GIS for Morphometric Analysis of River basins

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Abstract

GIS techniques are being effectively used in recent times in determining the quantitative description of the basin geometry and associated parameters. The present study depicts the process to evaluate the various morphometric parameters of a river basin in Nagpur district, Maharashtra using GIS software (SPANS ver 7.0) as a tool. The linear, areal and relief parameters were computed mathematically to analyse the characteristics of different morphometric parameters at sub basin level. The analysis indicates that the sub basins of 1, 2, 4, 5, 17 and 18 consist of very steep slopes, very high drainage density, stream frequency, texture ratio, lowest form factor, circulatory ratio and elongation ratio. The sub basins of 12, 19, 10 and 11 are associated with nearly level to level slopes, low drainage density, stream frequency, texture ratio and lowest form factor. The morphometric analysis at sub basin level revealed that a good interrelationship existed among the morphometric parameters and the terrain characteristics. The systematic analysis of linear, areal and relief quantitative morphometric parameters in GIS will be of immense utility in river basin evaluation, understanding the soil resources distribution, watersheds prioritization, sediment load estimation and natural resources assessment, planning and management at river basin level.

Introduction

The quantitative morphometric analysis of river basins is carried out to understand the relationships among the different aspects of the drainage parameters and resources distribution. Such parameters have been studied earlier using conventional methods (Strahler, 1957 and 1964, Morisawa, 1959, Leopold and Miller, 1956, Krishnamurthy et. al., 1996). Evaluation of the morphometric parameters necessitates preparation of a drainage map, ordering of the various streams, measurement of the catchment area, length and perimeter of drainage channels, drainage density, drainage frequency, bifurcation ratio, texture ratio and circulatory ratio (Kumar et al., 2000). Quantitative description of the basin morphometry requires measurement of linear and areal features, gradient of channel network and contributing ground slopes of the drainage basin. Drainage basins, as either single units or group of basins, comprise a distinct morphologic region and have special relevance to geomorphology (Doornkamp and Cuchlaine, 1971). The development of drainage pattern depends on the slope, bedrock lithology and associated geological structures. GIS techniques are being effectively used in recent times in determining the quantitative description of the basin geometry ie., morphometric analysis. GIS provides an excellent means of storing, retrieving, manipulating and analysing geo-referenced drainage information. It also provides a powerful mechanism not only to upgrade and monitor morphometric parameters but also permits the analysis of drainage information in association with other resources and environmental parameters (Jain et al.,1995). In the present study, an attempt has been made to evaluate linear, areal and shape morphometric parameters and their inter-relationships using GIS tools.

Study Area

The study area is situated between 20°45' 18" to 21°13' North latitudes and 78°42' to 79°08' 44" East longitudes and is located in western part of Nagpur district, Maharashtra with an area of about 1152.91 sqkm. The elevation of the basin is ranges from 240 m to 520 m above msl.

Methodology

The Vena river basin of Nagpur district was delineated based on water divide line concept. Drainage network of the basin was digitized as available on toposheets (1:50,000) and some of the first order steams were updated from satellite data. Few of the drainage lines were extended through water bodies with the help of collateral data to facilitate the measurement of different drainage parameters. The basin was divided into 19 sub basins and morphometric analysis was carried out at sub basin level in SPANS GIS system. Some area has been left out in the process of delineation of sub basins and was considered as unclassified area. Based on the drainage order, the drainage channels were classified into first to sixth order streams (Strahler, 1964). One of the first attributes to be quantified was the hierarchy of stream segments according to an ordering classification system. In this system, channel segments were ordered numerically as order number 1 from a stream's headwaters to a point down stream. The stream segment that results from the joining of two 1st order streams was assigned order 2. Two 2nd order streams formed a 3rd order stream, and so on. The sub basin area, perimeter and cumulative length of streams were calculated in GIS and expressed as A, P and L respectively. The parameters computed include basin length, ruggedness number, drainage density, bifurcation ratio, stream frequency, texture ratio, form factor, circulatory ratio and elongation ratio. The linear, areal and relief parameters were computed mathematically to evaluate the characteristics and the pair-wise relationships of the different morphometric parameters. The analysis of inter-relationships helps in understanding the terrain characteristics, slope, landforms, soils, soil erosion and ground water potential for watershed planning and management.

morphometric analysis of river basins is carried out to understand the relationships among different aspects of drainage parameters and resources distribution

Results & Discussions

Slope

Majority of the area is under nearly level to level slopes (0-1%) in the unclassified area and in the sub basins of 10,11 and 12. The foot slopes of the upland areas and isolated places in the sub basins of 6,7,14 and 15 have very gentle slopes (1-3%). Gentle slopes (3-5%) are observed in undulating terrain and intermittent valley zones in almost all the sub basins except the10th sub basin. Moderate slope areas (5-10%) lower parts of all the sub basins except 9 and 10 sub basins. Majority of the strong slopes (10-15%) are found in the sub basins of 1,2,4,8,15,17 and 18 in the western, north-western and south-eastern parts of the study area. Steep slopes (15-30%) are found in the sub basins of 1,2,4,8,15,17 and 18. Steep slopes are characterized with high drainage density and high stream frequency. Very steep slopes (>30%) are mainly spread in the upper parts of 1,2,4,8,15,17 and 18 sub basins.

Lithology

The development of drainage pattern depends on the bedrock lithology and geological structures of the area. Lithologically, the study area is covered by basaltic lava flows of Lower Eocene to Upper Cretaceous, commonly known as "Traps". The terrain consist of sub-rounded to rounded, discodal, tabular rock fragments ranging from small pebbles to cobbles of dark grayish black basalt in an uncomposed matrix of coarse to fine sand, silt and clay. Sand stone formations are found in isolated pockets in the north-western part of the study area. The younger alluvium overlaid on the parent material basalt represents flood plain deposits along the channel courses and low land areas.

Characteristics of linear, areal and relief morphometric parameters

Linear parameters

Stream orders

Stream order analysis based on Strahler's method shows that the main basin is of sixth order. However, the sub basins of 7, 10 and 19 are classified as third order basins where as the 2, 5, 15 and 16 sub basins are classified as fifth order basins (Fig.1). The ratio between the total number of first order streams and area of the basin reveals that the sub basins of 1 and 2 have highest and the sub basin 19 is having lowest number of first order streams. The highest number of first order streams in smaller area shows the terrain complexity and compact bedrock lithology.

Cumulative lengths of Stream

Number of streams in each order was calculated and total length of each order was computed at sub basin level. In addition, the cumulative lengths of all stream orders were calculated at sub basin level. The analysis shows that the sub basins 15 and 16 have highest cumulative length of streams where as the sub basins 7 and 10 have lowest cumulative length of streams and are attributed to the relief and lithology besides the area of the basin.

Bifurcation Ratio (Rb)

The term bifurcation ratio (Rb) 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 (Rb= Nu/Nu+1). Where Nu is total number of streams in Nth order and Nu+1 is the total number of streams in the next higher order. The lower Rb values (first to second order streams) in the sub basins of 6,10 and 12 are the characteristics of less structural disturbances and hence the drainage pattern has not been distorted (Strahler, 1964). Where as higher Rb in the sub basins of 2,8 and 9 indicate high structural complexity and low permeability of the terrain.

Relief parameters

Basin relief (Bh)

Relief aspects of the sub basins play an important role in drainage development, surface and subsurface water flow, permeability, landforms development and associated features of the terrain. Bh value is the maximum vertical distance between the lowest and the highest points of a sub basin. The analysis reveals that the sub basins 1,2,4,5,13 and 15 are having the relief more than 150 m. The high Bh value indicates the high gravity of water flow, low infiltration and high runoff conditions of the sub basins.

Ruggedness number (Rn)

Ruggedness number (Rn) is defined as the product of the basin relief and its drainage density. It indicates the structural complexity of the terrain in association with relief and drainage density. The analysis shows that in the sub basins 1 and 2 the Rn is more than 0.5 and it is less than 0.10 in the sub basins of 10,11 and 19. The basins having high Rn value are susceptible to soil erosion and sedimentation load.

Areal parameters

Drainage Density (Dd)

Drainage density is a measure of the length of stream channel per unit area of drainage basin (Dd= L/A). Low Dd exists in 9,11 and 19 sub basins having high permeable sub soil material under dense vegetation cover and low relief. In contrast, high drainage density is found in 1, 2 and 17 sub basins due to the presence of impermeable sub surface material and high relief. The measurement of drainage density provides a numerical measurement of landscape dissection and runoff potential.

Stream Frequency (Fu)

Stream frequency (Fu) is expressed as the ratio between the total number of streams and area of the basin (Fu= N/A). Low value of Fu exists in 7, 9 and 19 sub basins, shows high permeable lithology and low relief of the basins. Whereas high value of Fu is noticed in 1 and 2 sub basins, which is resultant of high relief, impermeable sub surface material and low infiltration capacity of the basins.

Texture Ratio (T)

The texture ratio (T) is expressed as the ratio between the first order streams and perimeter of the basin (T=N1/P) and it depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. Highest T values are found in the sub basins of 16 and 2, whereas the lowest T values found in the sub basins of 7, 12 and 19 respectively. The basins having high T value indicates the low infiltration capacity and high runoff conditions.

Form factor (Rf)

The form factor (Rf) is expressed as the ratio between the basin area and square root of the basin length (Rf= A/ (Lb)2). Basins having low Rf have less side flow for shorter duration and high main flow for longer duration and vice versa. The low Rf is found in 1 and 2 sub basins, which have less side flow for shorter duration and high main flow for longer duration. High Rf exists in 9 and 11 sub basins having high side flow for longer duration and low main flow for shorter duration causes high peak flows for a shorter duration.

Circulatory Ratio (Rc)

Circulating ratio (Rc) is the ratio between the area of the basin and the area of the circle having the same perimeter as that of the basin (Rc= 4 P A/P2). Rc values approaching 1 indicates that the basin shapes are like circular as a result it gets scope for uniform infiltration, it takes long time to reach excess water at basin outlet, which is further subjected to lithology, slope and land cover. The sub basins of 9 and 11 are having highest Rc value of 0.80 and 0.81 respectively and support the above concept.

Elongation Ratio (Re)

Elongation ratio is the ratio between the diameter of the circle having the same area (as that of basin) and the maximum length of the basin {(Re= (2/Lb)* A/Ö A/P)}. The higher Re values indicate high infiltration capacity and low runoff conditions. The sub basins of 9 and 11 are characterized by high Re and 1 and 2 sub basins have low Re values.

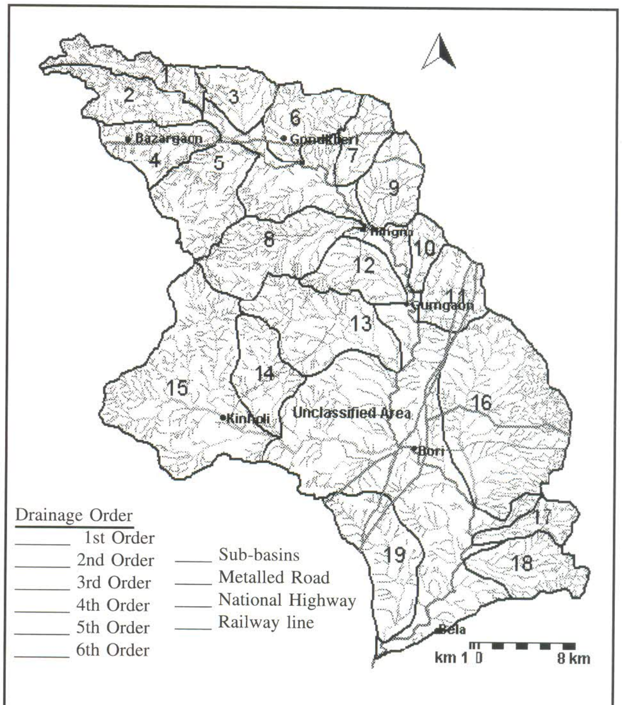

Fig 1. Stream Orders

Constant Channel Maintenance (C)

The inverse of drainage density is expressed as the 'constant of channel maintenance' (C) and it is defined as the area of basin surface needed to sustain a unit length of stream channel (Schumm, 1956). The constant (C) is expressed as km2/km and it depend on the rock type, permeability, climatic regime, vegetation cover and relief as well as duration of erosion. The sub basins of 1 and 2 have low C values of 0.30 and 0.35 respectively. It indicates that these sub basins are under the influence of high structural disturbance, low permeability, steep to very steep slopes and high surface runoff. The sub basins of 7 and 9 have highest C values of 0.57 and 0.62 respectively and are under very less structural disturbances and very less runoff.

Inter-relationship among linear, shape and relief parameters

Total number of streams (N) vs Cumulative length of streams (L)

The total number of streams and cumulative length of streams at sub basin level reveals that in some sub basins (1,2,4,5,15,16,17 and 18) the N exceeds over the L, which indicates low permeability, structural disturbances and high ruggedness number (Fig.2a). These sub-basins have more number of 1st and 2nd order streams indicating low infiltration rate and existence of shallow soils under excessive drainage. In the sub-basins of 6,7,8,9,13 and 19 the L is more than the N, which shows that these sub basins are favourable for longer flow and good infiltration.

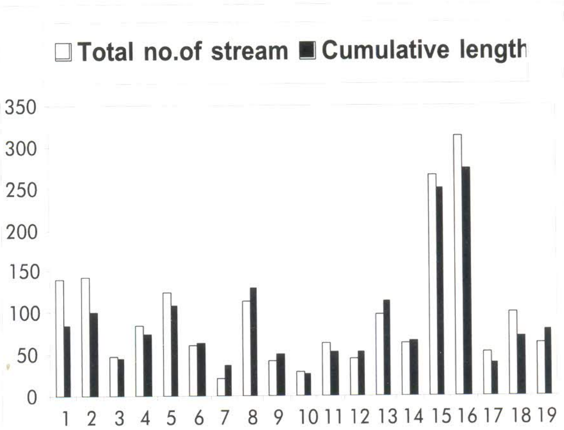

Fig. 2a

Cumulative length of streams (L) vs Drainage density (Dd)

Analysis of cumulative length of streams and drainage density of the sub basins reveals that higher L and Dd (basins 1,2 and17) indicates more number of drainage lines in a smaller area (Fig. 2b). These sub basins are having low permeability, high resistance under sparse vegetation with high ruggedness number. The lower L and Dd conditions (basins 9,13 and 19) are favorable

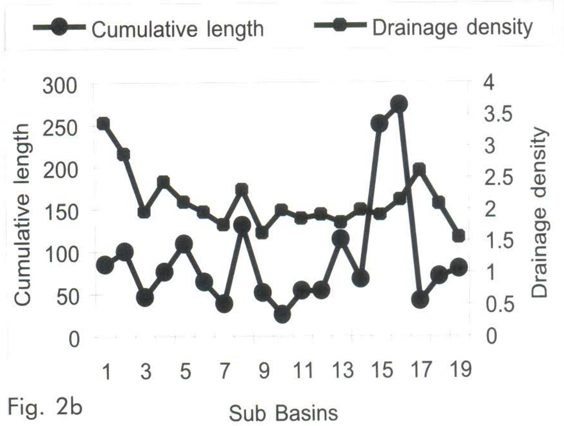

Fig. 2b

factors for high infiltration and low surface runoff and the development of moderate deep soils.

Cumulative Length of streams (L) vs Form factor (Rf)

High Rf with relatively low L values in the sub basins of 9 and 11 indicate that the total volume of water is running into few channels in a shorter duration (Fig.2c). Since, these sub-basins are under nearly level to level slopes that lead to development of deep soils, low soil erosion and sedimentation load shows favourability of alluvial deposits in the low land areas. Conversely, the sub basins 1 and 2 have low Rf and relatively high L values indicating longer duration of high volume of surface water flow. Thus unfavourable for high infiltration and the development of deep soils.

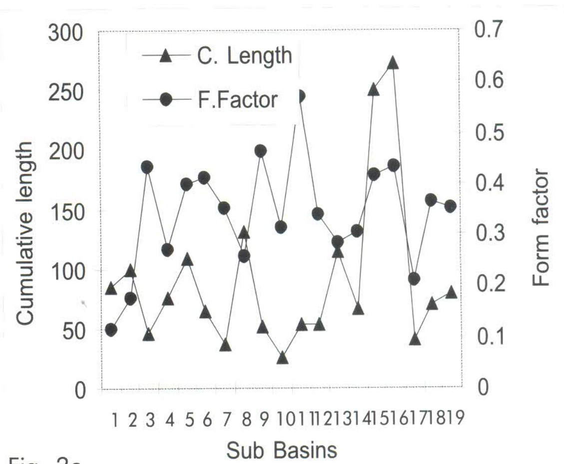

Fig. 2c

Form factor (Rf) vs Circulatory Ratio (Rc)

The analysis of form factors and circulatory ratio of the sub basins shows that Rc values are exponentially increasing with Rf with high positive correlation (R=0.933) (Fig.2d). It indicates that the basin shapes tend to be circular, as a result took more time for water flow from lower to higher order streams. This slow runoff is favourable for physical and chemical weathering processes. The high Rf and Rc values in the sub basin 11 are favourable for deep to very deep soils.

The low Rf and low Rc values are found in the sub basins of 1 and 2 and have the existence of impermeable lithology, steep slopes, longer water flow only along the main channel.

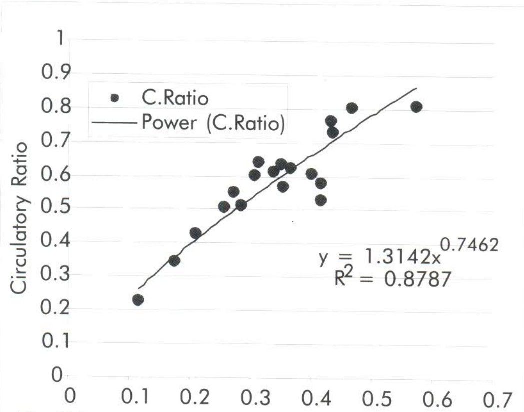

Fig 2d

Stream frequency (Fu) vs Constant channel maintenance (C)

The correlation between stream frequency and constant channel maintenance reveals that good negative exponential correlation exists showing R value - 0.911. The analysis shows that the sub basins having high value of Fu are in association with low value of C (Fig. 2e). The lower Fu value is characteristic of the sub basins, which have suffered less structural disturbances where the drainage pattern has not been distorted due to the structural disturbances (Strahler, 1964). Low values of C indicate high structural complexity and low permeability of the terrain. The high Fu and low C values in the sub basins of 1,2 and 17 are associated with less infiltration capacity, high ruggedness number and high runoff. Conversely the low Fu and high C value are found in the sub basin of 19 and indicates the favourability for the development of deep soils, because of longer duration of surface water flow and high infiltration capacity.

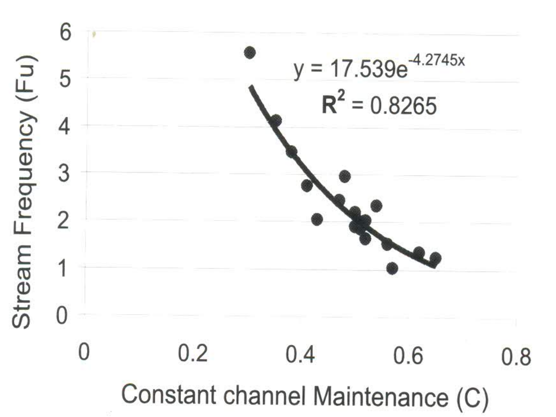

Fig 2e

Drainage density (Dd) vs Constant channel maintenance (C)

The exponential negative correlation (R= -0.989) between drainage density and constant channel maintenance reveals that the basins having high Dd values have low C values (Fig. 2f). The sub basins of 1 and 2 have high Dd value of 3.36 and 2.88 and low C value of 0.30 and 0.35 respectively. These sub basins are found mainly under the influence of high structural disturbance, low permeability, steep to very steep slopes and high surface runoff. The sub basins of 9 and 19 are having highest values of C ie., 0.62 and 0.65 with low Dd of 1.62 and 1.55 respectively. These three sub basins are subjected to very less structural disturbances and very low runoff.

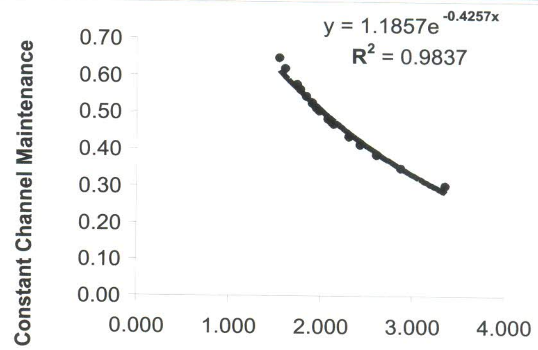

Fig 2f

Conclusions

The study reveals that GIS facilitates in evaluation and computation of various morphometric parameters. The evaluated morphometric parameters and their relationships help in understanding the role of each parameter in resources analysis. The inter-relationship among the basin morphometric parameters shows the terrain bedrock lithology, infiltration capacity, surface runoff, sedimentation load and the development of soil resources. The quantitative analysis of morphometric parameters ie., linear, areal and relief will be of immense utility in river basin evaluation, watersheds prioritization for soil and water conservation and natural resources management at micro level. These results are in agreement with the values obtained in similar terrain conditions (Subramanian and Subramanyan, 1978). Similar studies in conjunction with high resolution satellite data in different geological and climatic conditions help in better understanding of the status of landforms and their processes, soils, soil erosion, drainage management and evaluation of groundwater potential conditions for watershed planning and management.

Acknowledgement
The authors are thankful to Mr. Sunil Meshram for his assistance and mapping and Mrs. Rohini Watekar for word processing.