= Basin Relief, Dd= Drainage density.	Schumn, 1956

Stream Length (Lμ)

The study of Stream Length (Lμ) is important to understand the basic hydrological characteristics of the bedrock and the drainage extent (Rai *et al*., 2014). The length of the streams has been calculated using Arc GIS 10.2.1 software by following the law proposed by Horton (1945) shown in Table 1. Normally, the total length of the stream segments is highest in the 1st order streams and decrease with the increase in stream order (Pande and Moharir, 2015). Numerous streams with very short length are developed in the areas having steep slopes and less permeable bedrocks, whereas, longer lengths of stream are formed in a well-drained watersheds (Strahler, 1964; Sethupathi *et al.*, 2011; Rai *et al.*, 2014; Pande and Moharir, 2015). The result of order-wise stream length is shown in Table 2. It has been observed that the cumulative length of the 1st order stream is 103.1 km, 2nd order stream is 22.23 km, 3rd order stream is 4.76 km, 4th order stream is 4 km and 5th order stream is 5 km. The cumulative length of the stream order is the highest for 1st order stream and has decreased as the stream order has increased.

Mean Stream Length (L_{sm})

The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964). It is calculated by dividing the total stream length of order by the number of stream segment in the same order. The L_{sm} values for the Geil river basin ranges from 0.83 to 5 km with the mean stream length of 56.61 km (Table 2). It is observed that the mean stream length of the study area increases with the increase of stream order.

Stream Length Ratio (L_{ur})

Stream length ratio is the ratio of the mean length of the stream of a given order to the mean length of the streams of the next lower order. The L_{ur} of the study area varies from one order to the next order. This change due to variation in slope and topography indicates youth stage of geomorphic development in the streams of the study area (Singh and Singh, 1997; Vittala *et al*., 2004; Rai *et al*., 2014).

Bifurcation Ratio (Rb)

The term bifurcation ratio (Rb) was introduced by Horton in 1932 and he considers it to be an index of relief and dissection. It 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 dimension less property that shows the degree of integration prevailing between streams of various orders in a drainage basin. The values of Rb characteristically range between 3.0 and 5.0 for drainage basin in which the geological structures do not disturb the drainage pattern (Strahler, 1964). The mean bifurcation ratio (Rbm) 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 Rb for the Geil river basin varies from 2.50 to 4 with an Rbm of 2.87 (Table 2). The higher values of Rb indicate a strong structural control in the drainage pattern whereas the lower values indicate that the basin is less affected by structural disturbances (Strahler, 1964; Vittala *et al*., 2004; Chopra *et al.*, 2005; Rai *et al*., 2014). The variations in the values of bifurcation ratio throughout the drainage basin indicate the influence of hilly and highly dissected geologic structure to the drainage basin.

Areal Aspects

Areal aspects deal with two dimensional parameters like Basin Area, Basin Perimeter, Form Factor (F), Circulatory Ratio (C), Drainage Density (Dd) and

Table 2. Stream length and stream length ratio in Geil River Basin

Stream Order	Stream Number	Bifurcation Ratio (Rb)	Stream Length (Lμ) (km)	Cumulative stream length (Km)	Stream Length Mean (L_{sm})	Length Ratio (L_{ur})
1st order	154	–	103.1	103.1	0.67	–
2nd order	40	3.85	22.23	125.33	0.56	0.83
3rd order	10	4.00	4.76	130.09	0.48	0.86
4th order	4	2.50	4	134.09	1.00	2.08
5th order	1	4.00	5	130.09	5	5
Total	209	14.35	130.09	–	7.71	8.77
Mean	–	2.87	56.61	–	1.54	1.75

Drainage Texture (Dt). Various parameters for the areal aspect have been calculated and shown in Table 3.

Table 3. Results of Morphometric Analysis of Areal Aspects

Areal Parameters	Results
Basin Area (km^2)	25
Basin Perimeter (km)	23.46
Form Factor (F)	0.31
Elongation ratio (R_e)	0.56
Drainage Density (Dd) (km^2)	5.5
Stream Frequency (Df) (km^2)	8.36
Drainage Texture (Dt)	8.9

Basin Area

The area of the river basin is another important parameter like the length of the stream drainage (Pande and Moharir, 2015). The total area drained by a stream and its entire networks of subsequent segments is termed as the basin area. Basin area measures the average drainage area of streams in each order; it increases exponentially with increasing order. The total basin area of Geil River which is the fifth order stream along with its entire stream segment is 25 km^2 and the basin perimeter of the study area is 23.46 km (Table 3).

Form Factor (F)

Form factor is defined as the ratio of basin area to square of the basin length (Horton,1932). The form factor of a basin is determined by geological structure, topographical characteristics, compactness and hardness of soil, vegetation characteristics, slope characteristics etc. The value of form factor varies from 0-1 and higher the value of form factor the more circular the shape of the basin and vice versa (Singh, 2007). So since the form factor of the study area is 0.31 it can be concluded that the basin is highly elongated in shape.

Elongation Ratio (R_e)

Elongation ratio (R_e) is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length (Schumm, 1956). R_e has been categorized into three groups; (a) circular (>0.9), (b) oval (0.9–0.8), and (c) less elongated (<0.8) (Resmi *et al.*, 2019) and is a measure of the shape of the river basin. It depends upon the climatic and geologic types (Rai *et al.*, 2014). A circular basin is said to be more efficient in runoff discharge than an elongated basin (Singh and Singh, 1997). R_e value of Geil river basin is 0.56 which indicates elongated basin. The lower R_e value of the river basin implies that the basin is highly susceptible to erosion and sediment load (Reddy *et al.*, 2004; Rai *et al.*, 2014).

Drainage Density (Dd)

Drainage density (Dd) is a measure of the total stream length in a given basin to the total area of the basin (Strahler, 1964). 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). It is a measure of how well or how poorly a watershed is drained by stream channels. According to Gregory and Walling (1973) drainage density is sensitive parameter which provides the link between the form attributes of the basin and the processes operating along the course. Drainage basin with high drainage density indicates high precipitation runs off and a low drainage density signifies higher infiltration of the rainfall with fewer channels (Roger, 1971). The drainage density (Fig. 2b) for the study area is done using Horton's formula and the computed result is 5.5 per km^2 indicating high drainage density and a high degree of surface runoff due to the steepness of the topography, impermeable subsurface material and sparse vegetation.

Stream Frequency (Df)

Stream frequency is defined as total number of streams of all orders per unit area (Horton, 1945). Low values of stream frequency (Df) indicate pres-

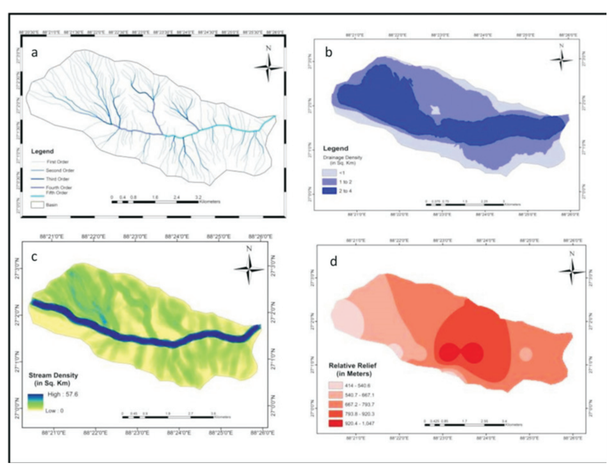

Fig. 2. Various morphometric parameters of the study area (a) stream order; (b) drainage density; (c) stream density; (d) relative relief

ence of a permeable subsurface material and low relief (Reddy *et al.*, 2004; Rai *et al.*, 2014). The Df value of the study area is 8.36 per km^2 (Table 3) which indicates a high stream frequency of the river basin (Fig. 2c). The high Df value is due to impermeable subsurface material and presence of steep and high relief. This high Df value also suggests that the surface runoff is faster and is more prone to frequent flooding (Kale and Gupta, 2001).

Drainage Texture (Dt)

Horton (1945) stated that the drainage texture is the total number of stream segments of all orders per perimeter of that area. It is basically used to find out the relative spacing of streams per unit area. The drainage texture of the study area is computed using Horton's method and the result is 8.9 which according to Smith (1935) mean very fine drainage texture of the study area.

Relief Aspects

Relief aspects deals with three dimensional parameters like Relative Relief (Rr), Dissection Index (DI), Ruggedness Index (Rn), Average Slope etc.

Relative Relief (Rr)

Relative relief or amplitude of relief is defined as differences between maximum height and minimum height. It is an important morphometric parameter for analyzing the overall morphological characteristics of terrain (Gayen *et al.,* 2013). Rr of the study area has been calculated following Smith's formula (Table 1). The Rr for the study area varies from 414 to 1047 meters. The only area where the relief is low is the narrow section at the eastern portion of the basin where the Geil River joins river Teesta.

Dissection Index

Dissection Index can be defined as the ratio of maximum relative relief to maximum or absolute relief. It is an important indicator of the nature and magnitude of the terrain. The Dissection Index of the study area is calculated using Dov Nir(1957)/Miller (1954) method. (Fig. 3a)

Ruggedness Index

Ruggedness Number is the product of maximum relief and drainage density (Strahler, 1964). It indicates the intensity of erosion and other geomorphic

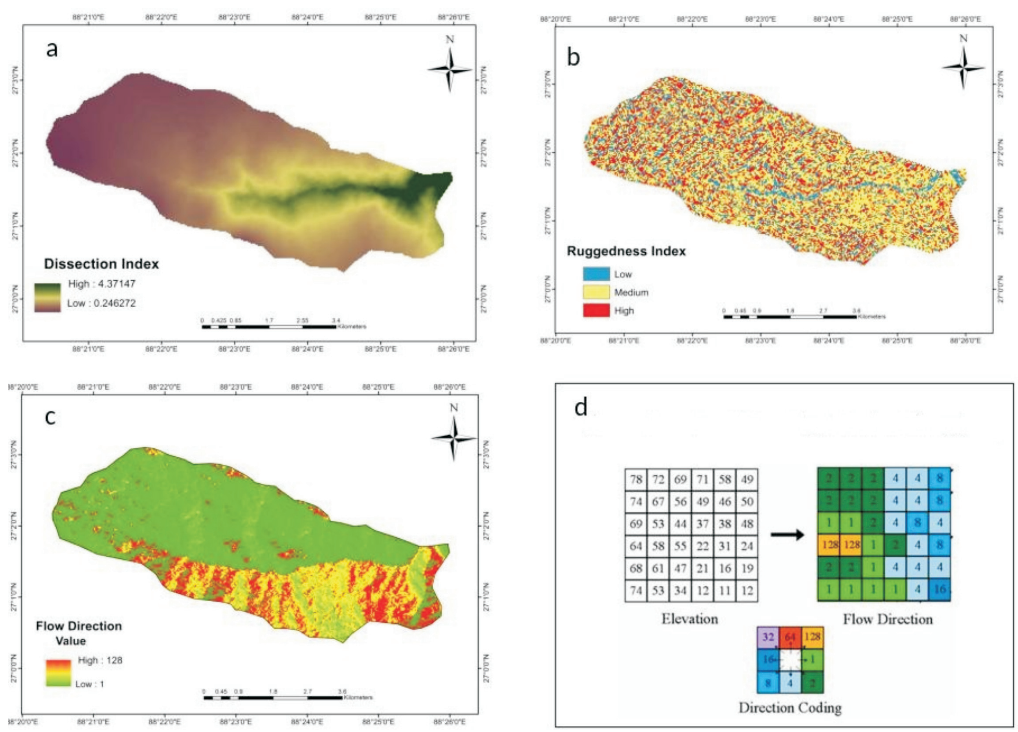

Fig. 3. Various morphometric and other parameters of the study area (a) dissection index; (b) ruggedness index; (c) flow direction; (d) flow direction encoding

processes over surface. Extreme high value of ruggedness number tends to occurs when both variables are large and the slope is not only steep but as well as long (Strahler, 1964). The drainage basin has a high Ruggedness Number i.e 3.47, which is obvious because of the high relief feature and the high drainage density of the study area (Fig. 3b).

Flow Direction

The flow direction map of the river basin has been developed from DEM. In every pixel in a DEM dataset is said to have been potentially surrounded by eight neighbouring pixels (Pande and Moharir, 2015). The study area has the flow direction values ranging from 1 to 128 (Fig. 3c), these values represent different directions according to the eight direction flow model (Fig. 3d). This analysis reveals that the flow direction is mostly centered towards the eastern side (Fig. 3c), i.e. towards the very narrow confluence point where the Geil River meets the Teesta River.

Prioritization of the stream order

Linear morphometric parameters were used for developing the prioritization of the streams in a single basin study (Table 4). The prioritization of the streams helps in the identification of the streams/ stream orders where conservation measures of soil and water can be concentrated. The linear parameters like Bifurcation Ratio (Rb) and Stream Length (Lμ) are said to have direct relationship with erodibilty, higher the value more is the erodiblity and vice-versa (Nooka *et al.*, 2005). Therefore, the stream orders having the highest weighted index value which signifies high rates of soil erosion and overland water flow have been given the highest priority (Fig. 4). The first order streams are classed as high priority streams which are more prone to higher erosion and soil loss as compared to the other orders, hence necessary soil loss control measures and mitigation measures for erosion should be concentrated in the first order streams.

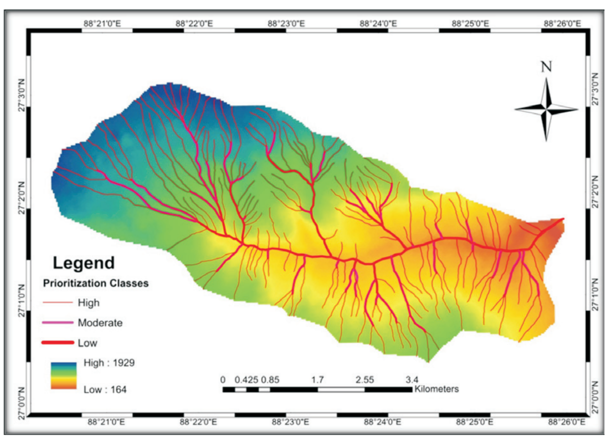

Fig. 4. Prioritization classes of the streams of the study area

Conclusion

Morphometric analysis of the river basin is a must for any type of hydrological study (Rai *et al.*, 2014) and helps in understanding the characteristics of the bedrocks, infiltration capacity, surface runoff, etc. (Pande and Moharir, 2015). The Geil river basin in its development has been influenced by the underlying structures and topography as it has developed a dendrictic drainage pattern. The river basin is a fifth order river basin and is dominated by lower order streams. The predominance of first order streams that run over a very short length over the steep slopes of the study area has produced a rugged terrain and deeply dissected valleys. The high variations in the bifurcation ratio indicate that the drainage basin is greatly influenced by the hilly and highly dissected geological structure. The high drainage density values of the river basin signify high degree of surface runoff due to the steepness of the topography, impermeable subsurface material and sparse vegetation. The dendrictic drainage pattern consisting of numerous short first order streams

Table 4. Morphometric Parameters used for Prioritization of Streams

Stream order(S_u)	Rb	Lμ	Lμ / S_u	Composite Index value	Weighted Index value
1st order	0	103.1	103.1	68.73	0.76
2nd order	3.85	22.23	11.15	12.41	0.13
3rd order	4.00	4.76	1.19	3.32	0.04
4th order	2.50	4	1	2.5	0.03
5th order	4.00	5	1	3.33	0.04

is indicative of presence of impermeable underlying bed rocks coupled with other factors like steep slopes, scanty vegetation and east oriented flow direction can result in flooding of higher order streams during heavy rainfall. The lower R_e value of the river basin indicates high surface runoffs and high susceptibility of erosion and soil loss. The prioritization of the stream orders based on linear parameters show, that the first order streams are high priority streams which are prone to higher rates of erosion and soil loss. Therefore conservation measures should be concentrated more in those areas where first order streams are present for effective management of the watershed.

References

Agarwal, C.S. 1998. Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P. *J Indian Soc Remote Sens*. 26: 169–175.

Arabameri, A., Tiefenbacher, J.P., Blaschke, T., Pradhan, B. and Bui, D.T. 2020. Morphometric analysis of soil erosion susceptibility mapping using Novel GIS based Ensemble method. *Remote Sens*. 12: 874. Doi: 10.3390/rs12050874. www.mdpi.com/journal/remotesensing.

Chorley, R.J. 1969. Introduction to physical hydrology. Methuen and Co. Ltd., Suffolk, p 211.

Chopra, R., Dhiman, R.D. and Sharma, P.K. 2005. Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. J Indian Soc Remote Sens 33, 531–539. https://doi.org/10.1007/BF02990738.

Clarke, J.I. 1966. *Morphometry from Maps.* Essays in geomorphology. Elsevier publication. Co., New York, pp 235–274.

Desai, M. 2014. *Darjeeling the Queen of the Hills: Geo-Environmental Perception*. KP Bagchi and Co, Kolkata, pp 20-26.

Dove Nir 1957. The ratio of relative and absolute altitude of Mt.Camel.Geog.Rev.47 pp 564- 569.

Frissel, C.A., Liss, W.J., Warren, C.E. and Hurley, M.D. 1986. A Hierarchical Framework for Stream Habitat Classification-Viewing Streams in a Watershed Context. *Environment Management.* 10: 199-214.

Gayen, S., Bhunia, G.S. and Shi, P.K. 2013. Morphometric analysis of Kangshabati-Darkeswar Interfluves area in West Bengal, India using ASTER DEM and GIS techniques. *Geol Geosci.* 2(4): 1–10.

Gregory, K.J. and Walling, D.E. 1973. Drainage basin form and process - a geomorphological approach. London: Edward Arnold

Grohmann, C.H. 2004. Morphometric analysis in geographic information systems: applications of free software GRASS and R. Comput Geosci 30:1055–1067.

Horton, R.E. 1932. Drainage basin characteristics. *Trans Am Geophys Union.* 13: 350–361.

Horton, R.E. 1945. Erosional development of streams and their drainage basins Hydro-physical approach to quantitative morphology. *Bull Geol Soc America*. 56:275–370.

Leopold, L.B., Wolman, M.G. and Miller, J.P. 1964. *Fluvial Processes in Geomorphology*. WH Freeman and Company, San Francisco

Kale, V.S. and Gupta, A. 2001. *Introduction to Geomorphology*. Orient Longman Ltd, India, pp 82-101

Magesh, N.S., Chandrasekar, N. and Soundranayagam, J.P. 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.

Magesh, N.S., Jitheshlal, K.V., Chandrasekar, N. and Jini, K.V. 2012. GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala. *India Earth Sci Inform*. 5(2): 111–121.

Mesa, L.M. 2006. Morphometric analysis of a subtropical Andean basin (*Tucuman, Argentina*). *J Environ Geol*. 50(8): 1235–1242.

Miller, V.C. 1954. A quantitative study of drainage basin characteristics in the Clibnch Mountain area, Virginia and Tennessee. Dept. of Geology, Columbia University , New York, Tech. Rept, No. 3, Office of Naval Researcher Contract N 60 NR 271-30.

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

Nautiyal, M.D. 1994. Morphometric analysis of a drainage basin, district Dehradun, Uttar Pradesh. *J Indian Soc Remote Sens*. 22(4): 251–261.

Nooka, R.K., Srivastava, Y.K., Venkateshwara, R.V, Amminedu, E. and Murthy, K.S.R. 2005. Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis- remote sensing and GIS perspective. *J Indian Soc Remote Sens*. 33(1): 25-38.

Pande, C.B. and Moharir, K. 2015. GIS based quantitative morphometric analysis and its consequences: a case study from Shanur River Basin, Maharashtra India. *Appl Water Sci.* 7: 861-871. DOI 10.1007/s13201-015-0298-7

Rai, P.K., Mohan, K., Mishra, S., Ahmad, A. and Mishra, V.N. 2014. A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. *Appl Water Sci.* 7:217–232. DOI 10.1007/s13201-014-0238-y

Reddy, O.G.P., Maji, A.K. and Gajbhiye, S.K. 2004. Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India-a remote sensing and GIS approach. *Int J Appl Earth Obs Geoinformatics*. 6: 1–16.

Roger Mccoy, M. 1971. Rapid measurement of drainage density. *GSA Bulletin.* v.82 (3): 757-762.

Sethupathi, A.S., Lakshmi, N.C., Vasanthamohan, V. and Mohan, S.P. 2011. Prioritization of mini watersheds based on morphometric analysis using remote sensing and GIS in a drought prone Bargur Mathur sub watersheds, Ponnaiyar River basin, India. *Int J Geomat Geosci*. 2(2): 403-414.

Schumm, S.A. 1956. Evolution of drainage systems and slopes in bed lands at Perth Amboy, New Jersey. *Bull Geol. Soc Am*. 67: 597–646.

Singh, S. and Singh, M.C. 1997. Morphometric analysis of Kanhar river basin. *Nat. Geog. Jour. of India.* 43(1) : 31-43.

Singh, S. 2007. Geomorphology. Prayag Pustak Bhawan, Allahabad, India. pp. 353-395.

Smith, G.H. 1935. The relative relief of Ohio. *Geograph. Rev.* 25: 272–284.

Smith, B. and Sandwell, D. 2003. Accuracy and resolution of shuttle radar topography mission data. *Geophys Res Lett.* 30(9): 20-21.

Strahler, A.N. 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

Vittala, S.S., Govindiah, S. and Honne Gowda, H. 2004. Morphometric Analysis of Sub-Watersheds in the Pawagada Area of Tumkur District, South India, Using Remote Sensing and GIS Techniques. *Journal of Indian Society of Remote Sensing*. 32: 351-362. https://doi.org/10.1007/BF03030860.”