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RS-GIS based Morphometric Analysis and Hydro-geomorphic Assessment of Rasulpur River Basin over Fluvio-coastal West Bengal

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Abstract:

Introduction: Drainage basin analysis based on morphometric parameters and indices is very important for the planning and development of any basin landscape. Morphometry is the measurement and mathematical analysis of landforms. *Morphometric analysis* is the best way to recognize the association and relationship of different facets in the basin/ watershed. Objectives: The end of the study is to compute and analyze the morphometric parameters and indices of Rasulpur river basin to assess its morphological and hydrological state and status and to read the basin landscape. Methods and Methodology: *RS-GIS-GPS based inspection* and linear, areal and relief based morphometric analysis have been the efficient tool and technique in this quantitative assessment. Structural form, morphometric, geometric and fluviometric analysis show statistical investigation, mathematical quantification and specific or overall estimation of various parameters of the basin. Findings: This basin is one of the important fluvio-coastal landscapes over South Bengal Basin whereas its recent morphometric quantification with proper theoretical approaches, mathematical doctrine and statistical and GIS software reflects the late mature to early old status on the evolutionary track of its hydro-morphological life cycle influenced by adjoined river Hooghly and Bay of Bengal. Application and Relevance: This study provides a scientific documentation and data book relating morphometric setting, fluviometric behavior, geometric response, hydrological status and landscape potentiality of the basin which may be helpful and applicable for its planning, development and management in terms of *landscape sustainability* alongwith further scope of research over time.

Keywords: *Rasulpur Basin, morphometric analysis, RS-GIS-GPS based inspection, hydro-morphological life cycle* and *landscape sustainability.*

I. Introduction

Morphometry is the measurement and mathematical analysis of the configuration of earth's surfaces, shape and dimension of its landforms. Drainage morphometry is defined as a measurement of linear, areal and relief characteristics of any drainage basin [4]. Drainage morphometry was first initiated by Horton [17]. The drainage morphometric characteris- tics are important to understanding the underlain structure. geomorphological formations and hydrological characteris- tics of any basin [29]. The relationship between drainage morphometric parameters to its underlain geology, geomorphology and hydrological characteristics is established through the work of different geologist and geomorphologist [54] [3]. Morphometry in simple term means the measurement of a shape or geometry [59]. Morphometry is not only related to the measurement but also to the mathematical analysis of the earth's surface configuration and dimensions of landforms [15]. Horton (1945) initiated the use of quantitative approaches in fluvial geomorphology to study the stream system of the drainage basin [16]. The entire area that collects the rainwater and contributes it to a particular channel is known as the drainage basin or catchment area [21]. River basins have special relevance to drainage pattern and geomorphology and consist of distinct morphologic regions [13]. Morphometric parameters comprises the form and structure characteristics of drainage basin and their associated drainage networks [10]. The

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morphometric characteristics of a watershed may reveal information regarding its formation and development because the hydrologic and geomorphic processes take place within the watershed [37].

There are several morphometric parameters and indices which are valuable in thoughtful the processes shaping the morphology of the basin. The most important factor is the basin shape which exerts a control over the geometry of the stream network. Circularity ratio, elongation ratio, form factor ratio and compactness coefficient are used to determine the shape of the basin [6]. GIS is a significant tool, which has the potential to give rapid and accurate analysis of the spatial information and is used to determine the characteristics of the watershed. Morphometric factors represent relatively simple approaches to describe the drainage basin processes and to compare the drainage basin characteristics [5] [13] [19] [20] [33] [34] [38] [46] [53] [59].

The purposeof the present study is to investigate the linear, aerial and relief morphometric parameters of the Rasulpur Basin. It is an attempt to understand the nature of the basin and to use it as an important tool for future planning and development of this basin landscape. The structural properties, drainage geometry, basin morphometry and fluviometry may be way to make the outline for management of any physical, geomorphological, environmental and landscape issue evolved in this technocentric era. In, on and for this river basin, there is not any significant study or research relating its geomorphological, hydrological, environmental, landscape based or eco-anthropogenic aspects or dimensions. Hence, there is observed the acute crisis of sufficient data or information for research or development purposes from academic or administrative platforms. Here, lies the essence of this study also.

II. About the Study Area

The study area, Rasulpur River basin is the intermediate part of Purba Medinipur Coast in between Pichhabani and Haldi River basins. About 40km east from Digha town to near Nij Kasaba(Khejuri), is Rasulpur river which opens onto the Hooghly estuary facing on the beginning stretch of Bay of Bengal. The Rasulpur River is a tributary of the Hooghly River. The Rasulpur flows through Paschim Medinipur and Purba Medinipur districts. It flows as Bagda River until Kalinagar and then flows as Rasulpur River upto its mouth met with River Hooghly and Bay of Bengal. Its tributaries are Kunjapur-Gorahar-Dekhali channel, Itaberia channel, Mugberia channel and Palabani channel. It joins the Hooghly shortly after Kaukhali lighthouse at the opposite of Sagar Island in South 24-Parganas. From the consideration of Basin Morphology of South Bengal, the most of the coastal stretch of Purba Medinipur is included of Rasulpur Basin enclosed by Kangsabati Basin in the north and Pichhabani and Subarnarekha Basins in the west and south-west. Administratively, Rasulpur basin covers entire or partial extension of Egra-I and II, PotashpurI and II, Bhagwanpur-I and II , Contai-I and III, Deshapran, Khejuri – I and II, Mohanpur, Dantan-I and II and Sabang CD Blocks along with Contai and Egra municipalities of Purba Medinipur District. Geographically this coast line contains a distinct geomorphic and biochemical diversity in respect of landforms, soil texture, fluvio-coastal plants, animals and other resource base. The latitudinal and longitudinal stretch of the study area is about 21°40'21"N to 22°10'01"N and 87°23'48"E to 88°00'24.29"E respectively.

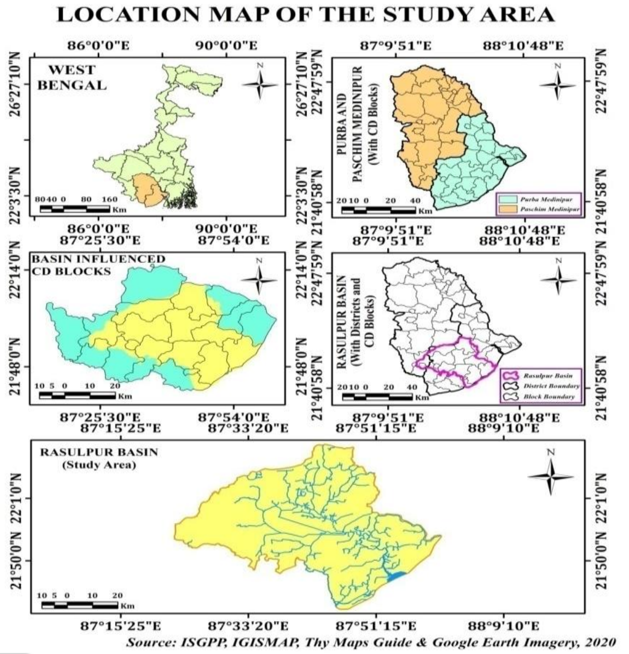

Figure 1: Location of the Study Area, Rasulpur Basin

III. Objective

The main objective of this study is the estimation of various morphometric parameters and indices to read the hydro-geomorphic set up, fluviometric behavior and structure-process response of Rasulpur river basin.

IV. Materials, Methods and Methodology

Table 1: Stage wise Methods, Tools and Techniques					
Stage -I		Stage - II		Stage -III	
Preparatory Phase		Collecting Phase		Processing & Analysis Phase	
Planning	Reviewing	Construction of Techniques and Tools for Data Collection & Pilot Study	Data Collection	Data Processing	Data Analyzing & Interpretation
Selection/	Review of Book,	Using available information,	Observation, Sampling for	Data gathering, compilation & organization	

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Formulation of research Problem	papers, articles, reports, drafts & historical documents	observation, Interviewing & Focus group discussion (in special cases)	both physical data (geomorphic data)	(Data input, editing, coding and spread sheet making)
Statement of the Research Problem Preparation of Research Design	Review of Research Work on same place/ same study	Administering written data collection tools and construction of survey schedule/ lab. book and making the attitude scale	Survey for morphometric, fluviometric, hydrological and geometric data (as per needs)	• Laboratory Analysis of collected samples & data documentation (as per necessity) • Various Statistical analysis and presentation with proper statistical and GIS software
Time, Labour and Expenditure Budget Making	Review of theories, principles, law, formula, maps/ figures/ models and previous data	Fixation of sampling techniques, constructing the techniques for instrumental survey	Photo Documentation as per necessary	• Mapping Analysis/ Digital Analysis of Remote Sensing Data: Morphometric, fluviometric and geometric mapping analysis with proper GIS software • Interpretation of all above statistical and mapping analysis
Collecting and Gathering Secondary Database for Field Survey & Preparation for Survey Tools and Techniques		Emphasizing the Stratified, Systematic and Purposive Sampling Techniques to collect the Required Primary Data and Samples from the Field		Emphasizing the Analysis of IRS and Landsat Imagery and Google Earth Image RS Database, Corresponding Toposheet Collected Primary Data and Secondary Database, etc. with the help of MS Excel, SPSS, Arc GIS 10.4.1, GPS Software
				Source: Author's Own Construction

Table 2: Major Database for this Study

Sl. No.	Satellite Image and Other Map/ Image Data	Acquisition Date
1.	Satellite Image: Landsat 8/ Sensor: OLI/ TIRS Path & Row: Plate-1: 138/ 045 & Plate-2: 139/ 045 Resolution = 30m, C=2 & L=2	Plate-1: 29.09.2020 & Plate-2: 04.09.2020
WRS: Worldwide Reference System, C: Collection, L: Level, OLI: Operational Land Imager, TIRS: Thermal Infrared Sensor, TM: Thematic Mapper		
		Source: www.earthexplorer.usgs.gov
2.	Google Earth Imagery	07.09.2020
		Source: SIO, NOAA, U.S. Navy, GEBCO, US Department of State Geographer
3.	Corresponding Toposheet: NF-45-7 (U502 Series)	1922-43
4.	Corresponding Toposheet: NF 45-11 (U502 Series)	1934-35
		Source: The Army Map Services (NSS & H), Corps of Engineers, U. S. Army, Washington D.C. & Survey of India (SOI)

Table 3: Parameter wise principles/ methods to estimate the morphometric dimensions of the basin

Sl. No.	Parameters	Methods by	Formula	Description	Applied Database, Tools & Techniques
1.	Stream Order (U)	Strahler (1964)	Hierarchical Rank		Google Earth Imagery, 2020 DEM Analysis & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
2.	Stream Number (N_u)	Horton (1945)	$Nu= N_1+N_2+\ldots N_n$	u= order of stream	
3.	Stream Length (L_u)	Horton (1945)			
4.	Stream Length Ratio (L_{ur})	Horton (1945)	Lur= Lu/Lu-1	Lu=Total stream length of order 'U', Lu-1=Stream length of next lower order	
5.	Bifurcation Ratio (R_b)	Horton (1945)	$R_b = N_u/ N_{u+1}$	Nu=Total number of stream segment of order 'u'; Nu+1=Number of segment of next higher order	Google Earth Imagery-2020 & & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
6.	Mean Bifurcation Ratio (R_{bm})	Horton (1945)		R_{bm} = average of bifurcation ratios of all order	
7.	Length of Main Channel (C_l)	GIS Analysis			
8.	Rho Coefficient (ρ)	Horton (1945)	$\rho= Lur/R_b$		
9.	Actual Distance of Main Channel (CD_A)	GIS Analysis			
10.	Straight Distance of Main Channel (CD_S)	GIS Analysis			
11.	Channel Sinuosity Index (CSI)	Leopold & Wolman (1957)	$CSI = CD_A/ CD_S$	Actual Distance of Main Channel (CD_A) & Straight Distance of Main Channel (CD_S)	
12.	Length of the Basin (L_b)	GIS Analysis	$Lb= 1.312*A^{0.568}$		ISGPP, IGISMAP & Google Earth Imagery-2020 and & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0)
13.	Basin Area (A)	GIS Analysis			
14.	Basin Perimeter (P)	GIS Analysis			
15.	Lemniscate (k)	Chorley (1957)	$k = Lb^{2/A}$		
16.	Form Factor Ratio (F_f)	Horton (1932)	$Ff= A/Lb^2$	A = area of the basin, km^2; and Lb = length	

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				of the basin, km	Software
17.	Elongation Ratio (R_e)	Strahler (1956)	Re= (2Lb)*$(A/\pi)^{0.5}$	A=Area of watershed, π=3.14, Lb=Basin length	
18.	Texture Ratio (R_t)	Horton (1932)	Rt= N_1/P		
19.	Circularity Ratio (R_c)	Miller (1953)	Rc= $4\pi*(A/P^2)$	A = area of the basin, km2; P= basin perimeter, km2; and Pc= perimeter of the circle having equal area as that of the drainage basin, km	
20.	Compactness Coefficient (C_c)	Gravelius	C_c= 0.2841*P/$A^{0.5}$	Basin Perimeter (P)	
21.	Fitness Ratio (R_f)		R_f= C_l/P	Basin Perimeter (P) & Length of Main Channel (C_l)	
22.	Wandering Ratio (R_w)		R_w= C_l/L_b		
23.	Drainage Frequency (D_f)	Horton (1932)	D_f= N_u/A	Nu =Total number of streams; A=Area of basin	Google Earth Imagery-2020 and & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
24.	Drainage Density (D_d)	Strahler (1964)	D_d= L_u/A	Lu=Total length of streams; A=Area of basin	
25.	Constant of Channel Maintenance (CCM)	Schumm (1956)	CCM= 1/D_d	Drainage Density (D_d)	
26.	Length of Overland Flow (L_{of})	Schumm (1956)	L_{of} = 1/2D_d	L_{of}= Length of Overland Flow D_d= Drainage Density	
27.	Drainage Intensity (Di)	Faniran (1968)	D_i= D_f/D_d	Drainage Frequency (D_f) & Drainage Density (D_d)	
28.	Drainage Texture (Dt)	Horton (1932)	Dt= Nu/P	Nu_1=Total number of first order streams; P=Perimeter of watershed	
29.	Maximum Height of the Basin (H)	GIS Analysis			Google Earth Imagery, 2020 & DEM Analysis and & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
30.	Minimum Height of the Basin (h)	GIS Analysis			
31.	Range of Total Basin Relief (R_R)		R_R = H-h	Minimum Height (h) & Maximum Height (H)	
32.	Relief Ratio (R_h)	Schumm (1956)	Rh= R_R /L_b	R_R = Mean Basin Relief, L_b= maximum basin length	
33.	Absolute Relief (R_a)	Smith (1935)			
34.	Relative Relief (R)	Smith (1935)	A_{max} - A_{min} = H- h	Maximum Height of the Basin (H) & Minimum Height of the Basin (h)	
35.	Mean Height of the Basin ($\bar{h}$)	GIS Analysis			ASTER GDEM from Earth Explorer, DEM from Google Earth Imagery, 2020 & & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
36.	Dissection Index (Dis)	Dov Nir & Miller (1949)	Dis= R/H	Mean Relative Relief (R) & Maximum Height of the Basin (H)	
37.	Ruggedness Index (R_n)	Strahler (1968)	(R*D_d)/1000		
38.	Average Slope (θ)	Wentworth (1930)	$\theta = \tan^{-1}\frac{N*i}{K}$	N=Number of contour crossing/ km, i= contor interval & K= Constant (636.6)	
39.	Hypsometric Integral (HI)	Strahler (1952)	$HI = \frac{A'}{At}$ [A'= $\frac{\sum X1Yi+1 - \sum Y1Xi+1}{2}$, A=1, X = $\frac{h}{H}$ & Y = $\frac{a}{A}$]	A'=Area between Hypsometric Curve and Datum Line, At = Total Area of the Square, $\frac{h}{H}$ =Relative Height & $\frac{a}{A}$ = Relative Area	DEM and Geo-statistical Method by Strahler & & Application of Arc Map/ Arc GIS Software (v. 10.4.1) and Google Earth Pro. (v. 7.0) Software
40.	Relative Proportion of Upland to Lowland (E)	Wood and Snell (1960)	E = $(\bar{h} - h)$/(H- h)	Mean Height ($\bar{h}$), Minimum Height (h) & Maximum Height (H)	ASTER GDEM from Earth Explorer, DEM from Google Earth Imagery, 2020
Source: Author's Own Construction					

V. CONCEPTUAL FRAMEWORK AND THEORETICAL BASES OF MAJOR MORPHOMETRIC PARAMETERS AND INDICES

Table 4: Conceptual Framework of Major Morphometric Parameters and Indices

Sl. No.	Major Morphometric Parameters &Indices	Conceptual Highlights and Theoretical Bases
1.	Stream Order (U)	Stream lengthis one of the most important hydrological characteristics of the area as it gives information about surface runoff characteristics. The river of quite a small length is a characteristic of regions with steep slopes and better textures. Rivers having considerably longer lengths are commonly suggestive of smoother slope. In general, the total length of river section is highest in first order stream since the length is inversely proportional to the stream order. Calculation of stream length favors the theorythat geometrical similarity is preserved usually in watershed of increasing stream order [16] [17] [24] [25] [26] [57] [35].
2.	Stream Number (N_u)	The number of stream segments in each order is known as stream number. Horton (1945) states that the number of stream segments of each order create an inverse geometric sequencewith order number [39] [40] [41] [42] [43] [24] [25]

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		[26].
3.	Stream Length (L_u)	Mean Stream length is a dimension less property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces [55]. Itis obtained by dividing the total length of streams of an order by total number of stream segments of that order.
4.	Stream Length Ratio (L_{ur})	Stream Length Ratio (RL) states that it is the ratio of the mean (Lu) ofstream segments of an order (Su) to mean length of segments of the next lower order (Lu-1),which tends to be constant throughout the successive orders of a basin [16] [57] [36] [36] [26] [14].
5.	Bifurcation Ratio (R_b)	The ratio of the number of the stream segments of given order 'Nu' to the number of streams in the next higher order (Nu+1) is term as bifurcation ratio. Horton (1945) consideredthe bifurcation ratio as index of relief and dissections [16]. Strahler (1957) confirmed that bifurcation ratio displays a small range of variation for different regions or different environments except where the powerful geological control dominates [54].
6.	Mean Bifurcation Ratio (R_{bm})	To arrive at a more representative bifurcation number Strahler (1953) used a weighted mean bifurcation ratio (Rbm) acquired by multiplying the bifurcation ratio for each successive pair of orders by the total number of streams involved in the ratio and taking the mean of the sum of these values [53] [39] [40] [41] [42] [43] [24] [26].
7.	Length of Main Channel (C_l)	This is the length along the longest watercourse from the outflow point of designated watershed to the upper limit of the watershed boundary [35] [37].
8.	Rho Coefficient (ρ)	The Rho coefficient is a significant parameter relating drainage density to physiographic development of a watershed which facilitates evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed [16].
9.	Actual Distance of Main Channel (CD_A)	Actual distance of main channel shows the actual/ existed distance between source and destination points of main channel or river or course.
10.	Straight Distance of Main Channel (CD_S)	It estimates the straight/ linear distance in between source and destination points of main channel or river or course.
11.	Channel Sinuosity Index (CSI)	Sinuosity deals with the pattern of channel of a drainage basin. Sinuosity has been definedas the ratio of channel length to down valley distance [35] [36] [37]. In general, its value varies from 1 to 4 or more. River's nature like straight having SI <1.05, small meandering SI = 1.05-1.3, moderate meandering SI = 1.3-1.5 and meandering SI> 1.5 [28] [30].
12.	Length of the Basin (L_b)	Schumm (1956) defined the basin length as the longest dimension of the basin parallel to the main drainage line [45]. Gregory (1977) defined the basin length as the longest length of the basin in which one end being the mouth [11]. Gardiner (1975) defined the basin length as the length of the line of a basin from the mouth to a point on the perimeter equidistant from the basin mouth in either direction [9].
13.	Basin Area (A)	The area of the watershed is another important parameter like the length of the drainage stream. Schumm (1956) established an interesting relation between the total watershed area and the total stream length, which are supported by the contributing areas.
14.	Basin Perimeter (P)	Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measuredalong the divides between the adjacent watersheds and may be used as an indicator of watershed size and shape.
15.	Lemniscate (k)	Chorely (1957), express the Lemniscate's value to compute the slope of the basin [2].
16.	Form Factor Ratio (F_f)	Form factor may be demarcated as the ratio of basin area to square of the basin length [17]. The form factor value would vary between 0 and 1 and may always be less than 0.754 (for a perfectly circular watershed). Higher value indicates circular shape while lower value shows elongated shape of the basin.
17.	Elongation Ratio (R_e)	According to Schumm (1965), 'elongation ratio' is defined as the ratio of diameter of a circle of the same area of the basin to the maximum basin length [45]. Strahler (1952) states that elongation ratio runs between 0.6 and 1.0 over a wide variety of climatic and geological types [54]. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5) for tectonically high active, active, slightly active and inactive settings, respectively [46].
18.	Circularity Ratio (R_c)	For the out-line form of watershed Strahler (1964) and Miller (1953) used a dimensionless circularity ratio as a quantitative method [56] [28]. Circularity ratio is defined as the ratio of watershedarea to the area of a circle having the same perimeter as the watershed and it is pretentious bythe lithological character of the watershed. Miller (1953) has described the basin of the circularity ratios range from 0.40 to 0.50, which indicates strongly elongated [28] and highly permeable homogenous geologic materials [35] [36] [37] [44] [48] [49].
19.	Compactness Coefficient (C_c)	According to Gravelius (1914), compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. The Cc is independent of size of watershed and dependent only on the slope [39] [40] [41] [42] [43] [44].
20.	Fitness Ratio (R_f)	Melton (1957) stated that, the ratio of main channel length to the length of the watershed perimeter is fitness ratio, which is a measure of topographic fitness [27] [39] [40] [41] [42] [43].
21.	Wandering Ratio (R_w)	According to Smart & Surkan (1967), wandering ratio is defined as the ratio of the main stream length to the valley length. Valley length is the straight-line distance between outlet ofthe basin and the farthest point on the ridge [32] [33] [35] [36] [37].
22.	Drainage Frequency (D_f)	The drainage stream frequency introduced by Horton (1932) means stream frequency (or channel frequency) Fs as the number of stream segments per unit area [17] [39] [40] [41] [42] [43]. The channel segment numbers for unit areas are difficult to be enumerated [47]. Higher frequencies are the measure to show the early stages of the fluvial cycle or rejuvenated erosional activities along the steep slopes [47].
23.	Drainage Density (D_d)	Drainage density is the stream length per unit area of basin or watershed [16] [17] [27] [54] [55] and is another element of drainage analysis. Drainage density is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology and structures and relief history of the region can be used as an indirect indicator to explain, those variables as well as themorphogenesis of landform [39] [40] [41] [42] [43].
24.	Constant of Channel Maintenance (CCM)	Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms [45]. The constant indicates the number of Km2/Km of basin surface required to develop and sustain a channel 1 km long [35] [36] [37]. The constant of channel maintenance indicates the relative size of landformunits in a

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		drainage basin and has a specific genetic connotation [55].
25.	Length of Overland Flow (L_{of})	Horton (1945) used this term to refer to the length of the run of the rain water on the groundsurface before it is localized into definite channels [16]. Since this length of overland flow, at an average, is about half the distance between the stream channels, Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density [39] [40] [41] [42] [43] [44]. River basins with lower overland flow values also designate that in such basins less rainfall is adequate to pay a substantial volume of surface run off to stream discharge [31].
26.	Drainage Intensity (Di)	Faniran (1968) defines the drainage intensity, as the ratio of the stream frequency to the drainage density. This low value of drainage intensity implies that drainage density and stream frequency have a little effect (if any) on the extent to which the surface has been lowered by agents of denudation. With these low values of drainage density, stream frequency and drainage intensity, surface runoff is not easily removed from the watershed or sub-watershed, making it very susceptible to flooding, gully erosion and landslide incidence [39] [40] [41] [42] [43] [44].
27.	Drainage Texture (Dt)	The treatment of drainage density does not appear to be complete except when the qualitative nomenclatures fit to the quantitative limits. Drainage density, no doubt, is a well-defined expression of texture than the measures of spacing as it includes all the channelsin the grid or a basin [47]. Drainage texture (Dt) is a vital concept of geomorphology which refers towards the relative spacing of drainage lines. Drainage texturedepends on the underlying lithology, infiltration capacity and relief aspect of the terrain. Dt istotal number of stream segments of all orders per watershed perimeter of that area [16]. Drainage texture has been classified 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) [52] [39] [40] [41] [42] [43].
28.	Relief Ratio (R_h)	Difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basinparallel to the main drainage line [45]. The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin was suggested by Schumm (1956) who found that sediments loose per unit area is meticulously associated with relief ratios [39] [40] [41] [42] [43].
29.	Absolute Relief (R_a)	The absolute relief is the difference in elevation between a given location and sea level [35] [36] [37].
30.	Relative Relief (R)	The maximum basin relief was attained from the highest point on the watershed perimeterto the mouth of the stream. Using the basin relief 174 m, a relief ratio was computed as suggested by Schumm [45].
31.	Dissection Index (Dis)	Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed [50]. On an average, the values of Dis vary between '0' (complete absence of vertical dissection/erosion and hence dominance of flat surface) and '1'(in exceptional cases, vertical cliffs, it may be at vertical escarpment of hill slope or at seashore) [39] [40] [41] [42] [43].
32.	Ruggedness Index (R_n)	Strahler's (1968) ruggedness number is the product of the basin relief and the drainage density and practically combines slope steepness with its length [39] [40] [41] [42] [43].
33.	Average Slope (θ)	Slope is one of the most important and specific feature of the earth's surface form. Soil erosion and flow line of surface water are influenced by slope of that area. Maximum slope is well noticeable in the way of a channel reaching downwards on the ground surface [44].
34.	Hypsometric Integral (HI)	Hypsometry, or the area-altitude analysis, first described by Strahler (1952) as a measure of the erosional state or geomorphic age of a drainage basin, relates the horizontal cross sectional area of a drainage basin to the relative elevation above the basin mouth [54]. The hypsometric integral expresses the volume of the basin that lies above the lowest point in the basin, and thus has not been eroded. The integral explains the distribution of elevation of a given area of the landscape, particularly a drainage basin.
		Source: Author's Own Construction based on Literature Review

Table 5: Various Morphometric Parameters based on dimension

Linear Aspects of the Basin		Areal Aspects of the Basin		Relief Aspects of the Basin	
Sl. No.	**Parameters**	**Sl. No.**	**Parameters**	**Sl. No.**	**Parameters**
1.	Stream Order	1.	Basin Area	1.	Minimum Height of Basin
2.	Stream Number	2.	Basin Perimeter	2.	Maximum Height of Basin
3.	Stream Length	3.	Relative Basin Perimeter	3.	Total Basin Relief
4.	Stream Length Ratio	4.	Length area relation	4.	Absolute Relief
5.	Mean Stream Length Ratio	5.	Lemniscate's	5.	Relative Relief
6.	Weighted Mean Stream Length Ratio	6.	Elongation Ratio	6.	Dissection Index
7.	Bifurcation Ratio	7.	Form Factor	7.	Relief Ratio
8.	Mean Bifurcation Ratio	8.	Circulatory Ratio	8.	Ruggedness Number
9.	Weighted Mean Bifurcation Ratio	9.	Drainage Density	9.	Average slope
10.	Rho Coefficient	10.	Drainage Frequency	10.	Hypsometric Integral
11.	Main Channel Length	11.	Drainage Texture	11.	Relative Proportion of Upland to Lowland (E)
12.	Basin Length	12.	Drainage Intensity		
		13.	Infiltration Number		
		14.	Length of overland flow		
		15.	Constant of channel maintenance		
Source: Theoretical Bases of Literature and RS-GIS-GPS Survey and Analysis					

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VI. RESULTS AND DISCUSSION

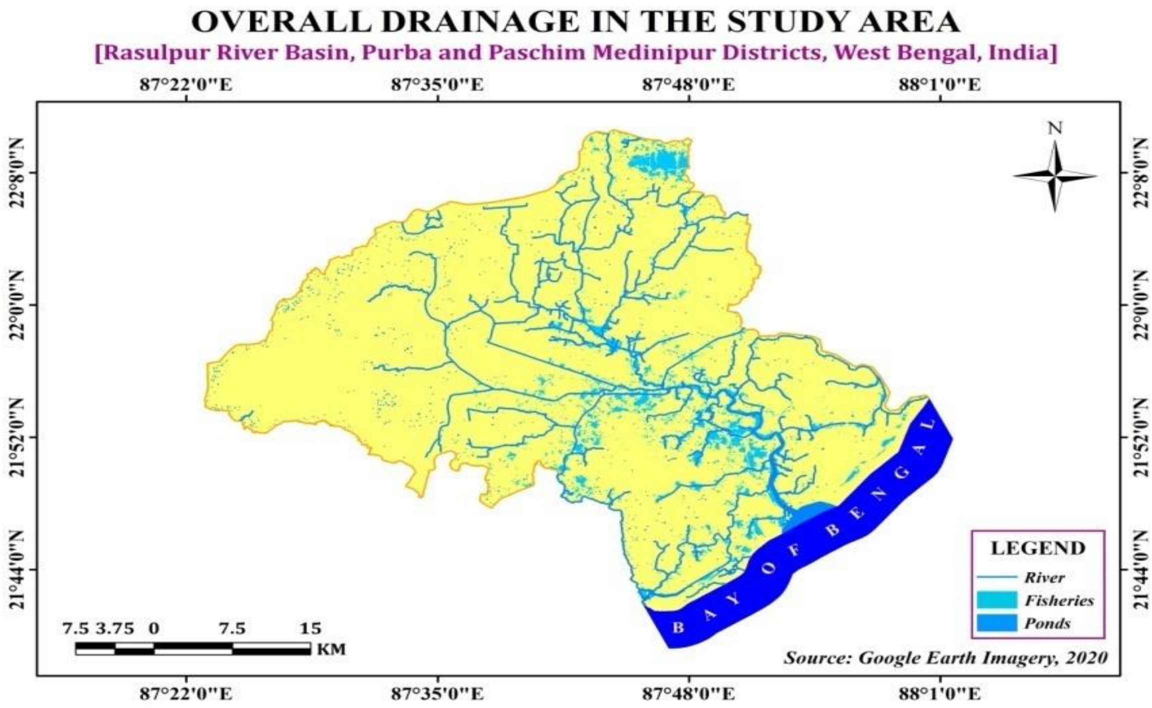

Figure 2: Overall Drainage Network of Rasulpur River Basin, 2020

Based on the literature review, theoretical study, geomorphic field survey and mathematical, statistical and GIS operations, the morphometric analysis has been resulted in form of morphometric, structural, geometric and fluviometric investigations. These segmental morphometric analyses have been shown in the table 6, 7, 8 and 9.

6.1 Morphometric Parameters/ Indices showing the Relief Nature of the Basin:

Table 6: Morphometric Parameters/ Indices showing the Relief Nature of the Basin

Sl. No.	Parameters	Result	Discussion on Basin Structural Parameter
1.	Maximum Height of the Basin (H)	19.2612 m	Mainly shown at the river source point.
2.	Minimum Height of the Basin (h)	0 m	Mainly shown on and along the base level and bank/ beach section of the basin
3.	Mean Height of the Basin ($\bar{h}$)	5.2413m	Average altitude/ elevation of the region in between 4-5.5 metre from mean sea level
4.	Range of Total Basin Relief (R_R)	19.2612 m	Range of the absolute relief has been justified with respect to the maximum and minimum height of the basin. Higher relief are mainly observed at the source zone and on and along the coastal dune stretch of the basin.
5.	Relief Ratio (Rh)	0.3903	It indicates the mean basin relief with respect to maximum basin length.
6.	Average Absolute Relief (Ra) $[\sum Mean\ Altitude = 1315.5696m\ \&\ Total\ Number\ of\ Grids = 282]$	8.6018 m	Relief features indicate the very low relative relief throughout the basin area whereas Average absolute and relative reliefs are 8.60m and 5.70 mere respectively.
7.	Basin Relative Relief (R)	19.2612 m	
8.	Average Relative Relief (R_m)	5.6955m	
9.	Dissection Index (Dis)	0.2956	It indicates the late mature to older status of basin existence.
10.	Ruggedness Index (Rn)	0.0023-0.0079	It has been justified with respect to relief and drainage which expresses the low to very low relief, texture and slope intensity throughout the basin area.
11.	Average Slope (θ) $[\sum Mean\ Slope = 49.0056°\ \&\ Total\ Number\ of\ Grids = 282]$	0°10'25.68"	Average slope of the overall basin is very low to level based situation except the source section and dune stretch zone.
12.	Hypsometric Integral (HI)	0.3451	This result reflects the late Maturity to Old Stage in its evolution.
13.	Relative Proportion of Upland to Lowland (E)	0.2721	

Source: Author's Own Construction based on Statistical and Mapping Analysis

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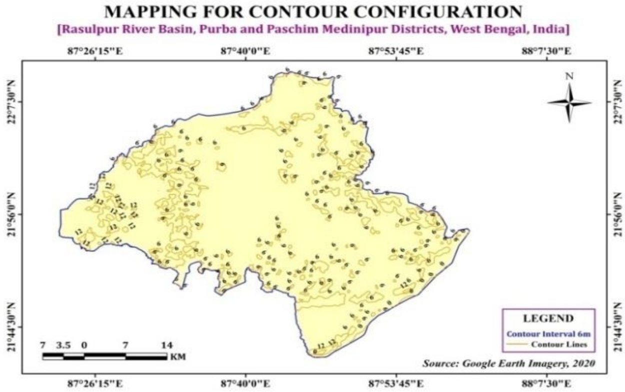


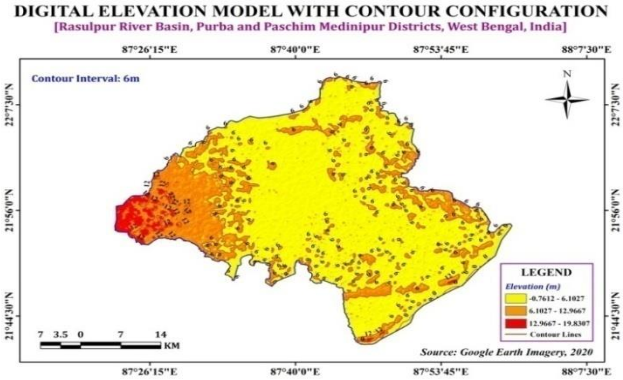


Figure 3: Contour Configuration of Rasulpur River Basin, 2020 &
Figure 4: DEM with Contour Configuration of Rasulpur River Basin, 2020

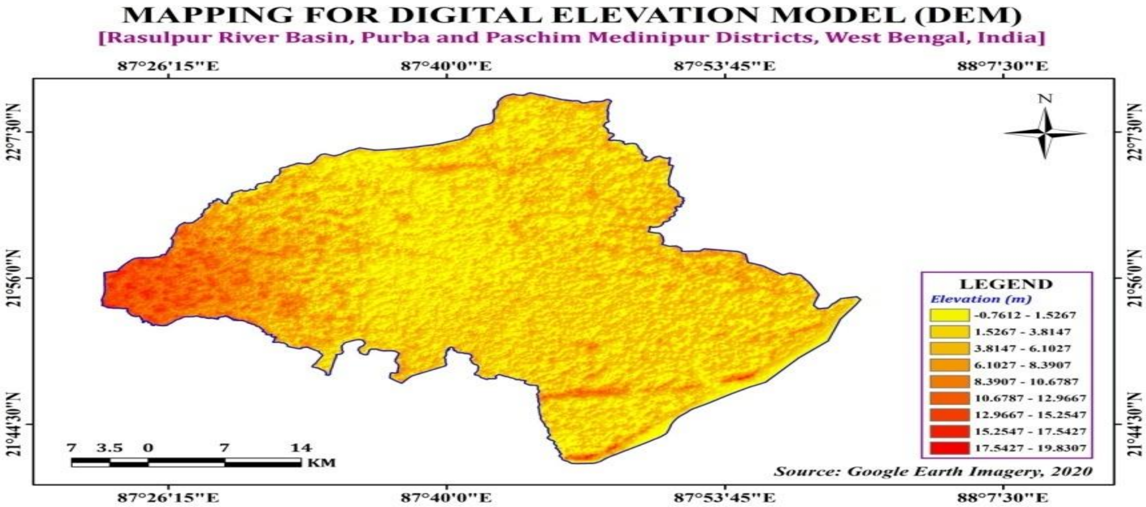
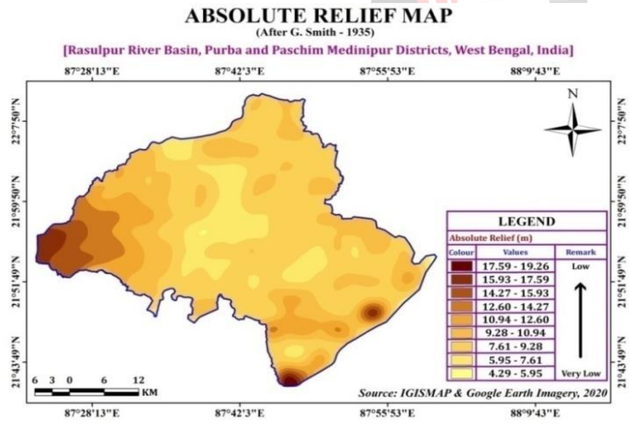


Figure 5: DEM of Rasulpur River Basin, 2020



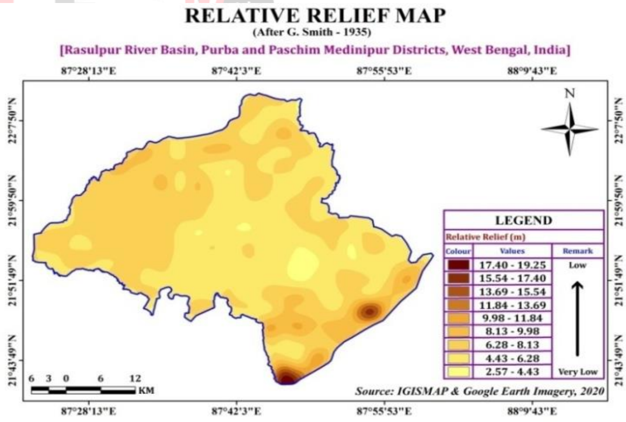
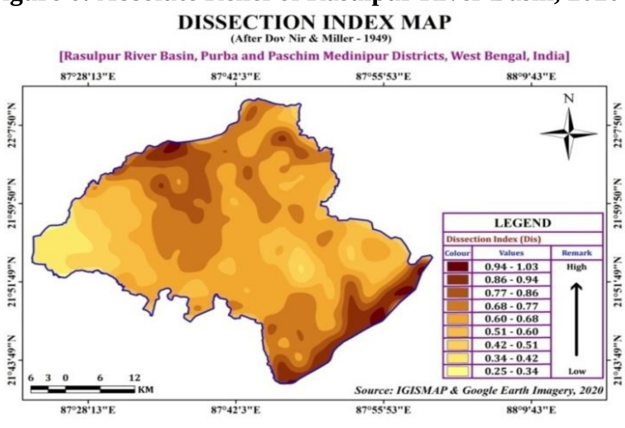


Figure 6: Absolute Relief of Rasulpur River Basin, 2020 & Figure 7: Relative Relief of Rasulpur River Basin, 2020



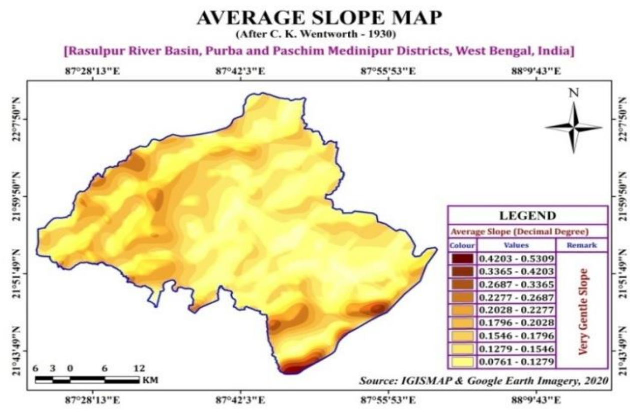


Figure 8: Dissection Index of Rasulpur River Basin, 2020 & Figure 9: Average Slope of Rasulpur River Basin, 2020

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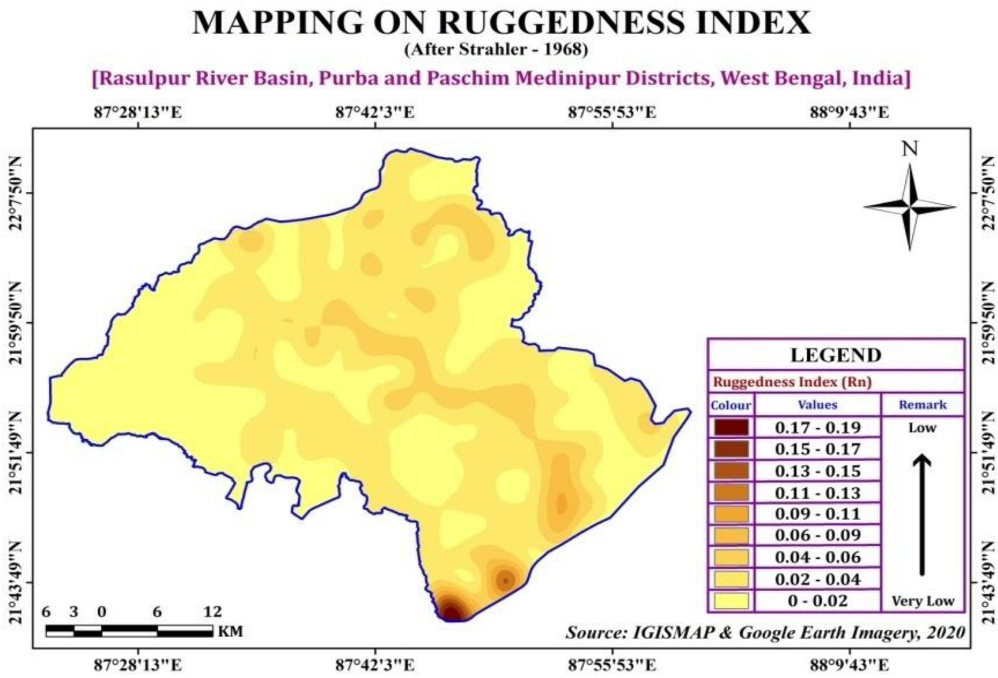

Figure 10: Ruggedness Index of Rasulpur River Basin, 2020

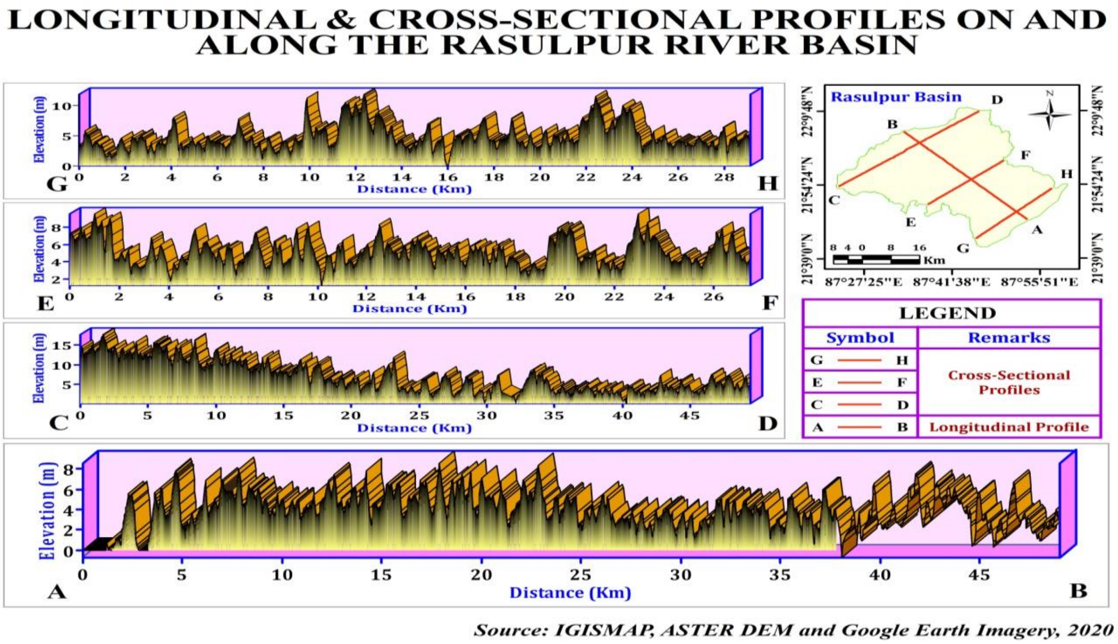

Figure 11: Longitudinal and Cross Sectional Profiles of the Rasulpur Basin

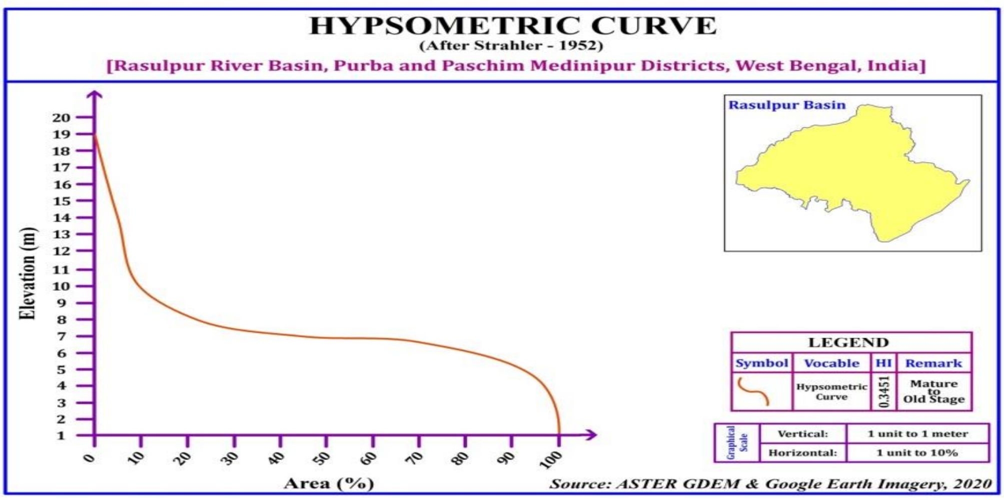

Figure 12: Hypsometric Curve of Rasulpur River Basin, 2020

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6.2 Drainage Network showing the Structural Features/ Properties of the Basin:

Table 7: Drainage Network showing the Structural Properties of the Basin

Sl. No.	Parameters	Result	Discussion on Basin Structural Properties/ Parameter
1.	Stream Order (U)	1 to 4	Lowest Stream Order is 1 and highest is 4 which indicates the main course of the basin.
2.	Stream Number (Nu)	248	Number of tidal feeding channels, courses and river is 248 whereas these are tributaries, sub-tributaries, distributaries and sub-distributaries in nature.
3.	Stream Length (Lu)	690.1946 km	Channel/ course length in total indicates approximately 690 km in the basin.
4.	Stream Length Ratio (Lur)	1.1672 – 3.8232	Stream length ratio shows the proportional measurement of the sequential stream lengths throughout the basin whereas it is ranged between 1.1672 and 3.8232 here.
5.	Bifurcation Ratio (Rb)	3.4808 - 14	Specific Bifurcation Ratios are in between 3.48 and 14 whereas Mean Bifurcation Ratio is 7.07 which indicates the flood prone behavior of this fluvio-coastal basin.
6.	Mean Bifurcation Ratio	7.0650	
7.	Length of Main Channel (Cl)	40.4993 km	Length of main channel, Rasulpur River is 40.50 km from its source to Ganga-Bay of Bengal meeting destination.
8.	Rho Coefficient (ρ)	0.2855	Rho Coefficient of the basin has been justified with respect to stream length ratio and bifurcation ratio whereas it is 0.29 (low) having the lower storage capacity of Rasulpur drainage network.
9.	Actual Distance of Main Channel (CD_A)	40.4993 km	Sinuosity Index (SI) of main channel, Rasulpur River shows the value as 1.57 reflecting its meandering channel pattern throughout the basin.
10.	Straight Distance of Main Channel (CD_S)	25.7904 km	
11.	Channel Sinuosity Index (CSI)	1.5703	

Source: Author's Own Construction based on Statistical and Mapping Analysis

6.3 Basin Geometry for making the Understanding about the Nature of Basin Hydrology:

Table 8: Basin Geometry for making the Understanding about the Nature of Basin Hydrology

Sl. No.	Parameters	Result	Discussion on Basin Geometry
1.	Length of the Basin (Lb)	49.56 km	Basin length as the longest dimension of the basin parallel to the main drainage line has been estimated as 49.56 km.
2.	Basin Area (A)	1692.174 km^2	Areal extension ofthe basin is 1692.174 km^2 showing the relation between the total basin area and the total stream length, which are supported by the contributing areas.
3.	Basin Perimeter (P)	242.323 km	Basin perimeter indicating the size and shape of the study area estimated in GIS platform is 242.323 km.
4.	Lemniscate (k)	1.4515	Lemniscate value to determine the slope of the basin is low (1.45) here which indicates the basin captures a maximum area beginning with a fewer number of higher stream order.
5.	Form Factor Ratio (Ff)	0.6889	The form factor ratio of the basin is 0.69 (<0.78) which indicates the elongated nature whereas it signifies low peak flows for longer duration while a circular basin having high peak flows for a shorterduration.
6.	Elongation Ratio (Re)	0.9368	Elongation ratio of the basin is higher (>0.90) having circular elongation which reflects the flat land with low relief and low slope.
7.	Texture Ratio (Rt)	0.7469	The basin has very coarse/ coarse texture or the very low texture ratio (<8) indicates very low risk of soil erosion.
8.	Circularity Ratio (Rc)	0.3622	The Rc value (0.36) is between 0.32 and 5.0 indicating the low Rc which shows the no structural disturbance in the basin.
9.	Compactness Coefficient (Cc)	1.6736	The compactness coefficient of the basin is 1.67 which shows the basin has lessconvincing nature.
10.	Fitness Ratio (Rf)	0.1671	Fitness ratio to show the topographic fitness of the basin is 0.17 which is not good from its relief strength.
11.	Wandering Ratio (Rw)	0.8172	Thewandering ratio of the basin is 0.82 which indicates river total and basin having plain nature.

Source: Author's Own Construction based on Statistical and Mapping Analysis

6.4 Fluviometric Indices/ Parameters for Drainage Texture Analysis of the Basin:

Table 9: Fluviometric Indices for Drainage Texture Analysis of the Basin

Sl. No.	Parameters	Result	Remarks on Basin Fluviometric Indices
1.	Drainage Frequency (Df)	0.1466	Lower drainage frequency implies the fewer amounts of streams with respect to area of the basin whereas number of distributaries and tributaries are less in number and role of main channel is very important.
2.	Drainage Density (Dd)	0.4079 km/ km^2	Very coarse drainage density (Dd<2) is reflected in the study area which indicates the fluvio-coastal nature of this basin. Lower drainage density (Dd) shows a poorly drained basin with a slow hydrologic response. Surface runoff is not rapidly removed from the basin making it highly susceptible to flooding, gully erosion, etc.
3.	Constant of Channel Maintenance (CCM)	2.4516 km^2/ km	Lower value of constant of channel maintenance and length of overland flow indicate short flow paths, more runoff, and less infiltration which leads to more vulnerable to the sudden flooding/ inundation in the basin.
4.	Constant of Channel Maintenance (CCM_A)	0.4897 km^2/ km	
5.	Length of Overland Flow (L_{of})	1.2258 km^2/ km	Lower value of length of overland flow (L_g = 0.2-0.3) indicate short flow paths, more runoff, and less infiltration which leads to more vulnerable to the sudden flooding/ inundation in the basin.
6.	Average Length of Overland Flow (L_g)	0.2449	

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7.	Drainage Intensity (Di)	0.3594	Lower drainage intensity signifies the low magnitude of streams where the role of main channel is very important in basin morphology as well as hydrology.
8.	Drainage Texture (Dt)	1.0234	The basin has very coarse/ coarse texture or the lower value of drainage texture (<8) indicates that it has no more risk of soil erosion.
Source: Author's Own Construction based on Statistical and Mapping Analysis			

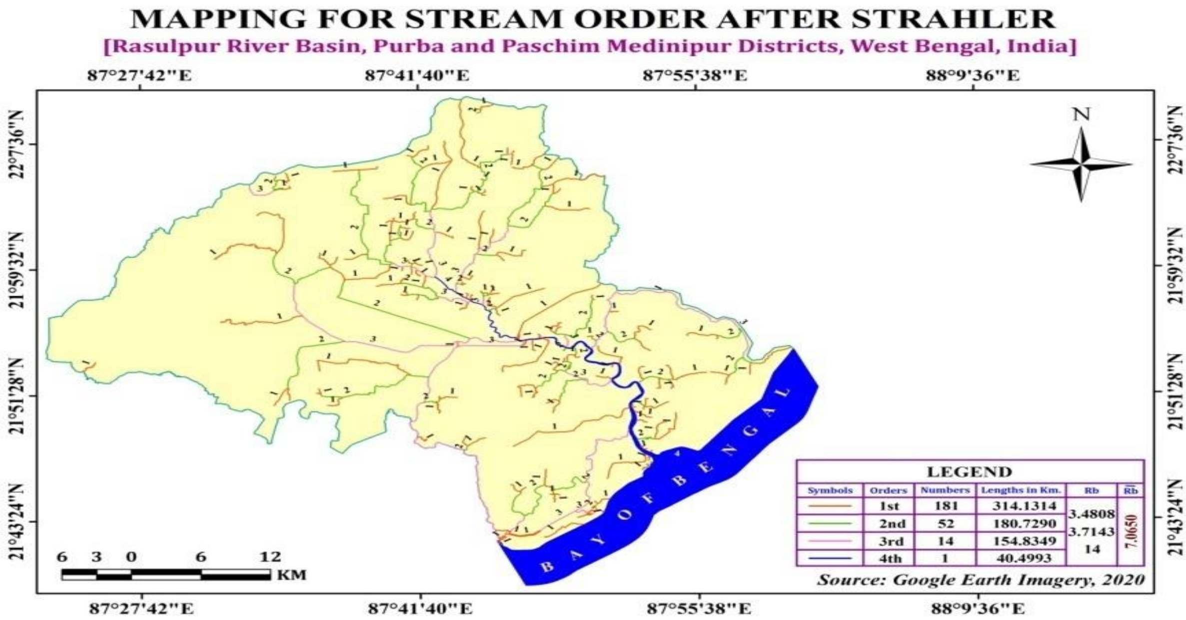
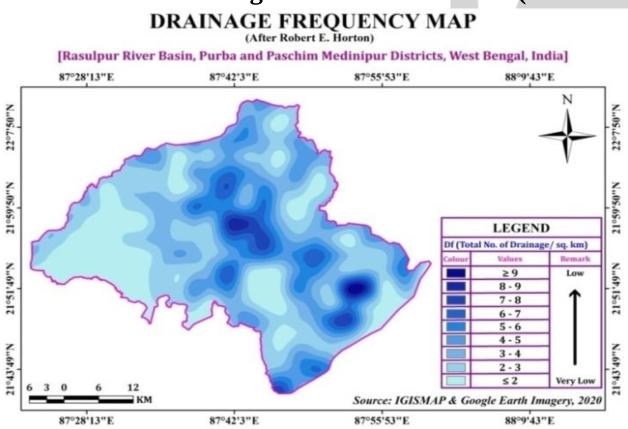


Figure 13: Stream Order (after Strahler) of Rasulpur River Basin, 2020



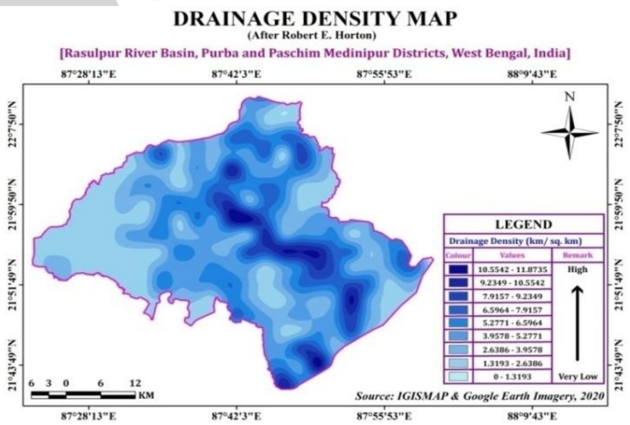
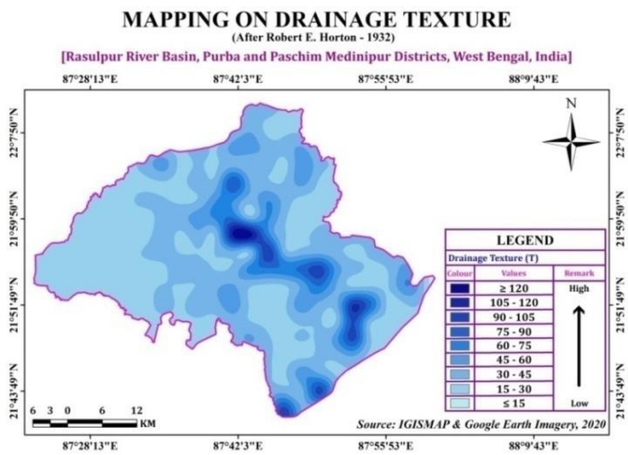


Figure 14: Drainage Frequency (D_f) of Rasulpur River Basin, 2020 &
Figure 15: Drainage Density (D_d) of Rasulpur River Basin, 2020



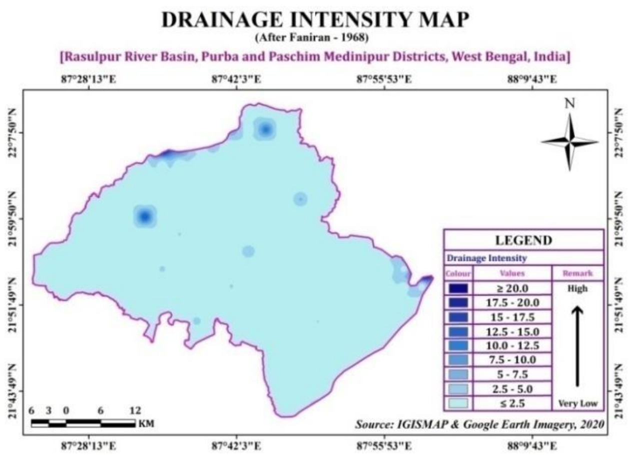


Figure 16: Drainage Texture (D_t) of Rasulpur River Basin, 2020 &
Figure 17: Drainage Intensity (D_i) of Rasulpur River Basin, 2020

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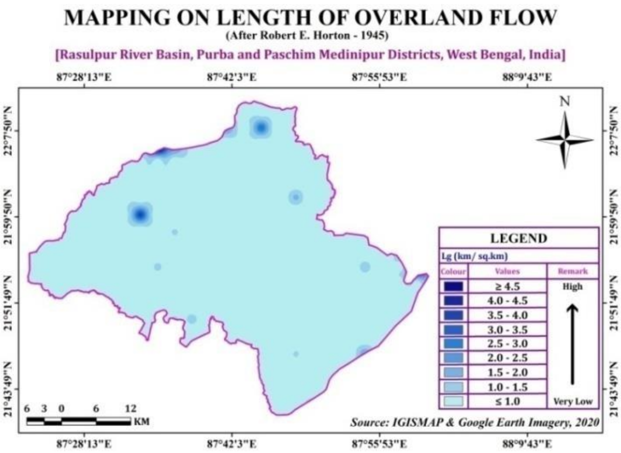

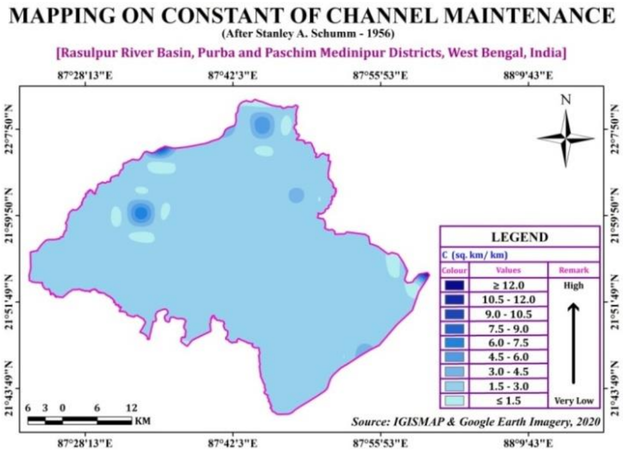

Figure 18: Length of Overland Flow (L_g) of Rasulpur River Basin, 2020 &

Figure 19: Constant of Channel Maintenance (CCM) of Rasulpur River Basin, 2020

VII. CONCLUSION

Morphometric analysis of drainage network is vital for responsibility of any hydro-morphological assessment and studies. Determination of drainage behavior, response, interaction and interrelation with each other is of great meaning. Remote sensing data and GIS techniques have been signified to be an efficient and effective updated tool in drainage, basins and watershed analysis. In this reaserch, morphometric investigation of the Rasulpur river basin is estimated discretely and basin morphometry has been justified from different angles of morphometric analysis. The morphometric analysis has been featured by the measurement of linear, areal and relief aspect of the basin whereas on the basis of dimensions, it has been emphasized in the light of structural properties, geometry, fluviometric and hydro-morphometric mirrors of geomorphology.

Drainage morphometric parameters are important indicator to understand the hydrological and morphological characteristics of any region. Present study aims to understand the hydrological and morphological characteristics from drainage basin morphometric parameters. Various stream properties can be evaluated with the help of morphometric studies. The morphometric analysis of drainage basin plays an important role in understanding the geo-hydrological behaviour of drainage basin [15]. The assessment of present condition of water resource in an area can be investigated with the study of drainage basin. The study area is a 4th order drainage basin. The mean bifurcation ratio indicates that the area is flood prone. The drainage density, stream frequency and the drainage intensity are correlated with the degree of dissection in the area having lower degree and magnitude on scale. Hence it is clear that intensity of dissection is lower in the study area and this can also be determined by the moderate dissection index value. Drainage density indicates that the study area is in sub-tropical region.

From the morphometric analysis, different parameters show the journey of after youth phase responses. Average elevation of the region is in between 4-5.5 metre from MSL where Higher relief are mainly observed at the source zone and on and along the coastal dune stretch of the basin. Relief features indicates the late mature to older status of basin existence. It has been justified with respect to relief and drainage which expresses the low to very low relief, texture and slope intensity throughout the basin area. Average slope of the basin is very low to level based situation except the source section and dune stretch zone. Hypsometric curve and integral reflect the late maturity to old Stage in its evolution.

From the background of structural dimensions, there is seen that Rasulpur River is 40.50 km from its source to Ganga-Bay of Bengal meeting destination.Number of tidal feeding channels, courses and river is 248 whereas these are tributaries, sub-tributaries, distributaries and sub-distributaries in nature. Stream length ratio shows the proportional measurement of the sequential stream lengths throughout the basin whereas it is ranged between 1.1672 and 3.8232 here and Mean Bifurcation Ratio is 7.07 which indicate the flood prone behavior of this fluvio-coastal basin. Rho Coefficient of the basin shows the lower storage capacity of thedrainage network. Channel Sinuosity Index (CSI) having 1.57 reflecting its meandering channel pattern throughout the basin.

Basin geometry of the Rasulpur drainage network reflects the disctinct fluvio-coastal hydrological behavior from its geometric analysis. Lemniscate value reflects the basin captures a maximum area beginning with a fewer number of higher stream order. The form factor ratio indicates the elongated nature whereas it signifies low peak flows for longer duration Elongation ratio of the basin is higher reflecting circular elongation which reflects the flat land with low relief and low slope. The basin showing very coarse texture indicates very low risk of soil erosion and the Rc deals with no structural disturbance in the basin. The compactness coefficient of the basin shows the basin has

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lessconvincing nature whereas fitness ratio is not good from its relief strength and the wandering ratio which indicates river total and basin having plain nature.

From the fluviometric point of view, lower drainage frequency of the basin indicates the fewer number of distributaries and tributaries are less in number and role of main channel is very important whereas very coarse drainage density (Dd<2) is reflected in the study area which shows a poorly drained basin with a slow hydrologic response. Surface runoff is not rapidly removed from the basin making it highly susceptible to flooding, gully erosion, etc. Lower value of constant of channel maintenance and length of overland flow indicate short flow paths, more runoff, and lessinfiltration which leads to more vulnerable to the sudden flooding/ inundation in the basin and lower value of length of overland flow leads to more vulnerable to the sudden flooding/ inundation in the basin. Not only that the basin has very coarse/ coarse texture showing less risk of erosion. Finally, it is clear that such type of study must be helpful to make the blueprint for the future planning and management of drainage basin since the landscape morphology and hydrology have been affecting from various human interference throughout the time. In self of sustainable journey of Rasulpur basin, this research may be the account of information for optimum use of its indigenous resources and far sighted development.

References

[1] Abdul Rahaman S, Abdul Ajeez S, Aruchamy S, 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, Tamilnadu. Aquatic Procedia 4 International Conference on Water Resources, Coastal and Ocean Engineering;1322-1330.

[2] Chorely, R., 1958. Aspects of the Morphometry of "Poly-Cyclic" Drainage Basin. The Geographical Journal, 124, 370-374, http://dx.doi.org/10.2307/1790789

[3] Chorley R.J., Schumm S.A., Sugden D.E., 1985. Geomorphology.Methuen and Co., Ltd., London

[4] Clarke J.I. 1996. Morphometry from Maps. Essays in geomorphology. Elsevier publication. Co., New York, pp 235-274.

[5] Das, A., Mondal, M., Das, B., and Ghosh, A. R., 2012. Analysis of drainage Morphometry and watershed prioritization in Bandu watershed, West Bengal through Remote Sensing and GIS technology.International journal of Geomatics and Geosciences, Vol.2 (4), pp. 995-1013

[6] Eze, E. B. and Efiong, J., 2010. Morphometric parameters of the Calabar river basin: Implication for hydrologic processes. Journal of Geography and Geology,Vol. 2 (1), pp. 18-26

[7] Faniran, A., 1968. The Index of drainage intensity- A provisional new drainage factor. Australian Journal of Science, v. 31, pp. 328-330.

[8] Fryirs, K. A. and Brierley, G. J., 2013. Geomorphic analysis of river systems: An approach to reading the landscape. West Sussex: Wiley Blackwell Publication, pp. 29-62

[9] Gardiner, V., 1978. Redundancy and spatial organization of drainage basin form indices , Transactions of the Institute of British Geographers, New Series 3: 416-431.

[10] Goudie, A. S., 2004. Encyclopedia of Geomorphology. London: Routledge publication.

[11] Gregory, K. J., 1978. Fluvial Processes in British Basins, in: C. Embleton, D, Brunsden and D.K.C. Jones (ed) Geomorphology-present problems and future prospects. OUP, NY, pp 40-72.

[12] Guarnieri, P., Pirrotta, C., 2008. The response of drainage basins to the late quaternary tectonic in the Sicillian side of the Messina Strait (NE Sicily), Geomorphology, 95, pp. 260-273

[13] Gundekar, H. G., Arya, D. S., and Goel, N. K., 2011. Morphometric study of Dudhana river basin, Maharashtra.Hydrology Journal, Vol. 34 (1 and 2), pp. 33-41

[14] Hack, J. T., 1957. Studies of longitudinal stream profiles in Virginia and Maryland. U.S. Cool. Survey Prof. Paper 294-B, B45-897

[15] Hajam, R. A., Hamid, A., and Bhat, S., 2013. Application of morphometric analysis for geo-hydrological studies using geo-spatial technology- A case study of Vishav drainage basin.Hydrology Current Research, Vol. 4(3), pp. 1-12

[16] Horton, R. E. 1945. Erosional Development of Streams and their Drainage Basins , Bulletin of the Geological Society of America, 56, pp-275-370

[17] Horton, R. E., 1932. Drainage-basin characteristics. Transactions, American Geophysical Union, 13, 350–361

[18] Howard, A. D. 1967. Drainage analysis in geologic interpretation: a summation . AAPG Bull 51:2246–2259

[19] Javed, A., Khanday, M. Y. and Ahmed, R., 2009. Prioritization of Sub-Watersheds Based on Morphometric and Land Use Analysis Using Remote Sensing and GIS Techniques . Journal of the Indian Society of Remote Sensing. 37: 261. https://doi.org/10.1007/s12524-009-0016-8

[20] Javed, A., Khanday, M. Y. and Rais, S., 2011. Watershed prioritization using morphometric and Land Use/Land Cover Parameters: A Remote Sensing and GIS Based Approach . Journal of Geological Society of India. 78: 63. https://doi.org/10.1007/s12594-011-0068-6

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

[22] Khanday, M. Y. & Javed, A., 2016. Prioritization of Sub-Watersheds for Conservation Measures in a Semi-Arid Watershed using Remote Sensing and GIS . Journal of Geological Society of India. Vol. 88 (2), pp. 185-196

[23] Leopold, L. B. & Maddock, T. J., 1953. Hydraulic geometry of stream channels and some physiographic implications , U.S. Geol. Surv. Prof. Pap., 252, 55 pp., 1953

[24] Magesh N.S., Chandrasekhar N (2014) GIS model-based morphomet- ric evaluation of Tamiraparani sub basin, Tirunelveli district, Tamil Nadu, India. Arab J Geosci 7:131–141

[25] 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 , 64: 373 – 381

[26] 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 Science Information, v. 5, pp. 111–121.

[27] Melton, M. A., 1957. An analysis of the relations among elements of climate, surface properties and geomorphology (Project NR 389042, Tech. Rep. 11). New York, NY: Columbia University

[28] Miller, V.C., 1953. A Quantitative geomorphic study of drainage basin characteristics on the Clinch Mountain area, Virgina and Tennessee, Proj. NR 389-402, Tech Rep 3, Columbia University, Department of Geology, ONR, New York

[29] Morisawa M., 1985. Rivers-forms and process. Longman Group, London

[30] Muller, J.E., 1968. An introduction to the hydraulic and topographic sinuosity indexes. Ann. Assoc. Am. Geogr., v. 58, pp. 371–38

[31] Muthukrishnan, Manoj, K. S. & Banu, K. K., 2013. Drainage Morphometry Evaluation for Kodavanar sub basin to understand the Interrelationships in Morphological Systems and in Process-Response Systems , International journal of Geon

[32] Nautiyal, M. D., 1994. Morphometric Analysis of a Drainage Basin, Dist. Dehradun, Uttar Pradesh . J. Indian Soc. Remote Sensing, 22(4): 251-261

 DOI : 10.35291/2454-9150.2021.0453

[33] Obi, G. P., Reddy, G. P., Maji, A. K., Gajbhiye, K. S., 2002. GIS for morphometric analysis of drainage basins, Geological Survey of India, 11, pp 9-14. 2002
[34] Pandey, A., Chowdary, V. M. and Mal, B. C. 2004. Morphological analysis and watershed management using GIS , Hydrology J. 27, (3 & 4), 71-84
[35] Pareta K, Pareta U., 2012. Quantitative geomorphological analysis of a watershed of Ravi River Basin, H.P. India. Int J Remote Sens GIS 1(1):41–56
[36] Pareta, K. 2011. Geo-Environmental and Geo-Hydrological Study of Rajghat Dam, Sagar (Madhya Pradesh) using Remote Sensing Techniques , International Journal of Scientific & Engineering Research, 2(8) (ISSN 2229-5518), pp 1-8
[37] Pareta, K., and 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, Vol.2 (1), pp. 248-269
[38] Prakash, K., Rawat, D., Singh, S. et al., 2019. Morphometric analysis using SRTM and GIS in synergy with depiction: a case study of the Karmanasa River basin, North central India, Appl Water Sci.9: 13. https://doi.org/10.1007/s13201-018-0887-3
[39] Rai, P. K., Chandel, R. C., Mishra, V. N. and 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 (Springer), 8-15, pp. 1-16. .DOI: https://doi.org/10.1007/s13201-018-0660-7
[40] Rai, P. K., Chandel, R. C., Mishra, V. N. and 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 (Springer), 8-15, pp. 1-16. .DOI: https://doi.org/10.1007/s13201-018-0660-7
[41] Rai, P. K., Chaubey, P. K., Mohan, K. & Singh, P., 2017b. Geoinformatics for assessing the inferences of quantitative drainage morphometry of the Narmada Basin in India , Applied Geomatics (Springer), Vol. 9 (3), 1-23. DOI:10.1007/s12518-017-0191-1
[42] Rai, P. K., Mohan, K., Mishra, S., Ahmad, A. and Mishra, V. N., 2017. A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India . Applied Water Science, pp.1-16
[43] Rai, P.K., Mishra, V.N. & Mohan, K. 2017a. A Study of Morphometric Evaluation of the Son Basin, India Using Geospatial Approach , Remote Sensing Applications: Society and Environment, Vol. 7, 9-20. DOI: 10.1016/j.rsase.2017.05.001
[44] Rais, S. & Javed, A., 2014. Drainage Characteristics of Manchi Basin, Karauli District, Eastern Rajasthan Using Remote Sensing and GIS Techniques . International Journal of Geomatics and Geoscience, Vol. 5 (1), pp. 285-299
[45] Schumm, S. A., 1956. Evolution of Drainage Systems & Slopes in Badlands at Perth An boy, New Jersey , Bulletin of the Geological Society of America, 67, pp 597-646.22
[46] Sharma, S. K., Gajbhiye, S., Nema, R. K., Tignath, S., 2015. Assessing vulnerability to soil erosion of a watershed of Narmada basin using remote sensing and GIS . Int J Sci Innov Eng Technol, issue 1, ISBN 978-81-904760-6-5
[47] Singh, K. N. 1980. Quantitative analysis of landforms and settlement distribution in southern uplands of eastern Uttar Pradesh (India)
[48] Singh, P., Thakur, J. & Singh U. C. 2013. Morphometric analysis of Morar River Basin, Madhya Pradesh, India, using remote sensing and GIS techniques. Environ Earth Sci 68:1967–1977
[49] Singh, P., Thakur, J. K. and Singh, U. C., 2012. Morphometric analysis of Morar River Basin, Madhya Pradesh, India, using remote sensing and GIS techniques. Environmental Earth Science, v. 68, pp. 1967–1977.
[50] Singh, S., & Dubey, A., 1994. Geo-environmental planning of watersheds in India. Allahabad: Chugh Publications.
[51] Smart, J. S. & Surkan, A. J., 1967. The relation between mainstream length and area in drainage basins. Water Resources Research, 3, 963–973
[52] Smith, K. G., 1950. Standards for grading texture of erosional topography. Am. J. Sci.
[53] Sreedevi, P. D., Srinivasal U. S. and Kesava Raju, K., 2001. Hydrogeomorphological and groundwater prospects of the Pageru River basin by using remote sensing data. Environ Geo l, 40(8), pp10881094
[54] Strahler, A. N., 1952. Hypsometric analysis of erosional topography. Geological Society of America Bulletin, v. 63, 1117–1142.
[55] Strahler, A. N., 1957. Quantitative analysis of watershed geomorphology. Transactions of American Geophysics Union, v. 38, 913–920.
[56] Strahler, A. N., 1964. Quantitative geomorphology of drainage basin and channel networks. In: V. T. Chow (ed.) Handbook of applied hydrology, McGrawHill, NewYork, NY, USA, pp. 439-476.
[57] Strahler, A. N., 1956. Quantitative Slope Analysis , Bulletin of the Geological Society of America, 67, pp 571
[58] Strahler, A. N., 1975. Physical Geography (Fourth Edition). Singapore: John Wiley and Sons., pp. 455
[59] Vinoth Kumar, R., Arun Venkatesh, S., Janapriya, S., Rajasekar, M. & Muthuchamy, I., 2016. Morphometric analysis and prioritization of palathodi watershed in Parambikulam-Aliyar basin, Tamil Nadu using RS and GIS." Asian Journal of Environmental Science 11, no. 1 (2016): 51-58

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