



*International Journal of Humanities & Social Science Studies (IJHSSS)*  
*A Peer-Reviewed Bi-monthly Bi-lingual Research Journal*  
*ISSN: 2349-6959 (Online), ISSN: 2349-6711 (Print)*  
*Volume-II, Issue-IV, January 2016, Page No. 68-80*  
*Published by Scholar Publications, Karimganj, Assam, India, 788711*  
*Website: <http://www.ijhsss.com>*

---

## **Analysis of Hydrological Inferences through Morphometric Analysis: A Remote Sensing-GIS Based Study of Gandheswari River Basin in Bankura District, West Bengal**

**Biswajit Mondal**

*M. Phil Research Scholar, Dept. of Geography, Delhi School of Economics, New Delhi, India*

**Biswaranjan Mistri**

*Asst. Professor, Dept. of Geography, the University of Burdwan, Burdwan, India*

### **Abstract**

*Management of natural resources and to promote overall economic conditions are the major approach of watershed management. The main aspects of river basin management are to higher agricultural productivity and conserving natural resources and to improve rural livelihood. Morphometric analysis of a river catchment or basin provides a quantitative description of drainage system and relief characteristics. In the present study, morphometric parameters like basin geometry, drainage network, drainage texture have been analyzed through Remote Sensing (RS) and GIS techniques in Gandheswari river basin of Bankura district. Different types of thematic maps have been prepared through GIS techniques. The river basin covers an area of 364.9 Sq.km. The basin is in elongated in shape and is structurally controlled. Digital Elevation Model (DEM) has been prepared for the analysis of slope of the river basin.*

***Key Words: Morphometric Analysis, Gandheswari River Watershed, Digital Elevation Model, Basin Geometry, Drainage Texture.***

---

**1. Introduction:** Land, water and soil are limited natural resources and their wide utilization with increasing population is a major area of interest of most countries. In case of resource management and to mitigate the gap between demand and supply of resources, it is prime importance to conserve the natural resources with proper prioritization for its sustainable development (Panahalkar et al., 2012). According to Chopra and Kadekodi (Chopra & Kadekodi, 1993) the watershed management programme has an additional potential that of creating the possibility of a regeneration of natural capital. Morphometric analysis of a drainage basin provides a quantitative description of a drainage system. Morphometric properties of a drainage basin are quantitative attributes of the landscape that are derived from the terrain or elevation surface and drainage network within a drainage basin (Goudie, 2004). It is an important aspect of watershed characterization. Morphometric studies involve evaluation of streams through the measurement of stream properties such as length of channel, drainage density, drainage frequency, bifurcation ratio, texture ratio, circulatory ratio, stream ordering, basin area and perimeter of basin. A major emphasis in geomorphology over the past several decades has been focused on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1932). GIS and image processing techniques have been adopted for the analysis of drainage parameters to understand the impact of drainage morphometry on landforms. Especially in rugged terrain the importance of

remote sensing image and GIS techniques is immense value for the land use-land cover classification, land degradation, soil erosion etc. (Shrestha & Zinck, 2001; Saha et al., 2005; Pontius & Batchu, 2003; Read & Lam, 2002). It has also helped to understand the characteristics of the drainage basin. Timely and reliable information on cost effective manner in spatial and temporal domain, which can act as a reliable base line information on natural resources at scale ranging from regional to micro levels, can be generated by geographic information system (GIS), which can help for integrated analysis of natural resources inventory, management and planning the strategy for sustainable development and stand as a power effective administrative and management tool as decision making (Scaria & Vijayan, 2014).

**2. Objectives:** The main objectives of the study are:

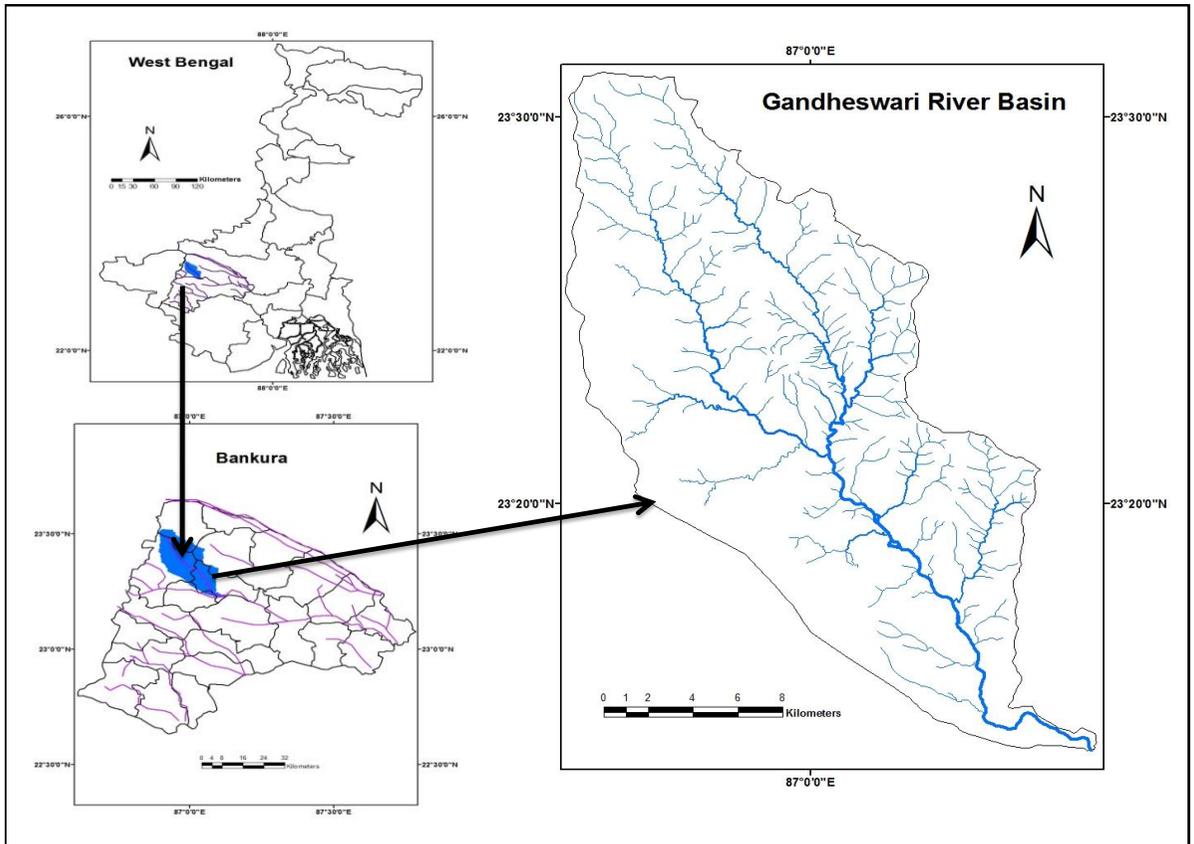
- I. To analyze the quantitative aspects of Gandgheswari River basin
- II. To infer hydrological characterizations of the basin

**3. Data base and Methodology:** This study has completed mainly on morphometric analysis of Gandheswari river basin. In the study various types of data such as topographical sheets (73I/14, 73I/15, 73M/3, 73M/4) of Survey of India, Landsat- ETM+ data (30m. resolution), SRTM and Google image have been used. For the study of geology and geomorphology of the study area, Geological Survey of India (GSI) map (District Resource Map of Bankura District, GSI, 2001) have been used.

To assess the morphometric conditions, mainly Survey of India toposheets at a scale of 1:50,000 and SRTM (30m.) data have been used. Subset and geo-referencing of satellite image and toposheets have been done by ERDAS Imagine 9.2. The basin demarcation, digitization of drainage has been carried out by Arc GIS 9.3 software. DEM map have been prepared on the basis of contours which are available on toposheets by Arc GIS 9.3 software and SRTM image.

Morphometric parameters such as drainage density, bifurcation ratio, drainage frequency, circulatory ratio, elongation ratio etc has been carried out through mathematical equation. Horton (1945), Schumm (1956), Strahler (1964) etc methods have been applied for the study.

**4. Study Area:** Gandheswari river, a tributary of Darakeswar, is a major river in Bankura District (Figure No. 1). Geomorphologically, the landscape of Bankura may be described as a connecting link between the plains of Bengal and the Chhotanagpur plateau. Gandheswari River flows North-Western part of the district through four blocks viz. Bankura, Saltora, Chatna, and Gangajalghati. It has originated at Saltora (BM-162m.) and flows towards South-East and meets with river Darakeswar near Bankura town (BM-76m.). Maximum and minimum elevation of the river basin is 440 meter and 76 meter. The total length of Gandheswari River is 49 km and is a 5<sup>th</sup> order stream. The latitudinal extension of the river basin is 23°13'28"N to 23°30'25"N and the longitudinal extension is 86°53'13"E to 87°07'30"E.

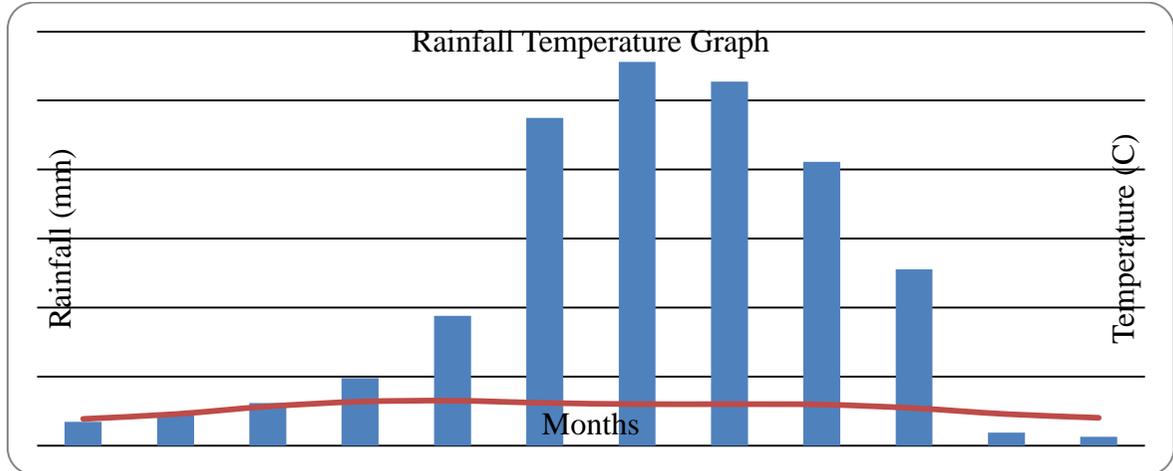


**Figure No. 1** Location Map of Gandheswari River Basin

## 5. Results and Discussions:

**5.1 Geology:** Large portion of the basin belongs to undulating surface except Eastern region of the basin which is nearly plain region. Gandheswari river basin geologically has been composed of pink granite and biotite granite gneiss rocks of Archaen age in Northern and middle part and the Southern part mainly occupied by laterite and older alluvium of Pleistocene age (District Resource Map of Bankura, 2001). The tributaries and distributaries of the basin area are mainly shallow river bed and due to of this shallow river bed in rainy season those river beds frequently overflow and causes flood. The extensive lateritic crust developed in the well drained upland areas sustains natural bushy vegetation growth and forest development in places. The depth of water tables ranges from 2 to 16m b. g. l. Low yield ground water development is feasible in this part by large diameter open dug wells (District Resource Map of Bankura, 2001).

**5.2 Climate:** The climate especially in the upland tracts to the West is much drier than in Eastern or Southern Bengal. Hot westerly winds blows from the beginning of March to early July. In this time temperature of the area is higher than the average temperature i.e. it exceeds 45<sup>0</sup>c. The monsoon months i.e. June to September are comparatively pleasant. The total average rainfall of the basin is 1400 mm (55in.). Winters are pleasant due to falling of temperature below 27<sup>0</sup>c (81<sup>0</sup>f) in December (Table No.1). A general rainfall-temperature graph has been given below (Figure No. 2).



**Figure No.2** Rainfall and Temperature of Gandheswari River Basin

### 5.3 Morphometric Analysis:

#### 5.3.1 Basin Geometry

##### 5.3.1.1 Basin Area (A) and Basin Perimeter (P)

Basin area, basin perimeter and channel length are significant morphometric variables which determine the shape, size and genetic aspect of relief, drainage network and characteristics of drainage basin. The drainage area is probably the single most important watershed characteristic to hydrological design and reflects the volume of water that can be generated from rainfall (Pal & Debnath, 2012). In the present study shows that the area of the basin is 364.9 sq.km and perimeter of the river is 101.54 km (Table No. 4).

##### 5.3.1.2 Basin Length (Lb)

Generally the basin length can be measure of main axis of flow on which the basin is divided. In that case the total length of Gandheswari river basin is 39.4 km.

##### 5.3.1.3 Form factor (Rf)

According to Horton (Horton, 1932) form factor is the ratio of the area of the basin to square of the basin length. In the present study, the value of form factor is 0.2351 (Table No. 4) which indicates the basin is elongated and will have a flatter peak of flow for a longer duration and are easier to manage the floods than the circular form of a basin.

##### 5.3.1.4 Shape factor (Sf)

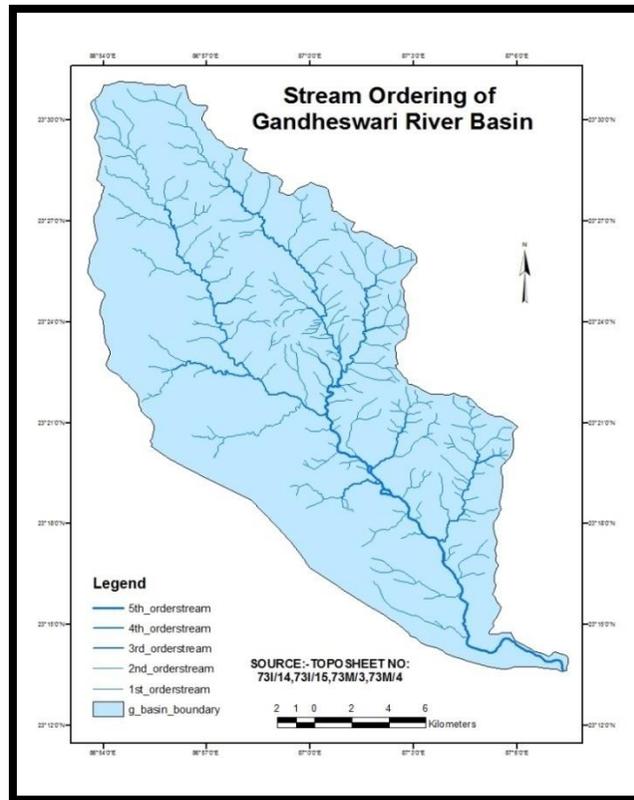
The shape factor can be defined as the ratio of the square of the basin length to area of the basin (Horton, 1932) and is inverse proportion with form factor. Shape factor of the river basin is 4.25, which indicates the elongated shape of the basin.

##### 5.3.1.5 Circulatory Factor (Rc)

Circulatory ratio is the total drainage basin area divided by the area of a circle having the same perimeter as the basin (Summerfield, 1991). Circulatory ratio of the river is 0.44. It has highlighted the elongation shape of basin.

### 5.3.1.6 Elongation Ratio (Re)

Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length (Schumm, 1956). In the present study, this value is 0.55 hence the basin is elongated shape (Strahler, 1952).



**Figure No. 3** Streams Order of Gandheswari River Basin

### 5.3.1.7 Texture Ratio (T)

Schumm (Schumm, 1956) defined, texture ratio is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. The texture ratio can be defined as the ratio of total number of streams of first order to the perimeter of the basin. Texture ratio of the basin is 2.85.

### 5.3.1.8 Drainage texture (Dt)

An important geomorphic concept is drainage texture by which we mean the relative spacing of drainage lines (Smith, 1939) while Horton (Horton, 1945) defined Drainage texture on the basis of stream frequency (number of stream per unit area). Drainage texture of the river basin is 1.38.

### 5.3.1.9 Compactness Coefficient (Cc)

It can be represented as basin perimeter divided by the circumference of a circle to the same area of the basin (Horton, 1945). This are indirectly related with elongation of the basin area. Lower values of this parameter indicate the more elongation of the basin and less erosion, while higher values

indicate the less elongation and high erosion. In this study, the value of compactness coefficient is 0.16 (Table No.4).

**5.3.1.10 Fitness ratio (F)**

It is the ratio of main channel length to the length of the watershed perimeter is fitness ratio (Melton, 1957), which is a measure of topographic fitness. Fitness ratio of the river basin is 0.48

**5.3.2 Drainage Network**

**5.3.2.1 Stream Ordering (Su) and Number of Stream (Nu)**

Stream order expresses the hierarchical arrangement between streams. It is a fundamental property of stream networks since it is related to the relative discharge of a channel segment (Summerfield, 1991). Gandgeswari river basin is a 5<sup>th</sup> order stream (Figure No. 3). Total number of stream of the river basin is 290. Stream segments in different order have been given in Table No 3.

**5.3.2.2 Stream Length (Lu) and Main Channel Length (L)**

Leopold et al., (1964) defined stream length as ‘the distance along a stream channel’. The calculated total stream length of the river basin is 399.25 km (Table No. 2) and the main channel length of the river basin is 49 km.

**5.3.2.3 Stream Length Ratio (Lur)**

Miller (1964) defined stream length ratio as ‘average ratio of average length of streams of a given order to average length of streams of next lower order’. Stream length ratio of the river basin is 2.61 (Table No. 2).

**Table No.2** Stream Length, Stream Length Ratio

Su	Nu	Lu	Lu/Nu	Lur	Lur-r	Lur × Lur-r	Lurm
1 <sup>st</sup> order streams	221	213.44	0.9658				2.16
2nd order streams	54	92.81	1.7187	1.78	306.25	545.12	
3rd order streams	11	48.66	4.4236	2.5738	141.47	364.12	
4th order streams	3	17.02	5.6733	1.2825	65.68	84.23	
5th order streams	1	27.32	27.32	4.8155	44.39	213.76	
Total	290	399.25	40.1014	10.4518	557.79	1207.23	
Mean				2.6126			

**Source:** Author’s Calculation

**5.3.2.4 Bifurcation Ratio (Rb)**

Bifurcation ratio (R<sub>b</sub>) which is related to the branching pattern of the drainage network, is defined as a ratio of the number of streams of a given order ((Nu) to the number of streams of the next higher order (Nu+1) and is expressed in terms of the following equation-

$$R_b = Nu / Nu+1$$

[Where, Nu= number of streams of a given order

Nu+1= number of streams of the next higher order]

Mean bifurcation ratio varies from 2.0 for flat or rolling basins to 3.0-4.0 for mountainous, hilly dissected basins (Horton, 1945). Bifurcation ratio of Gandheswari river basin has been calculated as 3.91. Thus the results suggest that the basin is situated in a dissected or hilly tract.

**5.3.2.5 Rho coefficient (R)**

The Rho coefficient is an important parameter relating drainage density to physiographic development of a 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). Rho values of the Gandheswari river basin is 0.52 (Table No.4).

### 5.3.2.6 Weighted Mean Bifurcation Ratio (Rbwm)

Strahler (1952) 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. The Weighted Mean Bifurcation Ratio of the river basin is 4.21 (Table No. 3).

**Table No.3** Stream Order, Number, Bifurcation Ratio, Weighted Mean Bifurcation Ratio

Su	Nu	Rb	Nur	Rb×Nur	Rbwm
1st order streams	221				4.21
Number of 2nd order streams	54	4.09	275	1124.75	
Number of 3rd order streams	11	4.91	65	319.15	
Number of 4th order streams	3	3.67	14	51.38	
Number of 5th order streams	1	3	4	12	
Total	290	15.67	358		
Mean		3.9175			

**Source:** Author's calculation

### 5.3.3 Drainage Texture Analysis

#### 5.3.3.1 Stream Frequency (F)

Stream Frequency defined as the Number of stream segments of all orders per unit area (Summerfield, 1991). Stream frequency of the basin is 0.79 (Table No. 4).

#### 5.3.3.2 Drainage Density (Dd)

Drainage density is defined as the mean length of stream channel per unit area. The drainage density (Horton, 1932, 1945) is the average length of stream channel per unit areas:

$D = \Sigma l / A$ , Where D is the drainage density per unit area  $\Sigma l$  is the summation of the length of channels within the area A. Drainage density of the river basin is 1.094 km per Sq.km.

#### 5.3.3.3 Drainage Intensity

It is the ratio of the stream frequency to the drainage density (Faniran, 1968). Drainage intensity of the river basin is 0.722 (Table No. 4).

#### 5.3.3.4 Constant of Channel Maintenance

Strahler (1952) stated that 'the constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation'. Channel maintenance constant of the watershed is 0.91 (Table No.4).

#### 5.3.3.5 Infiltration Number

The infiltration number of a watershed is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher ran-off (Pareta & Pareta, 2011). Infiltration number has calculated as 0.864 of the basin.

#### 5.3.3.6 Length of Overland Flow (Lo)

The distance covered from the water divide to the nearest channel represents the length of overland flow, an important variable on which runoff and flood processes depend (On the other hand,

according to Leopold et al., (1964), length of overland flow is 'mean distance from channels up maximum valley-side slope to drainage divide'. The length of overland flow of the river basin is 0.457 (sq. / km).

### **5.3.4 Relief Parameter**

#### **5.3.4.1 Absolute Relief (Ra)**

It is actual height of a place with respect to mean sea level. Absolute relief of the river basin has been given in Table No. 4

#### **5.3.4.2 Relative Relief (Rr)**

Relative Relief is defined as the differences in height the highest and the lowest points in a unit area. It is an important morphometric parameter which is used for the overall assessment of morphological characteristics of terrain. The relative relief of the basin is 366 m. Because of its close association with slope, the relative relief is more expressive and useful in different fields including relief dissection and surface ruggedness. When the amplitude of regional relief is greater, the surface roughness will be seen to vary significantly from unit to unit under the over thrusting natural set of hydromorphic condition. Thus the more is the local relative relief, the more is the roughness and there manifold decrease is the effective value of terrain for arable farming (Singh & Dhillon, 1984).

#### **5.3.4.3 Dissection Index (Di)**

The concept of relative is not entirely satisfactory as a criterion of the nature of relief. Dissection index indicates the intensity of effectiveness of relief intensity in achieving an apparent usability of an area unit. The dissection index gives clue to the development of land forms under the purview of fluvial geomorphic cycle of erosion" (Prasad, 1985). The dissection value of the river basin (Table no.4) indicates the basin situated in a hilly tract. Susunia hill (Height 440m.) is the highest elevation zone of the basin and except this hill other region is more or less little undulating surface.

#### **5.3.4.4 Ruggedness Number (Rn)**

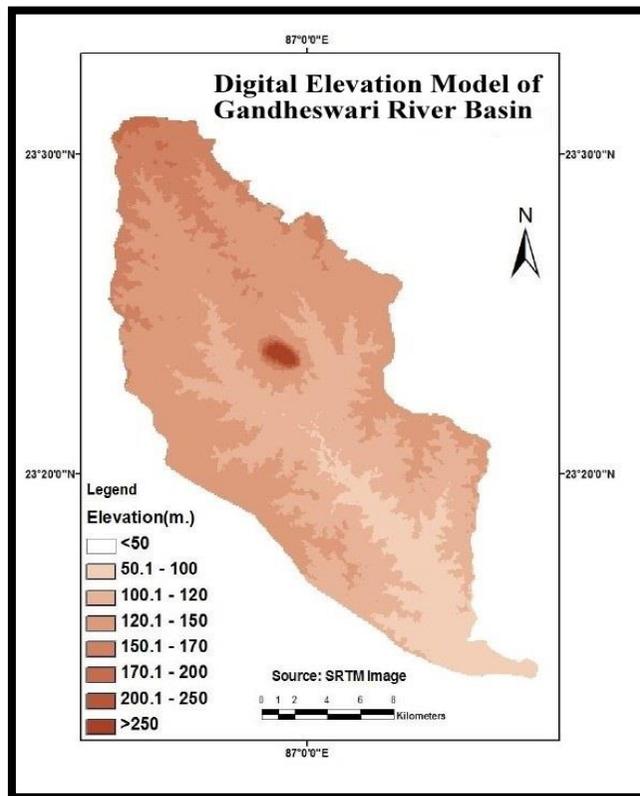
Goudie (2004) described the ruggedness of terrain as property of the landscape which describes the complexity of the topography and the roughness of the terrain. More rugged landscapes tend to exhibit a greater amount of complexity, having rough and uneven surfaces. According to Leopold et al., (1964) Ruggedness number is 'basin relief multiplied by drainage density'. The ruggedness number in Gandheswari river basin is 0.40 which indicates the basin is less soil erosion prone and has inherent structural complexity in association with relief and drainage density.

#### **5.3.4.5 Relief ratio (Rh)**

Schumm (1956) stated the relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line. The total relief is the differences of highest elevation and lowest elevation of valley floor in the basin. The relief ratio of the river basin is 0.007.

#### **5.3.4.6 Watershed Slope (SW)**

Watershed slope is the ration between the total basin reliefs (H) divided by basin length (Lb). The calculated value of watershed slope is 0.009



**Figure No.5** Digital Elevation Map (DEM) of Gandheswari River Basin

**6. Hydrolic Characterizations of Gandheswari River Basin:** The morphometric parameters like drainage density, bifurcation ratio, stream frequency, elongation ratio, form factor can be termed as erosion risk assessment parameters which can be used to prioritize watershed (Biswas, 1999). Different studies on the issue of morphometric analysis and watershed management has suggested that there is positive relation between watershed development and conservation of natural resources. Thakuiah et al., (2012) suggested that the quantitative analysis and morphometric parameter are found to be of immense unity in river basin evaluation watershed prioritization for soil and water conservation and natural resource management at watershed level. Drainage morphometry is like a tool to understand the process of land form, soil and erosion characteristics.

Bifurcation ratio of the river basin (3.91) indicates that the basin situated in a dissected region and the higher value of bifurcation ratio indicates the basin is structurally controlled. Rho value also indicates the nature of hydrologic storage during flood and its effect on soil erosion. Field observations have suggested that during rainy season shallow river bed frequently overflow and causes flood. Low value of Stream frequency, Drainage density, Drainage intensity implies that surface runoff is not fast and makes it to susceptible to soil erosion, gully erosion, flooding.

Drainage density, Stream frequency, bifurcation ratio, drainage intensity are directly related to soil erosion. Higher value of those parameters indicates more susceptible for soil erosion and vice-versa. In case of the study the Drainage density, Stream frequency, bifurcation ratio, drainage intensity has indicated low to moderate nature of soil erosion.

The general slope of Gandheswari river basin is from North–West to South East. Circulatory ratio, elongation ratio, form factor, shape factor indicate the river basin in an elongated in shape. Lower value of form factor indicate that basin have a flatter peak of flow for a longer duration. Low ruggedness index indicates less soil erosion.

**7. Conclusion:** The study has been carried out through morphometric analysis on the basis of remotely sensed data, GIS and toposheet (Survey of India). Remote Sensing and GIS techniques help to understand the terrain characteristics of the basin such as nature of rock, infiltration capacity, runoff etc. The study reveals different types of morphometric analysis and their impact on soil, landforms. The study has carried out 35 different parameters such as basin geometry, drainage network, drainage texture, relief aspect etc. The basin is structurally controlled, dissected area, elongated in shape, peak discharge in rainy season and so on. The study has highlighted that the elongated nature of basin shape and is situated in dissected hilly terrain. Morphometric analysis, DEM helps to understand the nature of terrain, nature of soil erosion, infiltration capacity etc. The present study has huge potentiality to management of soil erosion, micro level watershed management.

**Table No.4** Morphometric analysis of Gandheswari River Basin

Sl. No.	Morphometric Parameters	Formula	Reference	Result
<b>Basin Geometry</b>				
1	Basin Area (A)	GIS software analysis	Schumm(1956)	364.9
2	Basin Perimeter (P)	GIS software analysis	Schumm 1956)	101.54
3	Form factor (Rf)	$Rf = A/L^2$	Horton (1945)	0.2351
4	Elongation Ratio (Re)	$Re = 2\sqrt{(A/\pi)/L}$	Schumm(1956)	0.55
5	Texture Ratio (T)	$T = Nu/P$	Horton ( 1945)	2.85
6	Circulatory Ratio (Rc)	$Rc = 4\pi A/P^2$	Miller (1953)	0.44
7	Drainage texture (Dt)	$Dt = Dd \times F$	Smith (1950)	1.38
8	Compactness coefficient (Cc)	$Cc = 0.2821 P/A^{0.5}$	Horton (1945)	0.16
9	Basin Length(Lb) kms	GIS software analysis	Schumm 1956)	39.4
10	Shape Factor (Sf)	$Sf = Lb^2/A$	Horton (1945)	4.25
11	Fitness Ratio	$F = L/P$	Melton (1957)	0.48
<b>Drainage Network</b>				
12	Stream Order (Su)	Hierarchical rank	Strahler (1952)	5
13	Stream Number(Nu)	$Nu = S1 + S2 + S3 \dots Ln$	Horton (1945)	290
14	Stream Length (Lu)	$Lu = S1 + S2 + S3 \dots Ln$	Strahler (1964)	399.25
15	Bifurcation Ratio(Rb)	$Rb = Nu/Nu+1$	Schumm 1956)	3.9171
16	Main Channel Length (L)	GIS software analysis		49
17	Stream Length Ratio (Lurm)	See table no.2	Strahler (1964)	2.61
18	Weighted Mean Bifurcation Ratio (Rbwm)	See table no.3	Strahler (1964)	4.21
19	Rho coefficient (R)	$R = Lur / Rb$	Horton (1945)	0.67
<b>Drainage Texture Analysis</b>				
20	Stream Frequency (F)	$F = Nu/A$	Horton (1945)	0.79
21	Drainage density (Dd)	$Dd = Lu/A$	Strahler (1964)	1.094

22	Constant of Channel Maintenance (C)	$C=1/Dd$	Schumm 1956)	0.914
23	Drainage intensity (Di)	$Di= F/Dd$	Faniran (1958)	0.722
24	Infiltration Number (If)	$If= F \times Dd$	Faniran (1958)	0.86
25	Length of overland flow (Lo)	$Lo= 1/Dd \times 2$	Horton (1945)	0.457
<b>Relief charecteristics</b>				
26	Height of the basin mouth m. (z)	GIS software analysis	-	74
27	Total Contour Lengths(Ctl) in kms	GIS software analysis	-	451.1685
28	Maximum height of the basin m.(Z)	GIS software analysis	-	440
29	Total basin relief (H)	$H=Z - z$	Strahler (1952)	366
30	Relief Ratio (Rh)	$Rh= H / Lb$	Schumm(1956)	0.00928
31	Absolute Ratio (Ra)	GIS software analysis		440
32	Dissection Index (Di)	$Di= H/Ra$	Singh and Dubey (1994)	0.83/0.52
33	Ruggedness Number (Rn)	$Rn=Dd \times (H/1000)$	Patton and Baker (1976)	0.4
34	Watershed Slope (Sw)	$Sw=H/Lb$	-	0.009

**Source:** Author's Calculation

**Table No.1** Temperature and Rainfall Scenario of Bankura District

Months	Average Monthly Rainfall in mm	Average Monthly Temperature in °C
January	17.2	19.3
February	22.1	22.8
March	30.9	28.3
April	48.7	31.8
May	94.0	32.5
June	237.5	30.9
July	278.0	30.0
August	263.7	30.0
September	205.7	29.7
October	127.6	27.1
November	9.3	22.8
December	6.4	20.1
Total	1341.1	

**Source:** Agricultural Meteorologist, Directorate of Agriculture, Government of West Bengal.

**References:**

1. Biswas, S., Sudhakar, S. & Desai V.R. (1999). Prioritisation of subwatersheds based on morphometric analysis of drainage basin: A Remote Sensing and GIS approach. *Journal of Indian Society of Remote Sensing*, 27(3), pp. 155-166.
2. Chopra, K., & Kadekodi, G.K. (1993). Watershed Development: A Contrast with NREP/JRY. *Economic and Political Weekly*, Vol. 28, No. 26, pp. A61-A63+A65-A67.
3. Datta, S. K., & Virgo, K. J. (1998). Towards Sustainable Watershed Development through People's Participation: Lessons from the Lesser Himalaya, Uttar Pradesh, India, *Mountain Research and Development*. Vol. 18, No. 3, pp. 213-233.
4. District Resource Map of Bankura. (2001). Geological Survey of India.
5. Faniran, A. (1968). The Index of Drainage Intensity - A Provisional New Drainage Factor. *Australian Journal of Science*, 31, pp. 328-330.
6. Goudie, A. S. (2004). *Encyclopedia of Geomorphology*. Volume 1, Routledge: London.
7. Horton, R.E. (1932). Drainage Basin Characteristics. *Transactions, American Geophysical Union*, 13, pp. 350-61.
8. Horton, R.E. (1945). Erosional Development of Streams and their Drainage Basins; Hydrophysical Approach to Quantitative Morphology. *Bulletin of the Geological Society of America*, 56, pp-275-370.
9. Jaganathan, R., Chelvaraajhan, K., & Mahaligam, S. (2010). Geomatics Based Assessment on Land use Changes and its Impact over the Groundwater Conditions in a newly developing sub urban area-A Case Study of Southern Chennai. *International Journal of Geomatics and Geosciences*, Volume 1, No.3, pp.271-281.
10. Leopold, L. B., Wolman, M. G., & Miller, J.P. (1964). *Fluvial Processes in Geomorphology*. San Francisco: Freeman.
11. Pal, S. C. & Debnath, G. C. (2012). Morphometric analysis and associated land use study of a part of the Darakeswar watershed, *International Journal of Geomatics and Geosciences*, Volume 3, No. 2, pp.351-363.
12. Panhalkar, S.S., Mali, S.P., & Pawar, C.T. (2012). Morphometric analysis and watershed development prioritization of Hiranyakeshi Basin in Maharashtra, India, *International Journal of Environmental Science*, Vol.3, No.1, pp.525-534.
13. Pareta, K. & Pareta, U. (2011). Quantitative Morphometric Analysis of a Watershed of Yamuna Basin, India using ASTER (DEM) Data and GIS, *International Journal of Geomatics and Geosciences*, Volume 2, No 1, pp. 248-269.
14. Pontius Jr, R.G. & Batchu, K. (2003). Using the Relative Operating Characteristic to Quantify Certainty in Prediction of Location of Land Cover Change in India. *Transactions in GIS*, 7(4), pp. 467-484.
15. Prasad, N. (1985). Determination of Stage of Land Landscape Evolution through Relief Measures, In: editor Kumar, A. *Facets of Geomorphology*. Sarojini Naidu Marg, Allahabad: Thinker Library 1 and C. p.20
16. Read, J.M. & Lam, N.S.N. (2002). Spatial methods for characterizing land cover and detecting land cover changes for the tropics. *International Journal of Remote Sensing*, Vol. 23, No. 12, pp. 2457-2474.
17. Saha, A.K., Arora, M.K., Csaplovics, E., & Gupta, R.P. (2005). Land Cover Classification Using IRS LISS III Image and DEM in a Rugged Terrain: A Case Study in Himalayas. *Geocarto International*, Vol. 20, No. 2, pp.33-40.

18. Scaria, R. & Vijayan P. K. (2012). Sustainable rural development with the application of Spatial Information Technology and Mahatma Gandhi national rural employment guaranteed Scheme, *International Journal of Geomatics and Geosciences*, Volume 2, No 4, pp.1048-1061.
19. Schumm, S.A. (1954). The relation of Drainage Basin Relief to Sediment Loss. *International Association of Scientific Hydrology*, 36, pp. 216-219.
20. Schumm, S.A. (1956). Evolution of Drainage Systems & Slopes in Badlands at Perth Anboy, New Jersey. *Bulletin of the Geological Society of America*, 67, pp. 597-646.
21. Shiva, H. A., & Fleming, B. (2006). A watershed management framework for mountain areas: Lessons from 25 years of watershed conservation in Nepal. *Journal of Environmental Planning and Management*, 49:5, pp.675-694.
22. Shrestha, D.P. & Zinck, J.A. (2001). Land use Classification on in Mountainous Areas: Integration of Image Processing, Digital Elevation Data and Field Knowledge (Application to Nepal). *International Journal of Applied Earth Observation and Geoinformation*, Volume 3, Issue-1, pp. 78-85.
23. Singh, S. (2007). *Geomorphology*. Prayag Pustak Bhawan: Allahabad.
24. Singh, J., and Dhillon, S.S. (1984). *Agricultural Geography*. Tata- McGraw Hill Co: New Delhi.
25. Smith, G.H. (1939). The Morphometry of Ohio: The Average Slope of the Land (abstract). *Annals of the Association of American Geographers*, 29, pp. 94.
26. Strahler, A.N. (1952). Hypsometric Analysis of Erosional Topography. *Bulletin of the Geological Society of America*, 63, pp. 1117-42.
27. Strahler, A.N. (1964). Quantitative Geomorphology of Drainage Basin and Channel Network. *Handbook of Applied Hydrology*, pp 39-76. McGraw-Hill, New York.
28. Summerfield, M .A. (1991). *Global Geomorphology, An introduction to the study of land form*. Pearson Prentice Hall: Singapore.
29. Thakuria, G., Jaiswal, M., & Saikia, R. (2012). Watershed based drainage morphometric analysis of Diyung River, Assam (India) using Geospatial tools. *The Clarion, International Multidisciplinary Journal*, Volume 1, No. 2, pp. 33-34.