Chapter-3 Basin Morphometry

Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the Earth's surface, shape and dimension of its landforms (Clarke, 1966; Agarwal, 1998; Obi Reddy *et al.,* 2002). Morphometric parameters of a drainage basin describe its form, structure and extension. It is actually quantitative analysis of basin's terrain and drainage network therein which helps us to understand the consequent development of drainage network and thereby enable us to have an idea of the geological and geomorphological processes over time. Thus, it gives us a cue of landform evolutionary phase that basin is currently going through as described in various morphometric studies (Horton, 1945; Strahler, 1952; Strahler, 1964; Shreve, 1969; Muller, 1968).

Horton is considered to be the pioneer in application of quantitative techniques in drainage basin analysis. In early days the method was very much manual which was both time taking and laborious (Horton, 1945; Strahler, 1952; Strahler,1964; Shreve, 1969; Muller,1968; Evans IS, 1972; Chorley *et. al.*, 1984; Strahler, 1957; Schumm, 1956; Chorley and Morgan, 1962). Then J.T. Hack's Stream-profile analysis and stream-gradient index proved to be significant in the quantitative description of drainage basins (Hack, 1973). The advent of Remote Sensing and Geographical Information System (GIS) techniques began to make things much easier and computation of results more accurate. Now much advancement in RS, GIS and personal computers has made possible its widespread application in quantitative geomorphology in general and in morphotectonic analysis of drainage basins in particular (Williams, 1972; Mesa,2006; Lyew-Ayee *et al.,* 2007; Altin and Altin, 2011; Buccolini *et al.,* 2012). Here in India too, quantitative techniques have been applied to study the morphometric analysis of different drainage basins (Vittala *et al.,* 2004; Chopra *et al.,* 2005, Vijith and Sateesh, 2006; Rudraiah *et al.,* 2008; Bagyaraj and Gurugnanam, 2011; Malik *et al.,* 2011; Thomas *et al.,* 2011; Magesh *et al.,* 2012; Singh *et al.,* 2012; Pareta and Pareta, 2012; Rai *et al.,* 2014; Biswas *et al.,* 2014; Chougale and Sapkale, 2017). Various Studies suggests morphometric properties of drainage basins as good indicators of structural influence on drainage development and neotectonic activity (Nag and Chakraborty, 2003; Das *et al.,* 2011; Bali *et al.,* 2012; Demoulin, 2011). There are many studies where morphometric analysis of drainage basins has been used to assess the groundwater potentiality of the basins and to locate suitable sites for construction of check dams and artificial recharge structures (Sreedevi *et al.*, 2005; Avinash *et al.*, 2011; Mishra *et al.*, 2011; Jasmin and Mallikarjuna, 2013). Watershed prioritisation based on morphometric characteristics has also been carried out and aids in the mapping of high flood potential and erosion prone zones (Javed *et al.*, 2011; Patton and Baker, 1976; Diakakis, 2011; Wakode *et al.*, 2011). The remote sensing and GIS nowadays have become cheap, convenient and gives higher accuracy level results in morphometric analysis of drainage basins. According to Rao *et al.* (2010) the fast-emerging spatial information technology, remote sensing, GIS, and GPS are effective tools to overcome most of the problems of land and water resources planning and management rather than conventional methods of data process. In the present chapter morphometric analysis was carried out at basin scale of the Chel River. Thus, all the morphometric characteristics have been calculated for the entire basin under the following three headings:

- Linear Aspects: one dimensional
- Areal Aspects: two dimensional
- Relief Aspects: three dimensional

3.1 Data and methodology

In the present chapter, Indian topographical maps 78 B/9 and 78 B/10 with a scale of 1: 50,000 (20m contour interval) were acquired from Survey of India. Two SRTM DEMs 1 Arcsec 30m tiles (n26_e088_1arc_V3 and n27_e088_1arc_V3) were downloaded from U.S. Geological Survey website using the Earth explorer interface: (http://earthexplorer.usgs.gov/.) as GeoTiff raster files and mosaicked into one in ArcMap 10.1. Topographic information was digitized and geo-referenced with UTM (WGS 1984, Zone 45N) in ArcMap 10.1. The watershed boundary and drainage lines were automatically extracted from the SRTM DEM using Arc hydro tools in ArcGIS 10.1 by collaborating SOI toposheets. DEM and contours maps were also generated for the basin. Spatial analyst tools in ArcGIS 10.1 software were largely used for computation of aspect, relief and slope of the basin. All morphometric parameters (linear, areal and relief) have been calculated as listed in table: 8 with the help of DEM in consultation with SOI topographical maps and Google Earth in GIS environment (ArcMap 10.1). Golden Surfer V.15 was used to prepare perspective view of the basin (Fig.3.1).

3.2 Linear Aspects

Linear aspects are the one-dimensional morphometric properties of drainage basins.

3.2.1 Stream Order (Su)

There are different systems available for ordering streams (Horton,1945; Strahler, 1952; Scheidegger,1965). Strahler's system, which is a slightly modified of Horton's system, has been followed here because of its simplicity. The smallest, unbranched fingertip streams are designated as 1st order, the confluence of two 1st order channels give a channel segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. When two channel of same smaller order join then the next higher order is maintained. The trunk stream is the stream segment of highest order. Based on the method proposed by Strahler (1952), the Chel river is 5th order stream. Altogether 152 streams were identified out of which 114 are 1st order, 28 are 2nd order, 6 are of 3rd order, 3 are 4th order streams and lastly 1 is of fifth order (Table-3.1; Fig. 3.5D).

3.2.2 Stream Number (Nu)

The total number of stream segments present in each order is the stream number (Nu). Thus, Nu is number of streams of order u. As per Horton's law (Horton,1945) of stream numbers, ''the number of streams of different orders in a given drainage basin tends closely to approximate as inverse geometric series of which the first term is unity and the ratio is the bifurcation ratio''.

The study reveals that the development of 1st order streams is maximum in the Himalayan dissected zone (42 streams) followed by piedmont zone (37 streams) and marginally less in the alluvial plain zone (35 streams) (Table 3.1). For 2nd order, Himalayan dissected zone scores 11 streams followed by 10 streams in alluvial plain zone and minimum at piedmont zone with 7 streams. There are no 3rd order streams in alluvial plain zone whereas Himalayan dissected zone has four streams and piedmont zone has two.

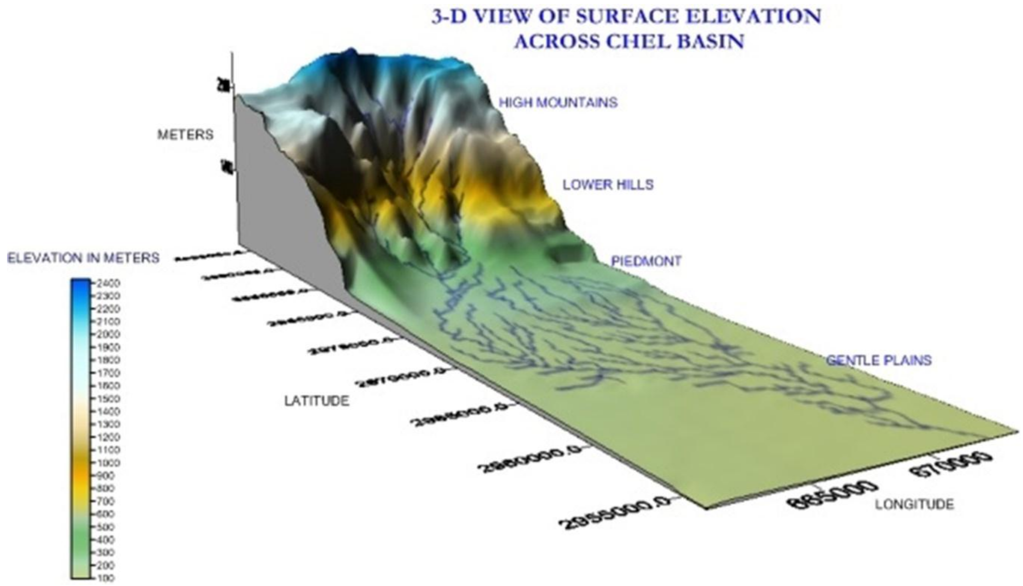


Figure 3.1 Perspective view of Chel River Basin (Study Area).

3.2.3 Stream Length (Lu)

The total length of individual stream segments of each order is measured by summing up the stream length of that order. Stream length measures the average (or mean) length of a stream in each order, and is calculated by dividing the total length of all streams in a particular order by the number of streams in that order. Average stream lengths distribution of stream segments of each of the successive orders in a basin tends to approximate a direct geometric series in which the first term is the average length of the stream of the first order (Horton, 1945). The stream length is a measure of the hydrological characteristics of the bedrock and the drainage extent. Wherever the bedrock and formation is permeable, only a small number of relatively longer streams are formed in a well-drained watershed, a large number of streams of smaller length are developed where the bedrocks and formations are less permeable (Sethupathi *et al.,* 2011). In general, the stream length in each order increases exponentially with increasing stream order. But in Chel basin distribution of stream length varies widely with increase in order. The highest stream length (181.54 km) is recorded for 1st order streams followed by 2nd order streams (81.54 km) then comes 5th order stream (39.22 km) followed by 4th order streams (25.27 km) and lastly by 3rd order streams (14.66 km) (Table 3.2).

3.2.4 Mean Stream Length (Lum)

Mean stream length of a stream channel segment of order ‘u’ is a dimensional property revealing the characteristic size of components of a drainage network and its contributing basin surface (Strahler, 1964). It is obtained by dividing the total length of stream of an order by total number of segments in the order The lengths of stream segments of up to 5th order are measured and the total length as well as Mean Stream Length (Lū) of each order is computed (Table 3.2). The mean stream lengths of stream increase with the increase of the order. But some basins show opposite relation, higher order stream has a small mean length.

Table 3.1 Stream Order, Stream Number and Bifurcation Ratio

S_u	N_u	R_b	R_{bm}	N_{u-r}	R_b * N_{u-r}	R_{bwm}
I	114	4.07		142	577.94	
II	28	4.66		34	158.44	
III	6	2		9	18	
IV	3	3	3.43*	4	12	4.05
V	1	0				
Total	152	0		189	766.38	
Mean		3.43*				

S_u= Stream Order, N_u= Number of streams, R_b= Bifurcation Ratio, R_{bm}= Mean Bifurcation ratio*, N_{u-r} = Number of streams used in the ratio, R_{bwm}=Weighted mean bifurcation ratio.

Table 3.2 Stream Length, and Stream Length Ratio of Chel Basin

S_u	**L_u (km)**	**Mean Stream Length,L_{um}**	**mean stream length ratio, L_{urm}**	**L_{ur-r}**	**L_{ur}* L_{ur-r}**	**L_{uwm}**
I	181.54	1.592456	0		0	
II	81.601828	2.914351	1.8300983	263.1418	481.58	
III	14.659879	2.443313	0.8383729	96.26171	80.9	2.16
IV	25.273743	8.424581	3.4480155	39.93362	139.8	
V	39.218084	39.21808	4.6551969	64.49183	303.15	
Total	342.29353	54.59279	10.771684	463.82896	1005.43	
Mean		10.92	2.693*			

Su= Stream Order, L_u= Stream Length, L_{um}= Mean Stream Length, L_{urm}= mean stream length ratio*, L_{ur-r}= Stream length used in the ratio, L_{uwm}= weighted Mean Stream Length

3.2.5 Stream Length Ratio (Lur)

Horton's law of stream length (Horton, 1945) points out that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with stream length increasing towards higher order of streams. Mean stream length ratio (Lurm) for whole Chel basin is 2.69 whereas weighted stream length ratio (Luwm) for the same is 2.16 (Table 3.2).

3.2.6 Bifurcation Ratio (Rb)

Horton, 1945 considered Rb as an index of relief and dissection while (Strahler, 1957) opined that Rb shows only a small variation for different regions with different environments except where powerful geological control dominates. According to Schumm, 1956, the term bifurcation ratio (Rb) may be defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher orders. It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin. Order wise bifurcation ratio of Chel basin ranges from 2 to 4.66. Mean bifurcation ratio for whole Chel basin is 3.43 where weighted mean bifurcation ratio for the same is 4.05 (Table 3.1). According to Strahler, 1964, the values of bifurcation ratio characteristically range between 3.0 and 5.0 for drainage basin in which the geological structures do not disturb the drainage pattern. The mean bifurcation ratio (Rbm) characteristically ranges between 3.0 and 5.0 for a basin when the influence of geological structures on the drainage network is negligible (Verstappen, 1983).

3.2.7 Weighted Mean Bifurcation Ratio (Rbwm)

To arrive at a more representative bifurcation number, Strahler (1952) used a weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values. Schumm, 1956 has used this method to determine the mean bifurcation ratio of the value of 4.87 of the drainage of Perth Amboy, N.J. Weighted mean bifurcation ratio for the Chel basin is 4.05 (Table 3.1).

3.2.8 Rho Coefficient (ρ)

The Rho coefficient is an important parameter relating drainage density to physiographic development of a watershed which facilitate evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed (Horton, 1945). The climatic, geologic, biologic, geomorphologic, and anthropogenic factors determine the changes in this parameter. Rho value of the Chel basin is $\rho = Lur/Rb = 2.7/3.43 = 0.79$ (Table 3.8). This is suggesting higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

3.2.9 Length of Main Channel (Cl)

This is the length along the longest watercourse from the outflow point of watershed to the upper limit to the watershed boundary. The computed main channel length by using ArcGIS-10 software is 58.23 Km (Table 3.8).

3.2.10 Length of the Basin (Lb)

Several people defined basin length in different ways, such Schumm, 1956 defined basin length as the longest dimension of the basin parallel to the principal drainage line. Gregory and Walling, 1968, defined the basin length as the longest in the basin in which is end being the mouth. The length of the Chel basin in accordance with the definition of Schumm, 1956, is 42.6Km (Table 3.8).

3.3 Areal Aspects

The areal aspects are the two-dimensional properties of a basin.

3.3.1 Basin Area (A)

The area of the watershed is another important parameter like the length of the stream drainage. (Schumm, 1956) established an interesting relation between the total watershed areas and the total stream lengths, which are supported by the contributing areas. The basin area computed by using ArcGIS-10 software is 321km^2 (Table 3.8).

3.3.2 Basin Perimeter (P)

Basin perimeter is the outer boundary of the watershed that encloses its area. It is measured along the divides between watersheds and may be used as an indicator of watershed size and shape. The basin perimeter computed by using ArcGIS-10 software is115.21 Kms (Table 3.8) Whereas Relative Basin Perimeter (Pr) is 2.79 km.

3.3.3 Length Area Relation (Lar)

Hack, 1957 found that for a large number of basins, the stream length and basin area are related by a simple power function as follows: Lar = 1.4 * A0.6. So “Lar” for Chel basin is 44.67 (Table 3.8).

3.3.4 Lemniscate’s Value (k)

Chorley, 1957 expressed the lemniscate’s value to determine the slope of the basin. In the formula $k = L_b^2 / A$. Where, L_b is the basin length (Km) and A is the area of the basin (km^2). The lemniscate (k) value for the Chel basin is 5.65 (Table 3.8).

3.3.5 Basin Shape

The shape of the basin mainly governs the rate at which the water is supplied to the main channel. The main indices used to analyze basin shape and relief is the elongation and relief ratios. The elongation ratio is calculated by dividing the diameter of a circle of the same area as the drainage basin by the maximum length of the basin, measured from its outlet to its boundary. Three parameters viz. Elongation Ratio (Re), Circulatory Ratio (Rc) and Form Factor (Rf) are used for characterizing drainage basin shape.

3.3.5.1 Elongation Ratio (Re)

Schumm, 1956 defined an elongation ratio (Re) as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. It is a measure of the shape of the river basin and it depends on the climatic and geologic types. The value of Re varies from 0 (in highly elongated shape) to unity *i.e.* 1.0 (in the circular shape). Thus, higher the value of elongation ratio more circular shape of the basin and vice-versa. Values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are usually associated with high relief and steep ground slope. These values can be grouped as (Table 3.3)

Table 3.3 Elongation ratio and basin shape

Elongation ratio	**Shape of basin**
<0.7	Elongated
0.8-0.7	Less elongated
0.9-0.8	Oval
>0.9	Circular

Higher values of elongation ratio show high infiltration capacity and low runoff, whereas lower Re values are characterized by high susceptibility to erosion and sediment load (Reddy et al., 2004). The elongation ratio of Chel basin is 0.47 which indicates highly elongated drainage basin (Table 3.8).

3.3.5.2 Form Factor (Rf)

Form factor is the ratio of the area of the basin and square of the basin length. It is commonly used to represent different basin shapes (Horton, 1932). The value of form factor is in between 0.1-0.8. The value of form factor would always be greater than 0.78 for perfectly circular basin. Smaller the value of form factor, more elongated will be the basin. The basins with high form factors 0.8, have high peak flows of shorter duration, whereas, elongated drainage basin with low form factors have lower peak flow of longer duration. Form factor for Chel basin is calculated as 0.18 (Table 3.8). Thus, the Chel basin is an elongated one where in highest flow is distributed over long duration and so potentiality of flood is less.

3.3.5.3 Circularity Ratio (Rc)

The circularity ratio is a similar measure as elongation ratio, originally defined by Miller, 1953 as the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter. He described Rc as a significant ratio that indicates the dendritic stage of a watershed. This is mainly due to the diversity of slope and relief pattern of the basin. The circulator ratio is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. Low, medium and high values of Rc indicate the young, mature, and old stages of the development of the tributary watershed (John Wilson *et al.*, 2012). The value of circularity ratio varies from 0 (in line) to 1 (in a circle). Higher value represents more circularity in the shape of the basin and vice-versa. Naturally all basins have a tendency to become elongated to get the mature stage. The circulatory ratio of Chel basin is 0.304. The structural control of drainage is probably responsible for the low values of circularity ratio (Table 3.8).

Table 3.4 Elongation ratio, Circulatory ratio and Form factor

Basin	**Elongation Ratio(Re) Re=2{√(A/π)}/Lb**	**Circulator Ratio(Rc) .c=4πA/p2**	**Form Factor (Rf) Rf=A/Lb2**
Chel	0.47	0.304	0.176

3.3.6 Drainage Area (Au)

The entire area drained by a stream or system of streams such that all streams originating in the area is discharged through a single outlet is termed as the Drainage Area. Drainage area measures the average drainage area of streams in each order; it increases exponentially with increasing order. The total catchment area of Chel is 321 km^2 (Table 3.8).

3.3.7 Drainage Density (Dd)

Drainage density (Dd) is a measure of the total stream length in a given basin to the total area of the basin (Strahler, 1964). The drainage density is affected by the factors that control characteristic length of the watershed. Dd is a measure of the texture of the network, and indicates the balance between the erosive power of overland flow and the resistance of surface soils and rocks. The factors affecting drainage density include geology and density of vegetation. The vegetation density influenced drainage density by binding the surface layer and slows down the rate of overland flow, and stores some of the water for short periods of time. The effect of lithology on drainage density is marked. Permeable rocks with a high infiltration rate reduce overland flow, and consequently drainage density is low. The mean Drainage density for the entire Chel Basin is 1.07 km/km^2 which indicate presence of resistant permeable subsurface material with moderate drainage and low to moderate relief (Table 3.8). Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture, high runoff and erosion potential of the basin area (Strahler,1964).

3.3.8 Drainage (Stream) Frequency (Fs)

The number of stream segments per unit area is termed Stream Frequency. Reddy *et al.*, 2004, stated that low values of stream frequency, Fs indicate presence of a permeable subsurface material and low relief. The stream frequency value of the Chel basin is 0.47 km/km^2 (Table 3.8). Stream frequency mainly depends on the lithology of the basin and reflects the texture of the drainage network. The value of stream frequency (Fs) for the basin exhibits positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density.

3.3.9 Drainage Texture

Horton, 1945 defined drainage texture as the total number of stream segments of all order in a basin per perimeter of the basin. It is important to geomorphology as it means the relative spacing of drainage lines. Drainage texture is controlled by the underlying lithology, infiltration capacity and relief aspect of the terrain. Drainage texture can be classified into 5 different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). Table-3.5 reflects the total drainage texture of the Chel basin is 1.32 km/km^2 which indicate very course drainage texture.

Table 3.5 Drainage density, Drainage frequency and Drainage texture

Basin	**Drainae Density (km/km^2)**	**Drainage Frequency (km/km^2)**	**Drainage texture Km/km^2**
Chel	1.07	0.47	1.32

3.3.10 Drainage Intensity (Di)

Faniran, 1968 defines the drainage intensity, as the ratio of the stream frequency to the drainage density. This study shows a low drainage intensity of 0.46 for the watershed (Table 3.8). This low value of drainage intensity implies that drainage density and stream frequency have little effect (if any) on the extent to which the surface has been lowered by agents of denudation. Rainwater is much absorbed in soil and flows downslope through substratum as throughflow. Seepage erosion is the dominant process where ready throughflow is not permitted; pore water pressure increased causing slope failure. Rills and gullies of restricted length may be developed on landslide scars.

3.3.11 Infiltration Number *(If)*

The infiltration Number is defined as the product of Drainage Density (Dd) and Drainage Frequency (Fs). Infiltration no. of Chel Basin is 0.501(Table 3.6). The higher the infiltration number the lower will be the infiltration and consequently, higher will be run off. This leads to the development of higher drainage density.

3.3.12 Length of Overland Flow *(Lg)*

The term length of overland flow is used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels. Horton, 1945 expressed it as equal to half of the reciprocal of Drainage Density (Dd). It is an important 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 and is quite synonymous with the length of sheet flow to a large degree. The length of overland flow bears an effective relationship with the drainage density and constant channel maintenance. Length of Overland Flow (Lg) of Chel Basin= 0.47 (Table 3.6).

3.3.13 Constant of Channel Maintenance (C)

This parameter indicates the requirement of units of watershed surface to bear one unit of channel length. Schumm, 1956 has used the inverse of the drainage density having the dimension of length as a property termed constant of channel maintenance. The drainage basins having higher values of this parameter, there will be lower value of drainage density. Constant of Channel Maintenance (C) of Chel basin is 0.93. It means that on an average 0.93 sq. ft. surface is needed in basin for creation of one linear foot of the stream channel. All the values are computed and shown in the (Table 3.6).

Table 3.6 Infiltration number, Length of overland flow and constant of channel maintenance.

Basin	Infiltration Number, If=Dd.Df	Length of Over land flow, Lg=1/2. AU/Σlu	Constant of channel Maintenance, C=1/Dd
Chel	0.501	0.47	0.93

3.4 Relief Aspects

Relief aspects are the three-dimensional morphometric parameters of drainage basins. Hence an additional height or depth element gets consideration in this category.

3.4.1 Slope

Slope is a significant parameter in the morphometric analysis of any drainage basin. It is the degree of inclination of topography with respect to horizontal plain. The slope of the Chel river basin was computed with the help of SRTM DEM using spatial analyst tool in ArcGIS 10.1 software. The slope values for the Chel basin ranges from 0° to 55.31°. The highest sloping surface with slope (35.6°-55.31°) is found in the structural ridges and valleys in a semi-circular pattern above the elevation of 380m (Fig. 3.5A and 3.5C) in the northern part of the basin. We observe a rapid decrease of slope with distance within the hilly region of the basin as the slope decrease to as low as 5° at beginning the piedmont zone (around 20 kms downstream from the source of the river Chel). For rest of the basin area the slope remains well below 5° with occasional small patches of surface having slope ranging from 5° to 13° in the central eastern parts of the basin known popularly as Rangamati surface. This spatial variation in slope gradient directly influences the flow direction, velocity, pattern of energy distribution leading to erosional and depositional characteristics of the channels within the basin.

3.4.2 Aspect

Aspect is the horizontal direction to which the surface slope faces. The aspect configuration significantly controls the micro climate within a basin. This is due to the varying duration and intensity of interaction between the sun's rays and the surface slope (Magesh *et al.*, 2012). Slopes exposed to sun's rays for longer duration and intensity will be warmer than the sheltered slopes and vice –versa. The aspect map of the Chel river basin is derived with the help of SRTM DEM using spatial analyst tool in ArcGIS 10.1 software. The derived raster map shows the direction of slopes for the Chel basin ranging from 0° to 360°, wherein 0° denotes the northerly direction, 90° refers to eastern direction and so on. A visual interpretation of the aspect map infers to the dominance of aspect ranging from 157.5° to 247.5° in most parts of the basin. This means most of the slopes are facing south and south west direction and are comparatively warmer than the slopes facing other directions. The north-western and southern parts of the basin have aspect towards the east whereas north-eastern parts of the basins have westerly aspect (Fig. 3.5B). This spatial variation in aspect greatly governs the rate and extent of weathering, types of vegetation, agriculture and erosion within the basin.

3.4.3 Relief

Relief is yet another important parameter for morphological analysis of any drainage basin. It infers to the range of elevation values within the drainage basin thereby giving idea about topographic variation and diversity. A relief map for the study area is derived from SRTM DEM using Spatial Analyst tool in ArcGIS 10.1 software. The prepared raster image shows five relief zones with the overall basin's relief of 2358m. The northernmost hilly part of the basin falls under highest relief zone (1709m to 2450m) whereas the relief values quickly reduce to below 350m beginning from piedmont zone till the confluence of Chel with Neora river (Fig. 3.3 and 3.5C). Spatial variation in relief distribution influences the flow direction and velocity of overland flow which translates into uneven distribution of erosion and deposition processes.

3.4.4 Channel Gradient

Channel Gradient is the total drop in elevation from the source to the mouth of the trunk channels in each drainage basin. In the present study 0.031 is the gradient for Chel River (Table 3.7).

3.4.5 Basin Relief (H)

Basin relief is the elevation difference of the highest and lowest point of the valley floor. For Chel river basin 2357 m is the maximum basin relief (Table 3.7 and Fig. 3.2A).

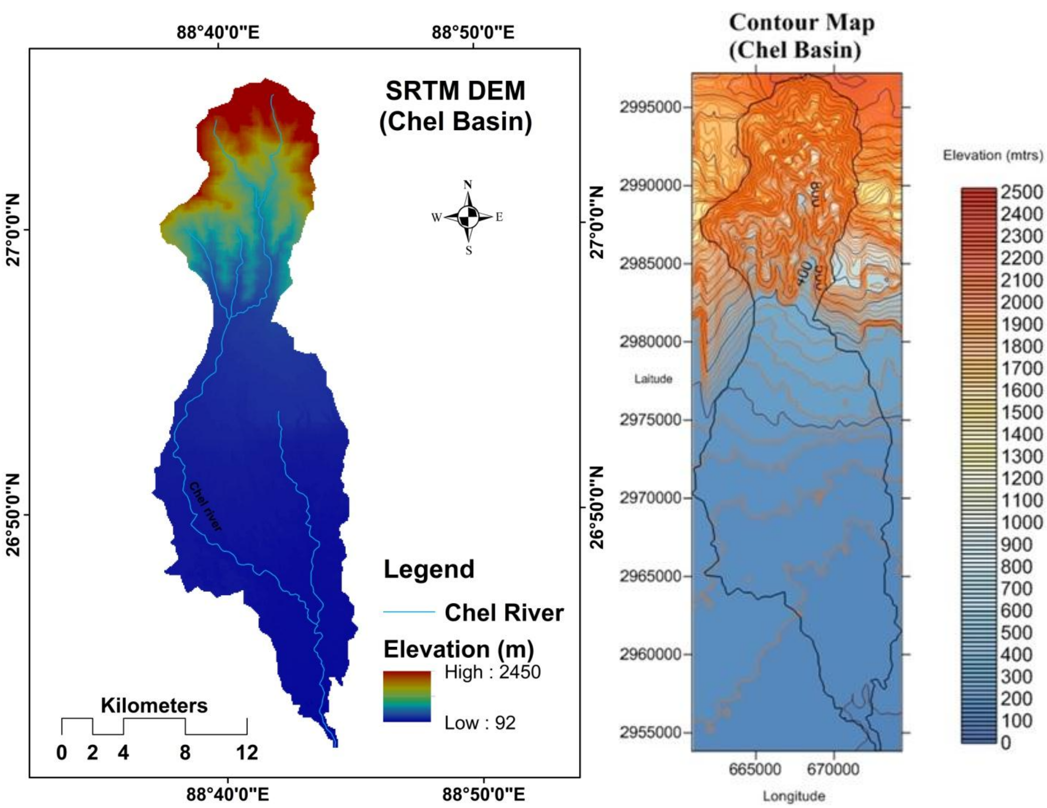
3.4.6 Relief Ratio (Rh)

Schumm (1946) states that the maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio. Difference in the elevation between the highest point of a basin and the lowest point on the valley floor is termed as the total relief of that river basin. He also stated that it is a dimensionless height-length ratio equal to the tangent of angle formed by two planes intersecting at the mouth of the basin, one representing the horizontal and other passing through the highest point of the basin.

Low value of relief ratios is mainly due to the resistant basement rocks of the basin and low degree of slope (Mahadevaswamy *et al.*, 2011). The Rh normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964). The Relief ratio value for the entire Chel basin is 55.3 (Table-8). The Rh normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964).The Relief ratio value for the entire Chel basin is 55.3 (Table 3.7).

3.4.7 Ruggedness Number (Rn)

Strahler,1964 describes ruggedness number (Rn) as the product of maximum basin relief and drainage density and it usually combines slope steepness with its length. Extremely high values of ruggedness number occur when slopes of the basin are not only steeper but long, as well. The Ruggedness number (Rn) for Chel basin is 2.52 (Table 3.7).



Contour Interval-20m

Figure 3.2 DEM (A) and Contour map (B) of Chel Basin.

3.4.8 Longitudinal Profile

The longitudinal profile of a stream is a property of stream geometry that can provide clues to underlying materials as well as insights into geologic processes and geomorphic history of an area (Hack, 1957). The long profile of river Chel was prepared in Microsoft Excel 2007 workbook by extracting and placing elevation values against the length and the obtained curve was given a smoothen effect to get rid of any unnecessary large misleading fluctuations. The prepared longitudinal profile indicates the presence of a few knick points at the steeper mountainous course of the river (Fig. 3.3). It also exhibits very high gradient (0.2) from its source (2449 m) to 10 kms downstream (around 500m) near Putharjhora T.E. where it leaves behind the Himalaya and enters the plains and due to sudden reduction of gradient it dumps huge quantity of unsorted sediments, consequently creates Piedmont surface. Then after the river flows sluggishly with lower gradient (0.015) up to 30kms over its own sediments creating braiding drainage pattern and farther downstream the longitudinal profile becomes almost parallel to the abscissa with very low gradient (0.004) and so exhibit meandering pattern of drainage.

Table 3.7 Channel gradient, Relief ratio and Ruggedness number

Basin	Elevation of Highest point on Basin Perimeter(m)	Elevation of lowest point at the mouth (m)	Maximum Basin Relief (H) m	Maximum Basin Length (Lb) km	Channel Gradient	Relief Ratio (Rh)	Ruggedness Number (Rn)= Dd*(H/1000) Patton & Baker(1976)
Chel	2449	92	2357	42.6	0.031	2449-92/42.6=55.3	2357/1000x1.07=2.52

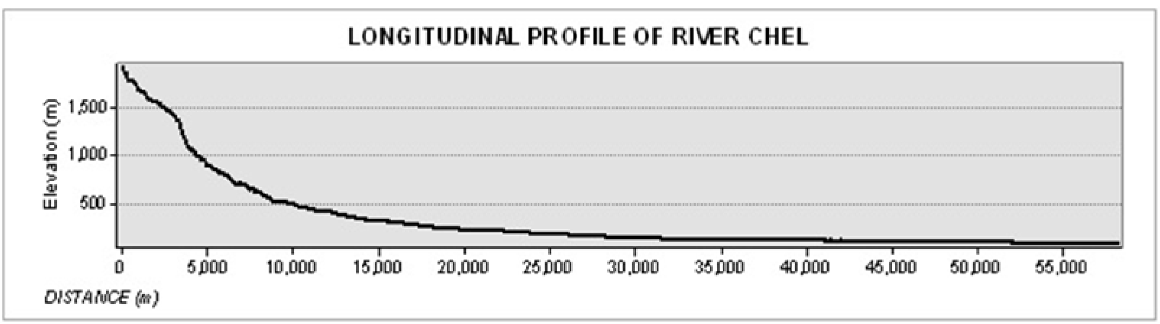


Figure 3.3 Longitudinal profile

3.4.9 Hypsometric Curve

Hypsometric curve was obtained by plotting the relative area along the abscissa and relative elevation along the ordinate. The relative area is obtained as a ratio of the area above a particular contour to the total area of the watershed encompassing the outlet. Considering the watershed area to be bounded by vertical sides and a horizontal base plane passing through the outlet, the relative elevation is calculated as the ratio of the height of a given contour (h) from the base plane to the maximum basin elevation (H) (up to the remote point of the watershed from the outlet (Sarangi *et al.*, 2001; Ritter *et al.*, 2002). This provided a measure of the distribution of landmass volume remaining beneath or above a basal reference plane (Singh *et al.*, 2008). The hypsometric curve of river Chel shows a steep initial fall with an increasing distance from the equilibrium line then followed by long gentle gradient and finally becoming almost parallel to the abscissa (Fig. 3.4). Generally, such curves represent an old stage of erosion cycle, having steep-sided low hills in the upper catchment region with narrow, entrenched, confined stream defiles, and subsequent valley broadening and floodplain development in the middle and lower reaches (Sarkar and Patel, 2011).

In case of Chel basin, elevation slabs are almost uniform in size above an elevation of 350m (approx.), whereas it is non-uniform and very small from the beginning of piedmont surface till the basin mouth. Thus, the cumulative '*h/H'* values keep arithmetical progression. Deviations from the equilibrium line are caused by the differing values of '*a*' in each elevation slab, which then has triggered a cascading effect during computation of the cumulative '*a/A'* values for the basin. When the '*a*' in an elevation slab is approaching minimum values near the basin mouth and increases little in the subsequent elevation slabs towards the basin mouth, the resultant curve shows an initial steep fall with an increasing distance from the equilibrium line. Large scale denudation in the upper reaches and consequent accretion of sediments in the lower reaches characterize such a basin. Therefore, the elevation slabs in the middle and lower basin reaches are wider as the channel's gradient is much declined, occupying much larger area. With an increase in the values of '*a*', the cumulative '*a/A'* values increase significantly across successive elevation slabs and thus the steeply falling hypsometric curve begins to taper off with a gentle gradient to finally run almost parallel to the abscissa. The greater the disparity of '*a*' values between elevation slabs of the upper and lower reaches, with the smaller values being recorded in the upper catchment, the more elliptic the curve becomes with greater initial downward deviation from the equilibrium line and greater concavity upwards. It is certainly indicative of a marked old stage in the basin's evolution, further attested to by very low hypsometric integral (H.I.= 0.15).

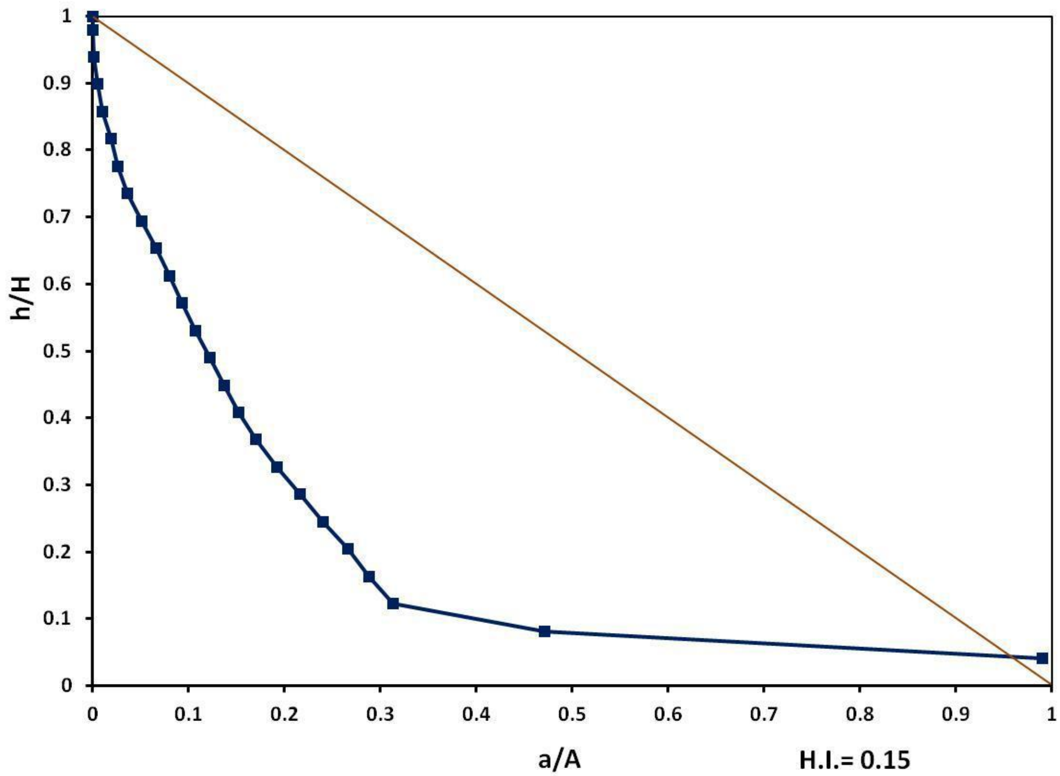


Figure 3.4 Hypsometric Curve of Chel Basin.

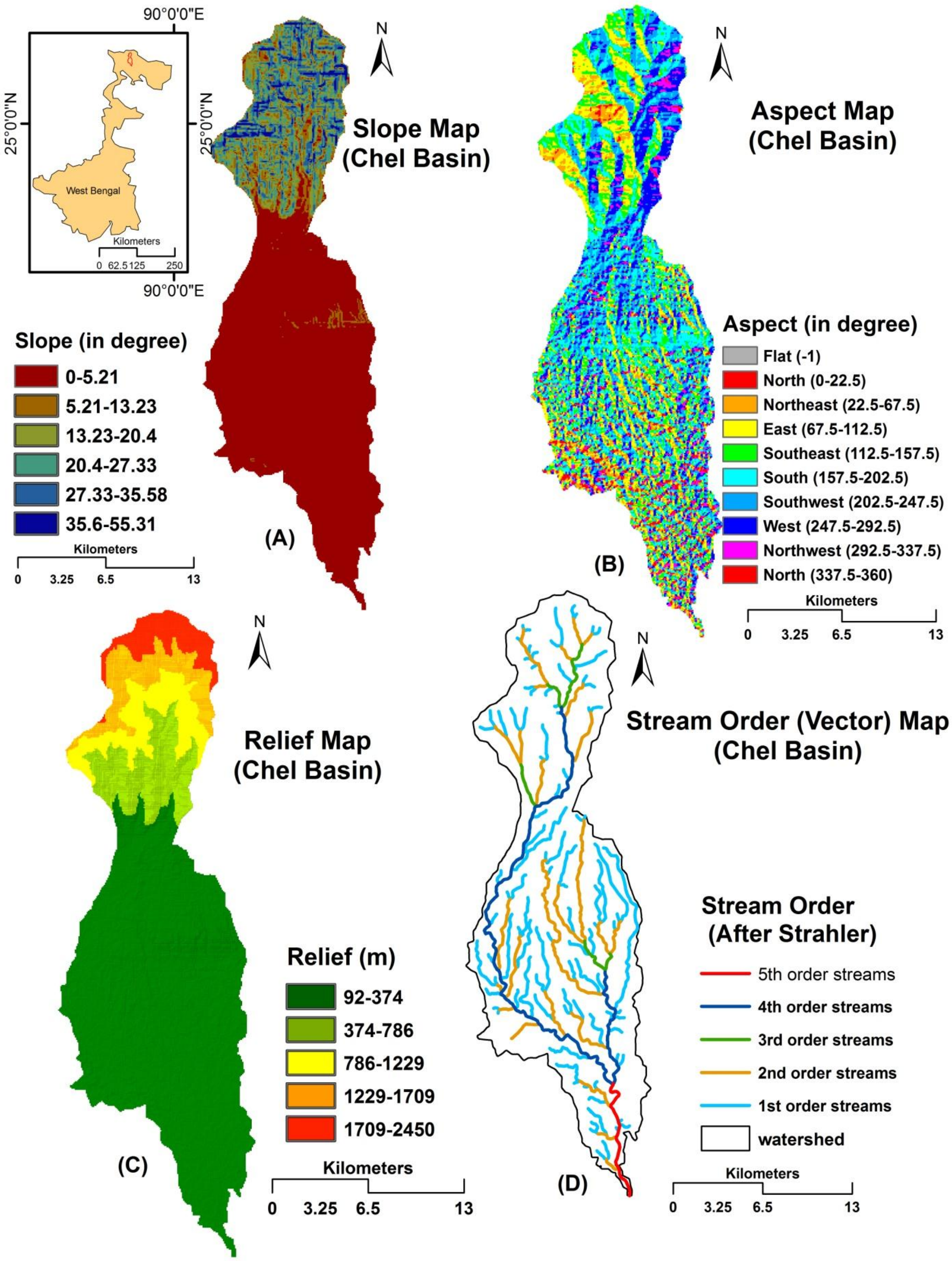


Figure 3.5 **(**A) Slope map, (B) Aspect map (C) Relief map and (D) Stream Order-Vector map of Chel River Basin (Study Area).

3.4.10 Estimation of Hypsometric Integral (HI)

Integration of the hypsometric curve gives the hypsometric integral (HI), which is equivalent to the elevation-relief ratio (E) as proposed by (Pike and Wilson, 1971). Mathematically, it is defined as E ≈ HI = [Mean elevation (E_{mean}) – Minimum elevation (E_{min})]/ [Maximum elevation (E_{max}) – Minimum elevation (E_{min}). It was also found by Strahler,1952 that the hypsometric integral is inversely correlated with total relief, slope steepness, drainage density and channel gradients. The geologic stage of landforms development and erosional status of the basins are quantified by hypsometric integral. High value of hypsometric integral indicates the youthful stage of less eroded areas and it decreases as the landscape is denuded towards the maturity and old stages. The HI is expressed as a percentage and is an indicator of the remnant of the present volume as compared to the original volume of the basin (Ritter *et al.,* 2002). The hypsometric integral is also an indication of the 'cycle of erosion' (Strahler, 1952; Garg, 1983). Although various methods are available to estimate the hypsometric integral (Singh *et al.*, 2008), the hypsometric integral values (Hi) in the present study were calculated using the elevation-relief ratio method as proposed by Pike and Wilson (Pike and Wilson, 1971) owing to its enhanced accuracy and ease of calculation within the GIS environment.

The Hypsometric Integral (H.I.) of Chel basin is 0.15 indicating the basin in senile stage. But a quick glance of hypsometric curve is enough to make an understanding that a distinction of appearance exists between the upper and lower part of the hypsometric curve. The curve for the upper part is similar to that for the 'late mature to early old stage' basins while the lower half's curve is similar to that for the 'senile stage'- a classic example of the basin straddle in the zone of transition between the dissected upper hill surface and the lower gently rolling plains (Sarkar and Patel, 2011).

Comparison of Drainage Basin Characteristics

The details of the morphometric analysis and comparison of drainage basin characteristics of Chel basin is presented below (Table 3.8).

Table 3.8 Morphometric parameters at a glance

Sl. no	Morphometric parameter	Formula	Reference	Result
		Linear Aspect		
1	Stream Order (S_u)	Hierarchical Rank	Strahler (1952)	1 to 5
2	Stream Number (N_u)	N_u = N1+N2+…Nn	Horton (1945)	152
3	Stream Length (L_u) Kms	L_u = L1+L2…Ln	Strahler (1952)	342.3
4	Stream Length Ratio (L_{ur})	see Table 2	Strahler (1964)	1.59- 39.22
5	Mean Stream Length Ratio (L_{urm})	see Table 2	Horton (1945)	2.69
6	Weighted Mean Stream Length Ratio (Luwm)	see Table 2	Horton (1945)	2.16
7	Bifurcation Ratio (R_b)	see Table 1	Strahler (1964)	2 - 4.66
8	Mean Bifurcation Ratio (R_{bm})	see Table 1	Strahler (1964)	3.43
9	Weighted Mean Bifurcation Ratio (Rbwm)	see Table 1	Strahler (1953)	4.05
10	Rho Coefficient (ρ)	$\rho = L_{ur} / R_b$	Horton (1945)	0.79
11	Main Channel Length (Cl) Kms	GIS Software	-	58.23
12	Basin Length (L_b) Kms	GIS Software Analysis	Schumm(1956)	42.6
		Areal Aspect		
13	Basin Area (A) km^2	GIS Software Analysis	Schumm(1956)	321
14	Basin Perimeter (P) kms	GIS Software Analysis	Schumm(1956)	115.21
15	Relative Basin Perimeter (P_r) kms	P_r= A / P	Schumm(1956)	2.8
16	Length area relation (L_{ar}), kms	L_{ar} = 1.4 * A0.6	Hack (1957)	44.67
17	Lemniscate's (K)	k = Lb2 / A	Chorley (1957)	5.65
18	Elongation Ratio (R_e)	R_e = 2 / Lb * (A /π)0.5	Schumm(1956)	0.47
19	Form Factor (R_f)	R_f = A / Lb2	Horton (1932)	0.18
20	Circulatory Ratio (R_c)	R_c = 12.57 * (A /P2)	Miller (1953)	0.304
21	Drainage Density (D_d)	D_d = Lu / A	Horton (1932)	1.07
22	Drainage Frequency (F_s) km/km^2	F_s= Nu / A	Horton (1932)	0.49
23	Drainage Texture (km/km^2)	ΣNu/P	Horton (1945)	1.32
24	Drainage Intensity (Di)	Di = F_s / D_d	Faniran (1968)	0.46
25	Infiltration Number (If)	If = F_s * D_d	Faniran (1968)	0.5
26	Length of overland flow (L_g) kms	1/2.A/ΣL_u	Horton (1945)	0.47
27	Constant of channel maintenance ©	C = 1 / D_d	Schumm(1956)	0.93
		Relief Aspect		

Sl. no	Morphometric parameter	Formula	Reference	Result
28	Height of Basin Mouth (z) m	GIS Analysis / DEM	-	92
29	Maximum Height of the Basin (Z) m	GIS Analysis /DEM	-	2449
30	Total Basin Relief (H) m	H = Z - z	Strahler (1952)	2357
31	Relief Ratio (R_{hl})	$R_{hl} = H / L_b$	Schumm(1956	55.3
32	Ruggedness Number (R_n)	$Rn = D_d * (H / 1000)$	Patton & Baker(1976)	2.52
33	Hypsometric Integral (H.I.)	$E \approx HI = [(E_{mean}) – (E_{min})]/ [(E_{max}) – (E_{min})$	Pike and Wilson (1971)	0.15

Major Findings

1. The study infers that Chel River is a 5th order stream with the length of 58.23 kms.

2. Lower order streams dominate the basin and overall the basin has a dendritic and semi-dendritic drainage pattern which thus indicates prevalence of homogeneous lithology.

3. The very low drainage density value (1.07) of the Chel basin suggests permeable subsurface. Large number of small streams disappears under the thick unsorted Himalayan sediment deposits in the piedmont zone (from approximately 15 km to 20 km downstream from source of river Chel), giving rise to coarse drainage in the basin.

4. An elongation ratio value of 0.47 suggests Chel basin is a highly elongated drainage basin. This also suggests that the basin is susceptible to high erosion and thus higher sediment load in the channels.

Conclusion

Morphometric analysis of drainage basin is an imperative requirement for any hydrological and quantitative geomorphologic studies. Here an attempt on morphometric analysis of Chel basin has been carried out based on several drainage parameters with the help of remote sensing and GIS tools. All morphometric parameters were categorized into three aspects namely linear, areal and relief aspect. The study infers that Chel River is a 5th order stream with overall length of 58.23 km. Lower order streams dominate the basin and overall, the basin has a dendritic and semi- dendritic drainage pattern which thus indicates prevalence of homogeneous lithology. In general, the stream length in each order increases exponentially with increasing stream order. But in Chel basin stream length is fluctuating with increase in order. The highest stream length (181.54 km) is recorded for 1st order streams followed by 2nd order streams (81.54 km) then comes 5th order stream (39.22 km) followed by 4th order streams (25.27 km) and lastly by 3rd order streams (14.66 km). Chel basin comprises an area of 321 km2 with basin perimeter of 115.21 km. The Stream frequency values decreases with the increase in stream order and vice-versa.

The very low drainage density value (1.07) of the Chel basin suggests permeable subsurface. Large number of small streams disappears under the thick unsorted Himalayan sediment deposits in the piedmont zone (from approximately 15 km to 20 km downstream from source of river Chel), giving rise to coarse drainage in the basin. An elongation ratio value of 0.47 suggests Chel basin is a highly elongated drainage basin. This also suggests that the basin is susceptible to high erosion and thus higher sediment load in the channels.