Catchment Area Analysis of Tarafeni River based on Morphometric Characteristics, West Bengal, India

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Abstract: ***River Basin is considered as the fundamental unit of fluvial geomorphology as they are well-defined areas, clearly separated from each other by drainage divides. The physical features of the basin with its erosional activities constitute the natural unit for the analysis of fluvial-eroded landscapes. A river basin always represents an area drain by a main stream and its tributaries It represents a set of networks, mostly tree-like, that consists of links and nodes. The networks are the combination of two aspects- topological, that describes the connectivity of the streams and geometrical, that includes shape, length, area, relief, etc. Tarafeni basin and its course form distinctive setting where the quantitative approach has been applied to understand the land forms in fluvial terrain. Entire watershed, the main channel with left and right banks and stream beds consist a typical riverine landscape of silt, sand, pebble, cobble, gravel, and boulders. Present study looks into the systematic and analytical study of the morphological characteristics of the catchment.***

Keywords: River Network, morphometric analysis, Tarafeni river, quantitative approach

1. Introduction

The study of river basin has always been considered as an important aspect since the inception of civilization. The catchment area from where river collects its water influences the people living within the region itself. Therefore proper understanding of the rivulets, streams and river is of utmost importance in developing and implementing watershed plans. The river basin, being a fundamental geomorphic unit (Chorley, 1969), portrays distinctive geometrical features and processes. Systematic and quantitative measurement of various parameters of the river basin in terms of relief, linear and areal aspects help largely to assess hydrological behavior of the basin. Morphometric analysis is the way for better understanding of spatial characteristics of river. The word morphometry means 'measurement of form', derived from 'morpho' (form) and 'metry' (measurement). The techniques related to the form measurements in geomorphology include measurement of large number of variables, spatial pattern and forms of the landform.

Clarke observed that since World War II, morphometry has entered a phase of micro-morphometry with the introduction of more micro level studies being 'closely associated with dynamic geomorphology'. Basically, morphometry includes the analysis of quantitative and qualitative variables. The quantitative variables are – Linear aspects, Areal aspects and Relief aspect and qualitative variables are – geology, structure, soil type, vegetation, landform type, terrace, water divide, drainage type, flood plain etc.

2. The identity of Study Area

The undulating tracts of Belpahari area of Binpur II and Binpur I block of Jhargram District display lateritic soil and a large number of streamlets and rivulets. The monsoonal channels flows down the slope and bring water into the next ordered streams. Most of the streams are non perennial in nature. River Tarafeni, a 5th order stream and tributary to the river Kangsabati, flows over the rugged surface for a length of about 48.7 km. It joins the Bhairabbanki river and meet Kangsabati. Its absolute location is within 22°34´12´´ N to 22°44´0´´N and 82°30´29´´ E to 86°33´55´´E and falls in the jurisdiction of Belpahari and Binpur Police Station.

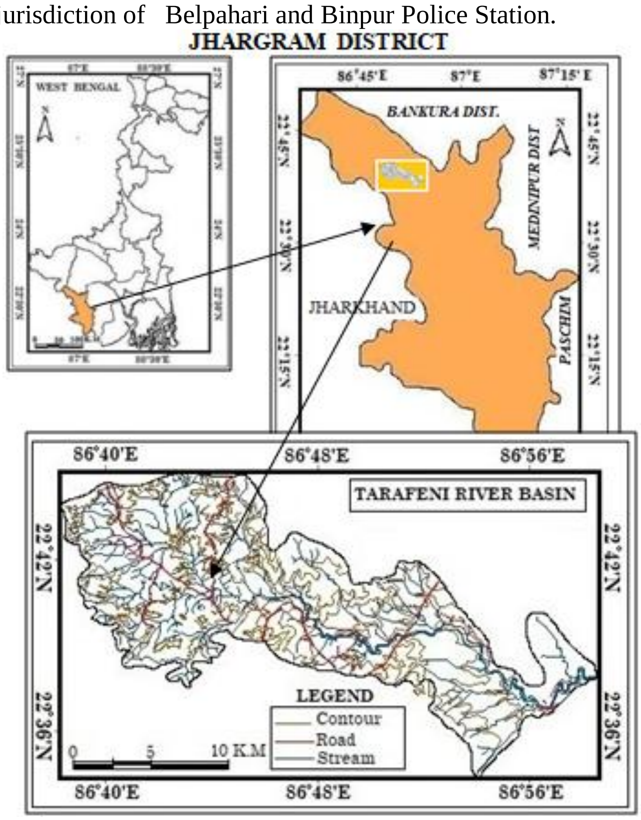

Figure 1: Location Map of the Study Area

Physiographically, it is located in the eastern end of the Choto Nagpur plateau .The area gradually slopes down over undulating terrain with infertile laterite soil. The basin experiences hot, humid climate with high temperature in summer months. The rainfall is poor to moderate in March to July; the average annual rainfall in the basin is 1,247mm. The vegetation of the basin is tropical deciduous plant species.

Table 1: Brief Profile of River Tarafeni

S. No.	Parameters	Values
1	Basin Area	529.05 Sq.Km
2	Perimeter	1268.71 Km
3	Number of 1st order streams	239
4	Number of 2nd order streams	68
5	Number of 3rd order streams	14
6	Number of 4th order streams	4
7	Total stream length	48.7 Km
8	Drainage Density	0.1598 Km/Sq.Km
10	Relative relief	190 m
12	Circulatory Ratio	0.2348
14	Elongation Ratio	0.5105

3. Objectives

The major objectives of the study include
1) To find out the geomorphic characteristics and to quantify different attributes of the Tarafeni River Basin.
2) To analyse the morphometric parameters of the basin.

4. Methodology

The morphometric analysis of this study area have commonly undertaken with the help of *Survey of India (S. O. I.)* topographical sheet, numbered 73/J- 9, 73/J- 10, 73/J-13, 73/J-14 on a scale of 1 : 50,000 with the contour intervals of 20 m. The database is created using various techniques for the watershed management. The maps are prepared by geo-referencing and digitization from SOI toposheets. The Survey of India toposheets of scale 1: 50,000 and DEM (Digital Elevation Model) is used for delineating the watershed boundary. Maps have been prepared by TNT Mips software. The stream order has been assigned by following Strahler's (1964) stream ordering technique. The drainage basin characteristics help in deciphering and understanding the interrelated relief and slope properties. The DEM has been prepared using the Cartosat-1 (DEM) data and GIS techniques to understand the relief, slope and flow direction.

The numbers of streams of different order in the watershed has been counted and their lengths from source to confluence are measured with the help of GIS software (TNT Mips). Different quantitative attributes (table:2) have been analysed based on various aspects of the cat

Table 2: Quantitative parameters of the Basin

Linear Aspect (One Dimension)	Areal Aspect (Two Dimensions)	Relief Aspect (Three Dimensions)
Stream Ordering	Basin Shape	Relative Relief (Rr)
Stream Length (Lu)	Drainage Density (Dd)	Relief Ratio (R)
Mean Stream Length	Stream Frequency (Fs)	Ruggedness number (Rn)
Stream Length Ratio (RL)	Horton's Form Factor (F)	Dissection Index (DI)
Bifurcation Ratio (Rb)	V.C.Miller's Circularity Ratio (Rc)	

5. Morphometric Characteristics and Quantitative analysis of the watershed

Morphometry is the measurement and analysis of shape of the river basin. This helps to discover holistic inherent properties of various stream attributes. It is important to appraise the characteristics of a basin. Another important property of catchment area is its hierarchical nature. Each tributary in this system has its own basin area contributing runoff. Following the pioneer work of R.E. Horton (1945) and A.N. Strahler (1952), many of the important properties of river can be expressed quantitatively. All this helps to compare one basin with another. Such quantitative description is termed as morphometric attributes and can be applied to the area and relief properties of basins as well as the characteristics of the river channel systems.

Fluvial morphometry has become a fundamental concern of post-war geomorphological research in US, UK and is being widely used in other areas, especially India (Vaidyanadhan, 1977), Brazil, Austalia and Canada. The analysis basically consists of several stages, like network delimitation, sampling, measurement, variable definition and analysis (Gardiner, 1975). Tarafeni catchment has a large number of variable of its linear, areal and relief properties.

5.1 Linear Aspect (One Dimension)

The linear aspects of basin include stream order, stream length, mean stream length, stream length ratio and bifurcation ratio. Actually, river networks with its differential channel pattern and orientation impacts the landscape of the river. Various drainage patterns are the result of the underlying structure but the surface expression is quite interesting in nature.

5.1.1. Stream Order (u)

There are four different system of ordering streams that are available [Gravelius (1914), Horton (1945), Strahler (1952) and Schideggar (1970)]. Strahler's system, which is a slightly modified form of Horton's system, has been followed because of its simplicity, where the smallest, unbranched 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 Tarafeni river is 5th order (figure: 2). In all, 326 streams were identified in the entire basin. Of which 239 are first order, 68 are second order, 14 are third order, and 4 in fourth order and 1 is fifth order (table:3). Drainage patterns of stream network have been observed as mainly of dendritic type which indicates the homogeneity in texture and lack of structural control.

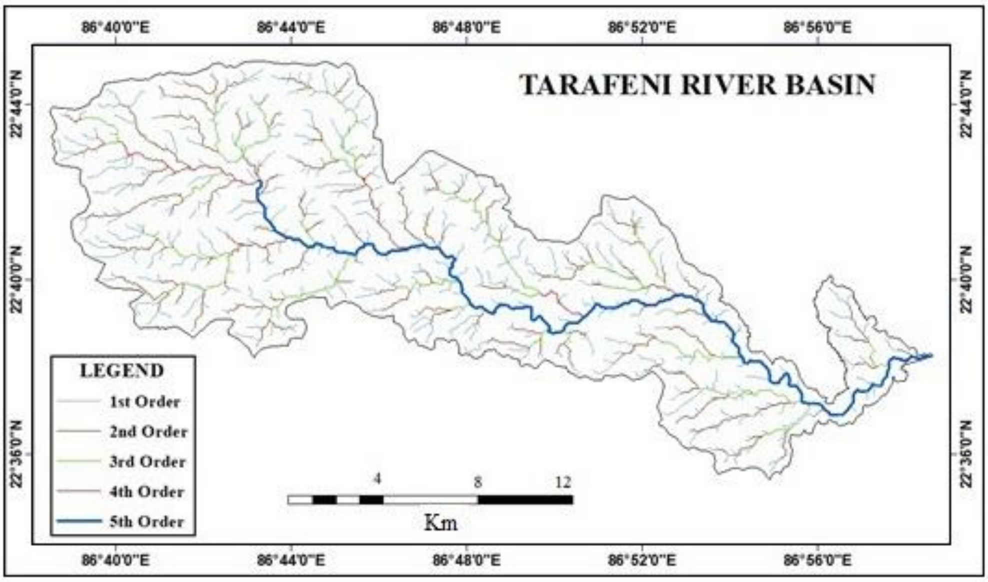

Figure 2: Stream Ordering followed by Strahler's method

5.1.2. Stream Length (Lu)

The stream length (Lu) has been computed based on the law proposed by Horton. It is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. The stream of relatively smaller length is characteristics of areas with greater slopes and finer textures. Longer lengths of streams are generally indicative of flat gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as stream order increases. The total length of all first order streams is 172.663 km, second order stream is 94.787 km, third order stream is 50.569 km, fourth order 13.03 km and fifth order stream is 43.514 km. The change may indicate flowing of streams from high altitude, lithological variation and moderately steep slopes (Singh, 1997). 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. Horton applied morphometric analysis to the stream attributes of basin which is known as the *Laws of drainage composition*. The regression line indicates Horton's *Law of Stream Numbers*. It shows that Number of streams decreased to higher orders causing a negative functional relationship (r = 0.84). As the stream order increases, the number of streams decreases (figure: 3). Remarkable departure in 1st order streams here means more tributaries join in upper reaches. But departure in 2nd and 3rd order signifies lesser number of streams than the normal.

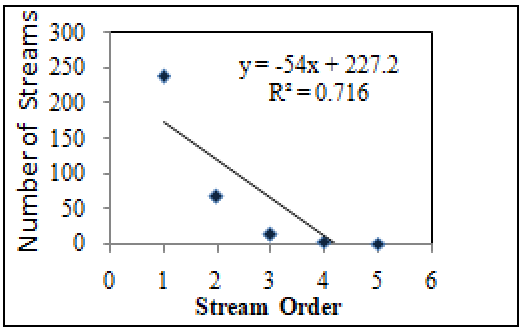

Figure 3: Relationship between stream order and number of streams

5.1.3. Mean Stream Length (Lsm)

The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964). 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 0.72 km for first order, 1.39 km for second order, 3.61km for third order, 3.26 km for fourth order and 43.514 km for fifth order. The mean stream length of stream increases with increase of the order (Figure 4).

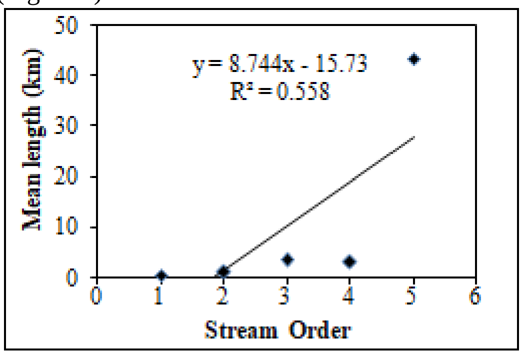

Figure 4: Relationship between stream order and stream length

The 1st order stream segments of have shorter length but the mean length increases with the increasing order. This follows the general rules of *Laws of Stream Length* of Horton. Total stream lengths continue to decrease from the 1st order to successive higher orders. Mean stream length of river Tarafeni and its order present a direct relationship (r = 0.75). Mean stream length increase with increase in order.

5.1.4. Stream Length Ratio *(RL)*

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 (Horton, 1945). The *RL* values between streams of different order in the basin reveal that there are variations in slope and topography. The stream length ratio of study area is 0.003 for first order, 0.021 for second order, and 0.26 for third order, 0.81 for fourth order and 43.51 for fifth order. The mean stream length of stream increases with increase of the order of the stream. *Mean length ratio* of the basin varies a little and shows the dependence on relief. Drainage network is developed in orderly manner and the basin is shaped by the process of lateral planation.

5.1.5. Bifurcation Ratio (Rb)

Bifurcation ratio *(Rb)* may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumn 1956). Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that the bifurcation ratio shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. It is observed that R_b is not the same from one order to its next order. In the study area, mean R_b varies from 3.51 to 4 and the mean R_b of the entire basin is 3.97 (table 3). Usually these values are common in the areas where geologic structures do not exercise a dominant influence on the drainage pattern.

Table 3: Empirical Study of the river Catchment

Stream Order (u)	Number of Streams (Nu)	Bifurcation Ratio (R_b)	Total Length in km (Lu)	Mean length km (L_{sm})	Cumulative Mean Length in km	No. of Stream (%)
1	239		172.66	0.72	0.72	73.31
2	68	3.51	94.78	1.39	2.11	20.86
3	14	4.85	50.57	3.61	5.72	4.28
4	4	3.50	13.03	3.25	8.98	1.22
5	1	4.00	43.51	43.51	52.49	0.33
Total	326	Mean -3.97		52.49		

5.2. Areal Aspect (Two Dimensions)

It deals with the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes tributaries of lower order. Total area of the catchment is 529 sq. km (approx.) as measured with the help of GIS software and from the survey of India toposheets. It comprises of basin shape, drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow.

According to the *Law of Basin Area* as propounded by Horton, the first order basins have the smallest mean basin area and the successive higher order represents an increase in areas. It signifies the main river i.e. the 5th order possess the largest basin area. The regression line is drawn to test the validity of positive exponential function model of the Law of Basin Area that clearly indicate a negative relationship (r =0.73) with some departure from normal (figure: 5).

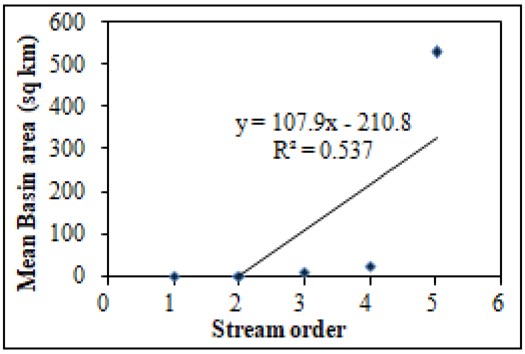

Figure 5: Relation between mean basin area and stream order

5.2.1 Basin Shape

The geometry of basin shape is of paramount significance as it helps in the description and comparison of different forms of basins. The ideal drainage basin is usually of pear shaped but since it is dependent on the size and the length of the master stream and basin perimeter, the differences also been observed. The other variables such as absolute relief, slope, geological structure and lithology etc. also are important determinant. Thus, various methods have been suggested to calculate the shapes of the basin. Different popular methods of computation are as follows- i) Horton's Form Factor(1932), ii) Stoddart's Elipticity Index, iii) V. C. Miller's Circularity Index, iv) S. A. Schumm's Elongation Ratio.

- **Horton's Form Factor (*F*)**

Form factor (F) is defined as the ratio of the basin area to the square of the basin length. This factor indicates the flow intensity of a defined area (Horton, 1945).

$F = \frac{A}{Lb^2}$ Where, F = Form factor indicating elongation of the basin shape,

A = Basin area, Lb = Basin length.

The form factor value should be always less than '1' (the value corresponding to a perfectly circular basin). The smaller value'0' of the form factor, the more elongated will be the basin. Basins with high form factors experience larger peak flows of shorter duration, whereas elongated watersheds with low form factors experience lower peak flows of longer duration. The *F* value for study area is 0.38, indicating highly elongated basin with lower peak flows of longer duration than the average.

- **Circularity Ratio (*Rc*)**

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 (Miller, 1953). The value of *Rc* varies '0' (a line) to '1' (a circle). It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate and slope of the basin.

$$Rc = \frac{\text{Area of the basin}}{\text{Area of the circle with same perimeter as the basin}} \text{ (Miller, 1953)}$$

Where, *Rc* = Circularity Index.

The Rc value of whole basin is 0.46 and it indicate the area is characterized by elongated one with moderate to low relief (table: 5) and drainage system seems to be less influenced by structural disturbances. The high value of circularity ratio shows the late maturity stage of topography.

The *Rc* value of different order basin has been displayed in the (figure: 6)

Figure 6: Circularity ratio of 1st, 2nd, 3rd and 4th order streams

- **Elongation Ratio *(R_e)***

Schumm (1956) 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. The ratio is measured by the following equation

$$R_e = \frac{\text{Diameter of the circle with same area as basin}}{\text{Basin Length}} \text{ (Schumm, 1956)}$$

Values of *Re* generally vary from 0.6 to 1.0 over a wide variety of climatic and geological formation. *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 (Strahler 1964). 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 0.64 indicates moderate to less slope ground and area when collaborated with Strahler's range seem to suggest an elongated shape (table: 5).

5.2.2. Drainage Density (Dd)

Horton (1932), introduced the drainage density (Dd) is an important indicator of land form elements in stream eroded topography. Stream length per unit area is called drainage density (Horton, 1945)..The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin.

It has been observed from drainage density measurement made over a wide range of geologic and climatic type that a low drainage density is more likely to occur in region of highly resistant of highly permeable subsoil under dense vegetative cover and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahler, 1964).The drainage density *(Dd)* of study area is 0.160 km/Sq.km indicating the basin possess highly permeable subsoil and vegetative cover (Nag, 1998).

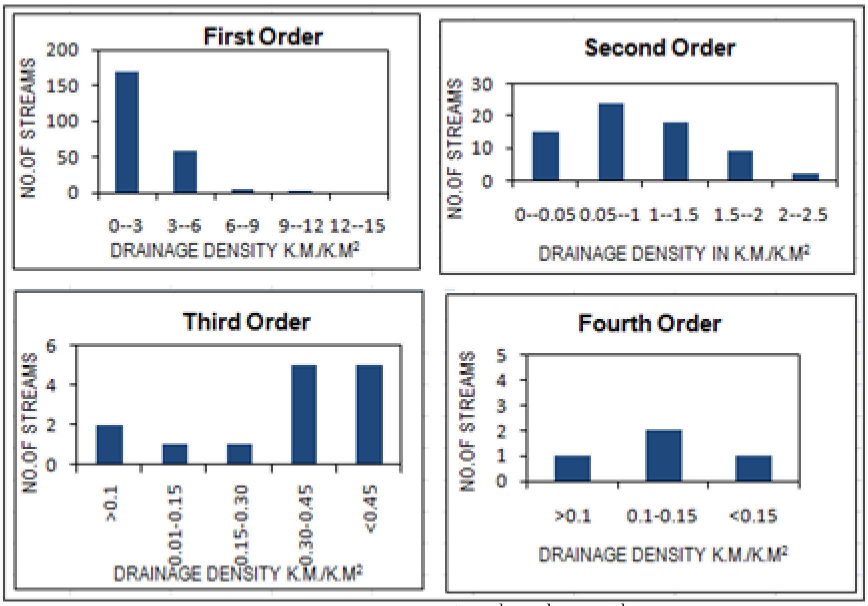

Figure 6: Drainage density of 1st, 2nd, 3rd and 4th order basin

5.2.3. Stream Frequency (Fs)

Stream frequency (Fs), is expressed as the total number of stream segments of all orders per unit area.

$\mathbf{Fs} = \frac{\mathbf{Nu}}{\mathbf{A}}$ (Horton, 1945), Where, Nu = Total number of streams in all order and A = Area of the basin. It exhibits positive correlation with drainage density in the watershed indicating an increase in stream number with respect to increase in drainage density. The *Fs* for the basin is 1.19 streams/ sq.km.

5.2.4 Drainage Texture *(RT)*

Horton (1945) stated drainage texture is the total number of stream segments of all orders per perimeter of that area. Which are simply define as following equation

$RT = \frac{Nu}{P}$ (Horton, 1945), Where, RT= Drainage Texture, Nu = Total number of streams in all order and P = Perimeter of the watershed. Here, the value of '*RT*' is 2.60, which denotes the course drainage texture (Smith, 1950).

Table 5: Areal aspects of Tarafeni basin

River order	Mean relative relief (m)	Drainage density	Relief ratio	Circularity ratio	Elongation ratio
1	11.74	3.79	0.01	0.64	0.59
2	22.05	0.25	0.01	0.84	0.95
3	65.00	0.19	0.01	0.51	0.67
4	90.00	0.24	0.01	0.24	0.41
5	190.00	0.05	0.00	0.49	0.60
	Tarafeni basin		0.005	0.46	0.64

5.3 Relief Aspect (Three Dimensional)

The relief aspects of the drainage basin are three directional features including area, volume and altitude of vertical dimension where different morphometric methods are used to analysis terrain characteristics. There is a close relationship among drainage density, mean slope and relief. Difference in elevation between the highest and lowest point in a basin is termed as relief. Relief of an area influences the slope and stream gradient involving the slope processes, erosion, transportation and deposition. Increase in relief is due to incision of streams.

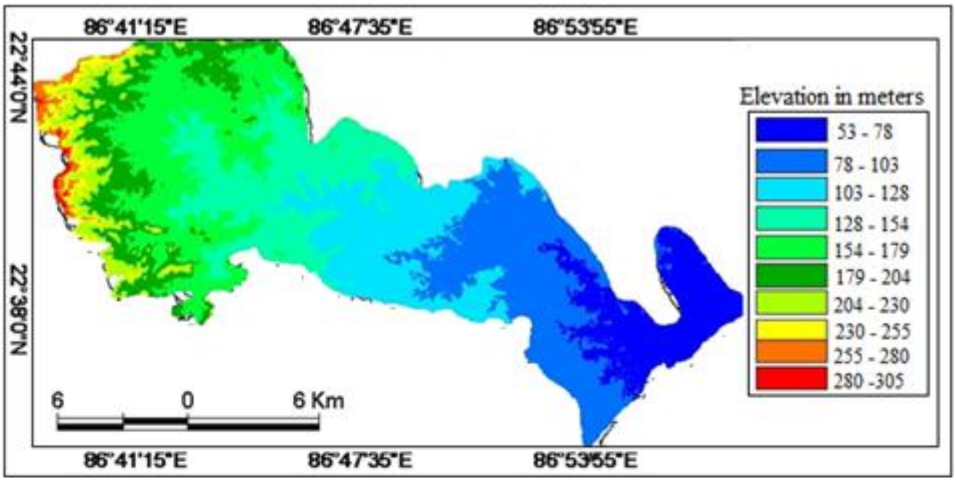

Figure 7: DEM showing altitudinal zones

5.3.1. Relative Relief *(Rr)*

Relative relief termed as 'amplitude of available relief' or 'local relief' and is defined as difference in heights between the highest and the lowest point of any area. M. A. Milton (1957) suggested to calculate relative relief by dividing the difference of the height between the highest and lowest points. The maximum elevation of the basin lie near the source area and it is 260 m. At the point where the main river meets *Bhairabbanki* is the lowest elevation point .The relief at confluence is 70 m. First order and second order basins shows very little variation in relief while the third order and fourth order stream exhibits comparatively larger variation (figure 8)

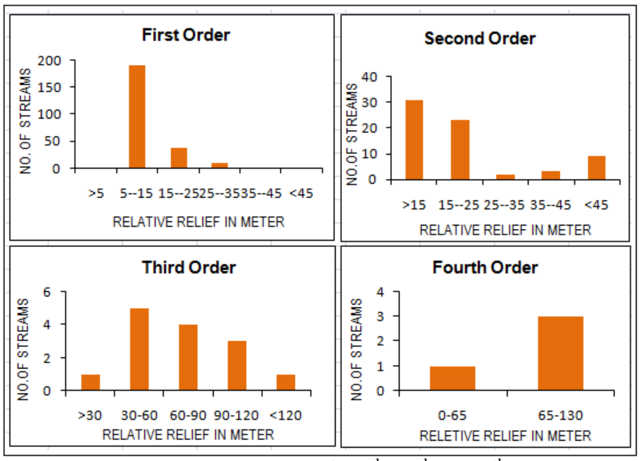

Figure 8: Relative relief of 1^{st}, 2^{nd} , 3^{rd} and 4^{th} order basin

The slope map (Figure: 9) of the basin clearly points out the maximum slope direction with small inlet's slope pattern in various other direction. The slope condition with variation in relief obviously directs the stream and streamlets to accumulate their water in well distinguished flow channels. Relief controls the rate of conversion of potential to kinetic energy of water draining through the basin. Run-off is generally faster in steeper basins, producing more peaked basin discharges and greater erosive power. The DEM produced by TNT Mips software considering the contour values clearly shows the point of maximum elevation, the area with gentle gradation and the land with very little variation in topography.

5.3.2. Relief Ratio *(Rr)*

The relief ratio, *(Rr)* is ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). This is a dimensionless height- length ratio and allows comparison of relative relief.

Rr =Maximum Basin Relief/ Maximum Basin Length.

The *Rr* normally increases with decreasing drainage area and size of watersheds of a given drainage basin (Gottschalk, 1964). Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). The value of *Rr* in basin is 0.005 indicating moderate relief and moderate slope.

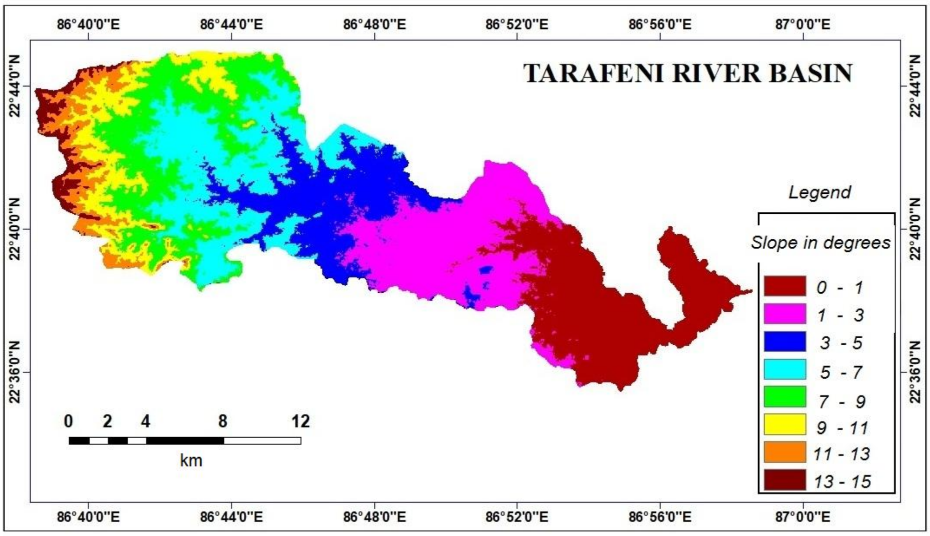

Figure 9: Slope map of the basin

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5.3.4 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 (Strahler, 1956). The value of ruggedness number in present basin is 3.02. (Schumm, 1956).

5.3.5 Dissection Index *(DI)*

Dissection index express a ratio of the maximum relative relief to the maximum absolute relief is an important morphometric indicator of the nature and magnitude of dissection of terrain. Dov Nir (1957) suggested the following formula for the derivation of dissection index :
DI = Relative Relief (Rr) / Absolute Relief (Ar).
The *DI* value is 0.73 for the basin indicate moderate to high intensity of erosion in the area.

6. Conclusion

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management at a micro level. The analysis carried out in the Tarafeni river basin shows that the basin is having a landform comprising of hilly tracts to plains. Entire basin area is characterised with elongated tributaries flowing parallel or sub-parallel to the main stream. In some parts the dipping and jointing of the streams reveals parallel and radial pattern. Drainage pattern displays more or less dendritic nature. Low value of length of the overland flow signifies that most part of the basin has been developed on the undulating hilly terrain where different geological structures have played an important role in the development of drainage network. Remotely sensed datasets merged with GIS based tools is helpful enough in evaluation of drainage morphometric parameters and their influence on landforms, soils and eroded land characteristics. The low bifurcation ratio signify a high drainage density, low permeability of the terrain and indicate areas with uniform surface materials where geology is reasonably homogeneous. The stream frequency of the study area shows a positive correlation with the drainage density, which indicates that the stream numbers increases with the increase of drainage density. Therefore quantitative measurement of morphometric attributes has been successfully used to make inferences about the catchment characteristics and various surface processes operated over the basin.

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