Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 7 ~ Issue 1 (2021) pp: 96-104
ISSN(Online) :2348-2532
www.questjournals.org

Research Paper

Quantitative Morphometric Analysis Using Remote Sensing and GIS Techniques

Mitali Hansda
(Department of Geology, Government General Degree College, Gopiballavpur-II, Jhargram, West Bengal, India)

ABSTRACT: *Rapid urbanization has resulted in increased water consumption, leading to an acute shortage of groundwater. In this situation, for the development of regional hydrological models, Remote sensing and GIS are very effective techniques for morphometric analysis leading to the solution of various other hydrological problems. In the present study, morphometric analysis in the Joyponda River basin, Bankura district, West Bengal has been carried out using Remote sensing and GIS techniques. The river basin is a left-hand tributary of the Shilabati River flowing through four blocks of the Bankura district of West Bengal. The basin covers an area of 396.47 km^2. For a detailed study, Shuttle Radar Topographic Mission (SRTM) was used for delineating basin boundaries using GIS software. and GIS technique was also used to determine linear, areal and relief aspects of morphometric parameters. As revealed by present morphometric studies, it can be stated that the erosional development of the basin by the stream has progressed beyond maturity and drainage development was to some extent dependent upon the lithology of the basin. Studies so far can be beneficial for watershed management and suitable planning for rainwater harvesting. They can also help the local population for optimum utilization of resources leading to the sustainable development of the basin.*
KEYWORDS: *Morphometric Parameters, SRTM, Remote sensing and GIS.*

Received 18 Dec, 2020; Revised: 05 Jan, 2021; Accepted 12 Jan, 2021 © The author(s) 2021. Published with open access at www.questjournals.org

I. INTRODUCTION

Morphometry being the science of measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms [1]. Morphometric analysis of any basin or watershed helps to formulate a quantitative description of the drainage system such as geology, geomorphology, slope, rock hardness, structural controls etc which are essential for the characterization of a basin or watershed [2]. Therefore, it is essential for hydrological investigations of any basin or watershed and subsequent management [3]. The development of quantitative physiographic methods helps to describe the evolution and behavior of surface drainage networks and also provides useful clues to understanding basin geometry [4,5]. Remote sensing methods with satellite images are an effective tool to carry out morphometric analysis. Overall view of a large area can be observed with satellite remote sensing and can be utilized to analyze drainage morphometry. To arrive at a valuable interpretation with ground surveys and field checks is much more time consuming compared to the image interpretation techniques.

II. DESCRIPTION OF THE STUDY AREA

The area of study, the Joyponda River, a left-hand tributary of the Shilaboti River lies in the Bankura District of West Bengal, bearing coordinates 22^{0}53′33.87″N to 23^{0}10′31.68″ N and 86^{0}50′56.035″E to 87^{0}12′52.68″ E which constitute approximately the basin area of 396.47 km^2 and perimeter being 143.94 km. It originates from the Indpur block of Bankura district, West Bengal. Then the river runs from NW to SE direction through Indpur, Onda, Taldangra and Simlapal blocks of Bankura district and meets the Shilaboti River at Chakrasol village of Simlapal block. Accompanying Figure 1 represents the area of study and drainage pattern where the morphometric process of the catchment area has been analyzed at the basin level. The river's total length is 62.38km with an elongated shaped basin. The basin under investigation experiences a subtropical climate with low rainfall and high evaporation. Temperature in summer is extremely high and becomes low in winter and this variation causes dryness in this area. Rainfall recorded is more or less 1400 mm [6]. Pre-Cambrian metamorphic rocks of Chotangpur Granite Gneissic Complex and older alluvium mainly comprise the basin area [7]. The upper part of the basin appears to be more undulating which could be due to the presence of a pediment-peneplain complex [8]. Because of the low retention capacity of the soil and semi-arid dry climate along with the presence of hard crystalline rock, most of the water is drained, consequently, there is an intense deficiency of surface water [9].

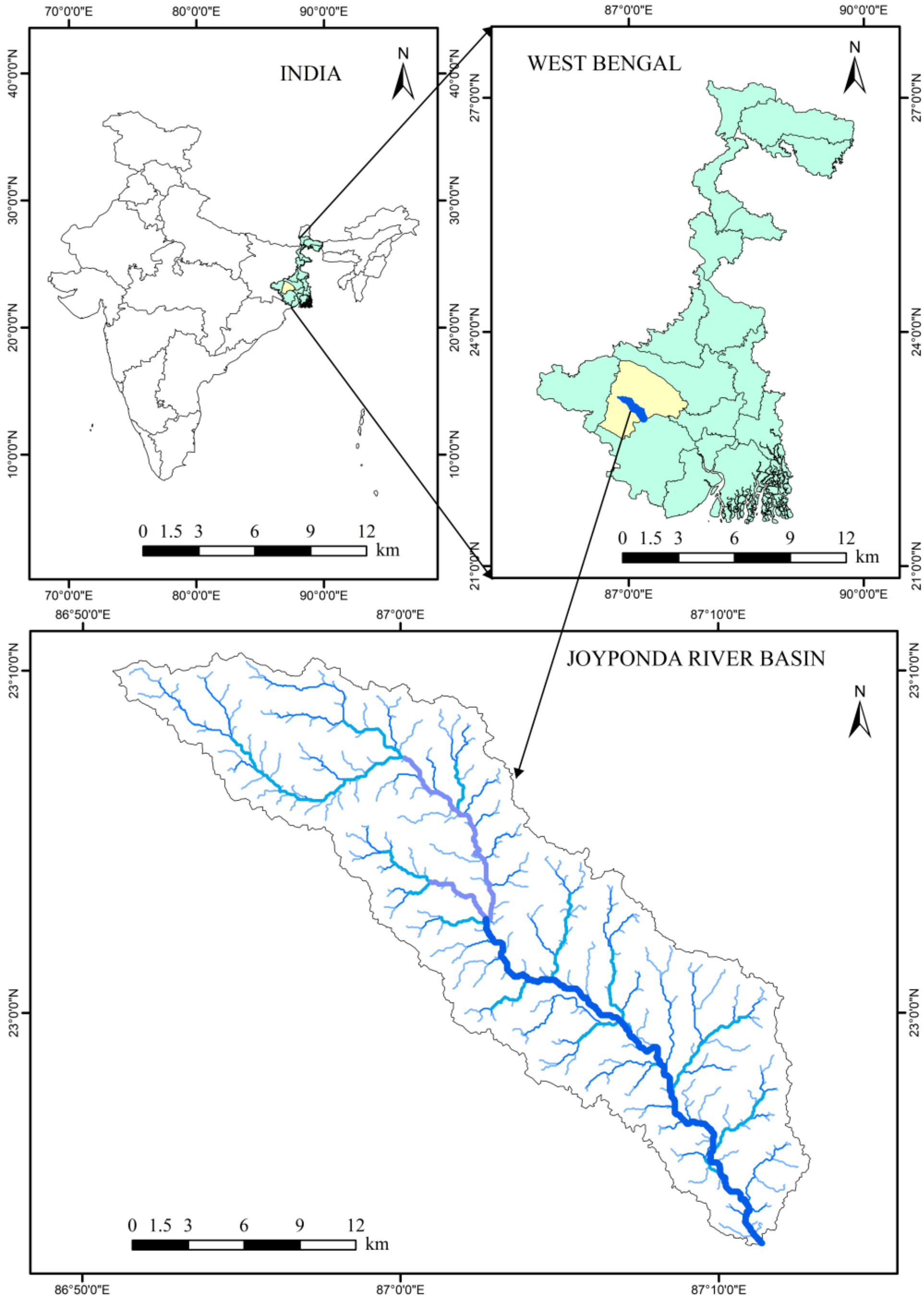


Figure 1. Location Map of Joyponda River Basin

III. SOURCE OF DATA AND METHODOLOGY

Water scarcity is very much prevalent in the present study area and topographical maps along with satellite remote sensing data have been used for updating drainage and updated drainages are subsequently used for morphometric analysis. The topographical map and the drainage network map of the basin have been prepared for this study using Survey of India (SOI) topographic sheets on the 1:50,000 scale. After geometrical rectification and mosaicking with the help of GIS software, the study area has been extracted by joining streams that are of first order to the river outlet. The basin demarcation and digitization of dendritic drainage patterns have been prepared by GIS software. For preparing the digital elevation model (Figure 2), the SRTM (30m resolution) DEM data were also used for this study. With the help of GIS software and standard formulas, different morphometric parameters have been calculated in this study (Table 1).

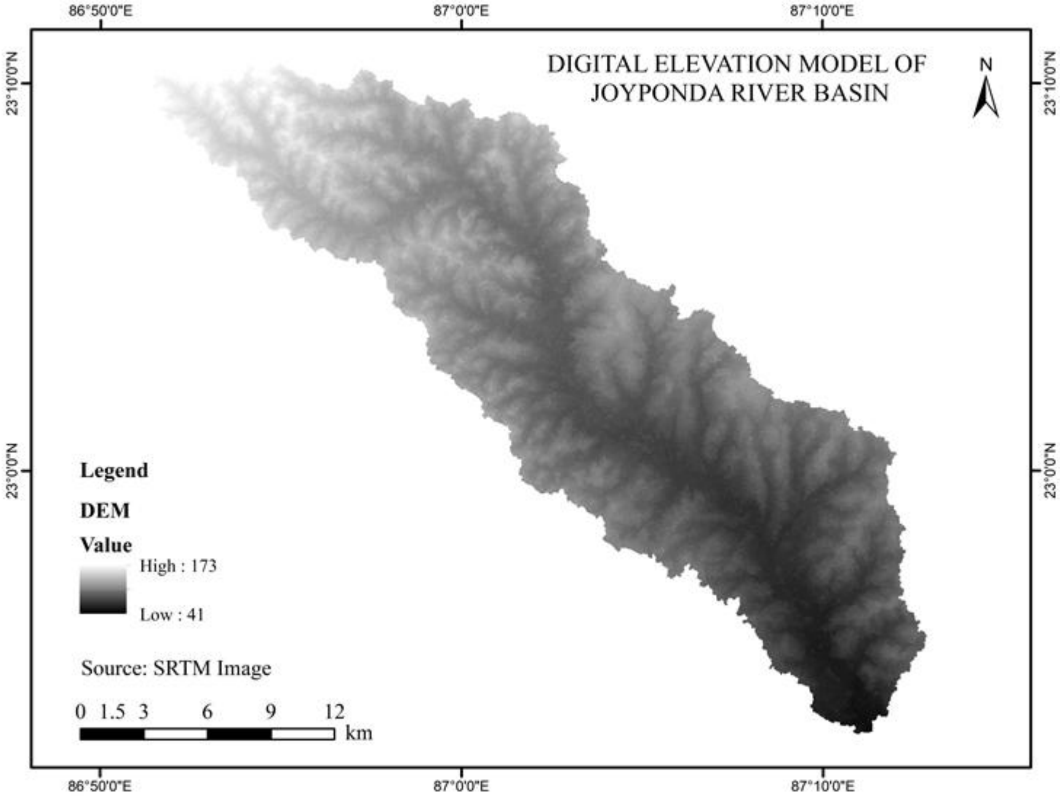


Figure 2. Digital Elevation Map (DEM) of Joyponda River Basin.

IV. RESULTS AND DISCUSSION

Based on the studies of eminent scientists, morphometric analysis of drainage basin and channel networks was made from qualitative and deductive studies [10-14]. Basins can be analyzed either as a single unit or a group of units that form a distinct morphological region having relevance to geomorphology [15]. Measurements of linear features, gradients of channel networks and contributing ground slopes of the basin area comprise of quantitative description of morphometric analysis. Here, an attempt has been made to relate the statistical parameters of the said drainage basin features. All the parameters in the Joyponda River basin have been grouped into linear, areal, and relief parameters respectively.

4.1 LINEAR PARAMETERS

4.1.1 Stream Order (Su)

Designation of stream orders is the first step in the morphometric analysis of a drainage basin and it is based on a hierarchic ranking of a stream. Stream orders for a stream network can be determined by different methods [2,4]. The smallest tributary is marked as order 1 and a segment of order 2 is formed where two first-order tributaries meet; similarly, a segment of order 3 is formed where two second-order tributaries join; and it goes on [2]. The main stream which carries all discharge of water and sediment forms the stream segment with the highest order. In this present study, the Joyponda River basin is the 5th (V) order drainage basin through which all the discharge of water and sediment passes (Figure 3). As the stream order increases it has been observed that there is a decrease in stream frequency. The physiographic and geological condition of the basin is responsible for variation in stream order.

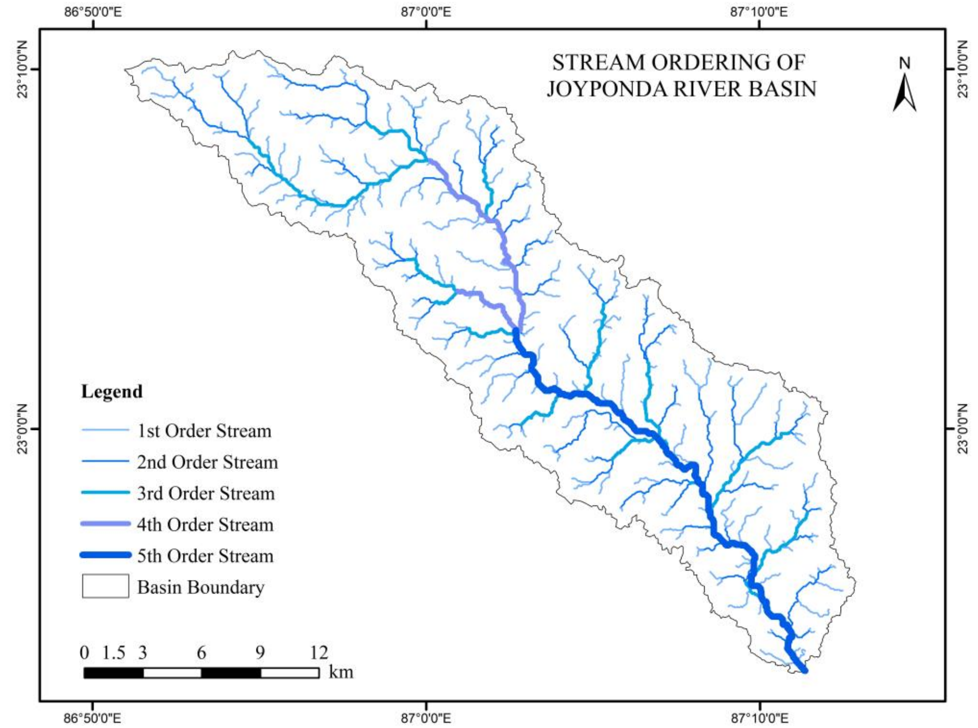
4.1.2 Stream Number (Nu)

Stream number comprises the number of stream segments of any particular order in a basin. The stream order and the stream number of any particular order are geometrically inversely related [4]. The total stream numbers and 'Nu' of each order in the Joyponda basin were determined with the help of GIS software (Table 1).

The total number of streams in the study area is 337, of which 260 streams are first order, second, third, fourth and fifth order streams are 60,14,2,1 respectively.

4.1.3 Stream Length (Lu)

The most significant hydrological feature of the basin is stream length as it shows surface runoff characteristics. Streams having relatively short lengths indicate steep gradients with finer textures and streams with longer lengths represent gentle gradients [2]. The total stream length of the Joyponda River under various orders is



calculated with the help of GIS software. Here, the total stream length is 442.85 km (Table 1)

Figure 3. Stream Order of Joyponda River Basin.

4.1.4 Stream Length Ratio (Lur)

The stream length ratio (Lur) is defined as the ratio of the average length segment of any order to the average length segment of the next lower order, which, in a basin or watershed, remains constant for successive orders [4]. Variations in stream length ratio 'Lur' between orders suggest their late youth stage of geomorphic development [16,17]. Here, it is computed that the 'Lur' differs from 0.94-10.79 and also observed that the 'Lur' between consecutive stream orders of the basin varies because of differences in gradient and topographical characteristics [18-21].

4.1.5 Bifurcation Ratio (Rb)

The bifurcation ratio (Rb) is defined as the ratio between the total number of streams of one order to that of the next higher order in a drainage basin [2]. It is a dimensionless property of drainage basin and is dependent on drainage density, stream entrance angle, lithological characteristics, basin shapes, basin areas etc [4]. High values of the Rb denote strong structural control on drainage pattern whereas low values suggest that the basin has suffered less structural disturbance and the drainage pattern has not been distorted [22]. The shape of the basin is indicated to some extent by the bifurcation ratio. Generally, it is found that an elongated basin is likely to have a high bifurcation ratio and a circular basin is most likely to exhibit a low bifurcation ratio. The Rb value of the basin ranges from 2 to 7.

4.1.6 Weighted Mean Bifurcation Ratio (Rbwm)

The weighted mean bifurcation ratio (Rbwm) is an index of the more indicative bifurcation ratio for each successive pair of orders, which is obtained by multiplying the bifurcation ratio for each successive pair of stream orders by the total number of streams involved in the ratio and then dividing the sum of these values by the sum of the total number of stream segments involved in each pair [23]. The effects of geological structures on the drainage networks are not so prominent as shown by Weighted Mean Bifurcation Ratio (Rbwm) [20]. The value of Rbwm in the basin is 4.41 (Table 1).

4.1.7 Length of Main Channel (Cl)

The length along the longest watercourse from the outflow point of the basin to the uppermost basin boundary is treated as the length of the main channel (Cl) and the same has been computed with the help of GIS software, which is 62.38 km (Table 1)

4.1.8 Rho coefficient (*ρ*)

The 'Rho' coefficient (*ρ*) is a characteristic parameter that relates drainage density to the physiographic growth of a basin which helps the evaluation of the storage ability of the drainage network because of the ultimate degree of drainage development in a given river basin [4]. The climatic, geological, biological, geomorphological, and anthropogenic factors are responsible for the changes in this parameter. The *ρ* value of the basin is 1.10 (Table 1) and signifying that it has higher hydrologic storage in floods period.

4.2 AREAL PARAMETERS

4.2.1 Basin Area (A)

Basin area is an important basin characteristic for hydrologic design and provides the volume of water that can be produced from rainfall [24]. The basin area has been calculated by the GIS software, is 396.47 km^2 (Table 1).

4.2.2 Basin Perimeter (P) and Basin Width (W)

The outer boundary of the basin that encloses its area is termed as basin perimeter (P). The Perimeter of the basin has been calculated with the help of GIS software which is about 143.94 km (Table 1).

4.2.3 Length of the Basin (Lb)

The length of the Basin (Lb) is defined by the lengthiest dimension of the basin considered parallel to the predominant drainage line [25]. It starts from a basin mouth to a point on the basin perimeter which rests furthest from the outlet. It is the essential input parameter as it has been used to count the major basin shape parameters. Here, the length of the basin is 46.17 km (Table 1).

4.2.4 Length area relation (Lar)

In the case of numerous basins, the stream length and basin area are associated by a simple power function as follows: $Lar = 1.4*A^{0.6}$ [26]. Using this relation, it has been found that the 'Lar' of the basin is 50.71 (Table 1).

4.2.5 Lemniscate's (k)

The Lemniscate's (k) value is used to measure the slope of the basin [27]. The Lemniscate's (k) value for the Joyponda River basin is 5.38 (Table 1). It is suggested that the basin covers the maximum area in its regions of inception with a large sum of streams of higher order.

4.2.6 Form factor (Ff)

Form factor (Ff) is defined by the ratio of the basin area to the square of the basin length and is used to interpret the intensity of a basin of a defined range [4,28]. The value of the form factor would always be less than 0.754 (for a perfectly circular basin). If the value of the form factor of the basin is low then the basin will be more elongated and indicates lower peak flows of longer duration whereas the high form factor of the basin shows high peak flows of shorter duration. The 'Ff' of the basin is 0.19 which represents no rapid peak discharge at the outlet (Table 1).

4.2.7 Elongation ratio (Re)

The ratio of the diameter of a circle of the same area of the basin to the maximum basin length is termed the Elongation ratio (Re) [25]. It has been observed that a circular basin is more effective in runoff discharge than an elongated basin [16,17]. The value of the elongation ratio (Re) varies between 0.6 to 1.0 over an extensive variation of climatic and geologic types. The elongation value can be classified into different categories, namely, circular basin (0.9–0.10), oval basin (0.8–0.9), less elongated basin (0.7–0.8), elongated basin (0.5–0.7), and more elongated basin (< 0.5). The elongation ratio 'Re' of the basin is 0.49, which represents the basin is more elongated in shape (Table 1).

4.2.8 Texture ratio (Rt)

The texture ratio (Rt) is defined by the ratio of the first order streams to the basin perimeter and it depends on the underlying lithology, infiltration ability and relief aspect of the topography [25]. The textural ratio (Rt) of the basin is 1.81 (Table 1).

4.2.9 Circularity ratio (Rc)

The circularity ratio (Rc) is described by the ratio between the basin area (A) and the area of a circle having the same perimeter (P) of the basin [2,29]. It depends on the geology, structure, relief, slope, climate, stream frequency and length of the basin area. The Circularity ratio (Rc) of the basin is 0.24 (Table 1).

4.2.10 Drainage texture (Dt)

The drainage texture (Dt) is defined as the ratio of the total stream number of all orders to the perimeter (P) of the basin. It depends on vegetation, climate, rock and soil type, infiltration ability, relief and stage of development [4]. The drainage texture has been grouped into five different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8) [30]. Here, the drainage texture (Dt) of the basin is 2.34 (Table 1) which indicates that the basin has a coarse drainage texture.

4.2.11 Compactness coefficient (Cc)

The compactness coefficient (Cc) can be described as the basin perimeter divided by the circumference of a circle to the same area of the basin [4]. It is indirectly correlated with the elongation of the basin area. Lower values of the Compactness coefficient (Cc) represent the basin showing more elongation with less erosion, whereas higher values of the Compactness coefficient (Cc) indicate less elongation of the basin and high erosion. The Compactness coefficient (Cc) of the basin is 0.17 (Table 1).

4.2.12 Fitness ratio (F)

Fitness ratio (F) is the ratio between the main channel length of the basin and the length of the basin perimeter, which is also a measure of topographic fitness [13]. The fitness ratio (F) of the basin is 0.43 (Table 1).

4.2.13 Stream Frequency (Fs)

The ratio between the total number of stream segments of all order and the area of that basin is known as the stream frequency (Fs) or channel frequency [31]. It mainly depends on the lithology of the basin and the texture of the drainage network. The Stream Frequency (Fs) of the basin is 0.85 which indicates that the increase in stream population is associated with that of drainage density (Table 1).

4.2.14 Drainage Density (Dd)

The ratio between the total lengths of streams in the basin and the area of that basin is termed drainage density (Dd). It is described as the closeness of the spacing of channels [4,23,32]. Drainage density is used to study the linear scale of landform elements in stream eroded topography, although a function of climate, lithology and relief of the area has been used as an indirect indicator to describe, those variables as well as the morphogenesis of landform. The drainage density (Dd) of the basin is 1.12 Km/Km^2 (Table 1). It is suggested that the value of 'Dd' indicates the basin is a moderately permeable sub-soil and thick vegetation area [22].

4.2.15 Drainage intensity (Di)

The drainage intensity (Di) is described by the ratio between the stream frequency and the drainage density of the basin [33]. Here, the Joyponda River basin shows a low drainage intensity (Di) which is 0.73 (Table 1). It indicates that the surface runoff is not quickly removed from the basin.

4.2.16 Constant of channel maintenance (C)

It is the inverse of drainage density or the constant of channel maintenance as a feature of landforms [25]. The comparative size of the landform unit of any drainage basin can be identified with its help [12]. It is mainly dependent on lithology, rock permeability, climatic regime, vegetation, relief feature, duration of erosion and climatic history. The Channel maintenance constant (C) of the basin is 0.86 Km^2/Km (Table 1).

4.2.17 Infiltration number (If)

The infiltration number (If) of a basin is designated as the product of drainage density and stream frequency. It gives an idea about the infiltration properties of the basin. The infiltration number (If) of the basin is 0.99 (Table 1). It is suggested that the value of 'If' indicates the low infiltration capacity and causes flooding during the rainfall season [34].

4.2.18 Length of Overland Flow (Lg)

The length of water flowing over the ground surface before entering into the definite stream channel is known as the length of overland flow (Lg) [4]. Here, the length of overland flow (Lg) is 0.43 Km (Table 1).

*Corresponding Author: Mitali Hansda

4.3 RELIEF PARAMETERS

4.3.1 Total Basin Relief (H)

The difference in elevation between the highest point and the lowest point on the valley floor is called total basin relief (H) [25]. The characteristic of the drainage system is indicated by the basin relief [35]. Here, the total basin relief (H) is 132m (Table 1).

4.3.2 Relief ratio (Rhl)

The ratio between the total relief in a basin and its longest measurement parallel to the drainage line is called the Relief ratio ‘Rhl’ [25]. Assuming a close relationship between the Relief ratio ‘Rhl’ and the hydrologic properties of a basin it has been observed that sediment lost per unit area is closely connected with the relief ratio [36]. It reflects the overall gradient of a particular basin and can identify its erosional intensity. The relief ratio is generally higher with decreasing drainage area and size. In the study area, the ‘Rhl’ is 0.003 (Table 1). A moderate value of relief ratio indicates areas having low to moderate relief and a low Relief ratio represents the possibility of resistant basement rocks and lower basin gradient [36].

4.3.3 Absolute Relief (Ra)

It is the actual height of a place concerning mean sea level. The river basin’s absolute relief (Ra) is 173m (table 1).

4.3.4 Dissection Index (Dis)

The dissection index characterizes the degree of dissection or vertical erosion and helps to understand the stages of terrain or landscape development in any given physiographic region or basin [37]. The value of the dissection index ranges between 0 to 1 and the higher value of the dissection index indicates the undulation and instability of the terrain under investigation. The dissection index (Dis) of the river basin is 0.763 (Table 1), indicating this to be moderately dissected.

4.3.5 Watershed Slope (Sw)

The ratio between the total basin reliefs (H) divided by basin length (Lb) is known as the watershed slope (Sw). The watershed slope (Sw) calculated value is 0.003 (Table 1).

4.3.6 Ruggedness Number (Rn)

The ruggedness of terrain is a property of the landscape enumerating the terrain’s complexity and roughness [38]. More rugged landscapes generally exhibit a greater complexity with rough and uneven surfaces. The ruggedness number in the Joyponda River basin is 0.15 indicating the basin is less prone to soil erosion with inherent structural complexity along with relief and drainage density (Table 1).

Table 1: Morphometric analysis of Joyponda River Basin

Sl.No.	Morphometric Parameters	Formula	Reference	Result
		LINEAR PARAMETERS		
1	Stream Order (Su)	Hierarchical rank	Strahler (1952)	1-5
2	Stream Number (Nu)	Nu=N1+N2+N3…Ln	Horton (1945)	337
3	Stream Length (Lu) km	Lu=L1+L2+L3…Ln	Strahler (1964)	442.85
4	Stream length ratio (Lur)		Strahler (1964)	0.94-10.79
5	Weighted mean stream length ratio (Luwm)		Horton (1945)	2.46
6	Bifurcation Ratio (Rb)	Rb=Nu/Nu+1	Schumm (1956)	2-7
7	Weighted Mean Bifurcation Ratio (Rbwm)		Strahler (1964)	4.41
8	Main Channel Length (Cl) km	GIS Analysis	-	62.38
9	Rho Coefficient (ρ)	ρ = Lur / Rb	Horton (1945)	1.10
10	Basin Length (Lb) Km	GIS Analysis	-	46.61
		AREAL PARAMETERS		
11	Basin Area (A) km^2	GIS Analysis	-	396.47
12	Basin Perimeter (P) km	GIS Analysis	-	143.94
13	Mean Basin Width (Wb) Km	Wb = A / Lb	Horton (1932)	8.59
14	Length Area Relation (Lar)	$Lar = 1.4 * A^{0.6}$	Hack (1957)	50.71
15	Lemniscate’s (k)	$k = Lb^2 / A$	Chorley (1957)	5.38
16	Form Factor (Rf)	$Ff= A/Lb^2$	Horton (1932)	0.19
17	Elongation Ratio (Re)	$Re = 2 / Lb * (A / \pi)^{0.5}$	Schumm (1956)	0.49
18	Texture Ratio (Rt)	Rt = N1 / P	Schumm (1956)	1.81
19	Circularity Ratio (Rc)	$Rc = 12.57 * (A / P^2)$	Miller (1953)	0.24
20	Drainage Texture (Dt)	Dt = Nu / P	Horton (1945)	2.34

21	Compactness Coefficient (Cc)	$Cc = 0.2821 * (P / A)^{0.5}$	Horton (1945)	0.17
22	Fitness Ratio (F)	Rf = Cl / P	Melton (1957)	0.43
23	Stream Frequency (Fs)	Fs = Nu / A	Horton (1932)	0.85
24	Drainage Density (Dd) Km / Km^2	Dd = Lu / A	Horton (1932)	1.12
25	Drainage Intensity (Di)	Di = Fs / Dd	Faniran (1968)	0.73
26	Constant of Channel Maintenance Km^2 / Km	C = 1 / Dd	Schumm (1956)	0.86
27	Infiltration Number (If)	If = Fs * Dd	Faniran (1968)	0.99
28	Length of Overland Flow (Lg) km	Lg = 1/ Dd*2	Horton (1945)	1.79
RELIEF PARAMETERS				
29	Height of Basin Mouth (z) m	GIS Analysis	-	41
30	Maximum Height of the Basin (Z) m	GIS Analysis	-	173
31	Total Basin Relief (H)	H = Z – z	Strahler (1952)	132
32	Relief Ratio (Rhl)	Rhl = H / Lb	Schumm (1956)	0.003
33	Absolute Relief (Ra) m	GIS Analysis	-	173
34	Dissection Index (Dis)	Dis = H / Ra	Singh and Dubey (1994)	0.763
35	Watershed Slope (Sw)	Sw = H / Lb	-	0.003
36	Ruggedness Number (Rn)	Rn = Dd * (H /1000)	Patton and Baker (1976)	0.15

V. CONCLUSION

The present study so far made reveals that morphometric parameters that define basin geometry, basin shape, stream length, stream network topology and topographic dissection along with stream number and basin relief can easily be obtained with the help of Remote sensing and GIS techniques. By measuring linear, areal and relief parameters of the basin, morphometric analysis was carried out. Morphometric parameters of the basin show a wide range of variation, both geologically and structurally as it belongs to the Chotanagpur plateau. The basin is elongated with medium relief, as revealed from overall morphometric studies. It also shows that the drainage network of the basin is of a dendritic and sub-dendritic pattern with a coarse drainage texture. Changes in slope and topography may also be responsible for variations in stream length ratio and the high bifurcation ratio in the basin suggests that the drainage of the basin is influenced by structural disturbances. Low drainage density in the basin indicates that it has high soil permeability. The overall study can be utilized for better watershed management, management of soil erosion even micro level watershed management, water conservation and natural resource management. This work can be utilized in the evaluation of basin hydrology, water resources and study of the hydrologic cycle and it may also open avenues of further work regarding groundwater storage, recharge rate and aquifers etc.

REFERENCES

[1]. Clarke J. I. (1966). Morphometry from Maps. Eassys in Geo- morphology, Elsevier Publishing Company, New York, pp. 235-274.
[2]. Strahler A.N. (1964). Quantitative geomorphology of drainage basin and channel network. Handbook of Applied Hydrology, McGraw Hill Book Company, New York, pp 39-76.
[3]. Magesh N.S. (2011). Chandrasekar N. & Soundranayagam J.P. Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. Environmental Earth Science, 64:373-381.
[4]. Horton R.E. (1945). Erosional Development of Streams and their Drainage Basins, Bulletin of the Geological Society of America, 56, pp-275-370.
[5]. Abrahams A.D. (1984). Channel networks: a geomorphological perspective. Water Resour Res 20:161–168.
[6]. Government of West Bengal (2014). District statistical handbook, Purulia. Bureau of Applied Economics and Statistics, Kolkata.
[7]. Vaidyanadhan R. & Ghosh R.N. (1993). Quaternary of the East Coast of India. Current Science 64:804–816.
[8]. Sen A., Das B. & Nandi M. (1998). Tectono – stratigraphic studies of the supracrustal rocks at the southern contact of the Chhotanagpur granite gniess with proterozoic mobile belt in Bankura and Purulia districts, West Bengal extending upto the northern flank of the Dalma volcanics. Geological Survey of India, Government of India, New Delhi.
[9]. Maity D.K. & Mandal S. (2017). Identification of groundwater potential zones of the Kumari river basin, India: an RS & GIS based semi-quantitative approach. Environ Dev Sustain 21:1013–1034.
[10]. Horton R.E. (1945). Erosional development of streams and their drainage basins hydrophysical approach to quantitative morphology. Bull. Geol. Soc. Am., 56: 275-370.
[11]. Leopold L.B. & Miller J.P. (1956). Ephimeral streams: Hydraulic factors and their relation to the drainage net. U.S. Geol. Surv., Paper, 282-A.
[12]. Strahler A.N. (1957). Quantitative analysis of watershed geomorphology". Trans. Am. Geophys. Union., 38: 913-920.

[13]. Melton M.A. (1957). An analysis of the relations among elements of climate, surface properties and geomorphology. Proj. NR 389-042, Tech. Rep. 11, Columbia University, Department of Geology, ONR, New York.
[14]. Morisawa M.E. (1959). Relation on morphometric properties to runoff in the Little Mill Creek, Ohio, drainage basin. Tech. Rep. 17, Columbia University, Department of Geology, ONR, New York.
[15]. Doornkamp J.C. & Cuchlaine A.M.K. (1971). Numerical analysis in Geomorphology – An Introduction. Edward Arnold, London, pp. 3-20.
[16]. Singh P., Gupta A. & Singh M. (2014). Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques. Egypt J Remote Sens Space Sci 17:111–121.
[17]. Rai P.K., Mohan K., Mishra S., Ahmad A. & Mishra V. (2014). A GIS based approach in drainage morphometric analysis of Kanhar river basin, India. Appl Water Sci.
[18]. Sreedevi P.D., Subrahmanyam K. & Ahmed S. (2005). Integrated approach for delineating potential zones to explore for groundwater in the Pageru River basin, Cuddapah District, Andhra Pradesh, India. Hydrogeol J 13:534–545.
[19]. Magesh N.S., Jitheshlal K.V., Chandrasekar N. & Jini K.V. (2012). GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala, India. Earth Sci Inform 5:111–121.
[20]. Magesh N.S., Jitheshal K.V., Chandrasekar N. & Jini K.V. (2013). Geographical information system based morphometric analysis of Bharathapuzha river basin, Kerala, India. Appl Water Sci 1–11.
[21]. Magesh N.S. & Chandrasekar N. (2014). GIS model-based morphometric evaluation of Tamiraparani sub-basin, Tirunelveli district, Tamil Nadu, India. Arab J Geosci 7:131–141.
[22]. Nag S. K. (1998). Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal, Journal of the Indian society of remote sensing, 26(l&2), pp 69-76.
[23]. Strahler A.N. (1952). Hypsometric Analysis of Erosional Topography. Bulletin of the Geological Society of America, 63, pp. 1117-42.
[24]. Pal S. C. & Debnath G. C. (2012). Morphometric analysis and associated land use study of a part of the Darakeswar watershed, International Journal of Geometics and Geosciences, Volume 3, No. 2, pp.351-363.
[25]. 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.
[26]. Hack J.T. (1957). Studies of longitudinal stream profiles in Virginia and Maryland. U.S. Geol. Survey Prof., Paper 294-B.
[27]. Chorley R.J. (1957). Illustrating the laws of morphometry. Geological Magazine, 94:140-150.
[28]. Sreedevi P.D., Sreekanth P.D., Khan H.H. & Ahmed S. (2013). Drainage morphometry and its influence on hydrology in a semi-arid region: using SRTM data and GIS. Environ Earth Sci 70(2):839–848.
[29]. Miller V.C. (1953). A quantitative geomorphic study of drainage basin characteristics on the Clinch Mountain area, Virginia and Tennessee, Project NR 389-402. In: Technical report 3. Department of Geology, ONR, Columbia University, New York.
[30]. Smith K.G. (1950). Standards for grading textures of erosional topography. Am J Sci 248:655–668.
[31]. Horton R.E. (1932). Drainage basin characteristics. Transaction Americam Geophysical Union, 13:350-61.
[32]. Melton M.A. (1965). The geomorphic and paleoclimatic significance of alluvial deposits in Southern Arizona. Journal of Geology, 73:1–38.
[33]. Faniran A. (1968). The index of drainage intensity - a provisional new drainage factor. Australian Journal of Science, 31:328-330.
[34]. Bhatt S. & Ahmed S.A. (2014). Morphometric analysis to determine floods in the Upper Krishna basin using Cartosat DEM. Geocarto Int 29(8):878–894.
[35]. Samal D.R., Gedam S.S. & Nagarajan R. (2015). GIS based drainage morphometry and its influence on hydrology in parts of Western Ghats region, Maharashtra, India. Geocarto Int 30(7):755–778.
[36]. Rai P.K., Chandel R.S., Mishra V.N. & Singh P. (2018). Hydrological inferences through morphometric analysis of lower Kosi river basin of India for water resource management based on remote sensing data. Applied Water Science 8:1-16.
[37]. Singh S. & Dubey A. (1994). Geoenvironmental planning of watershed in India. Chugh Publications, Allahabad, pp 28–69.
[38]. Goudie A. S. (2004). Encyclopedia of Geomorphology. Volume 1, Routledge: London.