Quantitative Morphometric Analysis Using Remote Sensing and GIS Techniques for Mandakini River Basin

Abdul Qadir1*, Mohammad Yasir2, Ismail Ahmad Abir1, Naseem Akhtar3, Lim Hwee San 1

1School of Physics, University of Science Malaysia, Minden-11800, Penang, Malaysia
2Interdisciplinary Department of Remote Sensing and GIS Applications, Aligarh Muslim University, Aligarh-202002, India
3School of Industrial Technology, University of Science Malaysia, Minden-11800, Penang, Malaysia

*E-mail: abdulqadiralig@gmail.com

Abstract. The current research in the State of Uttarakhand in Rudraprayag argued that the analysis of the morphometric drainage parameter is more appropriate than traditional approaches with a remotely sensed information and GIS-based approach. Various linear, aerial and relief aspects were considered to analyse study area morphometry and the digital elevation model (DEM) and catchment area slope map were created from 30 m resolution ASTER data. The drainage patterns were mainly dendritic to sub dendritic. The study area's slope was divided into five ranging from 0° to 77°. The study area's stream order ranged from 1st order to 7th order. The variation in the stream length ratio could be due to the disparity in slope and topographical conditions. Geometric characteristics in the region suggest that the area appeared to have an extended shape with an elongation ratio of 0.76 and less circulatory shape with a circulatory ratio of 0.47 suggests the varied homogenous geological and texture ratios preferred for its high texture ratio of 28.77 disfigured complex lithology. In topography and geographic growth, the range of the bifurcation ratio in the catchment area was between 3.84 and 5.30. The drainage level was medium at 2.34 km². The drainage texture was 38.10 demonstrating the nature of lithology.

Keywords: Digital Elevation Model (DEM); morphometric analysis; remote sensing; Geographic Information System (GIS).

1. Introduction

As the world's population rises and more urban development happens worldwide, the demand for water increases. Demand for water is rising with the growth of the world's population and rising urbanization around the world. In comparison, there are restricted water resources, rising competition for various waters, reducing access to better water quality and over-exploiting of most of the local low-quality water bodies [1, 2]. Land, water and soil are restricted natural resources and have a large area of concern for their widespread use with the growing population. It was necessary to protect the natural resources with an appropriate priority for its sustainable growth, to minimize demand and supply disparities among resources and that demand. In this context, a new path in morphometric studies was provided by the advent of remote sensing systems and GIS techniques [3]. Those techniques had been used for the planning and management of natural resources in recent decades. In other ways. Many scientists were
used for mapping groundwater potential region, command area monitoring, rainfall-runoff modelling, and many other applications by GIS and remote sensing applications [4-6]. A morphometric watershed analysis gives an interpretation of a drainage system. It is crucial to characterize the watershed. The watershed-planning plan has incredible potential for social equality, autonomy and sustainable growth. [7, 8] not only does the plan to protect and preserve the environment and contribute to the protection of livelihoods. The drainage properties of several river basins and sub-basins in various regions of the world had investigated with traditional methods [9].

Rahaman et al [10] Morphometric analysis of river basins is performed using remote sensing and geographic information system (GIS) techniques. Shrimali et al [11] a study was performed on the Sukhan Lake in the Shiwalik hills, which recognized and made soil erosion areas a priority. Ratnam et al [12] and Khanday & Javed [13] monitor dam location studies had carried out using a model of the sediment yield Index (SYI) and morphometric analysis to prioritize micro-watersheds. Therefore, the purpose of this study was to analysis the Mandakini river basin using remote sensing and GIS techniques. This study aimed to identify the drainage system and its interaction with nature, to recognize the morphometric parameters and their behaviour in the area and to analysis the Mandakini river valley through morphometric parameters.

2. Material and Methods

2.1 Study Area
The field of study is situated in subtropical, humid and humid climates, latitudinal extends are 30° 19' and 30° 49' N and longitudinal extent are 78° 21' 13" E of Mandakini river valley, Rudraprayag district in Uttarakhand. The altitude of the Mandakini river catchment extends from 562 m to 6952 m above mean sea level and the catchment area is about 1997 km². The Mandakini River emerges from the Chaurabari Glacier as Dudhganga and converges in Sonprayag with Vasuki Ganga. Besides this, the river meets several small tributaries. From the greater Himalayas, the Mandakini river goes south and reaches the Rudraprayag Alaknanda rivers. The study area is shown in (Figure 1).

2.2 Data source
The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM (Digital Elevation Model) data having 30-meter spatial resolution downloaded from the USGS (United States Geological Survey) website and was subsequently utilised for generating slope map of the study area. The topographical map used for this study was from the survey of India topographical sheets (53J/14, 53J/15, 53J/16, 53N/1, 53N/2, 53N/3, 53N/4 and 53N/6) published on the scale of 1:50,000 by the Government of India for drainage extraction.

2.3. Pre-processing
In pre-processing, the mosaicked DEM satellite images combined with topographic maps that were rectified and georeferenced under the GIS environment. A boundary of Rudraprayag district was digitized from the topographic map. The digitized shapefile was used to extract Rudraprayag district from DEM.

2.4. Linear Aspect
The average stream length (Lsm) was determined by extracting the entire stream length' u' from the number of stream segments of u' and the average stream length values for each stream order in this study were also calculated (Table 1). The length of the valley is called the valley length. It can be calculated through the measuring tools in ArcGIS10 software. A maximum aerial distance (Adm) is the shortest route between the origin and the mouth of this river. It was calculated through special tools in ArcGIS 10 software. Drainage density was used to measure the total stream length in a given region of the basin for the overall area.
The drainage density had been divided into seven various categories of drainage texture, i.e. less than 1 represents coarse, between 1 and 2 is moderately coarse, between 2 and 3 is very coarse, between 3 and 4 is very moderate, between 4 and 5 is moderate, between 5 and 6 is fine and above 6 is very fine drainage texture. It was calculated by dividing the stream frequency with the drainage density. It can be expressed into km\(^{-1}\). It was computed using different measurement techniques in ArcGIS 10 Software. Basin shape (Bs) is the relation between basin square length (Lb) and the basin area (A). The form factor (Rf) shows the structure and description of a drainage basin that can be interpreted to influence the conduct of flux. The circularity ratio is the ratio of a basin area to a region of a circle that the diameter of a basin is equivalent. This ratio refers in particular to the length and frequency of streams, geological formations, land use/land cover, environment, relief and basin slope.

### 2.5 Drainage mapping and morphometric analysis

The drainage map of the research area was represented in the fill, flow direction and flow accumulation processes in (Figure 2). The order of the stream was designated according to the Horton law [14] the un-branch strip classification of the first-order stream was allocated to the second-order when two first-order streams merged. Two-second steams were formed into the third order, etc. The number of streams of each order had been numbered and recorded. Based on stream orders, the subwatershed boundary was delineated (Table 1).
Table 1. Computation of morphometric parameters.

| Morphometric Parameters | Formula | Reference |
|-------------------------|---------|-----------|
| Stream order (Su)       | Hierarchal rank | Strahler [15] |
| Stream length (Lu)      | Length of streams | Horton [16] |
| Mean stream length (Lsm) | \( Lsm = \frac{Lu}{Nu} \) | Strahler [15] |
|                         | Where, \( Lsm = \) Mean stream length \( Lu = \) Total stream length of order ‘u’ \( Nu = \) Total no. of streams segments of order ‘u’ | |
| Stream length ratio (RL) | \( RL = \frac{Lu}{Lu1} \) | Horton [16] |
|                         | Where, RL = stream length ratio \( Lu = \) total stream length of order ‘u’ \( Lu1 = \) Total stream length of its next lower order | |
| Bifurcation Ratio (Rb)  | \( Rb = \frac{Nu}{Nu1} \) | Schumn [17] |
|                         | Where, Rb = Bifurcation ration \( Nu = \) Total no. of stream segments of order ‘u’ \( Nu1 = \) No. of segments of the next higher order | |
| Mean bifurcation ratio (Rbm) | \( Rbm = \) Average of bifurcation ratios of all orders | Strahler [18] |
| Texture Ratio (Rt)      | \( Rt = \frac{N1}{P} \) | Schumn [17] |
| Relief ratio (Rh)       | \( Rh = \frac{H}{Lb} \) | Schumn [17] |
|                         | Where, Rh = Relief ratio \( H = \) Total relief (Relative relief) of the basin (km.) \( Lb = \) Basin length | |
| Drainage Density (D)    | \( D = \frac{Lu}{A} \) | Horton [19] |
|                         | Where, D = drainage density \( Lu = \) Total stream length of all orders \( A = \) Area of the basin (Km2) | |
| Drainage Intensity(Di)  | \( Di = \frac{Fs}{Dd} \) | Faniran [20] |
| Stream frequency (Fs)   | \( Fs = \frac{Nu}{A} \) | Horton [19] |
|                         | Where, Fs = Stream frequency, \( Nu = \) Total no of streams of all orders, \( A = \) Area of the basin (km2) | |
| Drainage Texture (Dt)   | \( Dt = \frac{Nu}{P} \) | Horton [16] |
|                         | Where, Rt = drainage texture \( Nu = \) Total no. of streams of all orders, \( P = \) Perimeter of the basin (km) | |
| Form Factor (Rf)        | \( Rf = \frac{A}{Lb^2} \) | Schumn [17] |
|                         | Where, Rf = form Factor, \( A = \) area of the basin (km2) \( Lb^2 = \) Square of the basin length | |
| Circularity Ratio (Rc)  | \( Rc = 4*\pi*\frac{A}{P^2} \) | Horton [19] |
|                         | Where, Rc = Circularity ratio \( A = \) area of the basin \( km^2 \) \( P = \) Perimeter of the basin (km) | |
| Elongation Ratio (Re)   | \( Re = (2 / Lb)^*\sqrt{\frac{A}{P}} \) | Strahler [15] |
|                         | Where, Re = Elongation ratio \( Lb = \) Basin length \( A = \) area of the basin (km2) \( P = \) perimeter of the basin (km) | |
Figure 2. Drainage map showing the stream order of the Mandakini river basin.

3. Results and Discussion

3.1 Linear Aspect
The total basin area covers an area of 1997 km$^2$. With the rise in stream order, the number of streams decreases slowly, and the stream portion in each given order becomes less than the next lower order but more than the next higher order. The seventh order of streams planning an area of 1997 km$^2$ was related to 8781 streams. The number of stream channels in a given order known as the number of streams and the first-order stream includes the maximum number of streams while the lowest number of streams is seventh. The number of streams available in the first, second, third and fourth-order stream counts 6631, 1666, 387 and 66 streams and finally, the number of streams available in seventh order is only 1 (Table 1). As a general concept, the mean length of a given order's channel segments was greater than that of the next lower order but less than the next higher order. There is a divergence in the stream-length ratio in this region of research. The late geomorphic growth process of their youth was suggested by a shift in order. This difference can be relate to the modification in slope as well as topography.

The geological structures do not influence the drainage pattern since the ratio of bifurcation is between 3.84 and 5.30. If the bifurcation ratio is low, flooding will be high, since water tends to pool instead of spreading. Human influence is critical in reducing the bifurcation ratio, thereby increasing the risk of flooding inside the basin. Higher bifurcation ratio values show a strong structural influence on the pattern of drainage. Mandakini river basin shows a bifurcation ratio of 4.36, which can be obtain from the total bifurcation ratio that was 26.17, divided by the number of stream order, which was seven-stream order. The length from the outflow point of the river basin to the upper limit of the basin, the longest watercourse. The main channel length computed using ArcGIS 10 software, which was 76.84 km. The valley length was 60.39 km. The channel index of this study area is 1.09. The valley index of the study area is 0.85. The maximum aerial distance is 70.82 km (Table 2).
Table 2. Results of morphometric analysis showing linear aspects for the Song watershed.

| Linear Aspect                  | Results | References |
|--------------------------------|---------|------------|
| Stream order (Su)              | 1st     | 2nd        | 3rd        | 4th        | 5th        | 6th        | 7th        | Miller [21] |
| No. of streams (Nu)            | 6631    | 1666       | 384        | 73         | 19         | 4          | 1          | Horton [16]  |
| Stream Length (Lu) in Km       | 2544.95 | 1105.47    | 500.66     | 227.59     | 200.38     | 44.72      | 49.23      | Strahler [15] |
| Mean Stream Length (Lsm)       | 0.38    | 0.66       | 1.29       | 3.12       | 10.55      | 11.18      | 49.23      | Horton [16]  |
| Stream Length Ratio (RL)       | -       | 1.73       | 1.95       | 2.41       | 3.38       | 1.06       | 4.40       | Strahler [15] |
| Bifurcation Ratio (Rb)         | -       | 3.98       | 4.30       | 5.30       | 3.84       | 4.75       | 4.00       | Strahler [15] |
| Main Channel Length (Cl) Kms.  |         | 76.84      |            |            |            |            |            | Horton [16]  |
| Valley Length (Vi) Kms.        |         | 60.39      |            |            |            |            |            | Strahler [15] |
| Max. Areal Distance (Adm) Kms. |         | 70.82      |            |            |            |            |            | Horton [16]  |
| Channel Index (Ci)             |         | 1.09       |            |            |            |            |            | Horton [19]  |
| Valley Index (Vi)              |         | 0.85       |            |            |            |            |            | Horton [19]  |

Figure 3. Drainage density map of the Mandakini river basin.

3.2 Aerial Aspect

Aerial aspects involve form factor, elongation ratio, stream size, drainage rate, drainage texture, a form of the basin and the circularity ratio (Table 3). The drainage density value was 2.34 km/km² indicating high drainage density, of which the area of impenetrable subsurface and mountainous escape materials can be attributed as shown in (Figure 3 and Table 2). The value of drainage texture was 38.10 indicating that the Song water shade was a very fine texture. Mandakini watershed drainage intensity was 1.88 km⁻¹. The computed stream frequency value was noticed as 4.40 km⁻¹ that was attributed to low stream frequency value (Table 3). The basin length was 66.23 km (Table 3). The basin region or catchment region is a region where precipitation takes place and flows into a common outlet, such as a river, a bay
or other water bodies. The basin area in the study area was 1997 km$^2$ (Table 3). The basin perimeter was 230.5 km. The value of the basin shape was 2.19. The value of the type factor is usually smaller than that of 0.46 (for a circular basin). The value of form factor for the Mandakini watershed was observed to be smaller i.e. 0.37 showing that the watershed had a prolonged, flat peak flux drainage basin for a longer period. The circulation ratio was measured in value at 0.47, suggesting that the area of the catchment was less spherical in type with low to moderate reliefs and a few drainage systems with structural controls. Over a broad variety of climate and geological forms, the range of the elongation ratio is usually between 0.5 and 1. The values were divided into three types, i.e. circular (> 0.9), oval (0.9 to 0.8) and less elongated (< 0.7). The value of the elongation ratio for the Mandakini basin is measured as 0.76 which indicates that the form of the catchment area is less elongated although it had moderate relief. The overland flow of the Mandakini basin is 1.0 km wide, which means that the catchment area has a small runoff area. In the Mandakini basin, the value of constant channel maintenance was observed to be 0.43 (Table 3). It indicates that an average 0.43 feet$^2$ surface was required in the catchment area for the one linear foot formation of a stream channel.

**Table 3.** Results of morphometric analysis showing areal aspects for this study area.

| Areal Aspects                        | Method            | Result |
|--------------------------------------|-------------------|--------|
| Drainage Density (D) (km/km$^2$)     | $D = \frac{L_b}{A}$ | 2.34   |
| Drainage Texture (Dt)                | $D_t = \frac{N_u}{P}$ | 38.10  |
| Drainage Intensity (Di) (km$^{-1}$)  | $D_i = \frac{F_s}{D}$ | 1.88   |
| Stream Frequency (Fs) (km$^{-1}$)    | $F_s = \frac{N_u}{A}$ | 4.40   |
| Basin Length (Lb) km                 | ArcGIS 10 Software | 66.23  |
| Basin Area (A) km$^2$                | ArcGIS 10 Software | 1997   |
| Basin Perimeter (P) km               | ArcGIS 10 Software | 230.5  |
| Basin Shape (Bs)                     | $B_s = \frac{L_b^2}{A}$ | 2.19   |
| Form Factors (Rf)                    | $R_f = \frac{A}{L_b^2}$ | 0.46   |
| Texture Ratio (Rt)                   | $R_t = \frac{N_1}{P}$ | 28.77  |
| Circulatory Ratio (Re)               | $R_c = \frac{4\pi A}{P^2}$ | 0.47   |
| Elongation Ratio (Re)                | $R_e = \frac{2}{L_b} \sqrt{\frac{A}{P}}$ | 0.76   |
| Length of Overland Flow (Lg) (km)    | $L_g = \frac{1}{D} \times 2$ | 1.0    |
| Constant Channel Maintenance (C)     | $C = \frac{1}{D}$ | 0.43   |

### 3.3 Relief Aspect (AS)

Evaluation of some of the relief aspects such as slope (S), aspect (As), relief (R), relief ratio (Rh) and ruggedness number (Rn) for this study are described below: In this study, it had been divided into five categories of very low slope, low slope, medium slope, high slope, very high slope. Gentle is between 0˚ to 18˚, moderate is between 18˚ to 26˚, moderately slope is between 27˚ degree to 35˚, steep slope falls under 36-46˚ and lastly very steep slope is under 47-77˚ as shown in (Figure 4 and Table 4).

**Table 4.** Average slope classes.

| Slope class range (°) | Slope class category |
|-----------------------|----------------------|
| 0-18                  | Gentle               |
| 18-26                 | Moderate             |
| 27-35                 | Moderately Steep     |
| 36-46                 | Steep                |
| 47-77                 | Very Steep           |
Figure 4. Average slope of Mandakini river basin.

Divided in this research into 10 categories: Flat (-1), North (0-22.5), Northeast (22.5-67.5), East (67.5-112.5), Southeast (112.5-157.5), South (157.5-202.5), Southwest (202.5-247.5), West (247.5-292.5), Northwest (292.5-337.5) and North (337.5-360) in (Figure 5). The maximum elevation was at 6952 meters and the lowest is at 562 meters. Hence, the relief of the catchment area is 6390 meters. The relief ratio usually raises with the drainage area and size reduced. This research had a relief ratio of 0.096. The measured river basin had 14.95 of ruggedness number in (Table 5).

Table 5. Morphometric analysis showing relief aspects.

| Relief Aspect              | Method                                      | Result  |
|----------------------------|---------------------------------------------|---------|
| Relief (R)                 | The vertical distance between the lowest     | 6390    |
|                            | and highest points                          |         |
| Relief Ratio (Rh)          | Rh=R/Lb                                     | 0.096   |
| Ruggedness Number (Rn)     | Rn=R/D                                      | 14.95   |
4. Conclusion
This study shows that remote sensing techniques and the GIS play a crucial role in the timely and cost-effective preparation of revised drainage maps and morphometric analysis and the assessment of morphometric drainage parameters is more suitable than traditional ones. The elevation in the study area ranges between 562-6952 m above mean sea level that indicates that the area is highly elevated. Few portions of the study region fall below a gentle, moderate slope (0° to 17°) and (18° to 26°) respectively, while major part falls under moderately steep and steep slope and a very little portion is under steep slope in the northern direction. The stream order ranged from 1st order to 7th order. The increase in the ratio of stream length may be due to the variance between the slope and topography. The disparity in topography and geometrical growth is due to the variance of the bifurcation ratio within the catchment area. The drainage density was moderate. The mean ratio for bifurcation falls under the standard range for the basin. The high bifurcation ratio indicates that the area had a strong structural impact that affects the drainage. The circularity shows that the watershed is less circularity in shape and is elongated and drainage texture was lithology not so complex. Zonal static parameters were used to show the slope, drainage density, and slope aspects for the extraction of parameters, which show the physiographic characteristics of each factor, and for topography.

Acknowledgment
We are grateful to the School of Physics and the School of Industrial Technology at Sains Malaysia University for providing the research facilities needed for this work. We are also grateful to the reviewers for reviewing the paper and making crucial suggestions. We also appreciate the financial help received by University Sains Malaysia by grant 203/PFIZIK/6711608.
References

[1] Diwakar J and Thakur JK 2012 Environmental system analysis for river pollution control. Water Air Soil Pollut. 223(6) 3207-3218.

[2] Sappa G, Ergul S, Ferranti F, Sweya, Lukuba N and Luciani G 2015 Effects of seasonal change and seawater intrusion on water quality for drinking and irrigation purposes, in coastal aquifers of Dar es Salaam, Tanzania. J. Afr. Eart. Sci. 105 64-84.

[3] Qadir A, Mallick TM, Abir IA, Aman MA, Akhtar N, Anees MT, Hossain K and Ahmad A 2019 Morphometric Analysis of Song Watershed: A GIS Approach. Indian J. Ecol. 46(3) 475-480.

[4] Ebrahimi H, Ghazavi R and Karimi H 2016 Estimation of groundwater recharge from the rainfall and irrigation in an arid environment using inverse modelling approach and RS. Water Resour. Manag. 30(6) 1939-1951.

[5] Singh LK, Jha MK and Chowdary VM 2017 Multi-criteria analysis and GIS modeling for identifying prospective water harvesting and artificial recharge sites for sustainable water supply. J. Clean. Prod. 142 1436-1456.

[6] Sahoo S, Dhar A, Kar A, and Ram P 2017 Grey analytic hierarchy process applied to effectiveness evaluation for groundwater potential zone delineation. Geocarto Int. 32(11) 1188-1205.

[7] Rahmati O, Haghizadeh A and Stefanidis S 2016 Assessing the accuracy of GIS-based analytical hierarchy process for watershed prioritization; Gorganrood River Basin, Iran. Water Resour. Manag. 30(3) 1131-1150.

[8] Rana NK 2018 Analysis of Mahananda River Basin Using Geospatial Data. The Indian Rivers, Springer, Singapore, 2018 pp-239-250.

[9] Rai PK, Mishra VN and Mohan K 2017 A study of morphometric evaluation of the Son basin, India using geospatial approach. Remote Sens. App: Soci. Envmnt. 7 9-20.

[10] Rahaman SA, Ajeez SA, Aruchamy S and Jegankumar R 2015 Prioritization of Sub Watershed Based on Morphometric Characteristics Using Fuzzy Analytical Hierarchy Process and Geographical Information System–A Study of Kallar Watershed, Tamil Nadu. Aquat. Procedia 4 1322-1330.

[11] Shrimali S, Aggarwal SP and Samra JS 2001 Prioritizing erosion-prone areas in hills using remote sensing and GIS—a case study of the Sukhna Lake catchment, Northern India. Int. J. Appl. Earth Obs. 3(1) 54-60.

[12] Ratnam KN, Srivastava YK, RaoVV and Murthy KSR 2005 Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis remote sensing and GIS perspective. J. Indian Soc. Remote 33(1) 25.

[13] Khanday MY and Javed A 2016 Prioritization of sub-watersheds for conservation measures in a semi-arid watershed using remote sensing and GIS. J. Geol. Soc. India 88(2) 185-196.

[14] Rai PK, Mohan K, Mishra S, Ahmad A and Mishra VN 2017 A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. Appl. Water Sci. 7(1) 217-232.

[15] Strahler AN 1964 Part II. Quantitative geomorphology of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. Am. Bull. 75 597-646.

[16] Schumm SA 1956 Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. Am. Bull. 67(5) 913-920.

[17] Horton RE 1932 Drainage-basin characteristics Eos, Trans. Am. Geophys. Union 38(6) 913-920.

[18] Horton RE 1932 Drainage-basin characteristics Eos, Trans. Am. Geophys. Union 38(6) 913-920.

[19] Faniran A 1968 The Index of Drainage Intensity - A Provisional New Drainage Factor. Aust. J. Crop Sci. 31 328-330.

[20] Miller VC 1953 Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Technical Report (Columbia University. Dept. of Geology) 65 1 112-113.