INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES
Volume 3, No 2, 2012

Research article ISSN 0976 – 4380

Morphometric analysis and associated land use study of a part of the Dwarkeswar watershed

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ABSTRACT

In the present study, morphometrc analysis using remote sensing and a GIS techniques have been carried out in the upper part of the Dwarkeswar Watershed, Bankura and Puruliya district, West Bengal. For detailed study, we used ASTERGDEM data for preparing digital elevation model (DEM), and GIS was used in evaluation of basic, linear, areal and relief aspects of morphometric parameters. Watershed boundary, flow accumulation, flow direction, flow length, stream ordering have been prepared using Arc-Hydro Tool. Different thematic maps e.g. stream orders; drainage density, slope and relief have been prepared by using GIS software. Authors have computed almost 20 morphometric parameters of all aspects which are based on various morphometric analyses. The present morphometric analyses suggest that the erosional development of the area by the streams has progressed well beyond maturity and that lithology has had an influence in the drainage development. These studies are very useful for planning rainwater harvesting and watershed management.

Keywords: Morphometric Analysis, Dwarkeswar watershed, ASTERGDEM, DEM and GIS

1. Introduction

Basin morphometry is a means of numerically analyzing or mathematically quantifying various aspects of drainage channel and its characteristics that can be measured for comparison which includes, the number, length, drainage density and bifurcation of rivers as well as shape, area, relief and slope of the basin. Morphometric analysis using remote sensing and GIS techniques have been well demonstrated by some of the researchers (Nautiyal, 1994; Srivastava et al., 1995; Srivastava, 1997; Nag, 1998; Agarwal 1998; Biswas et al., 1999; Shreedevi et al., 2001, 2004, Vittala et al., 2004; Reddy et al., 2004). Remote sensing and geographical information system is used as powerful tools for studying basin morphometry and continuous monitoring. In the present paper an attempt has been made to i) find out characteristics of basin morphometry and ii) there influence on the present land use / land cover.

2. Study area

The upper part of the Dwarkeswar watershed looks like a semielliptical shape and occupies the Kashipur block which is situated in northeastern part of Puruliya district, but the major part of this study area is situated in Chhatna and Bankura-I block of Bankura district of West Bengal state, India. This study area is bounded by latitudes $23^0$08'59", to $23^0$31'02" and from longitudes $86^0$31'09" to $87^0$8'19". This study (Figure 1) area covers an area of 1808.5778 km^2. Gandheshwari is one of the major tributary of Dwarkeswar River. The climate is extreme with maximum temperature up to 42^0C and minimum temperature down to 6^0C. The annual rainfall of the study area varies between 1055 and 1070.3 mm. The maximum amount of rainfall received during the monsoon season from June to September about 80.73%. The relative humidity in the month of April is 61 (2008) and in the month of September is 99 (2008). The maximum altitude is 435 mt., demarcated in the middle part and the minimum elevation is about 67 mt. observed in the south eastern part of the watershed.

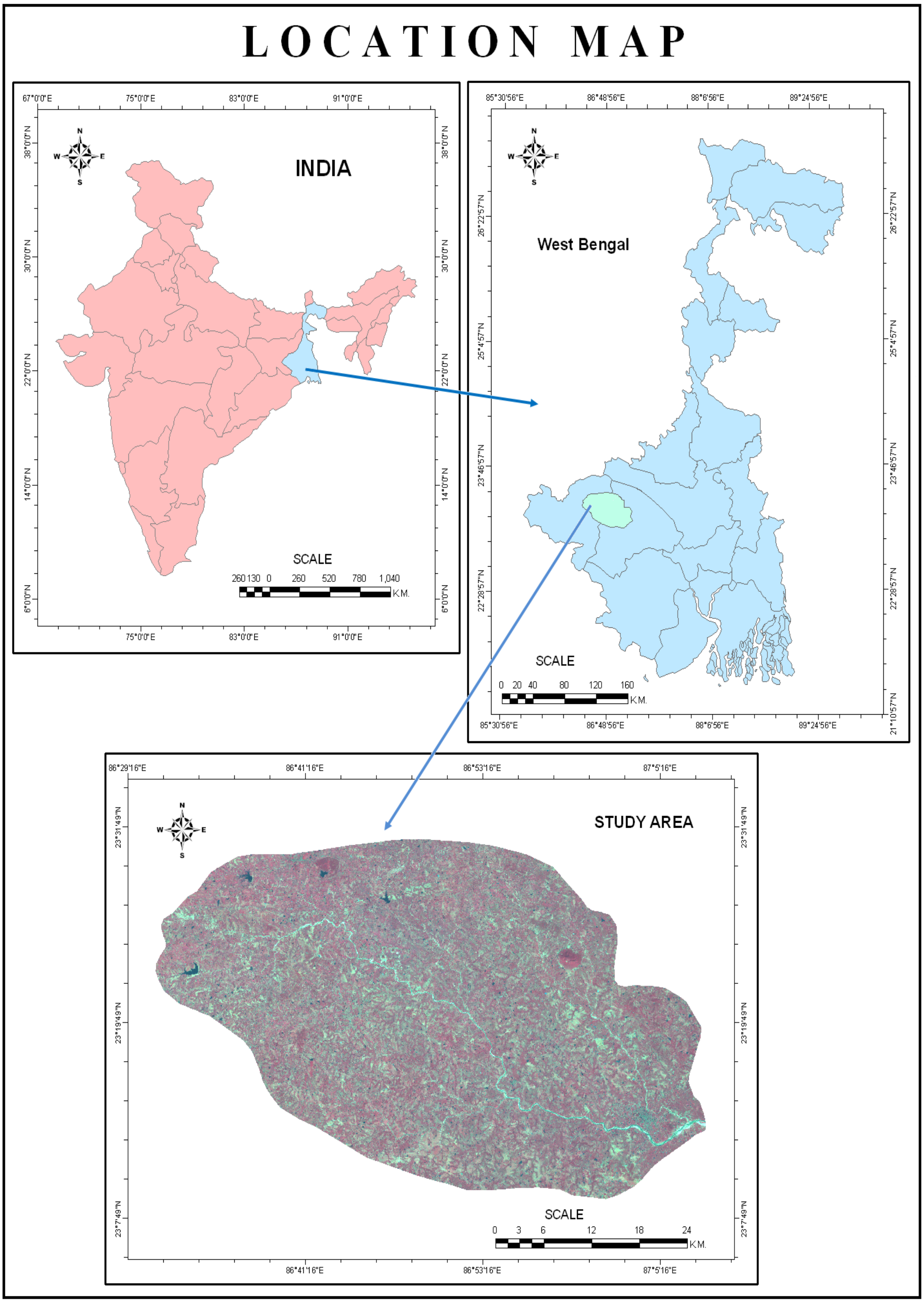

Figure 1: Map showing the study area

2.1. Data Used

Survey of India (SOl) topographical sheets (73 M and 73 I) on 1:250,000 scales have been used as a base map for the preparation of this study. Contours are available on SOI topographical maps. SRTM, ASTERGDEM, Google earth image and Geological map (1:250,000 scale) published by Geological Survey of India were also used. Except these, one satellite data (Table-1) is also used for this work which is in the following.

Table 1: Details of the satellite data used in this study

Satellite	Sensor	Path/Row	Bands	Date of acquisition	Spatial Resolution
LANDSAT	ETM+	139/044	1,2,3,4	Nov. 18th 2006	30*30mts.

2.2. Aim and objectives

The main objective of the present study is to derive the different drainage characteristics for the upper part of the Dwarkeswar watershed.

1. The quantitative analysis of drainage system.
2. To study drainage morphometry and its influence on the present land use / land cover.

3. Methodology

In the present study, morphometric analysis for the upper part of the Dwarkeswar watershed is based on the integrated use of remote sensing and GIS techniques. The remotely sensed data was geometrically rectified with respect to Survey of India (SOI) topographical maps at 1: 250000. Image enhancement techniques were applied for better interpretation of drainage from images. The digitization of dendritic drainage pattern was carried out in GIS environment.

The stream ordering was carried out using the Strahler's law. The fundamental parameters namely; stream length, area, perimeter, number of streams and basin length were derived from the drainage layer. The morphometric parameters for the delineated watershed area were also calculated Table-2. The morphometric parameters values namely; stream length, bifurcation ratio, drainage density, stream frequency, form factor, texture ratio, elongation ratio, circularity ratio and compactness constant were computed using mathematical formula given in Table 2 and the ASTERGDEM data were used for preparing digital elevation (Figure 5) model for this study.

4. Results and discussion

4.1 Geology

In order to understand the geomorphology of the study area, a general lithological map has been prepared with the help of LANDSAT ETM+ satellite imagery and the geological map prepared by the GSI (Geological Survey of India). The area comprises of Pre-Cambrian crystalline basement and recently deposited alluvium connected by an intervening tract. The area is predominantly a Pre-cambrian gneissic terrain. Here, the extension of Chotonagpur plateau gradually merges with the alluvial plain. The main rock types are granitoid gneisses, quartz schists and amphibolites. The upland surface is composed of lateritic hard crust with jointed structures and granular materials. The valley fill surface and younger terrace are composed of gravels or coarse sands.

4.2 Morphometric analysis

4.2.1 Basic parameters

Basic parameters include watershed area, perimeter and basin length (Table 2).

4.2.1.1 Area (*A*) and Perimeter *(P)*

The drainage area (A) is probably the single most important watershed characteristic for hydrologic design and reflects the volume of water that can be generated from rainfall. Present result shows that the basin covers an area about 1808.5778 km^2 while the basin perimeter (P) can be represented as length of the line that defines the surface divide of the basin. Perimeter of the watersheds is about 171.814 km. which is shown in Table 2.

4.2.1.2 Basin length

Basin length is usually defined as the distance measured along the main channel from the watershed outlet to the basin divide. Since the channel does not extend to the basin-divide, it is necessary to extend a line from the end of the channel to the basin-divide following a path where the greatest volume of water would travel. Thus, the length is measured along the principal flow path. Basin length is the basic input parameter to count the major shape parameters. In the result, basin length is 66.99790678 km, shown in table 2.

4.2.2 Linear parameters

Linear parameters include stream ordering, bifurcation ratio, stream numbers, stream length, mean stream length, stream length ratio and length of overland flow.

4.2.2.1 Stream ordering

The stream ordering is the first step in the drainage basin analysis. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964). It has observed that the maximum frequency is in the case of first order streams. It has also noticed that there is a decrease in stream frequency as the stream order increases (Figure 2).

4.2.2.2 Bifurcation ratio

It is defined as the ratio of the number of streams of a given order to the number of streams of the next higher order (Schumn 1956). Lower Rb values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Nag 1998). Table 2 shows that bifurcation ratios (Rb) for the upper part of Dwarkeswar watersheds which ranges between 3.4375 to 8 and the mean bifurcation of the entire basin is 5.15 (Table 2).

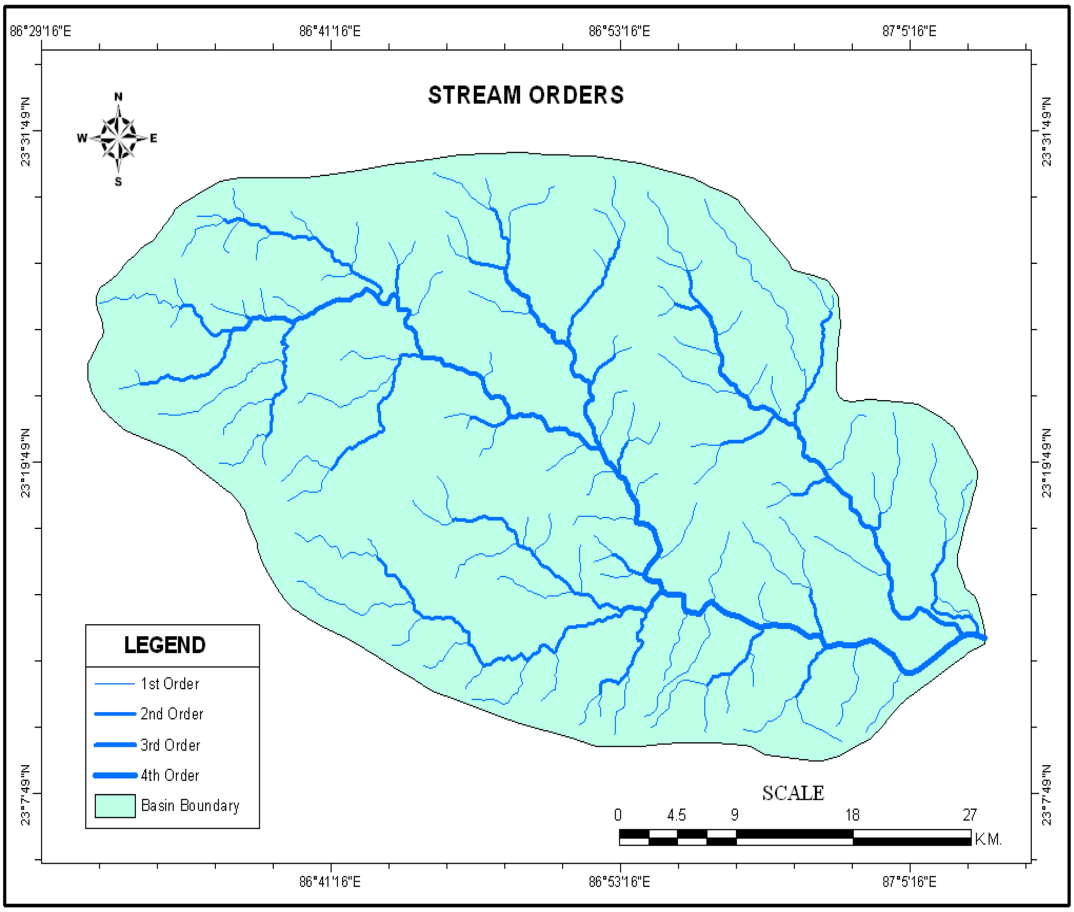

Figure 2: Map showing the stream orders

4.2.2.3 Stream Number (Nu)

The total of order wise stream segments is known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number, Table 2.

4.2.2.4 Stream length

Addition of the lengths of all streams, in a particular order, defines total stream length. The watershed shows that the total length of stream segments is maximum in first order streams and decreases as the stream order increases. The stream lengths of the various segments are measured with the help of GIS softwares.

4.2.2.5 Mean Stream length

Mean stream length (Lsm) is a characteristic property related to the drainage network components and its associated basin surfaces (Strahler, 1964). This has been calculated by dividing the total stream length of order (u) by the number of streams of segments in the order. The mean stream length is presented in Table 2.

4.2.2.6 Stream length ratio

Stream length ratio (RL) is the ratio of the mean length of the one order to the next lower order of the stream segments. The RL values are presented in Table 2.

4.2.2.7 Length of overland flow

It is the length of water over the ground before it gets concentrated into definite stream channels and is equal to half of drainage density (Horton 1945). Length of overland flow relates inversely to the average channel slope. Table 2 reveals the length of overland flow for the upper part of the Dwarkeswar watershed.

Table 2: Empirical formulas for computation of morphometric parameters

Sl. No.	Morphometric Parameter	Formula	Reference	Result
1	Stream Order (Nu)	Hierarchical rank	Strahler (1964)	1 to 4
2	Stream Length (k.m.)	Lu = L1+L2 ……Ln	Strahler (1964)	726.72
4	Mean stream length (k.m.)	Total stream length divide by total number of streams	Strahler (1964)	4.81
2	Bifurcation Ratio (Rb)	Rb= Nu/Nu+1 Where Nu= Total number of stream segment of order u Nu+1= Total number of stream segments in next higher order	Schumm (1956)	3.44 to 8
3	Mean Bifurcation Ratio (Rbm)	Rbm = Average of Bifurcation ratio of all orders	Strahler (1964)	5.15
5	Drainage Density (Dd) km/km^2	Dd =Lu/Au Where Lu =total length of stream segments cumulated for each stream order, Au= Basin area	Strahler (1964)	0.4018
6	Stream Frequency (F)	F = Nu/Au where Nu=total number of stream segments of all order, Au=Basin area	Horton (1945)	0.0835
7	Drainage Texture (T)	T= Dd x F Where Dd= Drainage Density, F= Stream Frequency	Smith (1950)	4.81
8	Circulatory Ratio (Rc)	$Rc=4\pi A/ P^2$ Where, Rc= Circularity Ratio, A= Area of the Basin (km^2), P = Perimeter (km)	Miller (1953)	0.31
9	Elongation Ratio (Re)	$Re=2 \sqrt{(A/\pi)} /Lb$ Where, Re=Elongation ratio Lb= Length of basin (km), A = Area of the basin (km^2)	Schumm (1956)	0.716
10	From Factor (Rf)	$Rf = A/Lb^2$ Where A = Area of the basin (km^2) Lb^2 = Square of the basin length	Horton (1945)	0.403
11	Texture Ratio (T)	T = Nu/ P Where Nu = Total number of streams of all orders, P = Perimeter (km)	Horton (1945)	0.878
12	Compactness Constant (Cc)	Cc = 0.2821 P/A*0.5* Where A = Area of the basin (km^2) P = Perimeter of the basin (km)	Horton (1945)	0.0536

13	Basin Relief (Bh)	Bh = H- h Where H = Maximum height of the basin, h = minimum height of the basin	Schumm (1956)	367
14	Relief ratio (Rh)	Rh =H/Lb, Where H=Total height (km), Lb=maximum basin length	Schumm (1956)	0.0064
15	Absolute Relief (Ra) m	GIS Software Analysis	------	435
16	Average Slope (S) in degrees	S = (Z * (Ctl/H)) / (10 * A)	Wenthworth's (1930)	$6^{0}15'7''$
17	Relative Relief (Rr) (mt.)	Rr= MH-mh Where MH = Maximum height of the basin, mh = minimum height of the basin	--	320
18	Length of the over land flow (Lo)	Lo = 1/D*2 Where Lo= Length of the over land flow, D= Drainage Density	Horton (1945)	1.24
19	Basin Area (A) Sq Km.	GIS Software Analysis	Schumm(1956)	1808.5778
20	Basin Perimeter (P) Km.	GIS Software Analysis	Schumm(1956)	171.814

4.2.3 Areal parameters

Areal Parameters include geometry of basin shape (include form factor, shape factor, circularity ratio and elongation ratio), texture ratio, drainage texture, stream frequency, drainage density, drainage pattern, compactness coefficient etc. (Table 2)

4.2.3.1 Geometry of basin shape

Different popular methods of computation of basin shape are as follows-

4.2.3.2 Form factor

The form factor can be defined as the ratio of the area of the basin to square of the basin length (Horton 1945). In the present study the value of form factor is about 0.403 indicating the watershed is elongated.

4.2.3.3 Shape factor

The shape factor can be defined as the ratio of the square of the basin length to area of the basin (Horton 1945) and is in inverse proportion with form factor (Rf). Shape factor lies between 2.27 to 3.42 in present work, which indicates the elongated shapes of basin.

4.2.3.4 Circularity ratio

Circularity ratio (Rc) is defined as the ratio of the basin area to the area of circle with same perimeter as the basin (Miller, 1953). It is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin for the upper part of the Dwarkeswar Watershed the ratio is 3.2. The upper part of the Dwarkeswar watershed has value of Rc less than 0.5 indicating that it is elongated.

4.2.3.5 Elongation ratio

Elongation ratio (Re) is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length Schumm (1956). A circular basin is more efficient in runoff discharge than an elongated basin (Singh and Singh 1997). The value of elongation ratio is varied between 0.0 to 1.0 and 1.0 are the typical regions of very low relief, whereas value ranged between 0.6 and 0.8 are associated with high relief and steep ground slope (Strahler 1964). The lower value of the elongation ratio indicates that particular watershed is more elongate than others. The elongation value can be grouped into three categories, namely circular basin (Re>0.9), Oval basin (Re: 0.9– 0.8), Less elongated basin (Re <0.7). In this study (Table 2), this value is 0.716 and hence the basin is elongated in shape.

4.2.3.6 Texture ratio

The texture ratio can be defined as the ratio of total number of streams of first order to the perimeter of the basin. The value of the texture ratio is 0.878 which is shown in Table 2. These values of runoff show the moderate runoff.

4.2.3.7 Drainage Texture (T)

The drainage texture (T) is an expression of the relative channel spacing in a fluvial dissected terrain. It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development of a basin (Smith, 1950). The value of T for the basin is shown in Table 2. According to Horton (1945), T is the total number of stream segments of all orders per perimeter of that area. The drainage density < 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and >8 is very fine drainage texture. In the present study, the value of drainage texture is 4.81 was noticed in satellite data and topographical map indicating moderate texture.

4.2.3.8 Stream frequency

Stream frequency or drainage frequency is the measure of number of stream segments of all orders per unit area (Horton, 1932). In the present study, the value of stream frequency of the Dwarkeswar watershed is 0.0835 which is shown in table 2. The value of stream frequency for the basin exhibit positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density.

4.2.3.9 Drainage density

Drainage density is the ratio of total length of all stream segments in a given drainage basin to the total area of that basin. The drainage density indicates the closeness of spacing of channels (Horton, 1932). A high value of drainage density is the result of impermeable sub-surface material, sparse vegetation, mountainous relief which influences low infiltration capacity and higher runoff and soil loss. Maximum drainage density is calculated as 1.97 km. per sq.km (Figure 3).

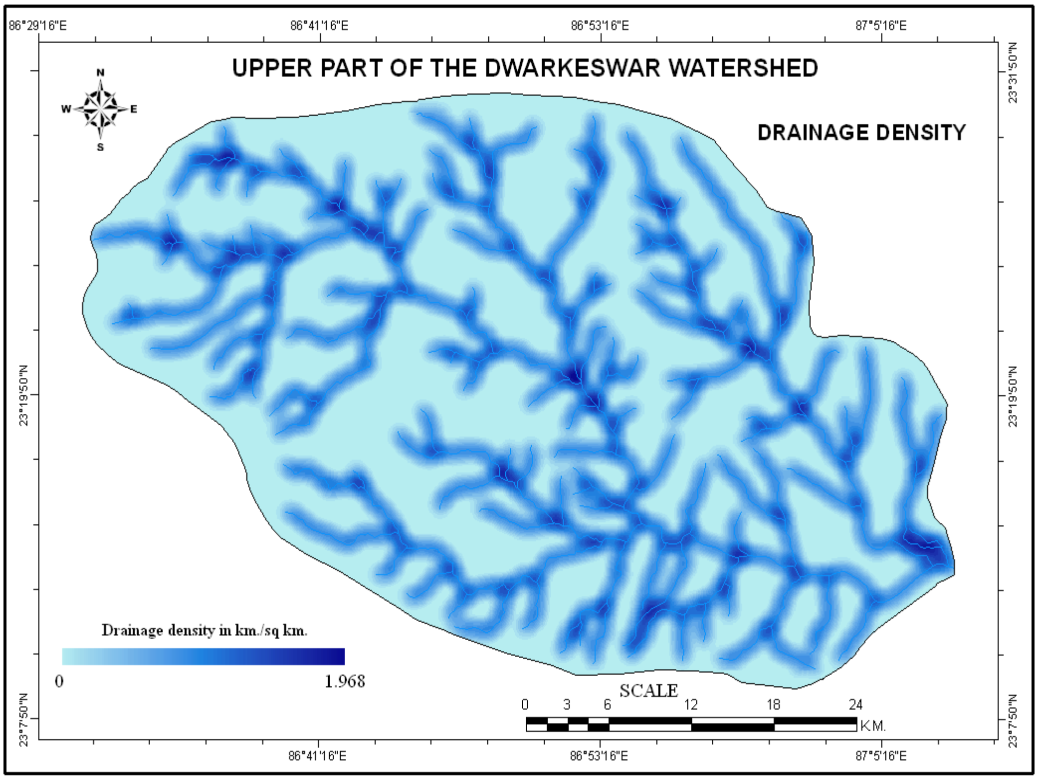

Figure 3: Map showing the drainage density

4.2.3.10 Drainage pattern

Dendritic drainage pattern is identified in the Dwarkeswar watershed (Figure 2). Dendritic pattern is most common pattern is formed in a drainage basin composed of fairly homogeneous rock without control by the underlying geologic structure.

4.2.3.11 Compactness Coefficient (Cc)

It can be represented as basin perimeter divided by the circumference of a circle to the same area of the basin and also known as the Gravelius Index (GI). This factor is indirectly related with the elongation of the basin area. Lower values of this parameter indicate the more elongation of the basin and less erosion, while higher values indicate the less elongation and high erosion. In this study the value of compactness coefficient is 0.0536 which shows in Table 2.

4.2.4 Relief parameters

Relief parameters include absolute relief, relative relief, dissection index and average slope.

4.2.4.1 Absolute relief

The difference in elevation between a given location and sea level is the absolute relief.

4.2.4.2 Relative relief

Relative relief is defined as the difference in height between the highest and the lowest points in a unit area. It is an important morphometric parameter which is used for the overall assessment of morphological characteristics of terrain. The maximum relative relief for the part of the Dwarkeswar watershed is 320 m in the north-eastern part of the study area.

4.2.4.3 Dissection Index

Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed (Singh and Dubey 1994). The value of dissection index ranges between 0 to 1. Higher value of the dissection index represents larger is the undulation and instability of the terrain. Maximum dissection index is calculated as 0.73 in the north-eastern part of the watershed.

4.2.4.4 Average slope

According to Wentworth's (1930), Erodibility of a watershed can be studied and can be compared from its average slope. More the percentage of slopes more are its erosion, if all other things are kept constant. In the gentle slope area the surface runoff is slow, allowing more time for rainwater to percolate, whereas high slope area facilitate high runoff allowing less residence time for rainwater hence comparatively less infiltration. Author has computed the maximum average slope of the study area, which is $6^{0}15'7''$ (Figure 4).

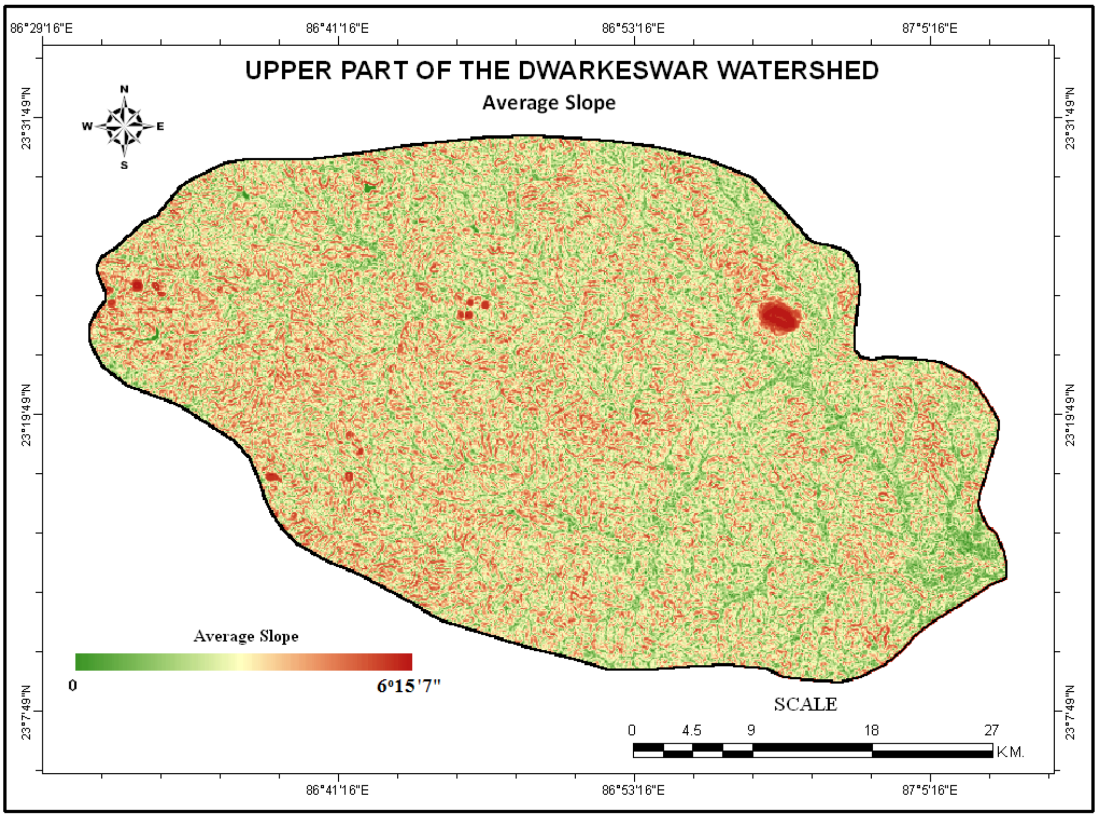

Figure 4: Map showing the average slope

4.2.4.5 Relief ratio (Rh)

The elevation difference between the highest and lowest points on the valley floor of a sub-watershed is known as the total relief of that sub-watershed. The relief ratio (Rh) of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as Rh (Schumm, 1956). There is also a correlation between hydrological characteristics and the Rh of a drainage basin. The Rh normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin (Gottschalk, 1964). The value of Rh is given in table 2 and which is 0.0064.

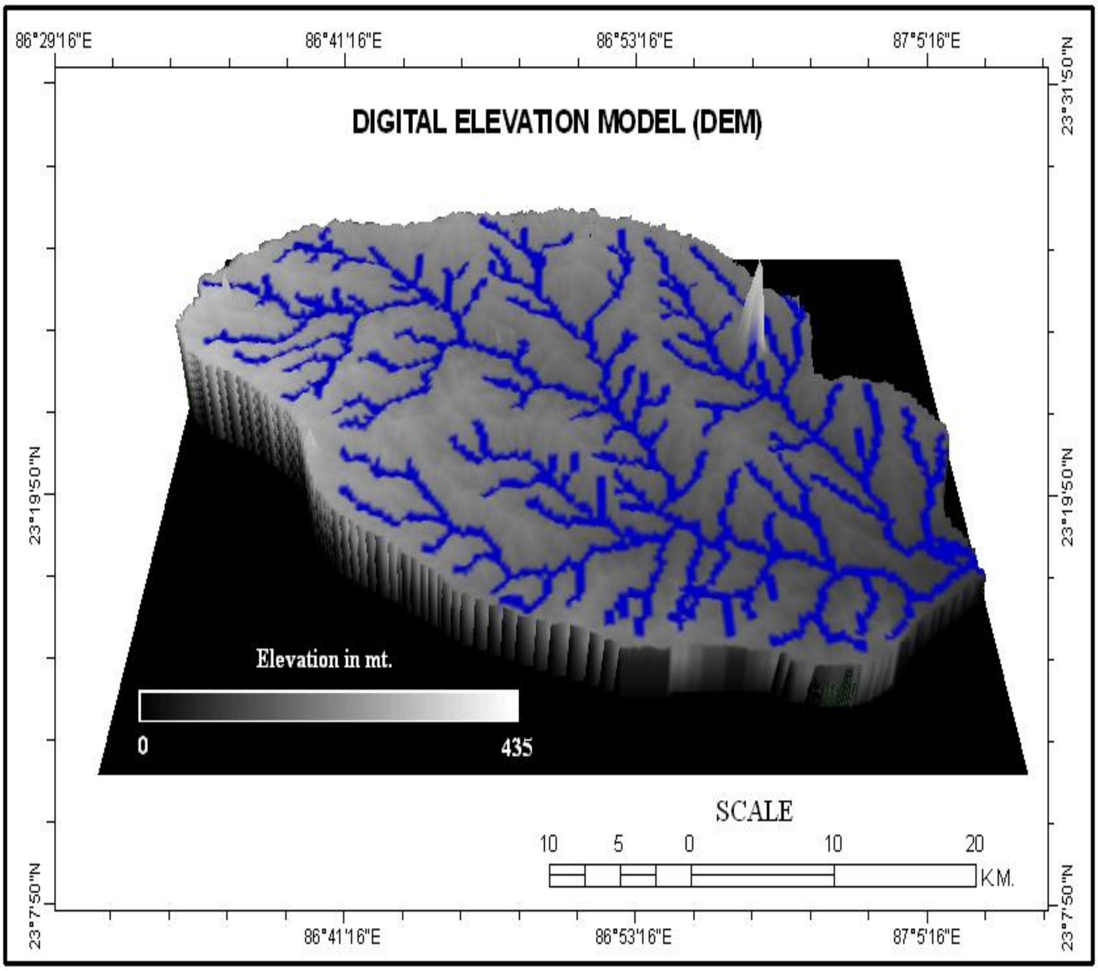

Figure 5: Map showing the digital elevation model

5.1 Land use and land cover

Land is the most important natural resource, which embodies soil, water and associated flora and fauna involving the total ecosystem (Rao et al., 1996). Comprehensive information on the spatial distribution of land use/land cover categories and the pattern of their change is a prerequisite for management and utilization of the land resources of the study area. The land use pattern of any terrain is a reflection of the complex physical processes acting upon the surface of the earth. These processes include impact of climate, geologic and topographic conditions on the distribution of soils, vegetation and occurrence of water. For better development and management of the watershed areas, it is necessary to have timely and reliable information on geomorphological as well as environmental status.

Keeping the above views in mind, the authors have prepared a land use/land cover map (Figure 6) using LANDSAT ETM+ satellite imagery. This figure depicts that there are nine land cover/land use categories in the study area, which are given below and shown on the map.

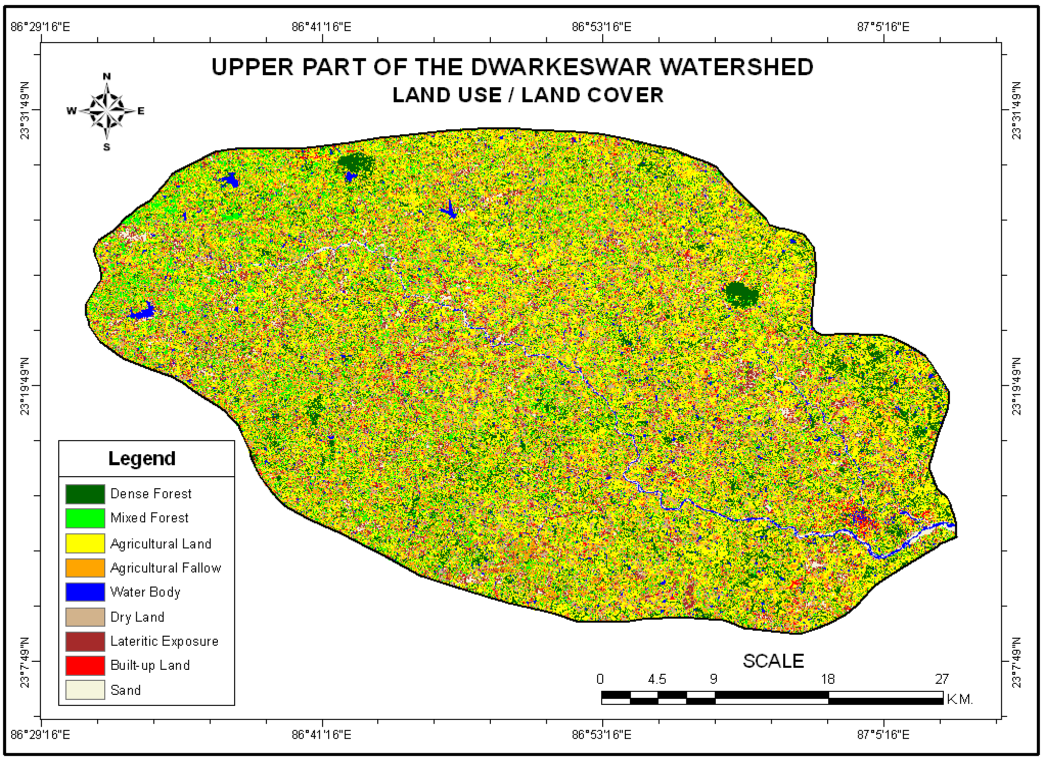

Figure 6: Map showing the land use / land cover

5.2 Conclusion

Remote sensing and GIS techniques have proved to be efficient tools in drainage delineation and their updation. These updated drainages have been used for the morphometric analysis. The morphometric analyses of the upper part of the Dwarkeswar watershed were carried out through measurement of basic, linear, areal and relief aspects of the watershed with almost 20 morphometric parameters. Dendritic drainage patterns with moderate drainage texture are found. High bifurcation ratio indicates a strong structural control on the drainage. The value of form factor and circularity ratio suggests that the Dwarkeswar watershed is less elongated. The value of stream frequency indicate that the watershed show positive correlation with increasing stream population with respect to increasing drainage density. The morphometric parameters evaluated using GIS which helped us to understand various terrain parameters such as nature of the rock, infiltration capacity, runoff, etc. The morphometric analysis has proved that it has better influence on presents landuse/ landcover which is very clear in the upper part of the watershed in this study area.

Acknowledgement

Author express special thanks to Dr. Subrata Pan, Assistant Professor of Geography Dept. (HOD), Bankura Christian College for given guide lines written this paper.

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