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# Morphometric Analysis of Drainage Basin through GIS: A Case Study from South Western part of Rangareddy District, Telangana State, India

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**ABSTRACT**

*In this study an attempt has been made to understand the morphometric characteristics of the Pargi river basin with an aim to compute the detailed morpho tectonic parameters and their bearing on the hydrogeological condition of the region. The analysis revealed that the drainage basin is characterized by dendritic to subdendritic drainage pattern. The development of stream segments in the basin area is more or less affected by rainfall. The total number as well as total length of stream segments is maximum in first order streams and decreases as the stream order increases. The bifurcation ratio (Rb) between different successive orders is almost constant revealing the partial structural control. The stream frequency (Sf) value of 2.99 exhibits positive correlation with the drainage density value of 2.17. The drainage density (Dd) indicates clearly that the region has permeable subsoil and relatively dense vegetation cover. Calculated Circularity Ratio (Rc) value of 0.44 and Elongation Ratio (Re) value of 0.20 indicates that the drainage basin is elongated in shape, has low discharge of runoff and relatively permeable subsoil condition. The value of Form Factor (Rf) 0.40, represents a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin. Hence from the study it is clear that the morphometric analysis based on GIS technique is very useful to understand the prevailing geo-hydrological characteristics and for watershed planning and management.*

***Key Words:*** ***Areal parameters, drainage basin, drainage morphometry, GIS and linear parameters.***

## I. INTRODUCTION

In countries like India, where the population pressure is continuously increasing land and water resources are limited and their wide utilization is imperative. Drainage basins, catchments and sub-catchments are the fundamental units for administrative purposes to conserve natural resources. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms [1];

[2]; [3]. The morphometric analysis is done successfully through measurement of linear, aerial, relief, gradient of channel network and contributing ground slope of the basin [4]; [5]; [6].

Drainage basin morphology reflects various geological and geomorphological processes over time is a widely acknowledged principle of morphometry, as indicated by various morphometric studies [7]; [8], [9]; [10]; [11]; [12]; [13]; [14]; [15]; [16]; [17]; [18]). It is well established that the influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics. The remote sensing technique is the effective method for morphometric analysis as the satellite images provide a synoptic view of a large extent and is very useful in the analysis of drainage basin morphometry. The fast emerging spatial information technology, remote sensing, GIS, and GPS have effective tools to overcome most of the problems of land and water resources planning and management rather than conventional methods of data process [19]. The present study aims at using the remote sensing and GIS technology to compute various parameters of morphometric characteristics of the study area, a tributary of the river Krishna.

## II. STUDY AREA

The study area is located in South-Western part of the Rangareddy district at a distance of 90 Kms from Hyderabad, covering an area of 381 km$^2$. Exists between 17$^o$ 05' to 17 $^o$ 28' North latitudes and 77$^o$ 76 ' to 77$^o$ 99 ' East longitudes and falls in the Survey of India Toposheet no. 56G/16 and 56F/16 (Fig.1). Average annual rainfall is about 833 mm. The minimum and maximum temperatures range from 15.1 to 40.9°C [20].

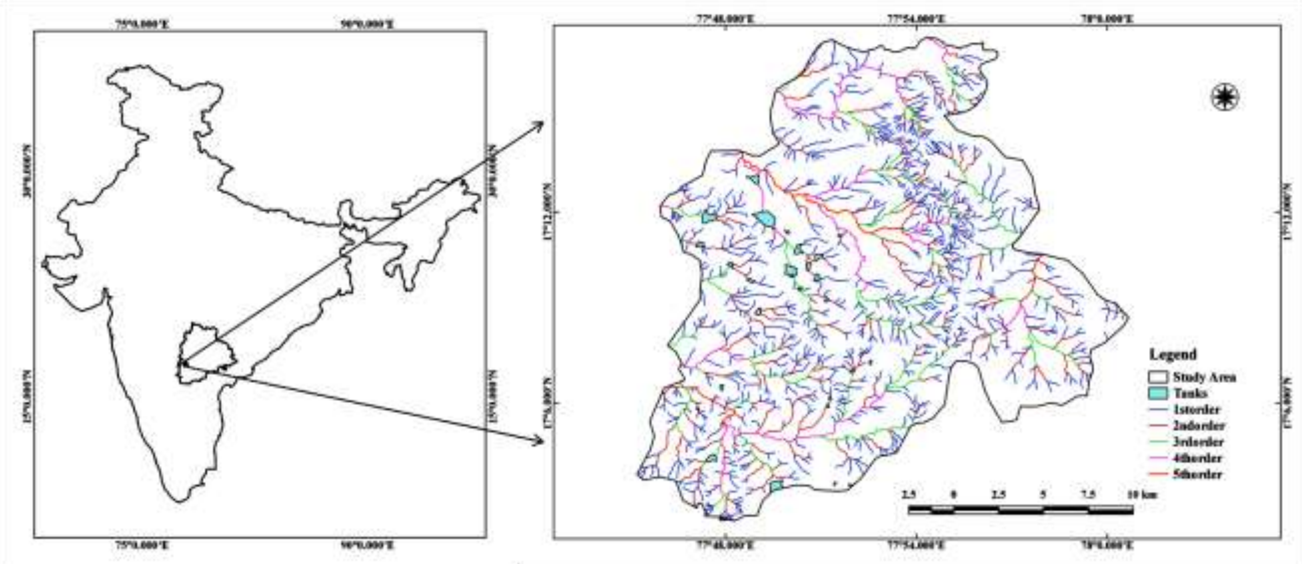


Fig.1. Location map of the study area

### 2.1.Geology of the area

The study area is characterized by a diverse geological record ranging in age from Pre-Cambrian to Recent. The Archaean crystalline rocks occupy major part of the study area comprising older metamorphic rocks, peninsular gneissic complex (PGC) and younger intrusive rocks. Intrusive of dolerite dyke are visible in the SSW part of the study area. The basaltic flows of the Deccan Traps cover the granitites in the NE and a part in NW part (Fig.2).

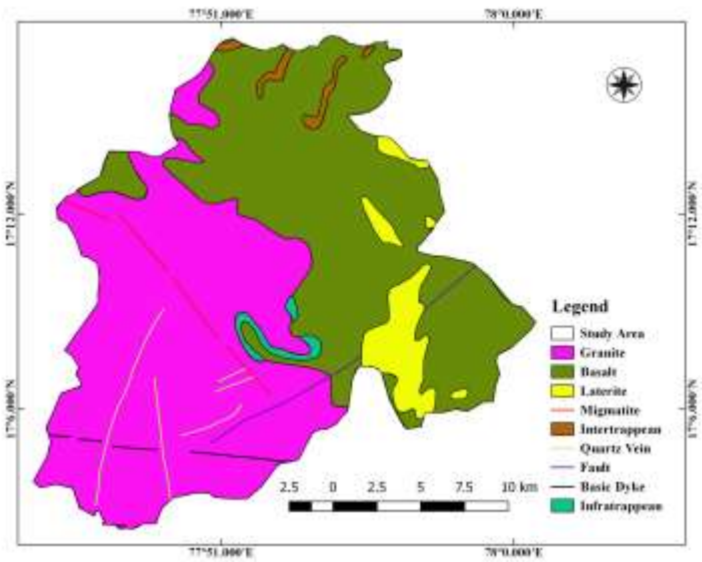


Fig.2. Geological map of the study area [21]

## III. METHODOLOGY

The study area is delineated from rectified, mosaiced SOI topographic maps with no. 56G/16 and 56F/16 on the scale 1:50,000 with the help of GIS software. Morphometric analysis of a drainage system requires the delineation of all the existing streams. Digitization of the drainage basin was carried out for morphometric analysis in GIS environment. The attributes were assigned to create the digital data base for drainage layer of the river basin. To evaluate the drainage basin morphometry, various parameters like stream number, stream order, stream length, stream length ratio, bifurcation ratio, basin length, basin area, relief ratio, elongation ratio, drainage density, stream frequency, form factor and circulatory ratio, etc., have been analysed using the standard mathematical formulae given in Table 1.

Table 1. Morphometric parameters with formulae

| S. No. | Parameters | Formula | Reference |
|---|---|---|---|
| 1 | Stream Order (Sμ) | Hierarchical rank | [9] |
| 2 | Stream Length (Lμ) | Length of the stream | [7] |
| 3 | Mean Stream Length (Lsm) | Lsm = Lμ/Nμ | [9] |
| 4 | Stream Length Ratio (RL) | RL= Lsm / Lsm-1 | [7] |

| | | | |
|---|---|---|---|
| 5 | Bifurcation Ration (Rb) | Rb = Nµ / Nµ +1 | [22] |
| 6 | Mean Bifurcation Ratio (Rbm) | Rbm = Average of bifurcation ratios of all orders | [9] |
| 7 | Drainage Density (Dd) | Dd = Lµ/A | [23] |
| 8 | Drainage texture (Dt) | Dt = Nµ /P Where, Nµ = No. of streams in a given order and P = Perimeter (Kms) | [24] & [7] |
| 9 | Stream Frequency (Fs) | Fs = Nµ/A | [7] |
| 10 | Elongation ratio (Re) | Re= √A /π / Lb Where, A= Area of the Basin (Km2) Lb=Maximum Basin length (Km) | [22] |
| 11 | Circularity Ratio (Rc) | Rc = 4πA/ $P^2$ Where, A = Basin Area ($Km^2$) and P= Perimeter of the basin (Km) Or Rc = A/ Ac Where, A = Basin Area ($Km^2$) and Ac = area of a circle having the same perimeter as the basin | [25] |
| 12 | Form Factor Ratio (Rf) | Rf = A/$Lb^2$ Where, A = Area of the basin and Lb = (Maximum) basin length | [23] |
| 13 | Length of Overland Flow (Lg) | Lg=(1/D)*2 Km Where, D=Drainage density (Km/Km2) | [7] |
| 14 | Relief (R) | R = H - h | [26] |
| 15 | Relief ratio (Rr) | Rr = R/L | [27] |

## IV. RESULTS AND DISCUSSION

The morphometric parameters of Pargi stream have been calculated and the results are given in the Table 2. The total drainage area of the study area basin is 381 $km^2$. The drainage pattern is dendritic in nature and it is influenced by the general topography, geology and rainfall condition of the area. Based on the stream order, the watershed basin is classified as fifth-order basin to interpret the morphodynamic parameters as listed in Table 1 ([23], [7]; [24]; [22], [27]; [26]; [9]; [28]; [29]).

Table 2. Linear Morphometric Parameters of the Drainage Basin

| Stream Order | No. of Streams | Stream Length (Lµ) (km) | Mean Stream Length (Lsm) (km) | Cumulative Mean Stream Length (Lsm) | Stream Length Ratio ($R_L$) | Stream frequnecy (Sf) (Sq.km) | Drainage Density (Dd) (Sq.km) | Bifurcation Ratio (Rb) | Mean Bifurcation Ratio (Rbm) | Drainage Area (Sq.km) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 864 | 452.54 | 0.52 | 0.52 | 1.71 | 2.27 | 1.19 | 4.11 | 4.15 | 381 |
| 2 | 210 | 188.58 | 0.90 | 1.42 | 2.48 | 0.55 | 0.49 | 4.5 | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 47 | 104.74 | 2.23 | 3.65 | 1.96 | 0.12 | 0.27 | 3.4 | |
| 4 | 14 | 61.06 | 4.36 | 8.01 | 1.55 | 0.04 | 0.16 | 4.7 | |
| 5 | 3 | 20.32 | 6.77 | 14.78 | | 0.01 | 0.05 | - | |
| | 1138 | 827.2 | | | | 2.99 | 2.17 | | 381 |

Table 3. Other Linear Morphometric Parameters of the Drainage Basin

| S .No. | Parameter | Calculated Value |
|---|---|---|
| 1 | Length of Overland Flow (Lg) | 0.92 km |
| 2 | Basin Perimeter (P) | 104.38 km |
| 3 | Basin Length (Lb) | 21.15 km |

Table 4. Areal Morphometric Parameters of the drainage network of the Drainage Basin

| S .No. | Parameter | Calculated Value |
|---|---|---|
| 1 | Drainage Texture (Dt) | 10.90-0.03 |
| 2 | Form Factor Ratio (Rf) | 0.85 |
| 3 | Elongation Ratio (Re) | 0.29 |
| 4 | Circularity Ratio (Rc) | 0.44 |
| 5 | Relief Ratio (Rr) | 8.13 |

### 4.1. Linear Morphometric Parameters

Linear aspects of the basins are related to the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system are analyzed. The morphometric investigation of the linear parameters of the basins includes stream order (Sμ), Stream number (Nμ), Stream Length (Lμ), Mean Stream Length (Lsm), Stream Length Ratio (RL), Bifurcation Ration (Rb), Mean Bifurcation Ratio (Rbm), Drainage Density (Dd), Drainage texture (Dt), Stream Frequency (Sf), Elongation ratio (Re), Circularity Ratio (Rc), Form Factor Ratio (Rf), Length of Overland Flow (Lg), Relief (R) and Relief ratio (Rr). Some of the important linear aspects have been computed as shown in (Table 2 and 3).

### 4.2. Stream order (Sμ)

Stream ordering is the first step of quantitative analysis of the watershed. In the present study, ranking of streams has been carried out based on the method proposed by [9]. The stream orders are classified up to fifth orders in the study area. Details of stream order of several tributaries of Krishna River and their sub-watershed area are shown in the (Fig. 1; Table 2). The maximum stream order frequency is observed in case of first-order streams and then for second order. Hence, it is noticed that there is a decrease in stream frequency as the stream order increases and vice versa.

### 4.3. Stream number (Nμ)

The total of order wise stream segments is known as stream number. As per [7] law of stream numbers of different orders and the total number of streams in the basin are counted and calculated in GIS platforms. During calculation it is identified that the number of streams gradually decreases as the stream order increases; the variation in stream order and size of tributary basins is largely depends on physiographical, geomorphological and geological condition of the region. 1138 stream lines were recognized in the whole basin, out of which 75.92 % (864) is $1^{st}$ order, 18.45 % (210) $2^{nd}$ order, 4.13 % (47) $3^{rd}$ order, 1.23 % (14) $4^{th}$ order and 0.26 % (3) comprises $5^{th}$ order stream (Table 2).

### 4.4. Stream length (Lμ)

In the present work, it was found that the stream segment lengths decreased with the increase in the stream order. It is evident that the result of order-wise stream length of the study area is shown in Table 2. The total stream length of the study area was 827.20 Km which includes 452.54 Km in 1st order, 188.58 Km in 2nd order, 104.74 Km in 3rd order, 61.06 in 4th order and 20.32 Km in 5th order respectively (Table 2). The Deviation may indicate flowing of streams from high altitude, variation in lithology or by high relief /moderately steep slopes [30].

### 4.5. Mean stream length (Lsm)

Mean stream length (Lsm) reveals the characteristic size of components of a drainage network and its contributing surfaces [9]. It has been computed by dividing the total stream length of order 'μ' by the number of stream segments in the order (Table 3). In the study area, it is noted that Lsm varies from 0.52 to 6.77 km (Table 2) and its value for any given order is greater than that of the lower order and less than that of its next higher order in the whole drainage basin. [9] indicated that the (Lsm) is a characteristic property related to the size of drainage network and its associated surfaces.

### 4.6. 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 having important relationship with surface flow and discharge and erosion stage of the basin [7]. It is noticed that the RL between successive stream orders of the basin vary due to differences in slope and topographic conditions [28]. The values of RL vary haphazardly from 1.55 to 2.48 (Table 2). Since the study area stream basin shows changes in RL from one order to another, this change might be attributed to variation in slope and topography, indicating the late youth stage of geomorphic development in the streams of the basin ([30]; [31]).

### 4.7. Bifurcation ratio (Rb)

Bifurcation ratio is related to the branching pattern of a drainage network and is defined as the ratio between the total numbers of stream segments of one order to that of the next higher order in a drainage basin [22]. It is a dimensionless property and shows only a small variation for different regions with different environments except where powerful geological control dominates (Strahler, 1964).Values of Rb typically range from the theoretical minimum of 3 to 5 for basins in which the geologic structures do not distort the drainage pattern [9]. The lower values of Rb are characteristics of the watersheds or drainage basins, which have suffered less structural disturbances and the drainage pattern has not been distorted because of the structural disturbances [9]; [5]. From the (Table 2), it is clear that the bifurcation ratio values of the study area drainage basin vary from 3.4 to 4.7 with the mean bifurcation ratio of 4.15. The highest Rb (4.7) is found between 4th and 5th order which indicates corresponding highest overland flow and discharge due to hilly less permeable rock formation associated with high slope configuration. The mean bifurcation ratio, which is the average of bifurcation ratios of all orders, is 4.15. This relatively lower value of mean bifurcation ratio suggests the geological heterogeneity, higher permeability and lesser structural control in the area.

### 4.8. Drainage density (Dd)

The drainage density is an expression of the closeness or spacing of channels [23]. The significance of drainage density is recognized as a factor determining the time travel by water [22]. The measurement of Dd is a useful numerical measure of landscape dissection and runoff potential [12]. On the one hand, the Dd is a result of interacting factors controlling the surface runoff; on the other hand, it is itself influencing the output of water and sediment from the drainage basin [32]. Dd is known to vary with climate and vegetation, soil, rock properties, relief and landscape evolution processes ([33]; [16]; [34]). The drainage density less than 2 indicates very coarse, between 2 and 4 as coarse, between 4 and 6 as moderate, between 6 and 8 as fine and greater than 8 as very fine drainage texture [35]. In the present study, it was found that the drainage density values 2.17 km/km$^2$ (Table 2) are variable and suggests that the study area falls into coarse texture category and indicates good permeability of sub-surface material in the study area except the first order streams and relatively dense vegetation cover and medium relief [36].

### 4.9. Drainage texture (Dt)

The drainage texture is considered as one of the important concept of geomorphology which shows the relative spacing of the drainage lines [12]. The drainage texture values are 8.28 (1st order streams), 2.01 (2nd order streams), 0.45 (3rd order streams), 0.13 (4th order streams) and 0.03 (5th order streams) (Table 4). Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture that in turn depends on the infiltration capacity of the mantle rock or bed rock [37].

### 4.10. Stream frequency (Sf)

Stream frequency (Sf) is the total number of stream segments of all orders per unit area [23]. [38] stated that low values of stream frequency Sf indicate presence of a permeable subsurface material and low relief. The channel segment numbers for unit areas are difficult to be enumerated [39], but an attempt has been made to count stream frequency in the study area of drainage basin. The stream frequency value of the basin is 2.99 km/ km$^2$ (Table 2).

### 4.11. Elongation ratio (Re)

Elongation ratio (Re) is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length [22]. It is a measure of the shape of the river basin and it depends on the climatic and geologic types. A circular basin is more efficient in runoff discharge than an elongated basin [30]. The value Re in the study area was found to be 0.29 (Table 4) indicating relatively moderate relief of the terrain and elongated shape of the drainage basin. Higher values of elongation ratio show high infiltration capacity and low runoff, whereas lower Re values which are characterized by high susceptibility to erosion and sediment load [38].

### 4.12. Circularity ratio (Rc)

Circularity ratio is the ratio of the area of the basins to the area of circle having the same circumference as the perimeter of the basin [25]. Rc as a significant ratio that indicates the dendritic stage of a watershed. This is mainly due to the diversity of slope and relief pattern of the basin. The circulator ratio is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. It is a significant ratio that indicates the dendritic stage of a watershed. Low, medium and high values of Rc indicate the young, mature, and old stages of the life cycle of the tributary watershed [40]. Rc value of the basin is 0.44 (Table 4) which indicate that the drainage basin is more or less elongated and is characterized by medium to low relief. Such drainage systems are partially controlled by the structural disturbances [41].

### 4.13. Form factor ratio (Rf)

Horton (1932) stated form factor as the ratio of the area of the basin and square of the basin length. The value of form factor would always be greater than 0.78 for perfectly circular basin. Smaller the value of form factor, more elongated will be the basin. The form factor value of the basin is low, 0.85 (Table 4) which represents elongated shape. The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin [42].

### 4.14. Length of overland flow (Lg)

Length of overland flow is defined as the length of flow path, projected to the horizontal, non channel flow from point on the drainage divide to a point on the adjacent stream channel [9]. Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density. Overland flow is significantly affected by infiltration (exfiltration) and percolation through the soil, both varying in time and space. In this study, the length of overland flow of the study area drainage basin is 1.09 kilometers (Table 3), which shows low surface runoff in the study area.

### 4.15. Relief (R)

Relief is the difference in elevation between any two reference points. Relief measure of a region indicates the potential energy of a drainage system. A region having a high relief can transfer high energy into the drainage system. Maximum relief within a region is naturally the difference in elevation between the highest and lowest points.

### 4.16. Relief ratio (Rr)

The difference in the elevation of the highest and lowest points in a watershed is its total relief, whereas the ratio of basin relief to basin length (horizontal distance along the longest dimension of the basin parallel to the principal drainage line) is Relief Ratio (Rh) [22]. It is used to measure the overall steepness of a river basin and is an indicator of intensity of erosion processes operating on the slopes of the basin. Normally, it has inverse correlation with drainage area and size of drainage basin. For the present study it obtains 8.13 shown in (Table 4).

## V. CONCLUSION

Morphometric analysis of drainage system is prerequisite to any hydrological study. Thus, determination of stream networks' behaviour and their interrelation with each other is of great importance in many water resources studies. The study reveals that GIS based approach in evaluation of drainage morphometric parameters at river basin level is more appropriate than the conventional methods. GIS based approach facilitates analysis of different morphometric parameters and to explore the relationship between the drainage morphometry and properties of landforms, soils and eroded lands. Based on the drainage orders the study area basin has been classified as fifth order basin. The mean Rb indicates that the drainage pattern is not much influenced by geological structures. Drainage density (Dd) and stream frequency (Fs) are the most useful criterion for the morphometric classification of drainage basins which certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. The Dd of the basin reveals that the nature of subsurface strata is permeable. This is a characteristic feature of coarse drainage as the density values are less than 5.0 reveals that the drainage areas of the basin are passing through an early mature stage of the fluvial geomorphic cycle. Lower order streams mostly dominate the basin. The development of stream segments in the basin area is more or less affected by rainfall. Rc, Rf and Re show the elongated shape of the basin have low discharge of runoff and medium relief of the terrain. It is noticed that stream segments up to 3rd order traverse parts of the high altitudinal zones, which are characterized by steep slopes, while the 4th and 5th order stream segments occur in comparatively flat lands wherein maximum infiltration of runoff occurs; these are important locations for constructing check dams. Hence from the study it is clear that GIS technique is a competent tool in morphometric analysis (for geo-hydrological studies). These studies are very useful for planning and drainage basin management.

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