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Morphometric Analysis of Reju Khal Drainage Basin using Geographic Information System (GIS) and SRTM data

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Abstract—This study aims to define the drainage morphometry of Reju Khal drainage basin using Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) data to evaluate the drainage condition of this river with the help of Geographical Information System (GIS) and Remote Sensing. The morphometric analysis of the Reju Khal drainage basin has been carried out through measurement of linear, areal and relief aspects. It is found that Reju Khal tributaries are of 6th order. Total 1008 streams are identified of which 796 are first order, 160 are second order, 34 are third order, 9 are fourth order, 3 are fifth order and 1 sixth order stream. Drainage patterns of stream network from the basin have been observed as mainly of dendritic type in the major area also some have rectangular and some trellis drainage pattern in north-eastern and eastern side of the area. 4th, 5th and 6th order streams have Bifurcation ratio (Rb) is near to 3.00, which indicate geomorpholgical control and 2nd and 3rd order streams have near to 5.00 which indicate the influence of structural control on the development of the drainage pattern. The presence of the maximum number of the first order segments and the values of the mean stream length ratio indicate differences in slope and topographic conditions of the basin. The slope map of the area reveals low and very gentle slope basin. Drainage density and texture ratio shows that the texture of basin is moderate which indicate medium resistant or permeable sub-soil materials, moderate vegetation and infiltration; the drainage texture shows fine texture indicating soft or weak rocks unprotected by vegetation. Compactness coefficient, circulatory ratio and elongation ratio shows that the shape of basin almost circular. The elongation ratio, length of overland flow and relief map of the basin shows that the major part of basin is of low relief and very young topography. The morphometric analysis of drainage basin reveal that the drainage basin is low laying flood prone drainage basin and have moderate to good groundwater prospect. There is also need to examine other factor of land use, climate, soil type, geological structure and stratigraphy to know hydrological process, landslide and flooding condition.

Index Terms— Morphometry, Drainage Basin, Geomorphology, Hydrology, Reju Khal, GIS, SRTM

1 INTRODUCTION

The fundamental unit of virtually all watershed and fluvial investigations is the drainage basin. In its simplest form, a drainage basin is an area that funnels all runoff to the mouth of a stream. Morphometry is an essential means in geomorphic analysis of an area. Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimension of its landforms [1]. The drainage basin analysis is important in any hydrological investigation like assessment of groundwater potential, groundwater management, pedology and environmental assessment. Hydrologists and geomorphologists have recognized that certain relations are most important between runoff characteristics, and geographic and geomorphic characteristics of drainage basin systems. Various important hydrologic phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the contributories etc. [2]. This modern approach of quantitative analysis of drainage basin morphology was given inputs by Horton [3] the first pioneer in this field. The influence of drainage morphometric system is very significant in understanding the landform processes, soil physical properties and erosion characteristics. Thus the role of lithology and geologic structures in the development of stream networks can be better understood by studying the nature and type of drainage pattern and by a quantitative morphometric analysis [4]. The morphometric analyses of different basins have been done by various scientists using conventional methods [2],[5],[6] but over the past two decades, this information has been increasingly deived from digital representation of topography, generally called the Digital Elevation Models (DEM) [7],[8]. The automated derivation of topographic watershed data from DEM is faster, less subjective and provides more reproducible measurements than traditional manual techniques applied to topographic maps [9]. The use of DEM through geographical information system (GIS) is a powerful approach in this mater, since automatic methods to analyze topographic features are allowed with both operational and quality advantages, while using SRTM (Shuttle Rader Topographic Mission) data with GIS. A (geographical Information System) technique is a speed, precision, fast and inexpensive way for calculating morphometric analysis [10],[11],[12],[13]. The objectives of the study are to extract drainage network from contour based DEM using Earth Observation Data and GIS technology; to analyze morphometric parameters of the Reju Khal drainage basin to study its significance.

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2 STUDY AREA

Cox's Bazar bearing the world's longest beach about 120 km long. The study area lies in the north of the Cox's Bazar district comprises the part of Ramu and Ukhia Upazila (Fig.1). The area is bounded by N 21° 10' 38.1532" to N 21° 23' 18.8188" latitudes and E 92° 1' 7.547234" to E 92° 13' 11.40643" longitudes. Most of the area is covered by Inani anticline structure. The Inani structure is represented by NNW-SSE trending low hillocks attaining maximum 542 feet elevation above sea level. The elongated Inani structure is bisected into two major parts by Reju Khal across the northern plunging area. Topographic sheet indicates 84 C/3 of Survey of Bangladesh over’s the area. The area was first systemically mapped by the Indian Geological Survey in 1937. But, later, a very few geological works have been carried out in the Inani hillrange. Pakistan Petroleum Limited (1951) worked on the stratigraphy and structure of Inani hill range based on earlier work undertaken by Burman Oil Company Limited. O.G.D.C (1963 & 1976) carried out geological studies on the Inani structure to establish the stratigraphy, structure and the petroleum prospects. Petrobangla (1980, 1981 & 1993) surveyed Inani and Dakhin Nhila area for stratigraphic classification and hydrocarbon prospect.

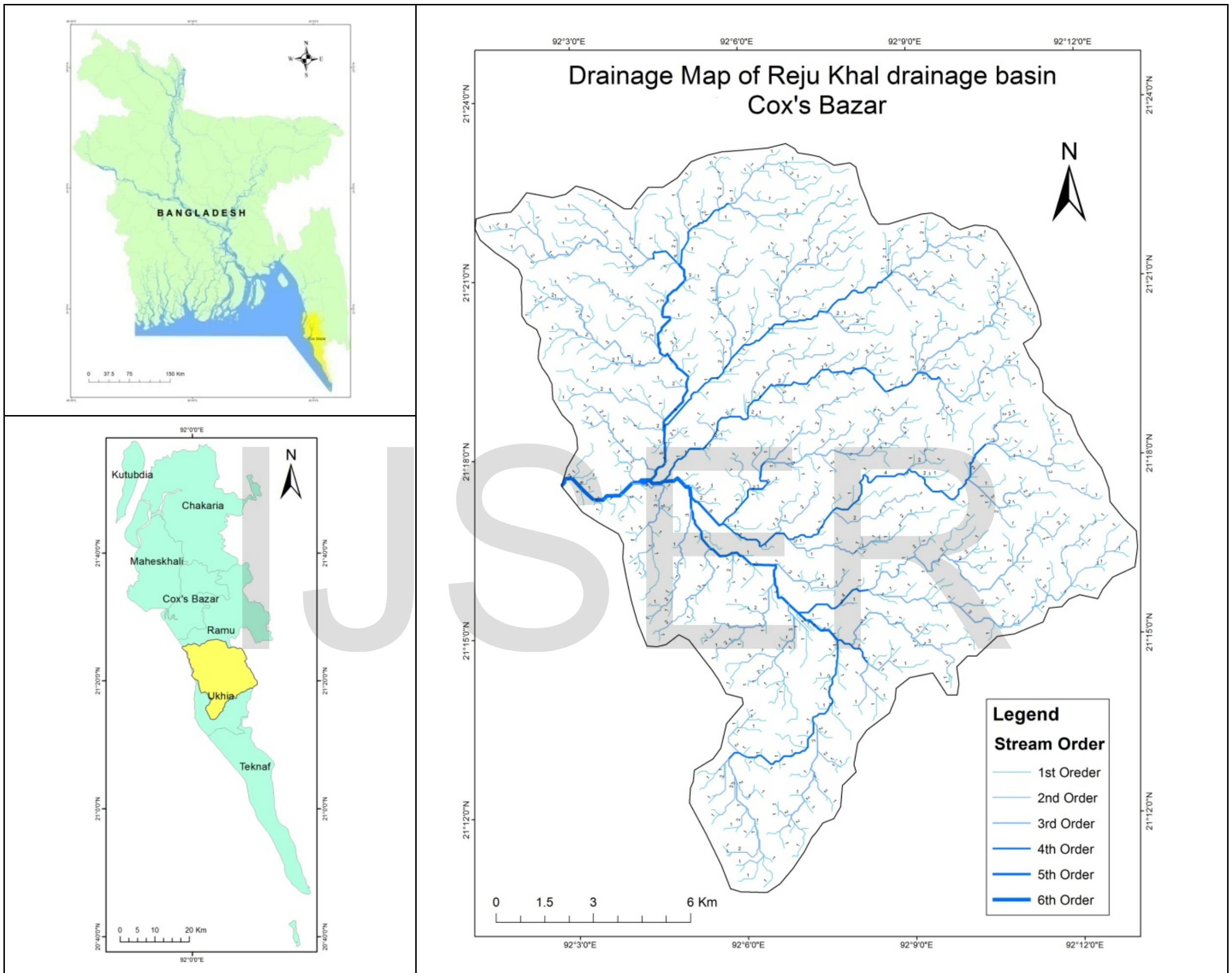

Fig. 1: Drainage Map of the Reju Khal drainage basin in Cox’s Bazar district.

3 Materials and Methods

The base maps of the Reju Khal drainage basin were prepared using of Survey of Bangladesh Toposheet map 84 C/3. The 30m resolution SRTM (Shuttle Radar Topographic Mission) Digital Elevation Model (DEM) data was downloaded from the website www.earthexplorer.usgs.gov and the study area has been extracted using base map. Based on these data, the slope, and topographic elevation maps for the drainage basin were prepared using GIS software. For detail morphometric analysis of the Reju Khal drainage basin at first the sixth order basins are delineated from Digital Elevation Model (DEM) generated from SRTM data. Then the morphometric parameters have been calculated and computed using GIS software in following heads:

Linear Aspects	: One dimension
Areal Aspects	: Two dimensions
Relief Aspects	: Three dimensions

Morphometric parameters under those heads are delineated using Spatial Analysis tool of ArcGIS 10.2 software and computed using standard methods and formulae. At first fill, flow direction and flow accumulation grid has been delineated using Hydrology tool in ArcGIS. Stream order, stream length and basin area has been computed from flow direction and flow accumulation grid using ArcGIS software. The fundamental parameter namely; stream length, area, perimeter, number of streams and basin length are derived from drainage layer. The values of morphometric parameters namely; stream length, bifurcation ratio, drainage density, stream frequency, form factor, texture ratio, elongation ratio, circularity ratio and compactness constant are calculated based on the formulae suggested by Horton [3], Miller [14], Schumn [15], Strahler [16], Nookaratm [17].

4 Results and Discussions

4.1 Morphometric Analysis of basin

Morphometric analysis provides a quantitative description of the basin geometry to understand initial slopes or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of the drainage basin [16]. The following paragraphs describe the physical meaning of various morphometric parameters. Linear, aerial and relief aspects of the parameters of the basin are obtained as per methods proposed by various researchers for the study area and indicated in respective descriptions.

4.1.1 Linear Aspect

The linear aspects of morphometric analysis of basin include stream order, stream length, mean stream length, stream length ratio, bifurcation ratio, mean bifurcation ratio, length of overland flow and RHO Co-efficient.

Stream Order (U): Strahler's system, which is a slightly modified of Hortons system, has been followed because of its simplicity, where the smallest, un-branched fingertip streams are designated as 1st order, the confluence of two 1st order channels give a channels segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. When two channel of different order join then the higher order is maintained. The trunk stream is the stream segment of highest order. It is found that Reju Khal tributaries are of 6th order. Total 1008 streams are identified of which 796 are first order, 160 are second order, 34 are third order, 9 are fourth order, 3 are fifth order and 1 sixth order stream. Drainage patterns of stream network from the basin have been observed as mainly of dendritic type in the major area which indicates the homogeneity in texture and lack of structural control but in the east side, the upper stream area in the north-eastern and eastern side of the map (Fig. 1) observed rectangular and some trellis drainage pattern in some sub-watershed. Also observed lineament of stream which indicate this area may be structurally disturbed or faulted.

Stream Length (L_u): The stream length (Lu) has been computed based on the law proposed by Horton. Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. Length of the stream is an indicator of the area contribution to the drainage basin, steepness of the drainage basin as well as the degree of drainage. Steep and well drained areas generally have numerous small tributaries; whereas, in plains, where soils are deep and permeable, only relatively long tributaries (generally perennial streams) will be in existence. Thus, this factor gives an idea of the efficiency of the drainage network. Generally the total length of the stream segments decrease with stream order. Deviation from its general behavior indicates that the terrain is characterized by high relief and /or moderately steep slopes, underlying by varying lithology and probable uplift across the watershed [18]. The numbers of streams are of various orders are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The length of first order stream is 321.1 km, second order stream is 149 km, third order stream is 92.4 km, fourth order stream is 50.92 km, fifth order stream is 17.82 km and sixth order stream is 5.15 km. The observation of stream order verifies the Horton's law of stream number i.e. the number of stream segment of each order forms an inverse geometric sequence with order number.

Mean Stream Length (L_{sm}): The mean stream length is a characteristic property related to the drainage network and its associated surfaces [16]. The mean stream length (Lsm) has been calculated by dividing the total stream length of order by the number of stream. The mean stream length of study area is 0.40 for first order, 0.93 for second order, 2.72 for third order, 5.66 for fourth order, 5.94 for fifth order and 5.15 for sixth order. The mean stream length of 4^{th}, 5^{th} and 6^{th} order stream are about to same which indicate the higher order area slope is very gentle and near to flat land.

Stream length ratio (R_L): The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and has an important relationship with surface flow and discharge [3]. The R_L values between streams of different order in the basin reveal that there are variations in slope and topography. R_L is the ratio (Table 1) computed for the Reju Khal drainage basin is presented in Table 2. The values of the mean R_L vary from 0.87 (6^{th} Order) to 2.92 (2^{nd} order) for the basin. It is noticed that the R_L between successive stream orders of the basin vary due to differences in slope and topographic conditions. R_L has an important relationship with the surface water discharge and erosional stage of the basin.

Table 1: Method of Calculating Morphometric Parameters of Drainage basin

Sl No.	Parameters	Formula/Defination	References
		Linear Aspects	
1	Stream order (U)	Hierarchical order	Strahler [16]
2	Stream Length (L_U)	Length of the stream	Hortan [3]
3	Mean stream length (Lsm)	Lsm=Lu/Nu; Where, Lu=Mean stream length of a given order (km), Nu=Number of stream segment.	Hortan [3]
4	Stream length ratio (R_L)	RL= Lu / L_{u-1} Where, Lu= Total stream length of order (u), L_{u-1}=The total stream length of its next lower order.	Hortan [3]
5	Bifurcation Ratio (R_b)	Rb = Nu / N_{u+1} Where, Nu=Number of stream segments present in the given order N_{u+1}= Number of segments of the next higher order	Schumn [15]
6	Mean Bifurcation Ratio (Rbm)	R_{bm} = Average of bifurcation ratio of all Orders	Strahler [16]
7	Length of overland flow (L_g)	Lg=1/2Dd Where, Drainage density	Hortan [3]
8	RHO Co-efficient (RHO)	RHO=R_l/R_b: The ratio between the stream length ratio and the Bifurcation ratio	Mesa [19]
		Aerial Aspects	
1	Area (A)	Area of the basin in km^2	
2	Perimeter (P)	Perimeter of the basin in km	
3	Form factor (R_f)	Rf=A/(Lb)^2 Where, A=Area of basin, Lb=Basin length	Hortan [3]
4	Basin shape (Bs)	Bs = Lb^2/ A	Horton [3]
5	Drainage density (D_d)	D_d=L/A Where, L=Total length of stream, A= Area of basin.	Hortan [3]
6	Stream frequency (F_s)	Fs=N/A Where, L=Total number of stream, A=Area of basin	Hortan [3]
7	Drainage texture (T)	T = D_d x F_s	Smith [5]
8	Texture ratio (Tr)	Tr=ΣNu/P,	Smith [5]
9	Compactness Coefficient (Cc)	Cc=P/Circumference of the circle of the same area	Gravelius [20]
10	Circulatory ratio (R_c)	Rc=4πA/P^2, Where A= Area of basin,π=3.14, P= Perimeter of basin.	Miller [14]
11	Elongation ratio (R_e)	Re=√(Au/π)/ Lb Where, A=Area of basin, π=3.14, Lb=Basin length	Schumn [15]
12	Constant channel maintenance (C)	Lof=1/D_d Where, D_d= Drainage density	Hortan [3]
13	Lemniscate's (k)	k = Lb^2 π/ (4A)	Chorely et al. [21]
		Relief Aspects	
1	Basin relief (B_h)	Vertical distance between the lowest and highest points of basin.	Schumn [15]
2	Relief Ratio (R_h)	Rh = Bh / Lb Where, Bh=Basin relief, Lb=Basin length	Schumn [15]
3	Slope	*Sb* = H-h/L^2 Where L= Basin length	Mesa [19]
4	Ruggedness Number (R_n)	Rn=Bh×D_d Where, Bh= Basin relief, D_d=Drainage density	Schumn [15]

Bifurcation ratio (Rb): This is the universal value for maturely dissected drainage basins [22]. The number of stream segments of any given order will be fewer than for the next lower order but more numerous than for the next higher order. According to Strahler [6], in a region of uniform climate and stage of development, the Rb tends to remain constant from one order to next order. The irregularities of the drainage watershed depend upon lithological and geological development, leading to changes in the values from one order to the next. An elongated watershed has higher Rb than the circular watershed. The computed values of Rb of 6th order is 3.00, 3.00 for 5th order streams, 3.78 for 4rd order streams, 4.71 for 3rd order stream and 4.98 for 2nd order stream (Table 2). The average of all the bifurcation ratios in a drainage basin gives the mean bifurcation ratio (Rbm). The Rb values less than 5.00 indicate geomorpholgical control, while Rb values greater than 5.00 indicate structural control on the development of the drainage pattern. The observed average values of Rb of second order streams and third order streams have an Rb near to 5.00 which indicates the influence of structural control on the development of the drainage network in these stream orders of the basin. It is mainly due to the structural disturbances in region. It is also noted that the 4th order streams, 5th and the 6th order streams have Rb equal to 3.78, 3.00 and 3.00 respectively, which indicate absence of any significant structural control on the development of the drainage. Strahler [6] demonstrated that bifurcation ratio shows a small range of variation for different regions/environment except where the powerful geological control dominates. If the Rb is not same from one order to its next order, then these irregularities are dependent upon the geological and lithological development of the drainage basin [16]. The mean bifurcation ratio (Rbm) for the basin is presented in Table 2. In the study area Rbm is 3.89, lower values of the overall basin suggest less structural disturbance.

Table 2: Linear morphometric parameters of the Reju Khal drainage basin

Stream Order	Number of Stream	Stream Length (km)	Mean Stream Length (Lsm) (Kms)	Cumulative Mean Stream Length (Lsm)	Stream Length Ratio (RL)	Bifurcation ratio (Rb)	Mean Bifurcation ratio (Rbm)	RHO Coefficient (RHO)
1st	796 (79.36%)	321.1 (50.46%)	0.40	0.40				
					2.31			0.46
2nd	160 (15.95%)	149 (23.41%)	0.93	1.33		4.98		
					2.92			0.62
3rd	34 (3.39%)	92.4 (14.52%)	2.72	4.05		4.71		
					2.08		3.89	0.55
4th	9 (0.90%)	50.92 (8.00%)	5.66	9.71		3.78		
					1.05			0.35
5th	3 (0.30%)	17.82 (2.80%)	5.94	15.65		3.00		
					0.87			0.29
6th	1 (0.10%)	5.15 (0.81%)	5.15	20.80		3.00		
Total	1003	636.39						
Mean	167.167	106.07						0.45

Length of over land flow (Lg): Length of overland flow is the flow of water over the surface before it becomes concentrated in definite stream channels. The length of overland flow is a measure of erodibility and is one of the independent variables affecting both the hydrologic and physiographic development of the drainage watershed. Horton [3] defined the length of overland flow as the length of flow path, projected to a horizontal plane of the rain flow from a point on the drainage divide to a point on the adjacent stream channel. The shorter the length of overland flow, the quicker the surface runoff from the streams [23]. Lg value is equal to 0.20 km km-2 is found in the study area which indicates short flow- paths.

RHO coefficient (RHO): It is considered to be an important parameter as it determines the relationship between the drainage density and the physiographic development of the basin and allows the evaluation of the storage capacity of the drainage network [3]. The mean RHO coefficient of the basin is 0.45 (Table 2). Higher values of RHO have higher water storage during flood periods and as such attenuate the erosion effect during elevated discharge [19].

4.1.2 Aerial Aspects: Areal aspects of a watershed of given order is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment of the given order including all tributaries of lower order [24]. The watershed shape has a significant effect on stream discharge characteristics. For example; an elongated watershed having a high bifurcation ratio can be expected to have alternated flood discharge. But on the other hand, a round or circular watershed with a low bifurcation ratio may have a sharp flood discharge. The shape of a watershed has a profound influence on the runoff and sediment transport process. The shape of the drainage watershed also governs the rate at which water enters the stream [25]. It comprises of area, perimeter, form factor, drainage density, stream frequency, drainage texture, texture ratio, compactness coefficient, circularity ratio, elongation ratio, constant channel maintenance and lemniscate's.

Drainage density (D_d): Drainage density is defined as the total length of streams of all orders to total drainage area. The drainage density, which is expressed as km/km^2, indicates a quantitative measure of the average length of the overland flow, and therefore, provides at least some indication of the drainage efficiency of the basin. Low drainage density generally results in the areas of highly resistant or permeable subsoil material, dense vegetation and low relief. High drainage density is the result of weak or impermeable sub-surface material, sparse vegetation and mountainous relief. Low density leads to coarse drainage texture while high drainage density leads to fine drainage texture. The low value of drainage density influences greater infiltration and hence the wells in this region will have good water potential leading to higher specific capacity of wells. In the areas of higher drainage density the infiltration is less and surface runoff is more. The drainage density can also indirectly indicate groundwater potential of an area, due to its surface runoff and permeability [25]. D_d of the Reju Khal drainage basin is 2.53. Classification based on D_d by Smith [26] found that the drainage basin belongs to moderate textured category of drainage density (Table 3).

Table 3: Classification based on D_d by Smith [26]

D_d (km/km^2)	Texture
< 1.24	Very Coarse
1.24-2.49	Coarse
2.49-3.73	Moderate
3.73-4.97	Fine
> 4.97	Very Fine

Stream frequency (F_s): Stream frequency (Fs), is expressed as the total number of stream segments of all orders per unit area. It exhibits positive correlation with drainage density in the watershed indicating an increase in stream population with respect to increase in drainage density [27]. The Fs for the basin is 3.98. The study basin belongs to high stream frequency (Table 4).

Table 4: Classification of drainage basin based on stream frequency (Fs) [28]

Fs (km^2)	Class
Below 2.5/km^2	Poor
2.5 to 3.5/km^2	Moderate
3.5 to 4.5/km^2	High
Above 4.5/km^2	Very High

Drainage texture (T): The drainage texture (T) depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development [5]. Amount of soils, which influences the rate of surface runoff, affects the drainage texture of an area [29]. The soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture. Sparse vegetation of arid climate causes finer textures than those developed on similar rocks in a humid climate. The texture of a rock is commonly dependent upon vegetation type and climate [30]. The T of the basin is 10.06. Based on the values of T, the basin belongs to Fine drainage texture.

Table 5: Classification based on T by Smith [5]

T (km/km^2)	Texture
< 4	Coarse
4-10	Intermediate
10-15	Fine
> 15	Ultra Fine

Texture ratio (Tr): It is an important factor in the drainage morphometric analysis, which depends on the underlying lithology, infiltration capacity and relief aspect of the terrain (Rama, 2014). Texture ratio for the basin is 13.06.

Compactness Coefficient (Cc): Compactness coefficient (Cc) is, also known as Gravelius Index (GI) used to express the relationship of a hydrologic basin to that of a circular basin having the same area as the hydrologic basin. A circular basin is the most susceptible from drainage point of view because it will yield shortest time of concentration before peak flow occurs in the basin [17]. Cc is indirectly related with the elongation of the basin area. Lower values of this parameter indicate the more elongation of the basin and less erosion and vice-versa [25]. Compactness coefficient of the basin is 1.37. The value indicates that the basin is more circular than the elongation.

Circulatory ratio (R_c): Circularity Ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin [14]. Greater the value more is the circularity ratio. It is the significant ratio which indicates the stage of dissection in the study region. Its low, medium and high values are correlated with youth, mature and old stage of the cycle of the tributary watershed of the region [25]. The Rc value of 0.4 and below indicates basin is elongated and values greater than 0.75 indicate circular basin. Rc values in 0.4-0.75 indicate intermediate shape of basin. The R_c value of basin is 0.54 and it indicating the basin is intermediate in shape and mature stage of the cycle of the tributary watershed of the region.

Elongation ratio (R_e): Schumm [15] defined elongation ratio as the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin. Values of Re generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. Re values close to unity correspond typically to regions of low relief, whereas values in the range 0.6–0.8 are usually associated with high relief and steep ground slope [16]. These values can be grouped into three categories namely (a) circular (>0.9), (b) oval (0.9-0.8), (c) less elongated (<0.7). The Re values in the study area is 0.50 indicating low relief ground slope and area when collaborated with Strahler's range seem to suggest an less elongated basin.

Constant channel maintenance (C): Schumm [15] used the inverse of drainage density as a property termed constant of stream maintenance (C). It indicates the number of Sq.km of watershed required to sustain one linear km of channel. It not only depends on rock type permeability, climatic regime, vegetation, relief but also as the duration of erosion and climatic history. The constant is extremely low in areas of close dissection [25]. The value C of basin is 0.40. It means that on an average 0.40 sq. km surface is needed in basin for creation of one linear km of the stream channel.

Lemniscate's (k): Chorely et al. [21] express the lemniscate's value to determine the slope of the basin. Higher value of laminiscate ratio indicates high runoff and vice-versa. The value of K of the basin is 1.0, which indicates a low value of K and low run-off of the drainage basin.

4.1.3 Relief Aspects: Relief aspects is an indicator of flow direction of water as it is an important factor in understanding the extent of denundational process that have undergone within the watershed [25]. It comprises of basin relief, relief ratio, slope, ruggedness number and Melton's Ruggedness number.

Basin relief (Bh): According to Schumn [15] the basin relief is the Vertical distance between the lowest and highest points of basin. The highest relief of the basin is 390 m above mean sea level and the lowest relief is 0 because the basin is near to the Bay of Bengal (Fig. 2). So, the Bh of the basin is 390 meter. 86.06 % area cover the elevation below 50 meter which indicates the drainage basin is low relief but only few percent of area reached up to 390 meter elevation.

Relief Ratio (Rh): Relief ratio is defined as the ratio between the total relief of a basin i.e. elevation difference of lowest and highest points of a basin, and the longest dimension of the basin parallel to the principal drainage line [15]. This is a dimensionless height-length ratio and allows comparison of the relative relief of any basin regardless of difference in scale or topography.

Table 5: Elevation, Area and percent of area coverage of each class

Elevation (in Meter)	Area in Sq. km	Percentage (%) of area coverage
<10	32.63	12.95
10 to 20	80.66	32.02
20 to 50	103.53	41.09
50 to 100	19.44	7.71
100 to 200	12.11	4.81
>200	3.57	1.42

Relief ratio is equal to the right angled triangle and is identical with the tangent of the angle of slope of the hypotenuse with respect to horizontal [16]. Thus is measure the overall steepness of a drainage basin is an indicator of intensity of erosion processes operating on the slope of the basin. Relief ratio normally increases with decreasing drainage area and size of a given drainage basin [31]. The Relief Ratio of the drainage basins is 21.78, where the relief ration indicates small area and small size of the basin.

Slope: Slope analysis is an important parameter in geomorphic studies. Slope map of the basin is presented in Fig. 3. The slope elements, in turn, are controlled by the climatomorphogenic processes in the area underlying the rocks of varying resistance. An understanding of slope distribution is essential, as a slope map provides data for planning, settlement, mechanization of agriculture, reforestation, deforestation, planning of engineering structures, morpho-conservation practices, etc [25]. The overall slope of the basin is 1.22 degrees indicate low

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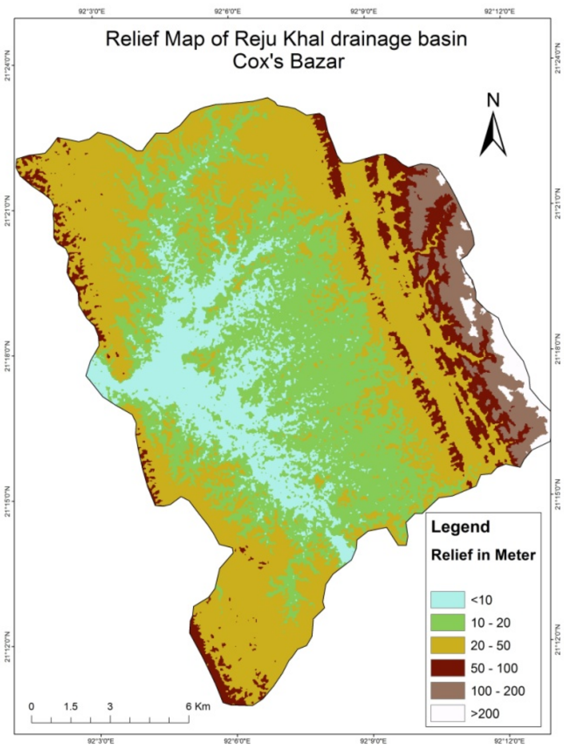

Fig. 2: Relief Map of the Reju Khal drainage basin.

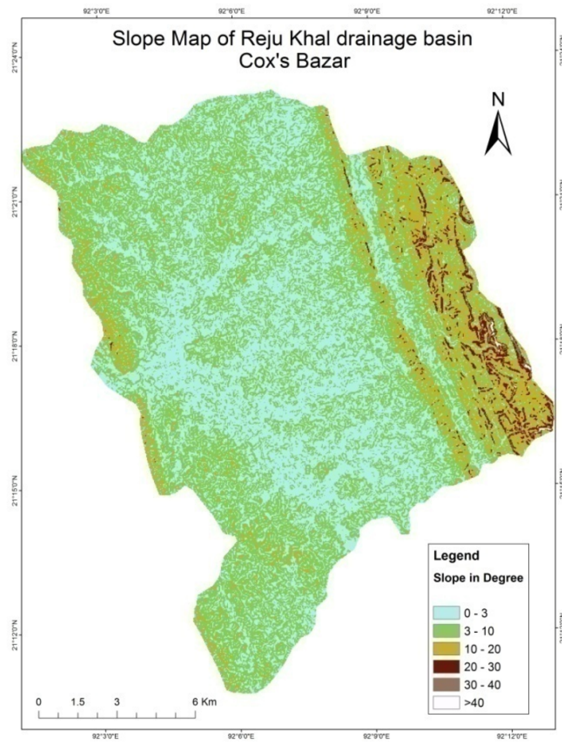

Fig. 3: Slope Map of the Reju Khal drainage basin.

slope basin. From the Fig. 3 it has been found that most of the area of the basin lying below 3 degree slope. So, the Reju Khal drainage basin is a very gentle sloped area with very few percent of area lying above 30 degree slope.

Ruggedness Number (Rn): It is the product of maximum basin relief (H) and drainage density (Dd), where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variables are large and slope is steep [32]. As topography becomes more convoluted, the ruggedness number increases. The value of ruggedness number in present basin is 985.28. High values of the Rn in the basin are because both the variables like relief and drainage density are enlarged and the topography of the basin is more convolved.

Table 6: Result of morphometric analysis of the Reju Khal drainage basin

Sl. No.	Parameters	Value
	Linear Aspect	
1	Stream order (U)	6
2	Stream Length (L_U)	636.39
3	Basin Length (Lb) (km)	17.91
4	Mean stream length (Lsm) (km)	106.07
5	Mean Bifurcation Ratio (Rbm)	3.89
6	Length of overland flow (L_g)	0.2
	Aerial Aspects	
1	Area (A) (sq.km)	251.9
2	Perimeter (P) (km)	76.81
3	Form factor (R_f)	0.79
4	Basin shape (Bs)	1.27
5	Drainage density (D_d) (km/km^2)	2.53
6	Stream frequency (F_s) (km^2)	3.98
7	Drainage texture (T)	10.06
8	Texture ratio (Tr) (Km)	13.06
9	Compactness Coefficient (Cc)	1.37
10	Circulatory ratio (R_c)	0.54
11	Elongation ratio (R_e)	0.50
12	Constant channel maintenance (C)	0.40
13	Lemniscate's (k)	1.00
	Relief Aspects	
1	Basin Relief (B_h) (Meter)	390
2	Relief Ratio (R_h)	21.78
3	Slope (Degree)	1.22
4	Ruggedness Number (R_n)	985.28

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4 Conclusion

GIS and Remote sensing techniques have proved to be accurate and efficient tool in drainage delineation and their updation [24]. The morphometric analysis has been carried out through measurement of linear, areal and relief aspects of basins. It has been found that the study area is a 6th order drainage basin. Stream order and stream pattern of the basin indicate that it is a 6th order drainage basin with dendritic drainage pattern but some of the area observed as rectangular and trellis drainage pattern. Bifurcation ratio observed for 2nd and 3rd order basin indicate some influence of structural control on the development of the drainage network in these stream orders of the basin which also can be concluded from rectangular and trellis drainage pattern in some areas. The presence of the maximum number of the first order segments (796) shows that the basin is subjected to erosion and also that some areas of the basin are characterized by variations in lithology and topography. Stream length (636.39 km), mean stream length (106.07 km) and stream length ratio reveal that the slope of the higher stream order area is very gentle. From the slope map it has been found that maximum area of the basin lies below the 3 degree and overall slope of the basin 1.22 degree indicate low and very gentle slope basin. The maximum elevation of the drainage basin is 390 m but 44.97% area lies below 20 m height. High values of RHO coefficient (0.45) of the basin indicate higher water storage during flood periods and as such attenuate the erosion effect during elevated discharge. Also the value of laminiscate's (k) is low (1.0) which reveals low run-off of the drainage basin. Drainage density (2.53 km/km^2) and texture ratio (13.06 km) shows that the texture of basin is moderate which indicate medium resistant or permeable sub-soil materials, moderate vegetation and moderate infiltration. The drainage texture (10.06) shows fine texture which indicates soft or weak rocks unprotected by vegetation. Compactness coefficient (1.37), circulatory ratio (0.54) and elongation ratio (0.50) shows that the shape of basin almost circular. The elongation ratio basin indicates that the major part of the basin is of low relief. The length of overland flow is 0.20, indicating very young topography. Overall morphometric analysis of drainage basin indicates that the drainage basin is low laying flood prone drainage basin and have moderate to good groundwater prospect. However, there is also need to examine other factor of land use, climate, soil type, geological structure and stratigraphy to know hydrological process, landslide and flooding condition.

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