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Drainage Basin Analysis through GIS: A Case study of Lakhnapur Reservoir Watershed in Rangareddy District, Telangana State, India.

Sreedhar Kuntamalla*
Sakram G**
Madhusudhan Nalla***
Praveen Raj Saxena****

Abstract

Water, land, and soil are limited natural resources and their extensive usage with increased populace is a major concern. To subdue the increasing demand of land and water resources, it is of prime important to conserve the natural resources for sustainable development. Morphometric analysis contributes a quantifiable description of drainage system which is a significant aspect of watershed delineation. This analysis was carried by using QGIS 2.14.1 (v) software on Survey of India topographic sheet of 1:50,000 scale was used for analysis. Drainage map and the Morphometric parameters such as linear, aerial and relief aspect of the watershed have been determined based on the formula suggested by Horton, Strahler. The analysis of linear aspects of drainage basin shows that the basin has a dendritic pattern with fifth order stream. Ratio of Bifurcation of basin was found to be (5.0 to 2.4) which falls under the range (2.0 and 5.0) in which the geologic structures do not alter the drainage pattern. Density of drainage, texture of drainage, ratio of elongation and ratio of relief value of Lakhnapur watershed was 2.46 Km/Km^2 and 7.72 confirms that the study area is underlain by impermeable subsurface material of Precambrian crystalline rocks having inadequate vegetation and high relief and steep slopes with very fine texture cause prone area of soil erosion risk in the area.

Keywords:

Drainage morphometry;
Drainage basin;
Areal parameters;
Linear parameters;and
GIS.

Author correspondence:

Sreedhar Kuntamalla,
Research Scholar, Department of Applied Geochemistry
University College of Science, Osmania University, Hyderabad, India- 500007.

1. Introduction

Morphometry is the mensuration and quantifiable analysis of the structure of the earth's surface, form and proportion of its landforms [1]-[3]. The morphometric analysis is done with success through measuring of linear, aerial, relief, gradient of channel network and tributary ground slope of the basin [4]; [5]; [6]; [7]; [8].

* Research Scholar, Dept. of Applied Geochemistry, University College of Science, Osmania University, Hyderabad
** Post Doctoral Fellow, Dept. of Applied Geochemistry, University College of Science, Osmania University, Hyderabad
*** Research Scholar, Dept. of Applied Geochemistry, University College of Science, Osmania University, Hyderabad
**** Professor, Dept. of Applied Geochemistry, University College of Science, Osmania University, Hyderabad, India.

The morphometric analysis of the rivlets, streamlets and channel network play a vital role in understanding the geo-hydrological behavior of drainage and expresses the changes in weather, topology, geomorphology, structural, etc., and origin of the small rivlets over time, as indicated by varied morphometric studies [9]; [10], [11]; [12]; [13]; [14], [15]; [16]; [17]; [18]; [19]; [20]; [21]; [22]; [23]; [24]; [25]; [26]; [27]; [28]; [7]; [8]; [29]; [30]. It is evident that morphometry is an important method in understanding the landform processes, soil properties and denudational characteristics. GIS-based assessment (SRTM) using Shuttle Radar Topographic Mission and (ASTER) Advanced Spaceborne Thermal Emission and Reflection Radiometer data has given a explicit, quick, and cost effective way for analysing hydrological systems [31]; [32]. The processed DEM (digital elevation model) was used with success to bring out the stream network and different supporting layers [33]; [34]. The purpose, of this research work was to evaluate the drainage morphometry, linear parameters, areal parameters to reduce the watershed related problems and delineation of the watershed topography using GIS tools for better treatment, land use/land cover and sustainable agricultural practices.

2. 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 99.97 km2. Exists between 17^{o} 05' to 17 ^{o} 28' North latitudes and 77^{o} 45 ' to 77^{o} 90 ' East longitudes and falls in the Survey of India Toposheet no. 56G/16 (Figure1). Average annual down pour is about 833 mm. The temperature range from 15.1 to 40.9°C, May is the hottest month, while temperatures range from 26 to 40.9 °C, December, the coldest, has temperatures vary from 14.5 to 28 °C.

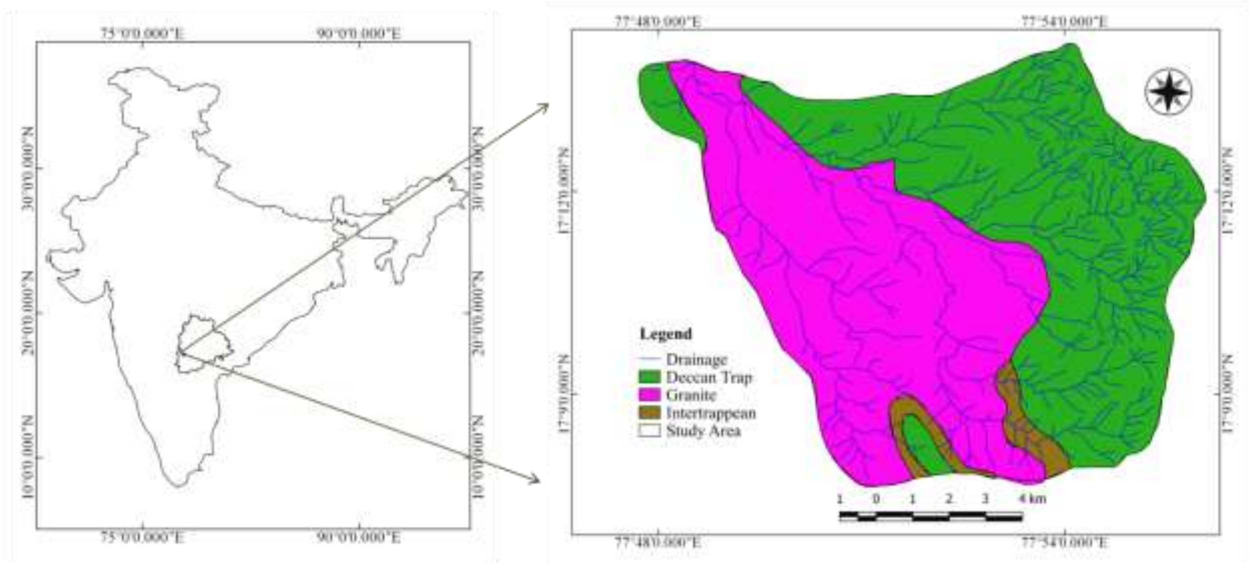

Figure1. Location and Geology map of the study area

2.1. Geology of the area

Geologically the area consists of Granites and Basalts a diverse geological record ranging in age from Pre-Cambrian to Recent. The Archaean crystalline rocks occupy half portion of the study area comprising older metamorphic rocks, peninsular gneissic complex (PGC) and younger intrusive rocks. Intrusive of dolerite dyke are visible in the Southern part and the basaltic flows of the Deccan Traps cover the granitites in the NE and a part in NW part of the area (Figure 1).

3. Methodology

The study area is delineated from rectified, SOI topographic map with no. 56G/16 on 1:50,000 scale with the help of QGIS (2.14.1v) software (Figure 2). Morphometric analysis of a watershed needs the drawing of all the present streams. Delineation of drainage network was done for morphometric analysis in QGIS environment. The attributes were chosen to make the digital information base for different layer creation. The identification of drainage morphometry for numerous parameters (quantitative relation) 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. was estimated using the standard mathematical formulae given in Table 1.

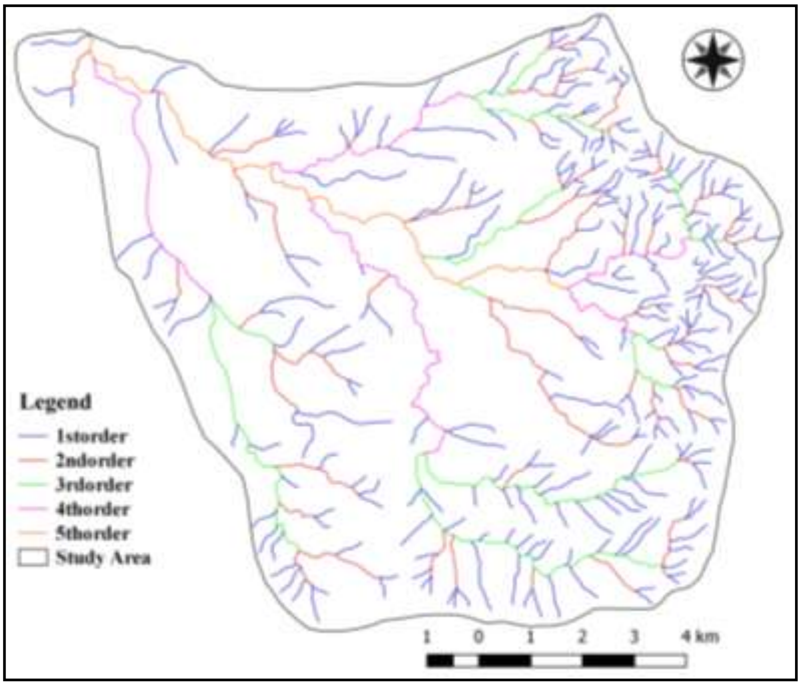

Figure 2. Order of the Stream map

Table 1. Parameters of Morphometry with formulae

S. No.	Parameters	Formula	Reference
1	Order of Stream (Sμ)	Hierarchical rank	[11]
2	Length of Stream (Lμ)	Stream Length	[9]
3	Average Length of Stream (Lsa)	Lsa = Lμ/Nμ	[11]
4	Ratio of Stream Length (RL)	RL= Lsm / Lsm-1	[9]
5	Ratio of Bifurcation (Rb)	Rb = Nμ / Nμ +1	[35]
6	Average Bifurcation Ratio (Rba)	Rbm = Average of bifurcation ratios of all orders	[11]
7	Density of Drainage (Dd)	Dd = Lμ/A	[36]
8	Texture of Drainage (Dt)	Dt = Nμ /P, Nμ = No. of streams in a given order and P = Perimeter (Kms)	[37]
9	Frequency of Stream (Fs)	Fs = Nμ/A	[9]
10	Ratio of Elongation (Re)	Re= √A /π / Lb, A= Area of the Basin (Km2) Lb=Maximum Basin length (Km)	[35]
11	Ratio of Circularity (Rc)	Rc = 4πA/ P^2, 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	[38]
12	Ratio of Form Factor (Rf)	Rf = A/Lb^2, A = Area of the basin and Lb = (Maximum) basin length	[36]
13	Overland Length of Flow (Lg)	Lg=(1/D)*2 Km, D=Drainage density (Km/Km2)	[9]
14	Relief (R)	R = H - h	[39]
15	Ratio of Relief (Rr)	Rr = R/L	[40]

4. Results and Discussion

The morphometric parameters of Pargi stream (the river Krishna tributary) are determined the results are presented in the Table 2. The total catchment of the drainage area basin is 99.97 km^2. The drainage arrangement is nerve fibre (dendritic) in nature, altered by the overall topography, geology and precipitation condition of the area. supported the stream order, the watershed basin is assessed as fifth-order basin to interpret the morphodynamic parameters listed in Table 1 in Table 1 [36], [9]; [37]; [35], [40]; [39]; [11]; [41]; [33].

Table 2. Linear Morphometric Parameters of the Drainage Basin

Stream Order	Number of Streams	Stream Length (Lμ) (km)	Mean Stream Length (Lsm) (km)	Cumulative Mean Stream Length (Lsm)	Stream Length Ratio (R_L)	Stream frequncy (Fs) (Sq.km)	Drainage Density (Dd) (Sq.km)	Bifurcation Ratio (Rb)	Mean Bifurcation Ratio (Rbm)	Water Shed Area (Sq.km)
1	255	132.63	0.52	0.52	1.59	2.55	1.33	4.55		
2	56	46.32	0.83	1.35	3.25	0.56	0.46	4.7		
3	12	32.25	2.69	4.03	1.65	0.12	0.32	2.4	4.16	99.97
4	5	22.15	4.43	8.46	2.73	0.05	0.22	5.0		
5	1	12.08	12.08	20.54		0.01	0.12	-		
Total	329	245.4								

Table 3. Drainage Basin Other Linear Morphometric Parameters

S .No.	Parameter	Calculated Value
1	Overland Flow Length (Lg)	0.81 km
2	Basin Perimeter (P)	42.60 km
3	Basin Length (Lb)	18.42 km

Table 4. Drainage Basin Areal Morphometric Parameters

S .No.	Parameter	Calculated Value
1	Texture of Drainage (Dt)	0.02-7.72
2	Ratio of Form Factor (Rf)	0.29
3	Ratio of Elongation (Re)	0.17
4	Ratio of Circularity (Rc)	0.69
5	Ratio of Relief (Rr)	7

4.1. Linear Morphometric Parameters

The delineation of linear morphometric parameters (quantitative relation) of the basin include Order of Stream (Sμ), Number of Stream (Nμ), Length of Stream (Lμ), Average Length of Stream (Lsm), Ratio of the Stream Length (RL), Ratio of Bifurcation (Rb), Mean Bifurcation Ratio (Rbm), Density of Drainage (Dd), Texture of Drainage (Dt), Frequency of Stream (Sf), Ratio of Elongation (Re), Ratio of circularity Ratio (Rc), Ratio of form factor (Rf), Overland Flow Length (Lg), Relief (R) and Ratio of Relief (Rr). A number of other vital linear aspects was computed as shown in (Table 2 and 3).

4.2. Order of Stream (Sµ)

Order of streams is the start of quantifiable analysis of the basin, ranking of streams was carried out with reference to the method proposed by [11]. The highest fifth order stream flowing, Details of order of streams interpreted in the study area was shown in (Fig. 2; Table 2). The most order of stream frequency is identified in first order streams and so for second order. Hence, it is observed that there is a decline in frequency of stream as the order of stream increases and vice versa.

4.3. Number of Stream (Nµ)

The order wise polyline of streams are known as stream number. As per [9] number of streams of various orders and the total stream number within the basin was considered and calculated in QGIS platform. However in calculation it is known that the amount of streams bit by bit decreases because the stream order increases; the variation in order of stream and size of stremlets basins is essentially depends on physiographical, geomorphological structural and geologic condition of the area. 424 stream lines were recognized within the whole basin, out of that 77.51 % of is first order, 17.02% is second order, 3.65% is third order, 1.52% is fourth order and 0.30 % includes fifth order stream (Table 2).

4.4. Length of Stream (Lµ)

In the present work, it was found that the lengths of the stream segment decrease with the increase in the order of stream. The total length of the stream was 245.40 Km which includes 132.63 Km, 46.32 Km, 32.25, 22.15 and 12.08 Km in first order, second order, third order, fourth order and fifth order respectively (Table 2). The variation in difference indicates change in lithology or by high relief /moderately steep escarpment streams flow from high elevation [42].

4.5. Average length of stream (Lsa)

Average length of stream (Lsa) reveals characteristic size of its contributing gradient and components of a streamlet network [11]. It is identified that Lsa varies from 0.52 to 12.08 km (Table 2) and its value for any given order is greater than that of the lower order and low than that of its next higher order in the whole basin area.

4.6. Ratio of Stream Length (RL)

The ratio of stream length can be defined as the ratio of the average length of the stream of a given order to the average length of the stream of next lower order [9]. It is observed that the RL between successive stream orders of the basin vary due to change in topographic condition and slope [41]. The values of RL vary distinctly from 1.59 to 2.73 (Table 2). Therefore RL from one order to another, attributed to variation in topography and slope, denote geomorphic development in the drainage basin in the late youth stage [42]; [43].

4.7. Ratio of Bifurcation (Rb)

Ratio of bifurcation is defined as the ratio between the total stream segments numbers of one order to that of the next higher order in a watershed [35]. It is a dimensionless property with small variation for different strata with different lithology except where dominant geological control arise [11]. From the (Table 2), it is clear that the bifurcation ratio values of the study area drainage basin vary from 2.4 to 5.0 with a mean Rb of 4.16. The highest Rb (5.0) is found between fourth and fifth order which indicates corresponding maximum overland flow and discharge due to ridge top low permeable rock formation associated with high escarpment regions. The mean bifurcation ratio, which is the average of bifurcation ratios of all orders, is 4.17. The lower value of mean bifurcation ratio suggests low structural control and high permeability in the geological environment.

4.8. Density of Drainage (Dd)

The density of drainage expressed as closeness or spacing between channels [36]. The importance of density of drainage is a factor contibuting to the water travel by time [35]. The measurement of (Dd) is a useful for morphometric measure of runoff potential and landscape dismemberment [16]. The Dd may be a results of interacting factors dominant the surface runoff; and influencing the output of water and sediment from the catchment area [44] and vary with topography, fauna, pedo, petra characteristics, relief and terrain transformation processes [45]; [20]; [46]. If the (Dd) less than two indicates very coarse, between two and four as coarse, between four and six as moderate, between six and eight as fine and greater than eight as very fine texture of drainage[47]. In the present study, (Dd) was identified as 2.46 km/km^2

(Table 2) are variable and advise that the basin area falls into coarse texture class and indicates erosion of sub-surface material except the first order streams and relatively thick flora growth and medium relief [48].

4.9. Texture of Drainage (Dt)

The drainage texture is considered as one of the important concept of geomorphology which shows the relative spacing of the drainage lines [16]. The drainage texture values are 5.99 (1st order streams), 1.31 (2nd order streams), 0.28 (3rd order streams), 0.12 (4th order streams) and 0.02 (5th order streams) (Table 4). Low density of drainage leads to coarse texture of outflow while high drainage density leads to fine texture of drainage that in turn depends on the infiltration capacity of the mantle rock or bed rock [49]. The (Dt) is a vital concept of geomorphology that shows the relative spacing of the catchment orders [16]. The observed (Dt) values are 5.99, 1.31, 0.28, 0.12 and 0.02 respectively for first, second, third, fourth and fifth order streams respectively (Table 4). Low (Dd) results in coarse texture of drainage whereas high (Dd) results in fine texture of drainage that aside depends on the infiltration capability of the subsurface strata or bed rock [49].

4.10. Frequency of Stream (Sf)

Frequency of Stream is that the total count of stream segments of all orders per unit space [36]. [50] Declared that low values of stream frequency indicate presence of a porus underground material and relief. The catchment numbers for unit areas are typical to be enumerated [51], however a trial has been created to count stream frequency within the basin area. The stream frequency of the basin look upto 3.29 km/ km^2 (Table 2).

4.11. Ratio of Elongation (Re)

Ratio of elongation is defined as the quantitative relation of diameter of a circle having an equivalent space as of the basin and most basin length [35], (Re) is a form of the basin and it depends on the climatic conditions and rock type. A circular basin is more efficient in runoff discharge than enlarged basin [42]. Re was found to be 0.17 (Table 4) indicating comparatively moderate relief and elongated form of the drainage area. Higher values of ratio of elongation show high penetration capability and little runoff, whereas lower Re values that represent high condition to washing away and sediment load [50].

4.12. Ratio of Circularity (Rc)

It is especially involved with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. Rc categoriged on the basis of relief and slope, low, medium and high values indicate the young, mature, and old stages of the life cycle of the tributary watershed [52]. Rc was found to be 0.69 (Table 4) represent that more or less elongated and described as medium to low relief controlled by the structural disorder [53].

4.13. Ratio of form factor (Rf)

According to [36], Ratio of form factor defined as the ratio of basin area to square of the basin length, for a perfectly circular watershed form factor would always be less than 0.754, smaller the Rf more elongated will be the drainage basin, high form factors have high peak flows, the calculated Rf value was 0.29 (Table 4), indicate to be in elongated shape and flow for long period, flows of such elongated basins are easier to maintain than of the circular basin [54].

4.14. Overland flow Length (Lg)

[9] used the term to confer with the length of the run off of the precipitation water on the earth's surface before it is regional into definite channels, despite, the overland flow length in general, is about half the distance between the tributaries on an average, [9] roughly taken it to be equal to half the reciprocal of the density of drainage, therefore the (Lg) of the basin is 0.81 kms (Table 3), which shows conservative surface runoff of the study area.

4.15. Relief (R)

Relief is the difference in elevation between any two reference points. A region having a high relief can transfer high energy into the drainage system. Maximum relief among a region is commonly the distinction in elevation between the highest and lowest points.

4.16. Ratio of Relief (Rr)

Ratio of Relief is the difference within the elevation between the highest point of a ridge portion and the lowest point on the valley, natural depression floor is understood, whereas the ratio of basin relief to basin length (horizontal distance on the longest dimension of the basin parallel to the principal drainage line) [35]. In the present study (Rr) was found to be 7.0 (Table 4) mainly due to the subsurface basement rocks of the basin and moderate degree of slope.

5. Conclusion

The Morphometric investigation of Lakhnapur reservoir watershed using GIS found that this tool helps to analyze the drainage basins easily and accurately in short time duration. The exercise on linear aspects of lakhnapur basin result shows that, the basin drainage formed with dendritic pattern with fifth order stream. The values of catchment range within (2.4 & 5.0) with a mean value of 4.16; from the ratio of bifurcation in which the morphology structures do not alter the drainage pattern. Drainage of density and texture of drainage was found as 2.46 Km/Km2 and 7.72 confirms the recognition that the basin area is underlined by impermeable subsurface material of crystalline rocks of granites and gneisses having inadequate vegetation and hilly alleviation with very fine texture hence more risk of soil erosion. The investigation on ratio of elongation and relief ratio indicates that drainage basin in nature was elongated with high ridges and escarpments causes risk of erosion intensity maximum in the area. Therefore, from the research it can be decided that drainage analysis with GIS techniques, prove to be an efficient tool in the proper delineation of the morphometric analysis which will help in understanding the groundwater management and sustainable development of the watershed.

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