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*Full Length Research Paper*

# Morphometric analysis of Dwarakeswar watershed, Bankura district, West Bengal, India, using spatial information technology

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**Spatial information technology that is, remote sensing (RS) coupled with geographical information system (GIS) has come out as an efficient tool in delineating drainage pattern and water resource management and its planning. GIS and Image Processing techniques have been adopted for the identification of morphological features and analyzing their properties in Dwarakeswar River Basin area in Purulia and Bankura districts of West Bengal, India. The basin morphometric parameters such as linear and aerial aspects of the river basin have been determined. The parameters worked out include both linear aspects [Stream order ($N_u$), Bifurcation ratio($R_{b)}$, Stream length($L_u$), Stream frequency] and aerial aspects [Form factor ($R_f$), Circulatory Ratio ($R_c$), Elongation Ratio ($R_e$) and Drainage Density]. The study reveals that the area is characterized by fine drainage texture and lower drainage density indicating the basin is characterized by highly resistant permeable material with low relief. The overall drainage pattern of the Dwarkeswar watershed reflects a dendritic pattern. Dendritic pattern, in general, is considered as a group of resequent streams within homogeneous lithology and gently sloping topography. This study would help the local people to utilize the resources for sustainable development of the basin area.**

**Key words:** Quantitative geomorphology, drainage basin, Dwarakeswar watershed, morphometric analysis, spatial information technology.

## INTRODUCTION

Water is one of the most precious gift with which nature has blessed mankind. Water is absolutely vital for the sustenance and maintenance of life. From the ever-increasing population and the need for security, it is realized that water and land resources need to be developed, used and managed in an integrated and comprehensive manner. The remotely sensed data with high spatial resolution coupled with topographical data analysis procedures have come out as highly effective tool to understand and manage the natural resources. It provides the real time and accurate information related to distinct geological formation, landforms and helps in identification of drainage channels, which are altered by natural forces and human activities. GIS is an effective tool to analyze spatial and non-spatial data on drainage, geology, landforms parameters to understand their interrelationship.

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.

Drainage characteristics of basin and sub-basin have been studied using conventional methods (Horton, 1945; Miller, 1953; Strahler, 1964). 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). As a common conclusion they indicated that remote

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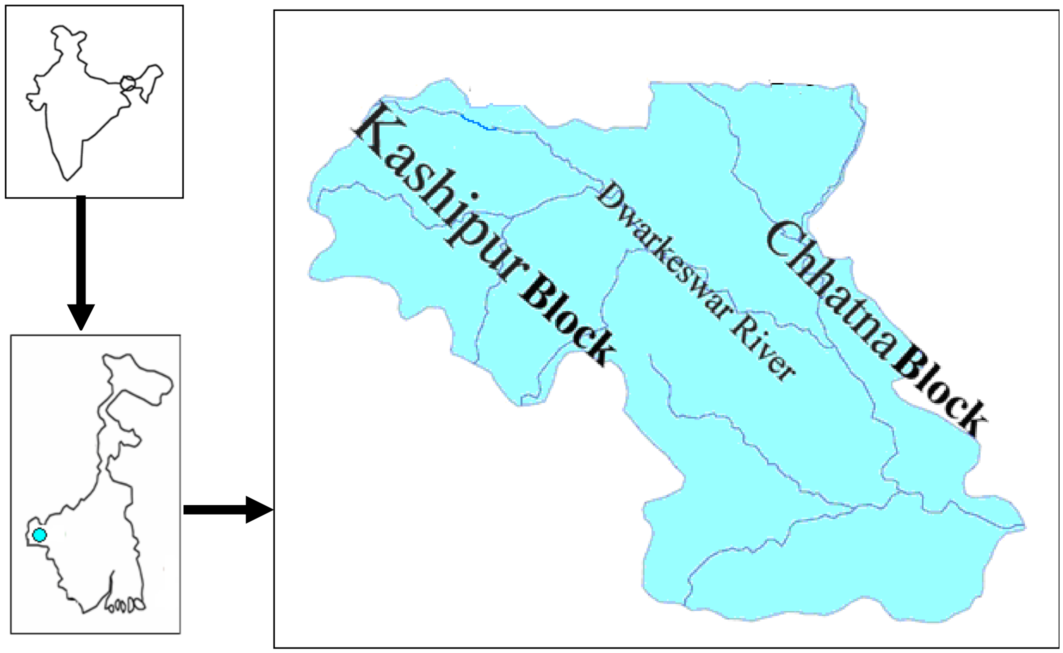


**Figure 1.** Key map of the study area.

sensing and geographical information system as powerful tools for studying basin morphometry and continuous monitoring . In the present paper an attempt has been made to (i) delineate different physical characteristics of the drainage basins and understand the relationship among them, (ii) understand the role of lithology and geologic structures in development of drainage pattern.

The importance of water has been recognized and more emphasis is being given on its economic use and better management. The basin morphometric characteristics of the various basins have been studied by many studied by scientists using conventional methods (Krishnamurthy and Srinivas, 1995, Srivastava and Mitra, 1995; Agarwal, 1998; Biswas et al., 1999, Narendra and Nageswara Rao, 2006).

## MATERIALS AND METHODS

### Study area

The study area comprises of Precambrian crystalline and recently deposited alluvium connected by an intervening tract. The Dwarkeswar watershed with a semi-elliptical shape occupies the Kashipur block which is situated in northeastern part of Puruliya district, but the major part of the Dwarkeswar watershed is situated in a part of Chhatna block of Bankura district of West Bengal State, India (Figure 1).

The Dwarkeswar watershed is bounded within 86°51′E and 87° 00′E longitudes and 23° 16′N to 23° 50′N latitudes. The Dwarkeswar River is one of the largest rivers in the region which flows up the hilly terrain of Puruliya district from northwest to south east, almost dividing the Chhatna block into two equal halves. The Dwarkeswar flows east upto Kashipur and then South east from 86° 44′E where it receives the Bekon Nala flowing east- south east. The other left bank tributary Dangra Nala has scissored the undulating surface into mesh of gully before entering the Bankura district as the Kumari Nala .The right bank tributaries of the Dwarkeswar river are the Futuari Nala flowing north east, Dudhbhaiya Nala flowing north and Arkasa Nala flowing east the last two having their sources near Hura block. The Arkasa turn north east in Bankura district where from its confluence , the Dwarkeswar river becomes a perennial stream. Dwarkeswar river and all above mentioned tributaries dry up during the cold and hot seasons. Gully erosion all along their channels is a very conspicuous feature.

### Data used and methodology

In the present paper, the database used for the study purpose includes:

(1) Drainage data of Survey of India Topographical map No. 73I/11, 73I/15 and 73I/16
(2) Geological map of the study area
(3) Satellite imagery IRS P6 L3 106-55, IRS P6 L3 107-55.

For the preparation of base map, three SOI top sheets on 1:50,000 scales in paper format were used. The digital data format from Indian remote sensing satellite (IRS –P6) of LISS-III with 23.5 m spatial resolution with four spectral bands was used to meet the requirement of area under study. The image taken was false colour composite (FCC) on 1:50,000 scale, having band combination of 3:2:1 (NIR: red: green) (Figure 2). The SOI top sheets and digital satellite data were geometrically rectified and georeferenced and merged using TNT mips v 7.4.

The morphometric analysis of the Dwarkeswar watershed has been analyzed using Indian remote sensing satellite imagery which were collected and registered to survey of India topographical sheets at 1:50,000 scale. These satellite image have been geo-referenced and merged using TNT mips version 7.4 (Figure 2).

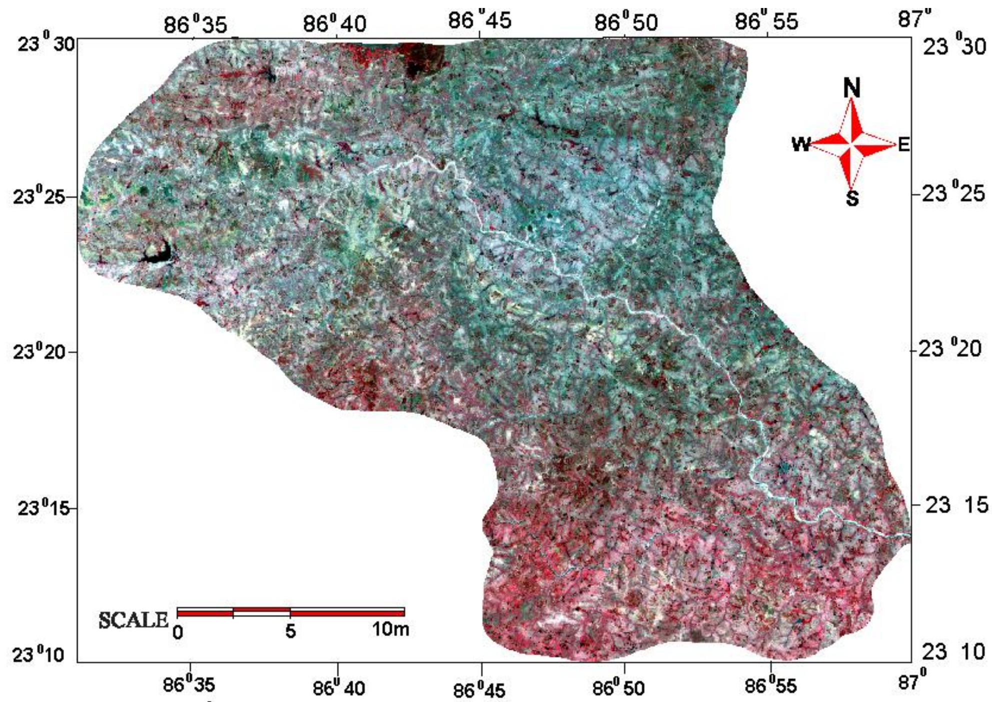


**Figure 2.** False colour composite of IRS LISS III data showing the basin area.

The study area has been subdivided into three sub-basins of Dwarkeswar River as shown in Figure 3. The three sub-basins are Basin-I with (Arkasa and Kansachara watershed), Basin-II with (Darubhanga, Furuari and Bekon watershed) and Basin-III with ( Dangra and Adali watershed) (Figure 3).

A quantitative, morphometric analysis of a drainage basin is considered to be the most satisfactory method because it enables (i) to understand the relationship among different aspects of the drainage pattern of the basin, (ii) to make a comparative evaluation of different drainage basins developed in various geologic and climatic regimes and (iii) to define certain useful variables of drainage basins in numerical terms.

The morphometric parameters computed include stream order (u), Bifurcation ratio ($R_{b)}$, stream length ($L_u$), stream frequency, basin shape, form factor ($R_f$), circulatory ratio ($R_c$), and drainage density (D), constant of channel maintenance.

## RESULTS AND DISCUSSION

Quantitative analysis of drainage basin and channel networks developed from qualitative and deductive studies subsequent to the valuable contribution of Horton (1945), Strahler (1957), Morisawa (1959), Melton (1957), Leopold and Miller (1956). The analysis of basins as either single unit or group of units comprises a distinct morphological region and it has a particular relevance to geomorphology (Doornkamp and Cuchlaine 1971).

Quantitative description of the watershed geomorphic analysis requires measurements of linear features, gradients of channel networks and contributing ground slopes of the watershed area. The analysis of drainage networks of all three basins showed, in general, that the granitic terrain exhibits a dendritic to sub-dendritic pattern. The quantitative morphometric analysis was carried out in all three basins independently for determining their linear aspects, such as stream order, bifurcation ratio, stream length and aerial aspects such drainage density and the constant of channel maintenance.

### Linear aspects

Stream order ($N_u$), stream length ($L_u$), stream length ratio, and bifurcation ratio ($R_{b)}$ are linear aspects that were determined and results have been given in Table 1.

### *Stream order ($N_u$)*

The first step in morphometric analysis of a drainage basin is the designation of stream orders. The designation of stream orders is based on a hierarchic ranking of stream. Measurements and statistical analysis of stream's lengths and overland flow length are among the most commonly used attributes. There are a number of methods of indicating stream orders for a stream network (Horton, 1945; Strahler, 1964). According to Strahler (1964), the smallest fingertip tributaries are designated as order 1. Where two first-order tributaries join, a tributary segment of order 2 is formed; where two

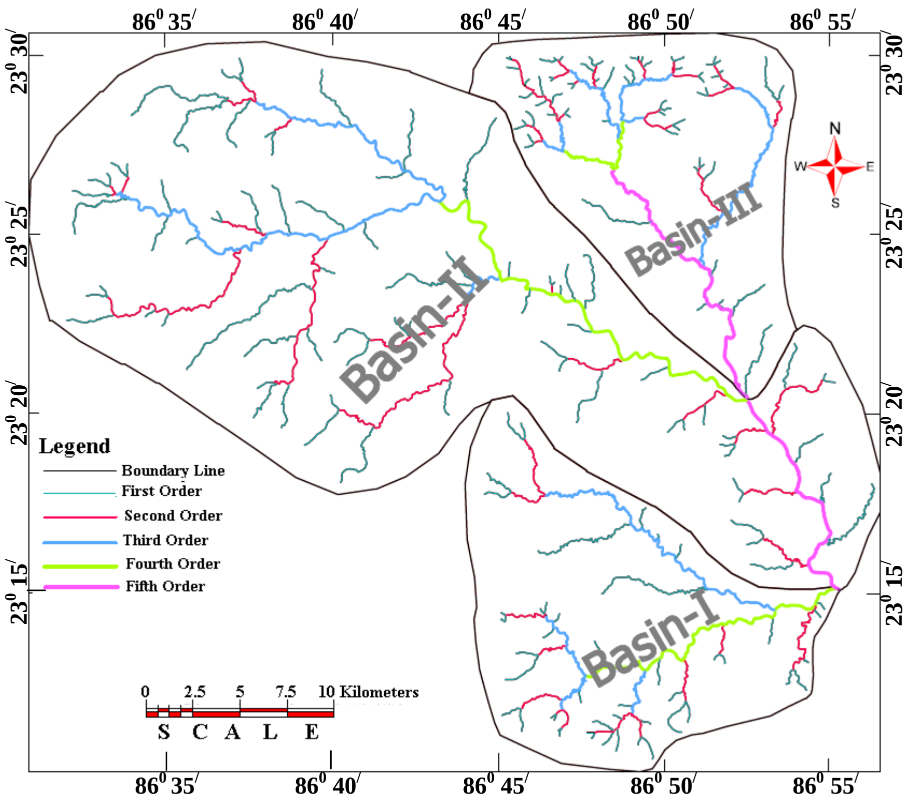


**Figure 3.** Map of Dwarakeswar watershed with its three sub-basins and stream orders.

of order 2 join, a segment of order 3 is formed; and so forth. The trunk stream through which all discharge of water and sediment passes is therefore the stream segment with highest order. The order wise stream numbers, area and stream length of Dwarakeswar river basin are given in ( Figure 3).

The order wise total number of stream segment is known as the stream number. Horton (1945) laws of stream numbers states that the number of stream segments of each order forms an inverse geometric sequence against plotted order. Most drainage networks show a linear relationship with small deviation from a straight line. Plotting the logarithm of number of streams against stream's order (Figure 4) shows a straight line. This means that the number of streams usually decreases as the stream order increases. The linear pattern is also an indicative of homogeneous rock material subjected to weathering. Deviation from its general behaviour indicates that the basin is characterised by lithologic and topographic variation.

### *Bifurcation ratio ($R_b$)*

The term bifurcation ratio ($R_b$) is used to express the ratio of the number of streams of any given order to the number of streams in the next higher order (Schumn, 1956). Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern (Strahler, 1964). The lower bifurcation ratio values are characteristics of the watershed, which has suffered less structural disturbances and the drainage pattern has not been distorted by the structural disturbances. The bifurcation ratio is also indicative of shape of the basin also. An elongated basin is likely to have a high $R_b$, whereas a circular basin is likely to have low $R_b$. The average bifurcation ratios calculated for three sub-basins are given in (Table 1).

### *Stream length ($L_u$)*

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. Streams with relatively short lengths are representative of areas with steep slopes and finer textures whereas longer lengths of stream are generally indicative of low gradients. The length of river network has been measured using GIS techniques. Length of the stream is indicative of the contributing area of the basin of that order. Generally, cumulative length of stream of a particular order is measured and the mean length ($L_u$) of that order (u) is obtained by dividing

**Table 1.** Different parameters of morphometric analysis.

| Sub-basin | Area (sq.km) | Stream Order (u) | No. of segments ($N_u$) | Total length of each segment (Km) | Bifurcation Ratio ($R_b$) | Stream length ($L_u$) | Cumulative stream length (Km) | Cumulative mean stream (length) | Form factor ($R_f$) | Elongation ratio ($R_e$) | Circulatory ratio ($R_c$) | Drainage Density (D) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 46 | 4.42 | 3.83 | 0.09 | 4.42 | 0.09 | | | | |
| I | 217.02 | 2 | 12 | 2.46 | 3 | 0.20 | 6.88 | 0.29 | 0.49 | 0.96 | 0.66 | 0.14 |
| | | 3 | 4 | 2.25 | 4 | 0.56 | 9.13 | 0.85 | | | | |
| | | 4 | 1 | 1.5 | | 1.5 | 10.63 | 2.35 | | | | |
| | | 1 | 77 | 14.52 | 4.27 | 0.18 | 14.52 | 0.18 | | | | |
| | | 2 | 18 | 6.25 | 6 | 0.34 | 20.77 | 0.52 | | | | |
| II | 649.27 | 3 | 3 | 3.5 | 3 | 1.16 | 24.27 | 1.68 | 0.32 | 0.88 | 0.52 | 0.17 |
| | | 4 | 1 | 2.15 | 1 | 2.15 | 26.42 | 3.83 | | | | |
| | | 5 | 1 | 1.2 | | 1.2 | 27.62 | 5.03 | | | | |
| | | 1 | 70 | 4.77 | 3.68 | 0.06 | 4.77 | 0.06 | | | | |
| | | 2 | 19 | 2.44 | 2.71 | 0.12 | 7.21 | 0.18 | | | | |
| III | 196.24 | 3 | 7 | 2.45 | 2.33 | 0.35 | 9.66 | 0.53 | 0.54 | 0.98 | 0.70 | 0.22 |
| | | 4 | 3 | 0.9 | 3 | 0.30 | 10.56 | 0.83 | | | | |
| | | 5 | 1 | 1.5 | | 1.5 | 12.06 | 2.33 | | | | |

cumulative stream length by the number of segments of that order ($N_u$). The mean stream length ($L_u$) of a stream-channel segment of order (u) is a dimensionless property, which reveals the characteristic size of components of a drainage network and its contributing basin surfaces. The stream length calculated for all three basins are given in (Table 1).

## Aerial aspects

Area and perimeter of a basin (A) and (P) are two important parameters in quantitative morphometry. The area of the basin is defined as the total area projected upon a horizontal plane contributing to cumulate of all order basins. Perimeter is the length of the boundary of the basin which can be drawn from topographical maps. Basin area is hydrologically important because it directly affects the size of the storm hydrograph and magnitudes of peak and mean runoff. It is interesting that maximum flood discharge per unit area is inversely related to the size of a watershed (Chorley et. al., 1957). The aerial aspects of the drainage basin such as form factor ($R_f$), circulatory ratio ($R_c$), elongation ratio ($R_e$), drainage density (D) have been calculated and given in Table 1.

### *Form factor ($R_f$)*

Horton (1932) outlined form factor as a dimensionless ratio of the area of the basin to the square of the length of the basin. Basin shape can be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length (Singh, 1998).The form factor calculated for all three basins are given in Table 1.

### *Circulatory ratio ($R_c$)*

Miller (1953) defined a dimensionless circulatory ratio ($R_c$) as the ratio between the area of the basin and the area of the circle having the same perimeter as that of the basin. He described the basin of the circulatory ratio range between 0.4 to 0.5 as strongly elongated and highly permeable and homogeneous rock type. The circulatory ratio

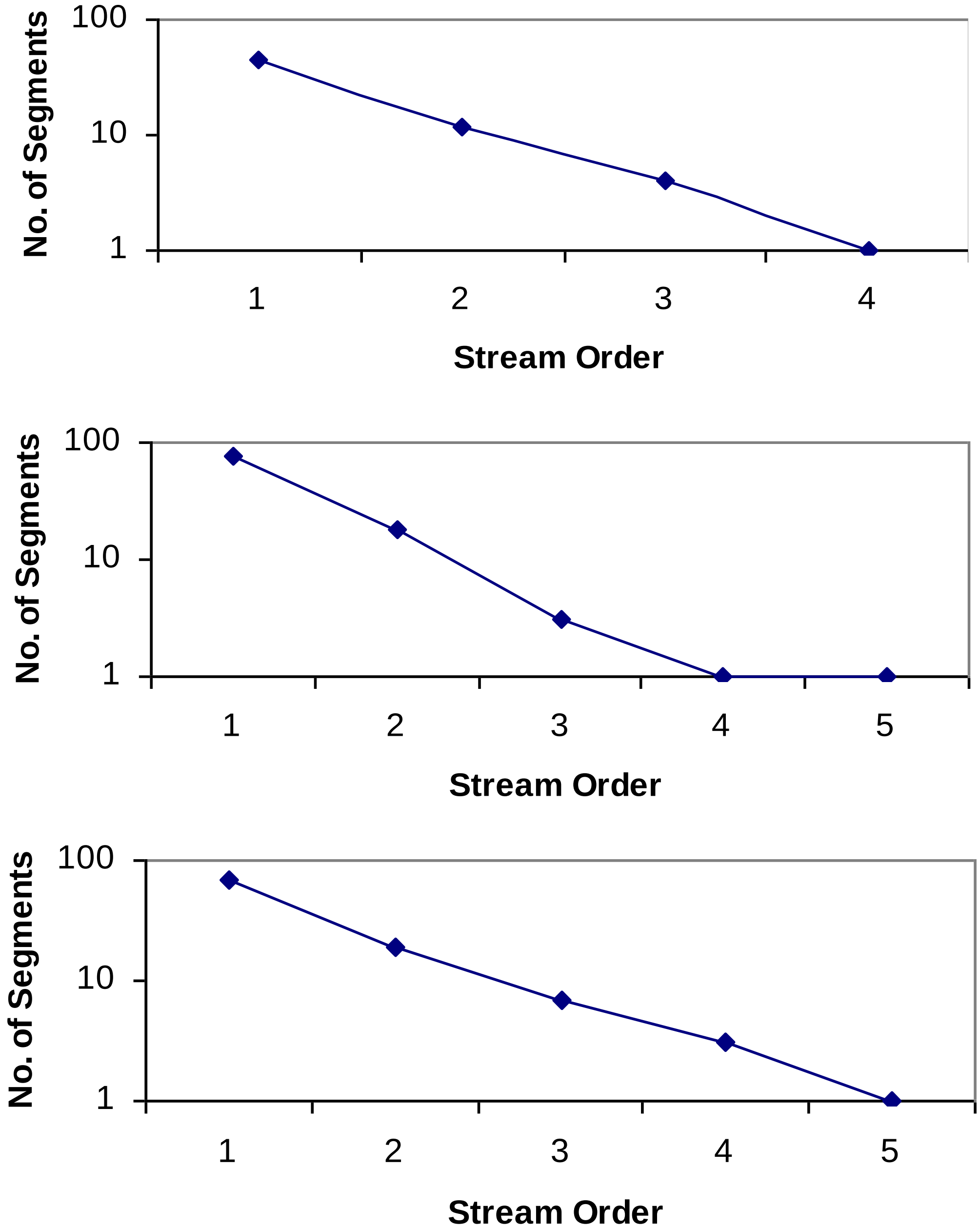


**Figure 4.** Plots of number of stream segments of each order against order number.

calculated for three sub-basins are given in Table 1.

### *Elongation ratio ($R_e$)*

Elongation ratio ($R_e$) is the ratio between the diameter of the circle having the same area (as that of the basin) and the maximum length of the basin (Schumn, 1956). It is a very significant criterion in basin shape determination. Values near 1.0 are typical of regions of very low relief (Strahler, 1964). The elongation ratio calculated for three sub-basins are given in Table 1.

### *Drainage density (D)*

Drainage density (D) is one of the important indicators of the linear scale of landform elements in stream-eroded topography; it was defined by Horton (1932) as the ratio of total channel segment lengths (cumulated for all orders) within a basin to the basin area. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the mean length of river network for the whole basin. It has been observed from drainage density measurements over a wide range of geologic and climatic types that a low drainage density

**Table 2.** Characterization of three drainage basins representing different geologic environment.

| Basin | I | II | III |
|---|---|---|---|
| Area (sq.km) | 217.02 | 649.27 | 196.24 |
| Max. length(km) | 21 | 45 | 19 |
| Stream length ratio | 2.2 | 1.8 | 2 |
| | 2.8 | 3.41 | 2.91 |
| | 2.67 | 1.85 | 0.85 |
| | | 0.55 | 5 |
| Mean bifurcation ratio | 3.61 | 3.56 | 2.93 |
| Stream frequency | 0.29 | 0.15 | 0.50 |
| Drainage texture | 0.98 | 0.80 | 1.69 |
| Constant channel maintenance | 20.41 | 23.50 | 16.27 |

is more likely represent the regions with resistant like area with permeable subsoil under dense vegetative cover, and where relief is low. In contrast, high drainage density is favoured in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief. The drainage density (D) calculated for all three basins are given in Table 1.

### *Stream frequency ($F_s$)*

Stream frequency or channel frequency ($F_s$) is the total number of stream segments of all orders per unit area (Horton, 1932). The stream frequency calculated for all three basins are given in Table 2.

### *Constant of channel maintenance (C)*

Schumm (1956) used the inverse of drainage density as a property termed "the constant of channel maintenance" (C), which may be simply defined as the area of basin surface needed to sustain a unit length of stream channel. The constant (C) is expressed as $km^2/km$, and depends upon not only the rock type and permeability, climatic regime, vegetation cover and relief, but also the duration of erosion and climatic history. The constant is extremely low in areas of close dissection. The values of the constant derived for all three basins are given in Table 2.

## Conclusions

The quantitative analysis of morphometric parameters is of immense utility in river basin evaluation, watershed analysis for soil and water conservation and natural resource management at micro level. The morphomtric parameters evaluated using GIS helped to understand various terrain parameters such as nature of bedrock, infiltration capacity, runoff, etc. The basin morphometric characteristics of different basins have been studied by many workers using conventional (Horton, 1945; Smith, 1950; Strahler, 1957) and remote sensing and GIS methods (Krishnamurthy and Srinivas, 1995; Srivastava and Mitra, 1995; Agarwal, 1998; Nag, 1998; Biswas et al., 1999; Narendra and Nageswara, 2006). The study reveals that drainage network of the basin is mainly dendritic type indicative of homogeneity in texture and lack of structural control. The linear pattern of the graphical presentation (Figure 4) indicates the weathering erosional characteristics of the area under study.

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