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Morphometric Analysis of Deepor Beel Basin Using GIS

Dipankar Sharma[1], Dr. Bibhash Sarma[2]

[1]Young Professional (WRE), North Eastern Regional Institute of Water and Land Management, Tezpur, Assam, India Email-dipankarsharma549@gmail.com

[2]Professor, Civil Engineering Department, Assam Engineering College, Guwahati, Assam, India

Email-bsghy@yahoo.co.in

Abstract- Morphology is a field of science which deals with the change of river plan form and cross sections due to sedimentation and erosion. A proper study of the basin morphometry helps a lot in the better understanding of the basin characteristic and thus helps in better planning and management of the basin. In the present study, morphometric analysis of the drainage basin has been carried using earth observation data and Geographical Information System (GIS) techniques. Basin morphometry has been generally analysed under three broad aspects and they are the linear, areal and relief aspects. These aspects of morphometric analysis have been studied extensively by generating DEM of the basin and formulating them in Arc GIS 10.4.1 and compute various physical properties of the basin. In the present study, Deepor Beel basin which is the only Ramsar Site in Assam has been selected for morphometric analysis. From the study, it is found that Deepor Beel catchment consists of 4th order stream covering an area of about 256 Km^2. Besides, a total no of 108 streams having total stream length of 185.98 Km distributed throughout the basin in a dendrite pattern.

Keywords —Arc GIS, Basin, DEM, Morphometric Analysis, Stream Order, Stream Length.

I. Introduction

The study of river basin is very important in fluvial geography. Analysis of basin morphometry is an integral part in the study of river basin. A basin or drainage basin of a water body is the whole area within which every single drop of water in the form of precipitation contributes to the flow of a particular master river. Morphological study provides quantitative description of the basin or sub-watershed sand fluvial geometry, structural controls, geological and geomorphic aspect of a drainage basin. The quantitative analysis of morphometric parameters is of much significance in river basin evaluation, watershed prioritization, soil and water conservation, and natural resources management at micro level. It is of great significance in understanding the hydrologic scenario of an area, because a strong mutual relationship exists between morphological variables and hydrological characteristics.

The quantitative analysis of morphometric parameters is of immense utility in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management at micro level. Geology, relief, and climate are the key determinants of running water ecosystems functioning at the basin scale (Frissel et al., 1986). Morphometric descriptors represent relatively simple approaches to describe basin processes and to compare basin characteristics (Mesa 2006) and enable an enhanced understanding of the geological and geomorphic history of a drainage basin (Strahler 1964). The conventional methods of calculation basin morphometry (Horton, 1945; Smith, 1950; Schumm, 1956 and Strahler, 1957) are most commonly used. GIS could be effectively used for the computation of these morphological characteristics of the watershed with greater efficiency and accuracy. The watershed has emerged as the basic planning unit of all hydrologic analyses and designs. Watersheds considered in engineering hydrology vary in size from a few hectares in urban areas to several thousand square kilometres for large river basins. Each watershed shows distinct characteristics, which are so much variable that no two watersheds are identical.

II. Objective of the Study

The objective of the present study has been summarized as follows

a) To find the basin morphometric parameters of Deepor Beel Basin of Brahmaputra Valley using Geographical Information System.
b) To generate various thematic maps of the basin.

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III. STUDY AREA

Deepor Beel is a vast low-lying area located in the western part of Guwahati and in the southern bank of the Brahmaputra River. It is the only Ramsar site in Assam and among the third Ramsar site of the north eastern region of India and situated at a distance of about 18 km from the Guwahati city centre. The beel and its adjoining wetlands cover an area of about 10.1 sq km (2500 Acres). The beel is surrounded by Maz Jalukbari, Paschim Jalukbari, Dharapur villages and NH37 in the North, Dakshin Jalukbari, Tetelia and Paschim Boragaon in the East; Garbhanga Reserve Forest, Chakordew Hill, Chilla Hill in the South West and Azara and Kahikuchi villages in the West. The beel is bounded by the steep highlands on the north and south, and the valley formed has a broad U-shape with the Rani and Garbhanga hills forming the backdrop. Basin of the Deepor Beel extends from 25˚59′45´´ N to 26˚12′15" N latitudes and 91˚36′25.2" E to 91˚50′42´´ E longitudes, covering an area of 256 sq km of which 26% (67 Sq Km) falls in Meghalaya and 74% (189 Sq Km) falls in Assam.

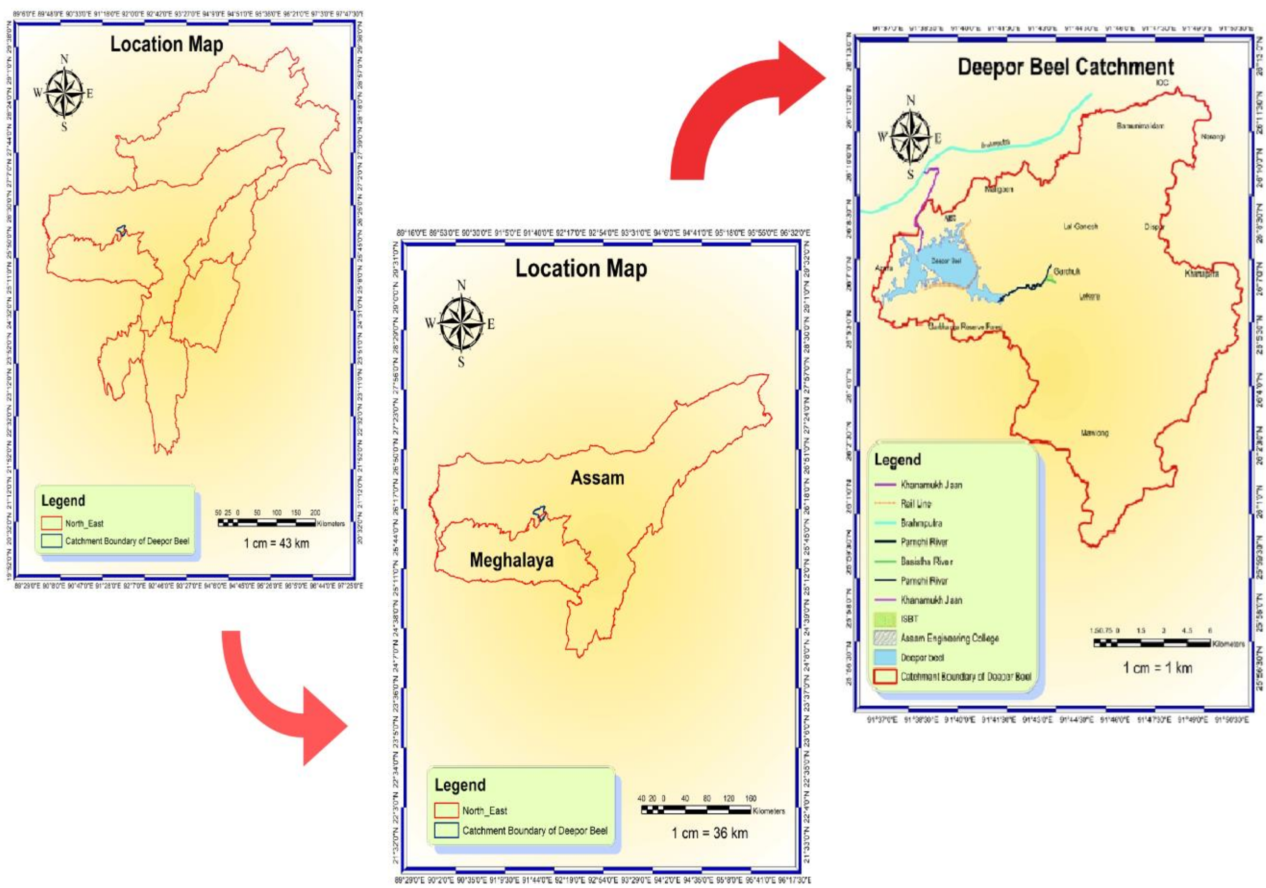

Fig 1: Location Map of Deepor Beel Basin

River Bashistha, Hathinala, Pamohi and Deepor Beel are the largest single drainage basin located at the southernmost part of the Guwahati Metropolitan Area. River Basistha finally discharges into Deepor Beel. The river Basistha and Ummariyang (later known as Bahini) originate from the hills of Meghalaya and flow north-easterly through the southern boundary of Guwahati city. River Bashistha and Morabharalu are basically considered as inlet of Deepor Beel and there is a single outlet to Brahmputra; locally known as the Khanajan that carries the storm discharge of Deepor beel to the river Brahmaputra. It flows in the north direction and after travelling about 5.20 km fall at river Brahmaputra at village Dongrabori. The Pamohi drain is actually a backwater of Deepor Beel and functions as a stream only during lean season. It is actually an outfall to Deepor beel downstream of the confluence of Mora Bharalu Drain and Basistha Drain near NH37. Water from the Deepor beel backflows to Pamohi drain particularly during the monsoon when the HFL of the beel exceeds the FSL of the drain. Apart from the Pamohi channel there are several secondary drains coming from the hills of Meghalaya and its surrounding areas outfall at Deepar Beel. The Khanamukh Channel is the only channel which carries the discharge of Deepar Beel and outfall at river Brahmaputra. Deepor Beel is one of the most important wetlands of Assam and is considered as hotspots for flora and fauna. However, the present scenario is totally different. The lake is degenerated due to encroachments, natural siltation, earth

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filling, growth of vegetation and hyacinth and dumping of solid waste.

IV. MATERIALS AND METHODOLOGY

The main objective of morphometric analysis is to find out the drainage characteristic to explain the overall evaluation of the basin and prepare different thematic maps. Morphometric analysis comprises of a series of sequential steps. This particular portion of the study is primarily focussed on evaluation of Deepor Beel Catchment as well as to delineate various thematic maps & different morphometric parameter of the catchment. To do so, CartoSat 1 DEM (Digital Elevation Model) of 2.5 m resolution is used in GIS environment.

Drainage network are delineated by using the ArcMap 10.4.1 using the DEM of CARTOSAT 1. The watershed is delineated using Hydrology tool under Spatial Analysis Tool of ArcGIS. After projecting the DEM using projected co-ordinate system as WGS 1984 UTM 46° N and various morphometric parameters are evaluated for the Deepor Beel basin. The morphometric parameters were divided in three categories: basic parameter, derived parameters and shaper parameters. Area, Perimeters, Basin Length, Stream Order, Stream Length, Maximum and Minimum Heights and slope come under first categories. Those of the second categories are Bifurcation Ratio, Stream Length Ratio, Stream Frequency, Drainage Density, Drainage Texture, Basin Relief and Relief Ratio are calculated with the help of standard formulae.

The Shape parameters are Elongation Ratio, Circularity Index and Form Factor. The drainage network of the basin has been analyzed as per Horton and laws and the stream ordering was made after Strahler (1964). After evaluating the morphometric parameters basin characteristics can be easily evaluated.

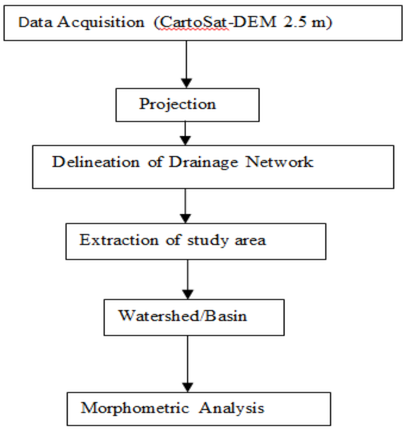

Fig 2: Flow Chart for Evaluation of Morphometric Parameter

V. MORPHOMETRIC PARAMETERS

5.1 AREA

The rate of runoff of any drainage basin depends on its area and physiography. The drainage basin area is a dimensional parameter and it is denoted by A. Area of basin of a particular order is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment of a given order including all the tributaries of the lower order. Larger the area, larger is the runoff and vice versa

5.2 PERIMETER (P)

Length boundary of a basin is known as the perimeter of the basin and it is denoted by P. The factors that are dependent on the basin parameter are elongation ratio and circulatory ratio. Earlier, the perimeter was measured with chartometer (i.e., a map measurer). Perimeters of different sub-watersheds were derived from GIS software that automatically gives the perimeter of each polygon.

5.3 STREAM ORDER (U)

The designation of stream orders is the first step in drainage basin analysis. It is based on hierarchic ranking of streams proposed by (Strahler, 1964). The first order streams have no tributaries. The second order streams have only first order streams as tributaries. Similarly, third order streams have first and second order streams as tributaries and so on.

5.4 STREAM NUMBER (N_U)

Number of streams is described as total counts of stream segments of different order separately and is inversely proportional to the stream order. Stream number is denoted by N_u.

5.5 TOTAL STREAM LENGTH (L_U)

Stream length is one of the most significant variables of a drainage basin characterizing runoff and basin features. It is an indicative of chronological developments of stream segments. Smaller length of stream segments is prominent in hilly areas with larger slopes whereas longer streams are generally indicative of flat areas with lesser slope and it is denoted by L_u.

5.6 MEAN STREAM LENGTH (L_{um})

Mean Stream length is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces (Strahler, 1964). It is obtained by dividing the total length of stream of an order by total number of segments in the order.

5.7 STREAM LENGTH RATIO (R)

Horton (1945, p.291) states that the stream length ratio is the ratio of the mean (L_u) of segments of order (S_o) to mean length of segments of the next lower order (L_{u-1}), which tends to be constant throughout the successive orders of a basin. It is denoted by R and expressed as,

$$R = L_u / L_{u-1}$$

5.8 BIFURCATION RATIO (R_b)

Bifurcation ratio related to the branching pattern of the drainage network. The bifurcation ratio is the ratio of the number of streams in lower order (N_u) to the next higher order (N_{u+1}). It is denoted by R_b

$$R_b = N_u / N_{u+1}$$

5.9 BASIN LENGTH (L_b)

It is the distance between the remotest point of the basin to the outlet. As the basin length increases, the peak discharge decreases. It is given by the formula (Nookaratnam et al 2005).

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$$L_b = 1.312A^{0.568}$$

5.10 LENGTH OF OVERLAND FLOW (L_o)

Horton (1945) used the term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. 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.

$$L_0 = 1/2D_d$$

5.11 FORM FACTOR (R_f)

According to Horton (1932), form factor may be defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.754 (for a perfectly circular watershed). Smaller the value of form factor, more elongated will be the watershed. The watershed with high form factors have high peak flows of shorter duration, whereas elongated watershed with low form factor ranges from 0.42 indicating them to be elongated in shape and flow for longer duration.

$$R_f = A/L_b^2$$

5.12 ELONGATION RATIO (R_e)

According to Schumm (1965, p. 612), elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. 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).

$$R_e = \frac{2}{L_b}\sqrt{\frac{A}{\pi}}$$

5.13 CIRCULATORY RATIO (R_c)

The circulatory ratio is influenced by the length and frequency of stream. The circulatory ratio is similar measure as elongation ratio, originally define by (Miller, 1953), as the ratio of the area of the basin to the area of the circle having equivalent circumference as the basin perimeter and is denoted by the (R_c) and is given by

$$R_c = (1.128 \times A^{0.5})$$

5.14 DRAINAGE DENSITY (D_d)

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed is drained by stream channels. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow. The unit of drainage density is km/km^2.

$$D_d = \frac{L_u}{A}$$

5.15 DRAINAGE FREQUENCY (D_f)

Drainage frequency may be expressed by relating the number of stream segments to the area drained. In other words, Stream frequency is the total number of stream segments in a watershed divided by the area of the watershed. Horton, 1932) introduced stream frequency or channel frequency as number of stream segments per unit area and is given by

$$D_f = \frac{N_u}{A}$$

5.16 DRAINAGE TEXTURE (T)

Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines. Drainage texture is on the underlying lithology, infiltration capacity and relief aspect of the terrain. Drainage texture is denoted by T and is total number of stream segments of all orders per perimeter of that area (Horton, 1945). It is given by

$$T = \frac{N_u}{P}$$

5.17 COMPACTNESS COEFFICIENT (C_c)

Compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed.

$$C_c = 0.2821\frac{P^{0.5}}{A}$$

5.18 CONSTANT OF CHANNEL MAINTENANCE (C_m)

Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms. The constant indicates the number of sq. km of basin surface required to develop and sustain a channel 1 Km long. The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). It is given by

$$C_m = 1/D_d$$

5.19 RELIEF RATIO (Rh)

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 basin. The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956)

$$R_b = H/L_b$$

5.20 RELATIVE RELIEF (R_f)

The maximum basin relief was obtained from the highest point on the watershed perimeter to the mouth of the stream. Using the basin relief, a relief ratio was computed as suggested by Schumm by dividing it with computed length of basin. Melton's relative relief was also calculated using the formula:

$$R_f = (H)/P$$

5.21 RUGGEDNESS NUMBER (R_n)

Strahler (1958) defined ruggedness number as a dimensionless number, as a product of total relief (H) and drainage density (D_d) in the same unit.

$$R_n = D_d \times H$$

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Table 1: Morphometric Parameter.

Morphometric Parameter	Formulae/ Relationship	Reference
Stream order	Hierarchical rank	Strahler, 1964
Stream length (L_u)	Length of stream	Horton, 1945
Mean Stream length (L_{um})	$L_{um}= L_u/N_u$, where L_u is the total stream length of order 'u', N_u number of stream segments of order 'u'	Strahler, 1964
Stream length ratio (R)	$R= L_u/L_{u-1}$, where L_u is the total stream length of order 'u, L_{u-1} is the total stream length of its next lower order	Horton,1945
Bifurcation ratio (R)	$R_b=N_u/N_{u+1}$, where N_u is the total number of stream segment of order 'u', N_{u+1} is the number of stream segments of the next higher order	Schumn, 1956
Mean bifurcation ratio (R_{bm})	R_{bm}= average of the birfurcation ratio of all the order	Strahler, 1957
Relief ratio (R_h)	$R_h= H/L_b$, where H is the total relief (relative relief) of the basin, L_b is the basin length	Schumn, 1956
Relative relief (R_r)	$R_r= H/P$, where H is the total relief (relative relief) of the basin, L_b is the basin length	Melton, 1957
Drainage density (D_d)	$D_d=L_u/A$, where L_u is the total stream length of order 'u' and 'A' is the basin area in km^2	Horton, 1932
Constant of channel maintenance (C_m)	$C_m= 1/D_d$, where D_d is the drainage density	Schumn, 1956
Length of overland flow (L_g)	$L_g= 1/(2 \times D_d)$, where D_d is the drainage density	Horton, 1945
Ruggedness number (R_n)	$R_n= D_d \times H$, where D_d is the drain age density and H is the total relief (relative relief) of the basin.	Strahler, 1958
Stream/Drainage frequency (D_f)	$D_f= N_u/A$, where N_u is the total number of stream segment of order 'u' and 'A' is the basin area in km^2	Horton, 1932
Drainage Texture (T)	$T= N_u/P$, where N_u is the total number of stream segment of order 'u' and P is the perimeter (km) of the basin	Horton, 1945
Form factor (R_f)	$R_f= A/L_b^2$, where A is the basin area in km^2 and L_b is the basin length (km)	Horton, 1932
Circulatory ratio (R_c)	$R_c= (12.57 \times A)/P^2$, where A is the area ($km^2$) and P is the perimeter (km) of the watershed	Miller, 1953

VI. RESULTS AND DISCUSSIONS

A thematic map is a type of map specifically designed to show a particular theme connected with a specific geographic area. A thematic map is a map that focuses on a specific theme or subject area. Thematic maps emphasize spatial variation of one or a small number of geographic distributions. The result of various thematic maps such as DEM, drainage basin map, slope map, flow direction, flow accumulation is prepared using GIS software. The thematic maps for main watershed are given below. Various thematic maps are prepared using ArcMap 10.4.1 using projected coordinated system as WGS 1984 UTM 46° N.

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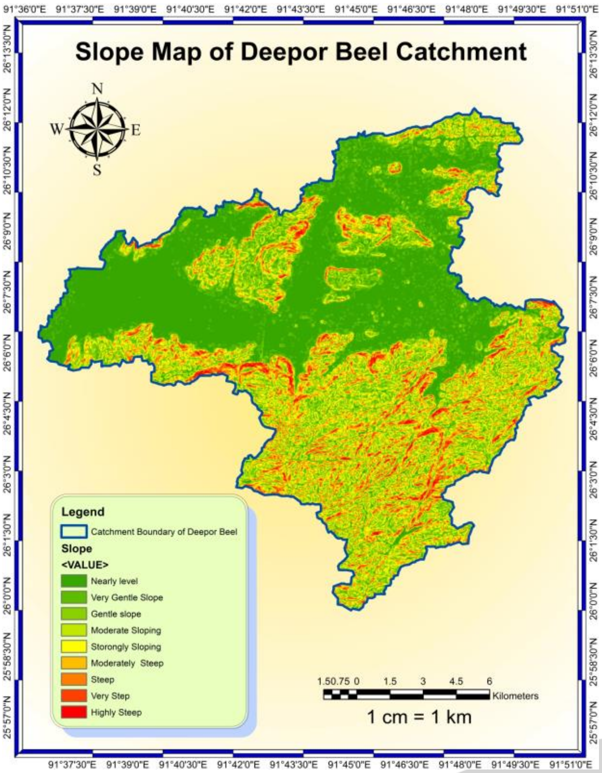

Fig 3: Slope Map of Deepor Beel

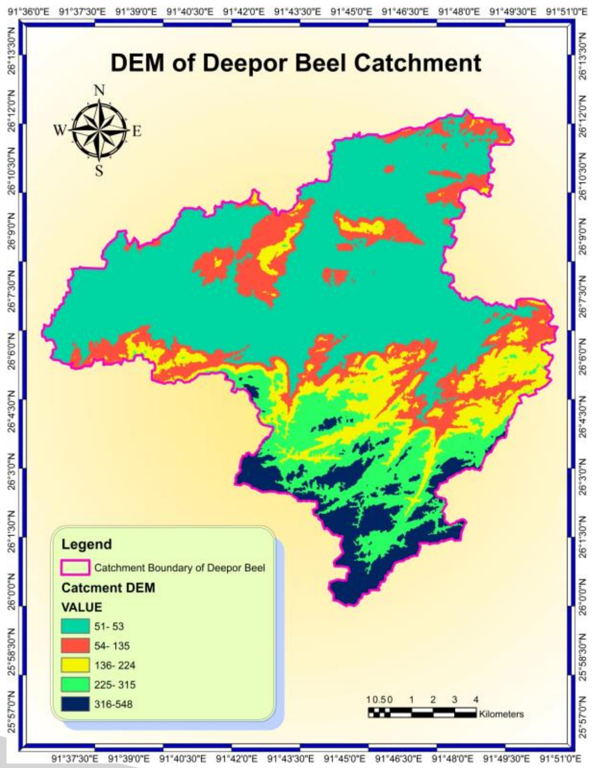

Fig 4: DEM of Deepor Beel Catchment

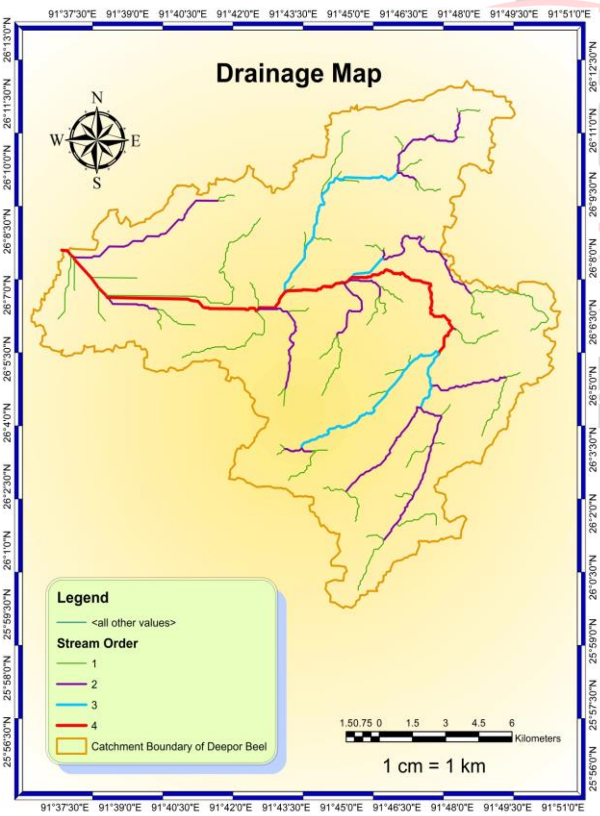

Fig 5: Drainage Map of Deepor Beel Catchment

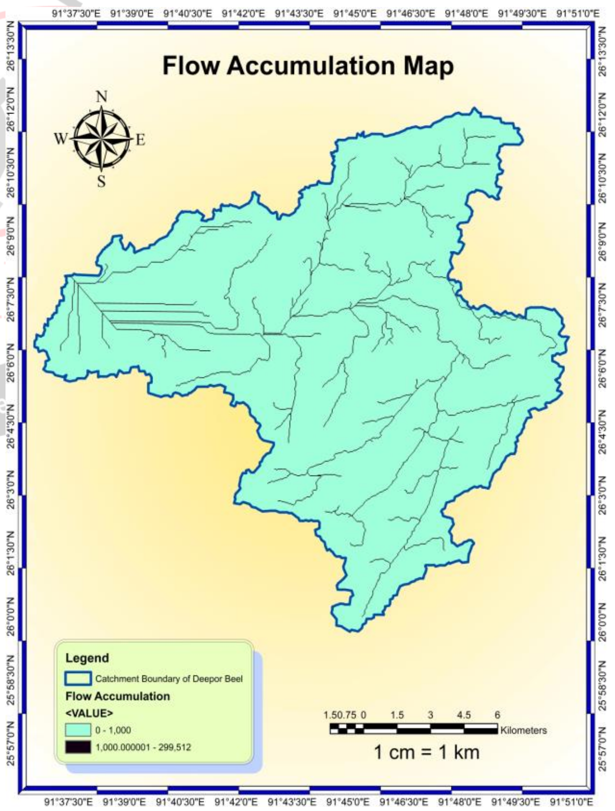

Fig 6: Flow Accumulation Map of Deepor Beel Catchment

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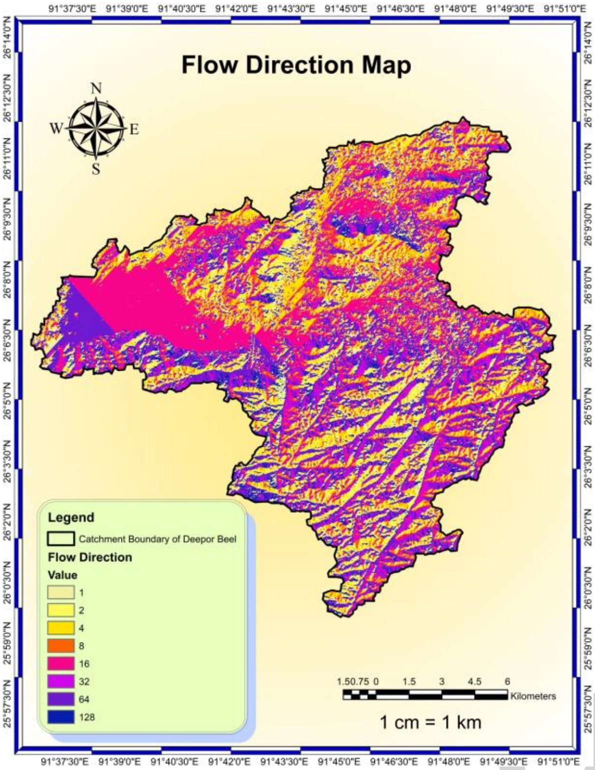

Fig 7: Flow Direction Map

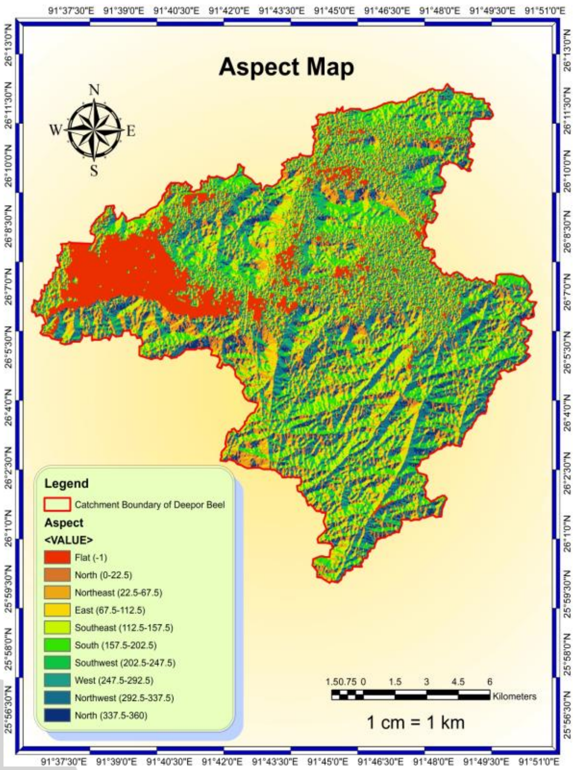

Fig 8: Aspect Map

Table 2: Slopes of the Basin. (Source- FAO's GUIDELINES FOR SOIL DESCRIPTION)

Slope Classes	Slope Range	Description
A.	0% - 3%	Nearly level
B.	4% - 7%	Very Gentle Slope
C.	8% - 12%	Gentle slope
D.	13% - 19%	Moderate Sloping
E.	20% - 25%	Strongly Sloping
F	26% - 30%	Moderately Steep
G	31% - 35%	Steep
H	36% - 39%	Very Step
I	>40%	Highly Steep

6.1 ESTIMATION OF MOPHOMETRIC PARAMETERS

The morphometric analysis of the parameters, namely area of the basin and perimeter of the basin are obtained from the sofware ArcGIS 10.4.1 and other parameters such as srtream order, stream length, drainage density, relief ratio, bifurcation ratio, elongation ratio, drainage frequency, basin length, drainage texture, ruggedness number, constant of channel maintenance, form factor, stream length ratio, circulatory ratio etc are calculated using various mathematical formulae from the topographic maps derived from CartoSat-1 DEM in GIS software.

Stream order	No. of Streams (Nu)	Length of Streams (km) (Lu)
1	75	88.03
2	17	52.17
3	15	22.46
4	1	23.32
Total	**108**	**185.98**

Table 3- Drainage analysis obtained from CartoSat-1 DEM and their results

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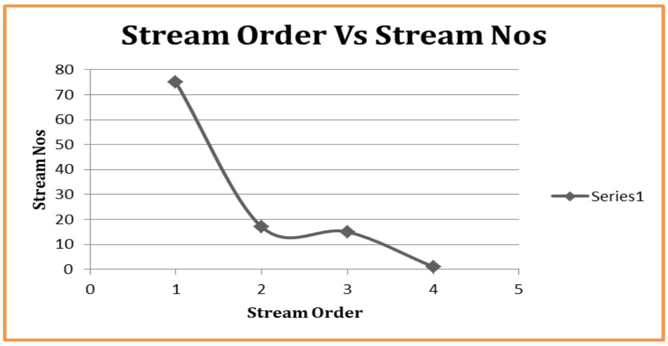

Fig 9: Stream order Vs Stream Nos

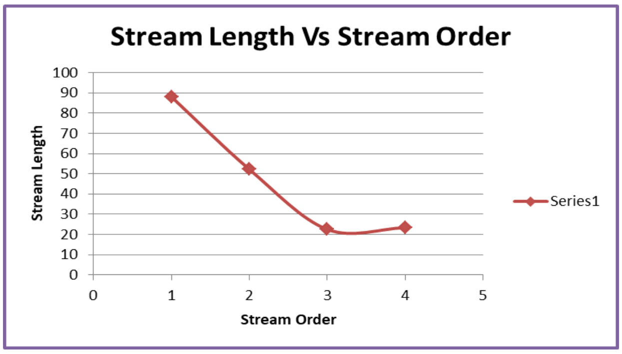

Fig 10: Stream order Vs Stream Length

Table 4- Results of Mophometric Parameter

Sl No	Morphometric parameters	Unit	Results	Significance
1	Area ,A	Sq. Km	256.00	Larger the area, larger is the runoff and vice versa
2	Basin Perimeter, P	Km	115.00	Elongation ratio and circulatory ratio depends upon basin perimeter
3	Basin Length, L_b	Km	30.61	As the basin length increases, the peak discharge decreases
4	Total no of Streams, N_u	Nos	108	Higher value means high drainage frequency
5	Total stream length, L_u	Km	185.98	Small value signifies hilly area, large value signifies flat area.
6	Drainage Density, D_d	Km/ Sq. km	0.73	Small value depicts relatively flat area and permeable underlying strata. It is a measure of how well or how poorly a watershed is drained by stream channels.
7	Constant of Channel maintenance, C_m		1.38	Low value indicates rocky impermeable underlying strata.
8	Total Relief, H	Km	0.4970	Increases with increase in elevation difference between source and outlet of the stream
9	Length of Overland Flow, L_o	Km	0.69	Independent variable which greatly affects the quantity of water required to exceed a certain threshold of erosion. This factor relates inversely to the average slope of the channel.
10	Drainage Frequency, D_f		0.42	It mainly depends on topographical features and drainage network of the area. Lower values of stream frequency indicate lower volume of surface runoff. Higher stream frequency is related to impermeable sub-surface material, sparse vegetation, high relief condition and low infiltration capacity.
11	Drainage Texture, T	Unit/ Km	0.94	Very course drainage texture (value<2)
12	Form Factor, R_f		0.27	Smaller value signifies elongated watershed and longer time of concentration, low peak flows of longer duration
13	Bifurcation Ratio, R_b		6.02	Bifurcation ratio is lower in alluvial region as compared to the hilly areas. Relatively high value signifies hilly terrain and the river is prone to flooding during rainy season.
14	Stream Length Ratio, R		1.39	
15	Elongation Ratio, Re		0.333	Smaller value means elongated watershed. indicates more elongation and more prone to erosion and sediment load with less infiltration capacity
16	Circulatory Ratio, R_c		0.243	Smaller value means elongated watershed. Lower value of circulatory ratio indicates less circular shape of a basin, slower discharge and possibility of erosion is less.
17	Relief Ratio, R_h		0.016	It is an indicator of intensity of erosion processes and sediment delivery rate of the basin, while lower values indicate the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope.
18	Relative Relief, R_r		0.004322	Increase with increase in total relief.
19	Ruggedness Number, R_n		0.36	Smaller value indicates relatively flat area of the basin and low drainage density.

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VII. Conclusion

The drainage basin is often selected as a unit of morphometric investigation because of its topographic and hydrological unity. GIS software has resulted to be of immense utility in the quantitative analysis of the geo-morphometric aspects of the drainage basins. The conventional methods of morphometric analysis are time consuming and error prone, so instead GIS technique has been used for more liable and accurate estimation of similar parameters of watersheds. The values of form factor, circulatory ratio and elongation ratio of the study area show that the basin is elongated and thus has a low peak flow of longer duration. Consequently, the storm water flow of this type of basin is very difficult to manage than a circular basin. Drainage density (D_d) of the study area is 0.73 km/km^2.Thus, in this study, the drainage density falls less than 5 km/km^2 which indicated that the area has a gentle slope and permeable bedrock. The relief ratio and relative relief of the basin is low, which is a characteristic feature of e presence of less resistant rocks. The lower values indicate the presence of basement complex rocks that are exposed in the form of small ridges and mounds with lower degree of slope. Low relief ratios also indicate that the recharge capability of the basin is moderate to low. The bifurcation ratio of the basin is relatively high. The high value of R_b for sub-watershed indicates high runoff, low recharge and mature topography. This high value indicates that the study area is relatively prone to flooding. The high R_b value indicates relatively more structural disturbance in the basin. The value of drainage texture is 0.94 for the basin which is an indication the basin has a very coarse texture. The present study is valuable for erosion control, watershed management, land and water resources planning and future prospective related to runoff study.

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