Evaluation of Morphometric Parameters of Gai River Basin, India using GIS

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Abstract: Morphometry is the study of physical and geometric aspects of a river basin and it is an integral part in the study of river basin characteristics. Morphometry incorporates quantitative study of the area, altitude, volume, shape, slope, profiles of the land and drainage basin characteristics of the area concerned. Remote sensing and Geographical Information System (GIS) techniques are very much useful and very convenient method in morphometric analysis of river drainage basins. The fast-emerging spatial information technology, remote sensing, GIS have effective tools to overcome most of the problems of land and water resources planning and management rather than conventional methods of data process. The present study aims at using the remotely sensed map such as Digital Elevation Map (DEM) to compute various parameters of morphometric characteristics of the Gai River watershed. The study area which lies between the latitude 27o48'0" N - 27o26'0" N and longitude 94o28'0" E - 94o45'0" E, is located in the Dhemaji district of Assam and West Siang of Arunachal Pradesh, with an elevation range of 93m to 1476m above the Mean Sea Level. The area of Gai river basin is about 500.5 km2 and it has 262 numbers of streams and highest order of stream is 5 and it follows dendritic drainage pattern.

Keywords: Morphometry, basin, GIS, DEM, watershed, latitude, longitude, Dendritic.

I. INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of the Earth's surface, shape and dimensions of its landforms (Clarke, 1966). Morphometry incorporates quantitative study of the area, altitude, volume, slope, profiles of the land and drainage basin characteristics of the area concerned (S. Singh,1972). The quantitative analysis of drainage system is an important aspect of characteristics of watershed (Strahler 1964). Morphometric analysis of a river basin can be achieved through measurement of linear, aerial and relief aspects of basin and slope contributions (Nag and Chakraborty, 2003). Morphometric properties of a drainage basin are the quantitative attributes of the landscape that are derived from the terrain or elevation surface and drainage network within a drainage basin. Morphological study provides a quantitative description of the basin or sub-watershed such as sand fluvial geometry, structural controls, geological and geomorphic aspects. The quantitative analysis of morphometric parameters has a great significance in river basin evaluation, watershed prioritization, soil and water conservation, and natural resources management at micro level. Evaluation of morphometric parameters requires the analysis of various drainage parameters such as ordering of the various streams, measurement of basin area and perimeter, length of drainage channels, drainage density (Dd), bifurcation ratio (Rb), stream length ratio (RL), and relief ratio (Rh). The morphometric analysis of the drainage basin is aimed to acquire accurate data of measurable features of stream network of the drainage basin. Various hydrological phenomena can be correlated with the physiographic characteristics of a drainage basin. Hence, morphometric analysis of a watershed is an essential first step, toward basic understanding of watershed dynamics.

II. STUDY AREA

This study concentrates in the Upper Brahmaputra floodplain drained by river Gai, which is a dynamic North-bank tributary of the River Brahmaputra, Assam, India. The river originates in the Eastern Himalayas, passes through a narrow outlet with a great velocity and enters the plains carrying a huge amount of sediment load. The study area is tectonically active. The catchment, both in the mountain and plain, experience heavy rainfall during the monsoon season resulting in excess surface runoff inundating huge area in the plains used primarily for agricultural purposes.

The study area (Shown in Fig 1) which lies between the latitude 27o48'0" N - 27o26'0" N and longitude 94o28'0" E - 94o45'0" E, is located in the Dhemaji district of Assam and in West Siang district of Arunachal Pradesh, with an elevation range of 93m to 1476m above the Mean Sea Level. The total area of the watershed is 500.51 KM2 and out of this 297.77 KM2 lies in Assam and 202.74 KM2 lies in Arunachal Pradesh.

Climate of the region is Pre-humid type characterized by high rainfall and a mild summer and winter. The area receives an annual rainfall of 2600–3200 mm. Temperature ranges are moderate in the region but summers are usually hot and humid. The temperature varies between 350C in summer to 50C in winter. Geologically the present study area comprises of Dafla Formation, Subansiri Formation and Kimin Formation of the Siwalik Group of tertiary age.

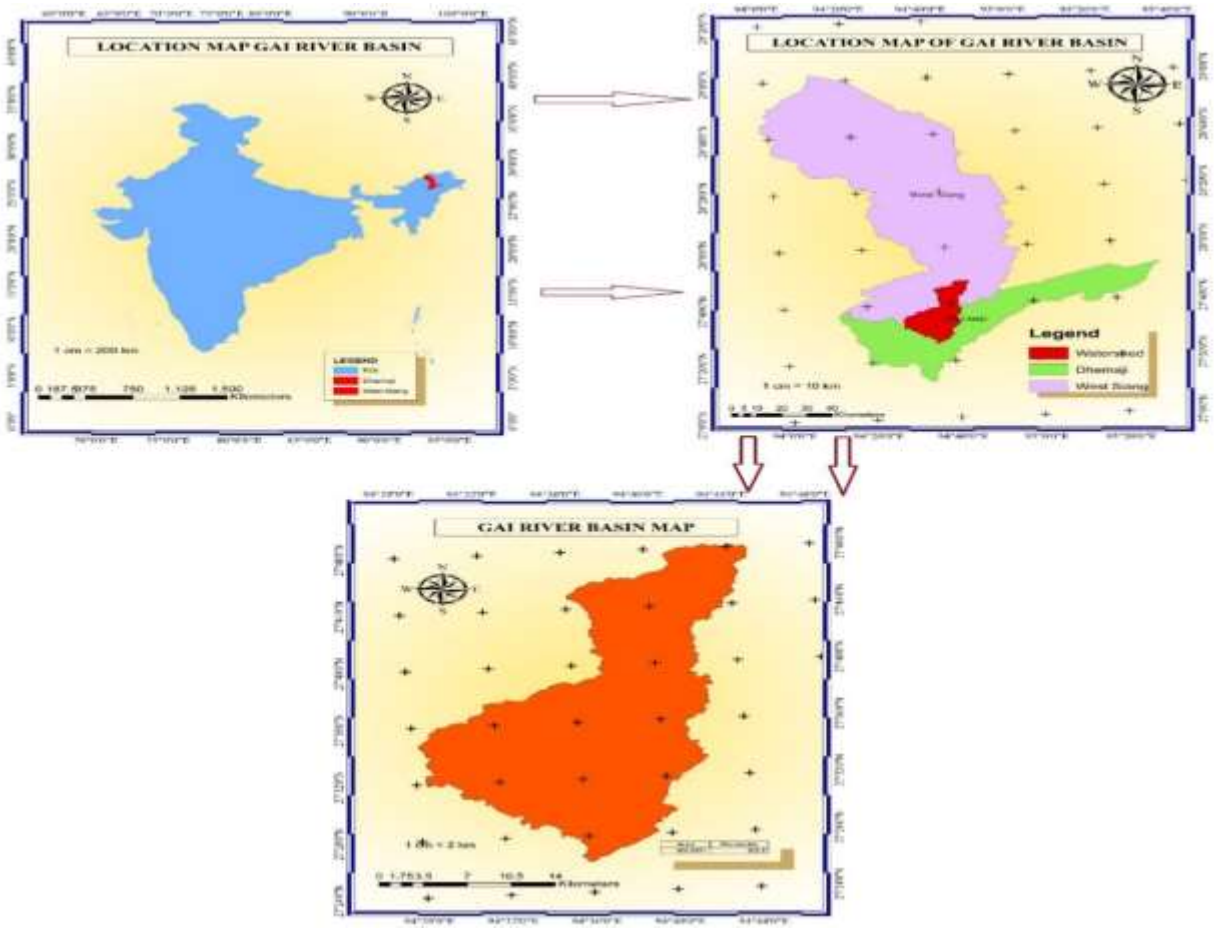

Fig 1 Location Map of Gai river basin

III. METHODOLOGY

The present study is mainly concerned to evaluate morphometric parameters of the river basin. To evaluate the morphometric analysis DEM data (90 m resolution) ASTER GLOBAL DEM is used in GIS environment. Delineation of the watershed is done with the help of ArcGIS 10.1 software and the streams are digitized using the hydrology tool of the software. The drainage network of the basin is analysed as per Horton's law. For ordering of streams Strahler's method of stream ordering is followed. The number and the length of streams of each order are calculated with the help of attribute table. The various morphometric parameters are then calculated with the help of established formulas and relationships which is shown in the table below. Various thematic maps are prepared in ArcGIS 10.1 software such as DEM map, slope map, aspect map, flow direction map, flow accumulation map etc.

The various morphometric parameters are divided in three categories:

1) Basic Parameters: Area, Perimeters, Basin Length, Stream Order, Stream Length, Maximum and Minimum Heights and slope.
2) Derived Parameters: Bifurcation Ratio, Stream Length Ratio, Stream Frequency, Drainage Density, Drainage Texture, Basin Relief and Relief Ratio.
3) Shape Parameters: Elongation Ratio, Circularity Index and Form Factor.

Table 1 Formulas and Relationships of Morphometric Parameters

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})	$L_{um}= L_u/N_u$ Lu=Total stream length of order 'u'	Strahler, 1964

	N_u=number of stream segments of order 'u'	
Stream length ratio (R)	$R = L_u/L_{u-1}$ L_u =Total stream length of order 'u' L_{u-1}=Total stream length of its next lower order	Horton,1945
Bifurcation ratio (R)	$R_b=N_u/N_{u+1}$ N_u =Total number of stream segment of order 'u' N_{u+1}=Number of stream segments of the next higher order	Schumn, 1956
Mean bifurcation ratio (R_{bm})	R_{bm}= average of the bifurcation ratio of all the order	Strahler, 1957
Relief ratio (R_h)	$R_h= H/L_b$ H=Total relief (relative relief) of the basin L_b=Basin length	Schumn, 1956
Relative relief (R_r)	$R_r= H/P$ H=Total relief (relative relief) of the basin, L_b=Basin length	Melton, 1957
Drainage density (D_d)	$D_d=L_u/A$ L_u=Total stream length of order 'u' A=Basin area	Horton, 1932
Constant of channel maintenance (C_m)	$C_m= 1/D_d$ D_d=Drainage density	Schumn, 1956
Length of overland flow (L_g)	$L_g= 1/(2 \times D_d)$ D_d=Drainage density	Horton, 1945
Ruggedness number (R_n)	$R_n= D_d \times H$ Dd=Drainage density H=total relief (relative relief) of the basin	Strahler, 1958
Stream/Drainage frequency (D_f)	$D_f= N_u/A$ N_u=total number of stream segment of order 'u' A=basin area in km^2	Horton, 1932
Drainage Texture (T)	$T= N_u/P$ N_u=total number of stream segment of order 'u' P=Perimeter (km)	Horton, 1945
Form factor (R_f)	$R_f= A/L_b^2$ A=Basin area in km^2 L_b=Basin length (km)	Horton, 1932
Circulatory ratio (R_c)	$R_c= (12.57 \times A)/P^2$ A=Basin area (km^2) P=Perimeter (km)	Miller, 1953

IV. RESULTS OF MORPHOMETRIC ANALYSIS

The number and length of streams in each order of the watershed is tabulated below in Table 2. It is seen that as the order of the stream increases the number of stream and length of streams decreases. Various thematic maps are prepared using ArcGIS 10.1 software namely, DEM of Gai river basin, drainage, flow direction, flow accumulation, aspect and slope map by adopting standard interpretation techniques using Satellite Imagery. Slope map is prepared by using 'slope" option under surface analysis function in ArcMap. These thematic maps give a good pictorial representation of the basin which are shown below in Fig 4- Fig 10.

Table 2 Stream Order and Stream Length of the Basin

Sl No	Order of streams	Number of Streams	Length of Streams (KMs)
1	1st order	141	182.96
2	2nd order	92	105.77
3	3rd order	15	45.76
4	4th order	13	50.88
5	5th order	1	2.18

Stream Order Vs Stream Number

A graph is plotted between Stream Order versus Stream Number as shown in fig 2. It is seen that R2 value of the graph is 0.914 which proves good correlation between them and the equation between the parameters is y = -0.5148x + 2.8251 which shows that Stream Order has a negative correlation with Stream Number.

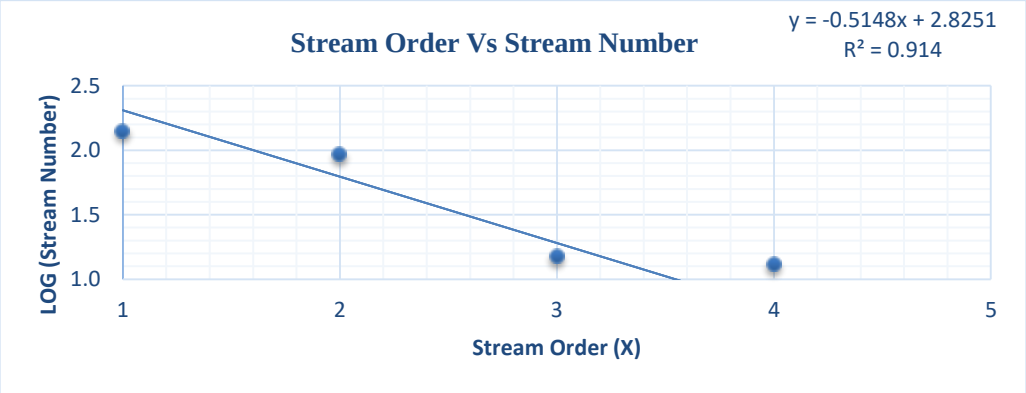

Fig 2 Stream Order Vs Stream Number

Stream Order Vs Stream Length

A graph is plotted between Stream Order versus Stream Length as shown in fig 3. It is seen that R2 value of the graph is 0.7798 which proves good correlation between them. The equation between the parameters is y = -0.4166x + 2.8481 which shows that Stream Order has a negative correlation with Stream Length.

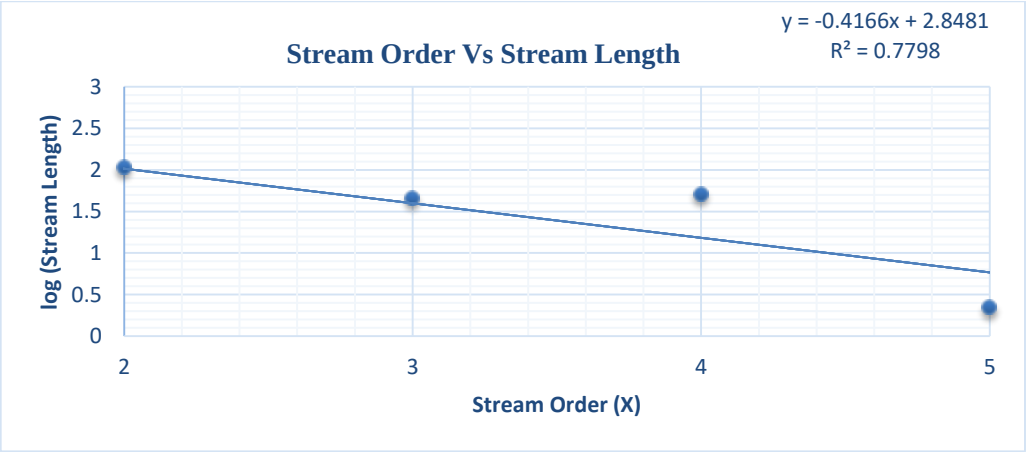

Fig 3 Stream Order Vs Stream Length

Fig 4 Basin Map of Gai river

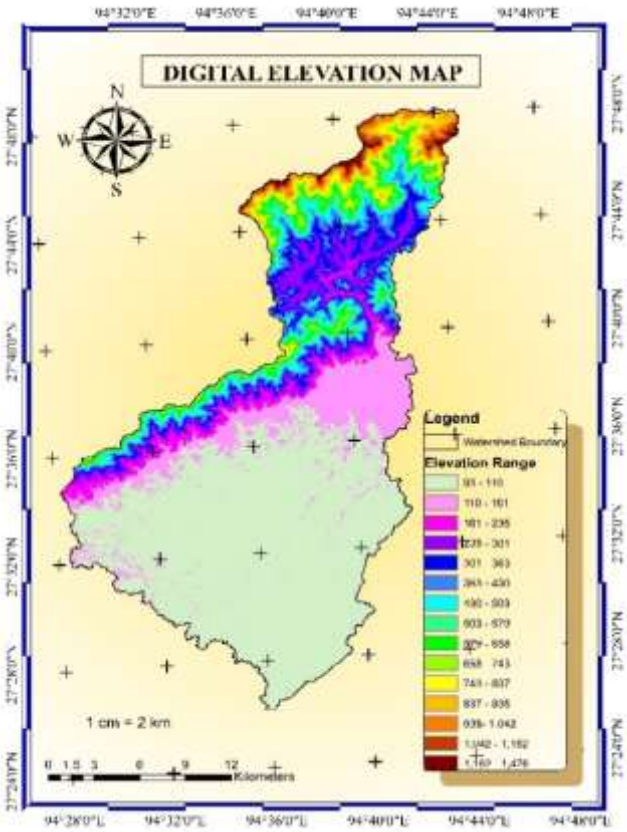

Fig 5 Digital Elevation Map

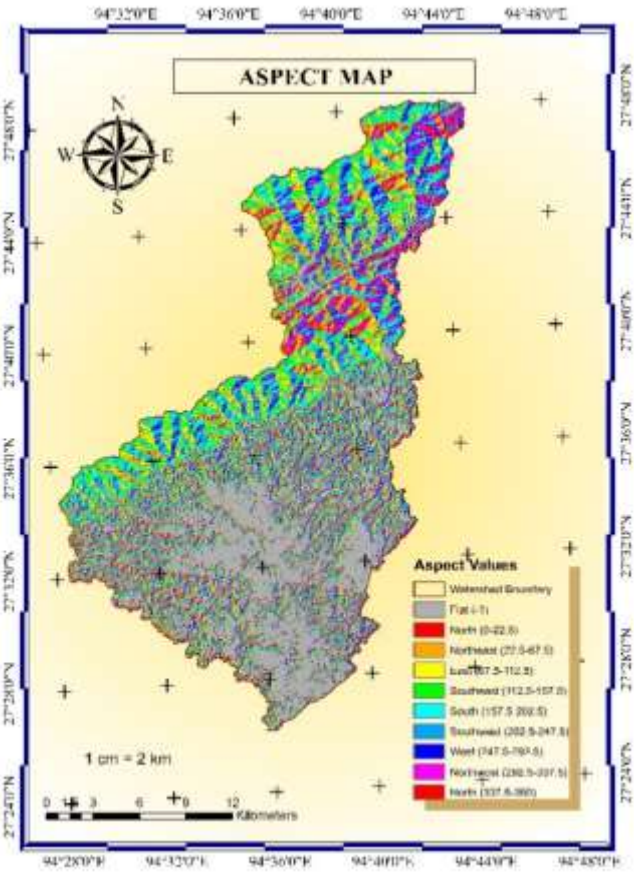

Fig 6 Aspect Map

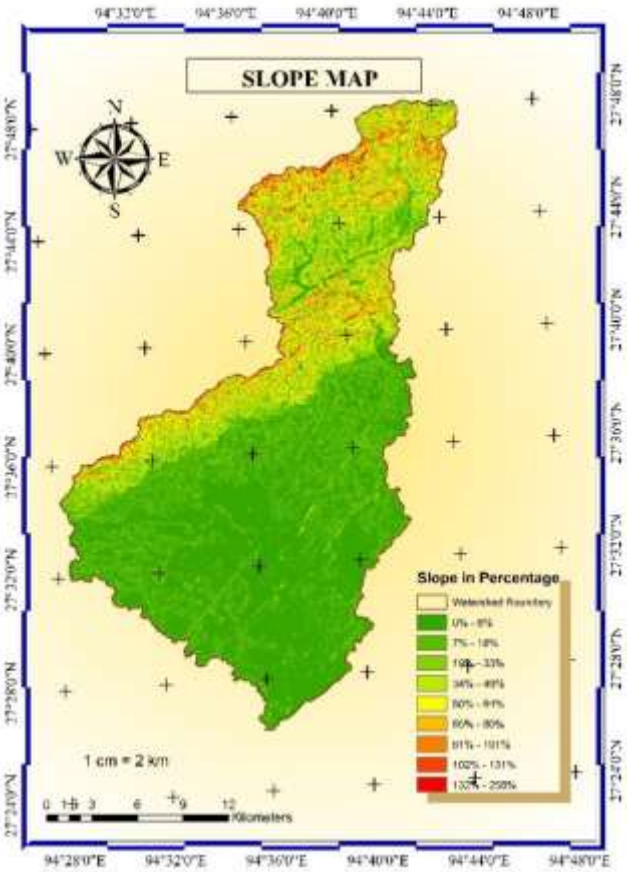

Fig 7 Slope Map

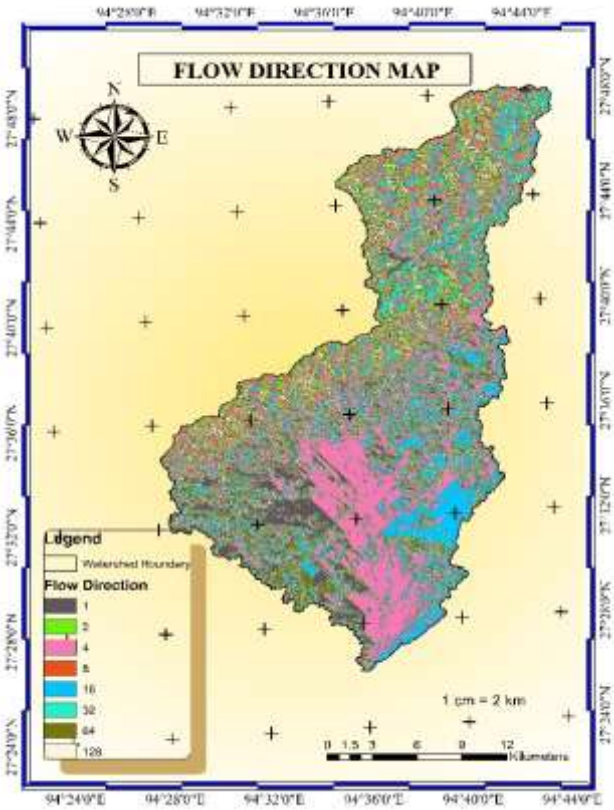

Fig 8 Flow Direction Map

Fig 9 Flow Accumulation Map

Fig 10 Stream Order Map

Table 3 Calculated Morphometric Parameters of Gai river basin

Sl No	Morphometric parameters	Unit	Results	Significance
1	Area, A	SqKm	500.51	Larger the area, smaller is the runoff and vice versa
2	Basin Perimeter, P	Km	202.50	Elongation ratio and circulatory ratio depends upon basin perimeter
3	Basin Length, Lb	Km	44.79	As the basin length increases, the peak discharge decreases
4	Total no of Streams, Nu	Nos	262	Higher value means high drainage frequency
5	Total stream length, Lu	Km	387.55	Small value signifies hilly area, large value signifies flat area
6	Drainage Density, Dd	Km/ SqKm	0.77	Small value depicts relatively flat area and permeable underlying strata.
7	Constant of Channel maintenance, Cm		1.29	Low value indicates rocky impermeable underlying strata.
8	Total Relief, H	Km	1.38	Increases with increase in elevation difference between source and outlet of the stream
9	Length of Overland Flow, Lo	Km	0.65	Independent variable which greatly affect 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, Df		0.52	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	1.29	Very course drainage texture (value<2).
12	Form Factor, Rf		0.25	Smaller value signifies elongated watershed and longer time of concentration, low peak flows of longer duration
13	Bifurcation Ratio, Rb		5.45	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		0.541	
15	Elongation Ratio, Re		0.318	Smaller value means elongated watershed. indicates more elongation and more prone to erosion and sediment load with less infiltration capacity.
16	Circulatory Ratio, Rc		0.153	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, Rh		0.031	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, Rr		0.01	Increase with increase in total relief
19	Ruggedness Number, Rn		1.07	Smaller value indicates relatively flat area of the basin and low drainage density

CONCLUSION

Morphometric analysis of a river using GIS platform have resulted to be of immense utility in analysis of the geo-morphometric aspects of the drainage basins. The study reveals that GIS based approach in evaluation of drainage morphometric parameters at river basin level is more appropriate and convenient than the conventional methods. The morphometric analysis shows that the Gai river is a 5th order basin and follows Strahler's rule of stream network. Drainage density (Dd) of the study area is 0.77 km/km2. Low drainage densities are often associated with widely spaces streams. Low drainage density signifies coarse texture and impermeable bedrock. Gai river basin is having low relief of the terrain and elongated in shape. Smaller value of Elongation Ratio means elongated watershed. indicates more elongation and more prone to erosion and sediment load with less infiltration capacity. Drainage network of the basin exhibits as mainly dendritic type which indicates the homogeneity in texture and lack of structural control. GIS based morphometric analysis helped us to understand various terrain parameters such as nature of the

bedrock, infiltration capacity, runoff, etc. Similar studies in conjunction with high resolution satellite data will help in better understanding the landforms and their processes and drainage pattern demarcations for basin area planning and management.

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