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Morphometric Analysis of Linear and Areal Aspects of the Puliyeru River Basin, Andhra Pradesh, India using Remote Sensing and GIS

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ABSTRACT

Understanding the hydrological structure of any terrain requires a quantitative investigation of the watershed. The current work uses Landsat 8 satellite data and Cartosat DEM 30m resolution data to quantify the Puliyeru River basin in Andhra Pradesh, India. Computations of linear and areal aspect, using conventional GIS methods, were used to evaluate watershed morphometric parameters. The Cartosat digital elevation model was used in an ArcGIS context for morphometric component analysis and river basin delineation (DEM). It was decided to focus on the Puliyeru River basin, which is comprised of branches of the Penna River. Approximately 834.18 km^2 of the basin's drainage area is characterized by a sub dendritic to dendritic pattern of drainage. The drainage density in the research region is 8.2 km/km^2 (the sixth order basin). Stream order, stream length, bifurcation ratio, drainage density and frequency, texture, form factor and elongation ratio were calculated within this basin and their hydrological consequences were addressed in detail. Using the database of morphometric characteristics, it is possible to pick the location of water-harvesting structures and flood-control measures in the basin based on scientific evidence. The information gleaned from this study might be used to future watershed categorization efforts.

***Key words*:** Remote sensing, Morphometric analysis, GIS, Dendritic drainage

The morphometric studies of the channel system and river basin has a noteworthy role in the comprehension of the geomorphology of the drainage basin. Morphometry is the estimation and scientific study of the setup of the Earth's surface, shape, and measurement of its territory structures [1-3]. From the most recent couple of decades in geomorphology physiographic techniques are produced for the depiction of surface drainage systems. Water, solutes, and silt are done by waterways from drainage territory to the ocean and this is very huge to geomorphologists, geologists, hydrologists, and even designers as water are a significant piece of society [4-5]. As per geologists and geomorphologists, the structure and shape of river and adjoining territories are changing persistently because of sedimentations and erosion which is the aftereffect of direct impact of transportation of water and silt. These changes can be as incline, shape, size, area of layer materials and so on. The main purposes of engineers to study such techniques are to evaluate the erosional processes, transportation and depositions of sediments by flow in the river [6-8]. The quantitative explanation of forms, in Geomorphology describes the accurate and objective measurements of different types of landforms. For example, the geometric properties of river and other basin are investigated by drainage & fluvial morphometry. Fluvial morphology is the study of science of landforms which are produced by different river actions and due to which it is also known as river morphology [9-14]. The geometry of the drainage basin and its system helps in the quantitative depictions of the waste system, investigating the effect of various variables like lithology, rainfall, rock structure, comparing different drainage networks. The morphometrics studies were carried out by different geomorphologists like Horton [15]. In the quantitative aspect of Geomorphology, different scholars describe the term morphometry as the estimation and scientific examination of the arrangement of the world's surface, the shape and measurements of its landforms. Thus morphometric investigation presents the quantitative parts of the geometry of the river basin to understand different types of imbalances in the rock hardness, the ongoing catastrophic and structural geomorphological and land infiltration history of the basin [16-20].

A branch of science which deals with landforms and their evolution through time is called geomorphology. In early times description of landforms was only geomorphology. The development of a drainage is influenced by several factors such as geology, climate, geomorphic structure, vegetation etc. of an

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area through which it flows. General geometry and geomorphometry are both subcategories of the word geomorphometry, which deals with analyzing the properties of individual landforms [21]. These quantitative qualities, which include relief, form, size, and textural properties, are generated from the elevation surface and drainage network within a drainage basin. Fundamentals of quantitative geomorphology include calculations of these attributes. Evaluation of morphometric parameters leads to discover the structural and lithological controls that innate in landscape, and help in understanding the tectonic history of the river basins [22].

In old times topographical maps were used for calculation of morphometric parameters of a drainage basin, but which is time consuming and has chances of encountering errors. DEMs have been constantly used for the analysis of morphometric parameters of river basins by extracting the topographic parameters and stream networks and the use of DEM have led to the advantages over traditional topographical maps. With the recent advancement in technology like RS and GIS, study of basin characteristics has become very popular and has been accepted worldwide. Cartosat DEM, SRTM DEM, ASTER – GDEM with powerful software like ArcGIS have been used by various researchers to generate morphometric parameters of the basin with great accuracy. The study has been carried out by using Cartosat DEM (23.5m) to analyse morphometric properties of drainage basin.

MATERIALS AND METHODS

For the present study Puliyeru river basin is selected in Andhra Pradesh, India having different physiographic areas. The Puliyeru river basin originate from Pattikonda hill area from Kurnool district and its merges in Penna River at Anantapur district in Andhra Pradesh.

Puliyeru River basin a sub tributary of Penna River originates from Anantapur district in Gooty. Puliyeru River is located between 77° 21’ 40 E to 77° 41’40 E longitudes and 14°55’ 50 N to 15°24’50 N latitudes covering an area of 834.18 km^2. The study area is included in the Survey of India (SOI) Toposheet No 57F/5, 57F/9, 57E/7, 57E/8, 57E/11 and 57E/12 at a scale of 1: 50,000. Physiography of the study area consists of mountains, ridges and hills forming gentle rolling topography. Alluvial plains are along the river courses where mainly alluvial deposits are found. The area has undulating topography and meandering streams.

In the months of monsoon (June to September) the area receives annual normal rainfall accounting 87% or 650 mm of annual precipitation. July is the wettest month. During pre-monsoon months (April and May) the rainfall is received in the form of thunderstorms. The western part of study area experiences moderately heavy rainfall which decreases rapidly in the east side. Temperature of the area range from 20 to 42°C. The climate of the study area is classified as Semi-arid and Mega thermal on the basis of Moisture Index and Potential Evapotranspiration (P.E.T) method.

Villages in the study area are well connected by metaled and unmetalled roads. Gooty, Pamidi and Pattikonda are the major townships located in the study area. The major part of the located in Anantapur District and some minor located in Kurnool District.

For the 1:50,000-scale morphometric examination of the Puliyeru River basin, the SOI topographical maps 57F/5, 5/7, 5/8, 5/11 and 5/12 were used. Analyzed are factors such as the order of the stream and its length, as well as the length-to-elongation ratio, circulation ratio, drainage density, drainage texture, and stream-to-stream bifurcation ratio. According to Horton [15] and Strahler [23], the basin's drainage system was analyzed. In ArcGIS desktop 10.8, the WGS-84 datum and UTM zone 44N projection were used to geo reference the SOI topographic maps.

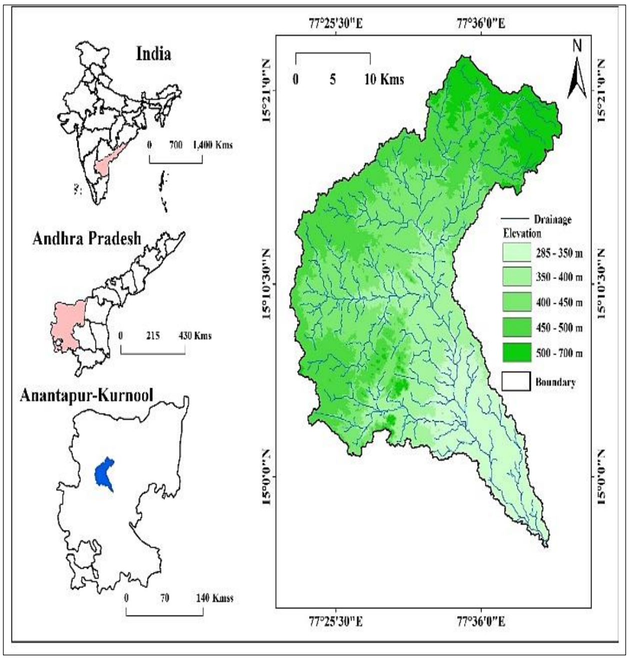

Fig 1 Location map of the Puliyeru River Basin, Andhra Pradesh, India

Data from multispectral satellites, the Cartosat DEM (Digital Elevation Model), and the SOI topographical sheets were used to create a database and extract several drainage characteristics in this study [24]. (Table 1) provides a breakdown of the data utilized in the study. As part of the research process, a global positioning system (GPS) measures the area's elevation and other properties. Cartosat DEM and SOI toposheets were used in this research to identify the Puliyeru River basin and its drainage network. A repair DEM and sink filling are also included in the package. A drainage network was created by calculating the flow direction for each pixel once the DEM was completed. The flow accumulation was taken into consideration, based on the flow direction of each cell [25]. Morphometric characteristics were analyzed and divided into three groups based on their spatial orientation. Methodology is given in (Fig 1) and includes linear and areal aspects, which are determined using formulae provided in (Table 2).

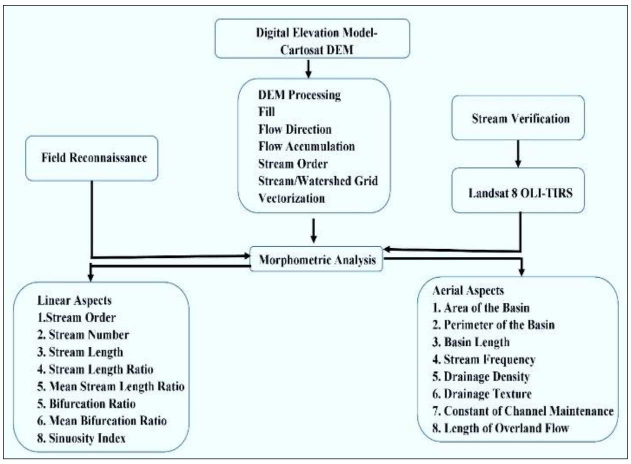

Fig 2 Methodology used for morphometric analysis of the Puliyeru River Basin, Andhra Pradesh, India

Table 1 Data used for morphometric analysis of Puliyeru River Basin, Andhra Pradesh, India

Types of data / Software	Details of data	Sources
Survey of India, Toposheets	Toposheets no's 57F/5, 57F/9, 57E/7, 57E/8, 57E/11 and 57E/12	https://onlinemaps.surveyofindia.gov.in/FreeMapSpecification.aspx
Landsat 8 Satellite Imagery	Path/row: 144/50 dated:	https://earthexplorer.usgs.gov/
Cartosat DEM	1-ARC (23.5 M), 2015	https://bhuvan-app3.nrsc.gov.in/data/download/index.php

Table 2 Methodology adopted for computations of morphometric parameters

S. No	Parameters	Formulae	References
1	Stream order (U)	Hierarchical rank	[23]
2	Stream length (Lu)	Length of the stream	[15]
3	Mean stream length (Lsm)	Lsm= Lu/Nu	[23]
4	Stream length ratio (RL)	RL =Lu/(Lu-1)	[15]
5	Bifurcation ration (Rb)	Rb =Nu/Nu+1	[26]
6	Mean bifurcation ratio (Rbm)	Rbm= average of bifurcation ratios of all order	[23]
7	Drainage density (Dd)	Dd=Lu/A	[15]
8	Drainage texture (T)	T= Dd * Fs	[27]
9	Stream frequency (Fs)	Fs =Nu/A	[15]
10	Elongation ratio (Re)	Re =D/L	[26]
11	Circularity ratio (Rc)	$Rc = 4pA/P^2$	[23]
12	Form factor (Ff)	$Ff = A/L^2$	[15]

Linear aspects

One dimension is linear aspect. It investigates the topology of the basin's stream segment and its various forms of channel pattern, open linkages, and topological properties. In this chapter, the Puliyeru basin's stream ordering, number, length, mean length, bifurcation ratio, weighted mean bifurcation ratio, and sinuosity index are all described in depth in detail [28].

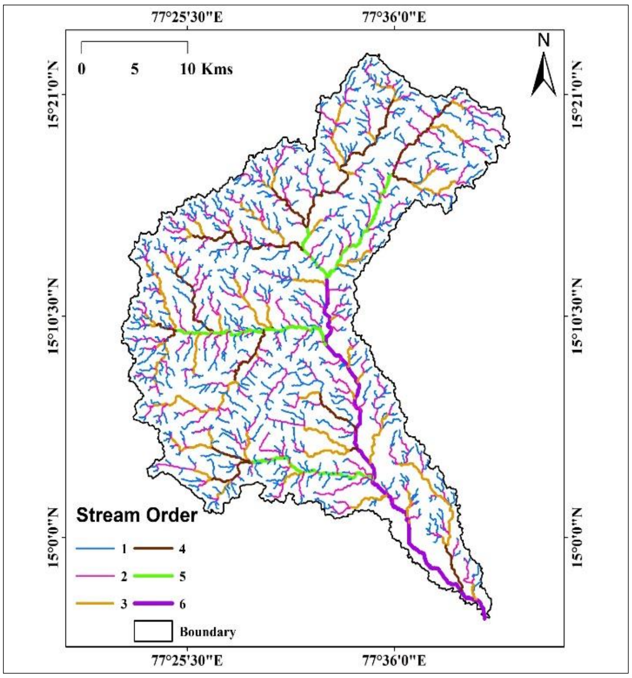

Fig 3 Stream orders of the Puliyeru River Basin, Andhra Pradesh, India

Stream order

Stream ordering is the first stage in a quantitative watershed study. Horton first proposed the idea of stream order in 1932. Stream ordering is the measurement of a stream's position in the tributary hierarchy. There are no tributaries in the first-order streams, therefore they typically flow during the rainy season. A DEM and Strahler's approach of stream ordering have been utilized in this work to demarcate streams. The Puliyeru River has the highest stream order, 6th, and for a variety of reasons (Fig 2). As the stream order rises, the number of streams diminishes, which agrees with Horton's [15] research that shows that streams occur most often in the first order. When it comes to Puliyeru's river basin, (Fig 2) displays the link between the river's stream order and its stream numbers. There is a decline in the number of streams, as can be seen from this graph. They're inversely related to one another.

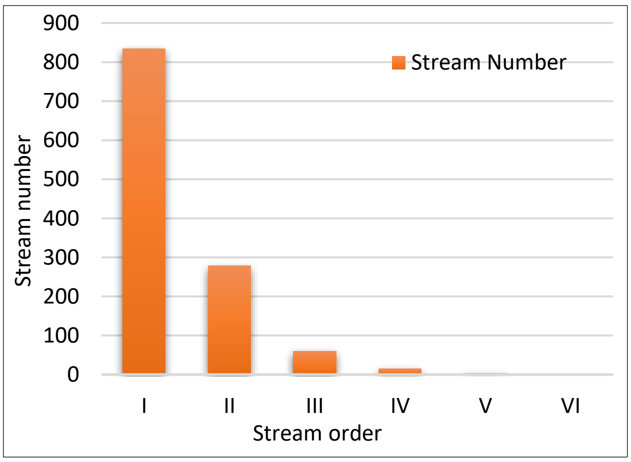

Fig 4 Bar graph showing the relationship between stream order and stream number

Stream number (Nu)

We counted all streams in each stream order using ArcGIS software for all basins. According to the basin's lithology and structure, each stream order might have a different number of streams. Typically, the number of streams reduces as the stream order rises. The Puliyeru River basin has a total of 1192 streams (Table 3). Because of the abundance of first-order streams, an unexpected flash flood is quite likely if there has been a lot of rain in the downstream area [29].

Table 3 Linear aspects of the Puliyeru river Basin, Andhra Pradesh, India

Stream order (w)	No. of streams (Nu)	Bifurcation ratio (Rb)	Mean bifurcation ratio (Rbm)	Total length of streams (km)	Mean length of streams (km)	Stream length ratio (RL)
I	834			642.07		
II	278	3		347.45		1.62
III	60	4.63		163.36		2.18
IV	15	4		89.09		2.18
V	4	3.75	3.88	51.02	1.12	2.15
VI	1	4		40.23		3.15
Total	1192	19.38		1333.22		11.28

Stream length (Lu)

Interlude tectonic disturbances are included in the historical evolution of stream segments when calculating stream length. The first term of a direct geometric series in which the average length of the first order stream is the stream length delineates the total length of stream segments in a basin [15]. Permeable areas have longer streams and a wider network of channels. Using the compute geometry function in ArcGIS, we were able to determine the length of each basin's stream in real time. According to the hypothesis that geometrical resemblance is kept in watersheds of increasing order, the Horton's law of stream length backs up this assertion [23]. In the current investigation, this rule holds true in every basin. The Puliyeru River basin's total stream length is 1333.22 kilometres (Table 3). The steep slopes and finer texture are represented by short length streams, while long length streams often reflect mild gradients [23].

Mean stream length (Lum)

The average stream length reflects the distinctive size of drainage network components and their contributing surface [23]. Stream length to stream segment length is expressed as a ratio, with Lum standing for "length to segment length." For each stream order, Lum will be higher than the previous one and lower than the subsequent ones in the watershed's hierarchy. A watershed's size and terrain are closely related to the Lum, and values might vary from basin to basin [30]. Strahler [23], Lum is a dimensional attribute that reveals the typical size of drainage network components, and the watershed surfaces they contribute. By dividing the total length of each stream in an order by the total number of streams in that order, Lum is computed in this research. Puliyeru River Basin has a score of 1.12. The mean stream length grows when the stream's order shifts to the next higher one. They're equidistant from one another.

Stream length ratio (Lur)

Stream length ratio can be defined as the ratio of the mean length (Lu) of the one order to the next order of streams (Lu – 1) [15]. As the stream length increases, stream length law shows that the mean stream length of each sequential order of a watershed tends to resemble a straight geometric series. The shift in stream length ratio from one order to the next order identifies the late juvenile stage of geomorphic development. Puliyeru River basin has a stream length ratio of 2.26. (Table 3).

Bifurcation ratio (Rb)

It was defined by Schumm [26] as the proportion of stream segments with a specific order (Nu) to those with a higher order (Nu + 1), and this has been used ever since. In Horton [15], Rb is a measure of relief and dissection. If you look at different locations or different climatic circumstances, Strahler [31] found that the Rb has a very modest degree of fluctuation. Using Rb, you can see the degree of integration between various stream orders, and it has no dimensions. Rb may go up or down in rank based on changes in the drainage basin's geology and lithology [23]. Variations in Rb might be as little as 3.0 or as large as 4.63. There have been less structural disturbances in this watershed, and the drainage pattern has not been affected by the structural disturbances [23]. There has been a bifurcation ratio of 4.63 in the Puliyeru River basin (Table 3).

Mean bifurcation ratio

All the orders' bifurcation ratios are averaged together to get the average bifurcation ratio for all of them. For those who don't understand it, consider this formula:

All orders of bifurcation ratio are averaged to get the Mean Bifurcation Ratio (Rbm) [31].

$= (3+4.63+4+3.75+4)/5$

$= 19.38/5$

$= 3.88$

In the present study the value of mean bifurcation ratio is 3.88. The range of mean bifurcation ratio is 3.88 (Table 3). It indicates that the geological structures are disturbing less to the drainage pattern.

Weighted mean bifurcation ratio (Rbwm)

Weighted mean bifurcation ratio (WMBR) was utilized by Strahler [32] to get the Rb number. For each sequential order pair, it is the sum of the Rb values for each pair of orders, divided by the total number of streams involved in the ratio. The Puliyeru River basin's Rbwm value is 3.88.

Sinuosity index

There are no straight rivers in nature because of the inherent curvature of the earth's terrain. As it turns out, a river's sinuosity index measures how far it deviates from its predicted straight route. The geological structure, temperature, time, vegetation, and so on all play a crucial role in shaping the river's serpentine flow. A river basin's morphometric characteristics may be determined by studying the sinuosity index. The river basin sinuosity index may be studied using a variety of qualitative and quantitative techniques. Since the channel length (CL) and valley length (VL) are inversely related, the sinuosity index (VL).

There are two types of rivers: Straight and meandering, which have a sinuosity index of 1.5 or greater, and those with a sinuosity index less than 1.5 are referred to be straight or sinuous [33]. Hydraulic and topographic sinuosity, as determined by Miller [34], may be expressed in terms of the ratio of CL, VL, and air distance from source to mouth of a river (AL). It is common for the topographic sinuosity index (TSI) to be bigger than the hydraulic sinuosity index (HSI) in mountainous areas, although this is not always true in plains, where topographic influence is less.

Consequently, the topographic and hydraulic sinuosity indices are key tools in morphometry for the study of river sinuosity and for determining the various phases in the erosion cycle. Eocene influences have reduced relief, resulting in the hydraulic sinuosity index (HSI > 60 percent) dominating the topographic sinuosity index (TSI more than 60 percent) at all ages, save for in the mature, late mature, and elderly phases. Sinuosity indices of many kinds are computed.

Areal aspects

The areal aspect describes two dimensional characteristics of the region. The region of river basin defines the total area of basin proposed upon the Earth surface. It introduces the concept of area which explains the length and width of a basin area. Anderson [35] described the basin as a 'devil's own variable because almost every watershed features is correlated with area. Areal aspect expresses the shape of a basin which shows the stream discharge characteristics. When the elongated shape basin with high bifurcation ratio may have an alternated flood discharge while the circular shape basin with a low bifurcation ratio may have a quickly peak flood discharge. The lower order stream occupies smallest basin areas, and the higher orders show increased areas continually. The largest area is occupied by the highest order of the stream [36-37]. The analysis of areal aspect includes such as basin length, perimeter, drainage density, stream frequency, texture ratio, length of overland flow, constant of channel maintenance and geometrical shape parameters of basin like form factors, circularity ratio etc. It is an important study for investigating of relationship between stream discharge and area of basin.

Basin length (Lb)

The basin's longest dimension perpendicular to the main drainage line, as defined by Schumm [26], is its length. As defined by Gregory and Walling [38], the length of the basin is the distance from one end to another, with the mouth being the longest distance. Both watersheds of the Puliyeru River basin in Andhra Pradesh, India, are 54.50 kilometers long, as established by the author using Schumm's definition from Schumm [26].

Basin area (A)

Basin area is an essential factor in determining the shape of a basin. Schumm [26] establishes an intriguing connection between the total watershed area and the total stream lengths that are supported by the contributing regions. This relationship is interesting. The Puliyeru River basin in Andhra Pradesh, India, has a basin area of 838.14 km^2 calculated using ArcGIS 10.8 software.

Basin perimeter (P)

The basin perimeter is the watersheds outside limit that encloses its region. As a measure of the size and form of a watershed, P may be taken along the dividing lines that separate them. The Puliyeru River basin, Andhra Pradesh, India, has a total area of 217.68 km.

Form factor (Ff)

Form factor (Ff) is a parameter that is used to predict the intensity of a basin in a particular area having a direct relationship to peak discharge [15]. Ff can be defined as the ratio of the area of a basin and square of the basin length [39]. The Ff value will al- ways be greater than 0.78 for a circular basin. The lowest value means Ff, more elongated. i.e., 0.28 (Table 4) indicates the elongated shape of the basin.

Elongation ratio (Re)

Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length [26]. Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of Re, i.e., < 0.5 (Highly elongated), 0.5 – 0.6 (Moderately elongated), 0.6 – 0.7 (Elongated oval), 0.7 - 0.8 (Semi-circular) and > 0.8 (Circular). The Re value of the Puliyeru River basin, Andhra Pradesh, India is 0.66 which represents elongation oval of the basin shape.

Circularity ratio (Rc)

A dimensionless circularity ratio was employed as a quantitative measure for the out-line shape of watersheds [23], [34]. Watershed area to a circle with the same perimeter is denoted as Rc, and this ratio is influenced by the watershed's geological composition. Rc ranges from 0.4 to 0.5, which suggests that the basins are substantially elongated and extremely permeable homogeneous geological materials. A lower Rc value shows that the basin is still in its early stages of growth and that the surface water flow takes less time to reach the basin outlet. A basin with a Rc value close to 1 has a comparable infiltration rate over the basin's whole surface [23]. Andhra Pradesh, India's Puliyeru River basin has a Rc value of 0.22. The Rc shows that basins have an extended form.

Drainage texture (Dt)

Total number of stream segments per perimeter according to Horton [15] is Dt. Dt is influenced by the underlying lithology, infiltration capability, and terrain relief. Very coarse (2), coarse (2-4), moderate (4-6) and fine (6-8) are the five texture grades of Dt defined by Smith [27]. The Puliyeru River basin in Andhra Pradesh, India, has a Dt of 2.26, which indicates that it is coarse.

Stream frequency (Fs)

The number of stream segments per unit area is referred to as "stream frequency." The Puliyeru River basin in Andhra Pradesh, India, has a stream frequency of 1.42 in the current research. Fs is influenced by the basin's lithology, which impacts drainage texture. When Fs grows, Dd likewise rises as a result of the positive correlation between the two variables [40].

Table 4 Areal aspect of the Puliyeru River basin, Andhra Pradesh, India

Basin area km^2	Perimeter (km)	Length (km)	Form factor	Elongation ratio (Re)	Circularity ratio (Rc)	Drainage density (Dd)	Stream frequency	Drainage texture
838.14	217.68	54.5	0.28	0.66	1.59	1.964	1.42	2.26

Drainage Density (Dd)

Another aspect of drainage analysis is the density of the drainage. An area's drainage density is determined by the amount of stream length per unit area [23]. Dd is estimated in this research using ArcGIS's Spatial Analyst Tool and comes out to 1.59 km/km^2 (Table 4). The Dd is governed by a lithology that is almost same in both rivers. Strahler [23] found that low-relief regions had low Dd values, whereas high-relief areas had high Dd values (Fig 4).

Constant of channel maintenance (C)

Drainage density or the constant of channel maintenance is a feature of landforms utilized by Schumm [26]. In order to support a channel that is 1 km long, a basin must have a surface area of at least 1 km^2. The landform units of a drainage basin and their genetic relationship may be inferred from the constant of channel maintenance, according to Strahler [31]. Andhra Pradesh, India's Puliyeru River basin has a C value of 0.63 km^2/km.

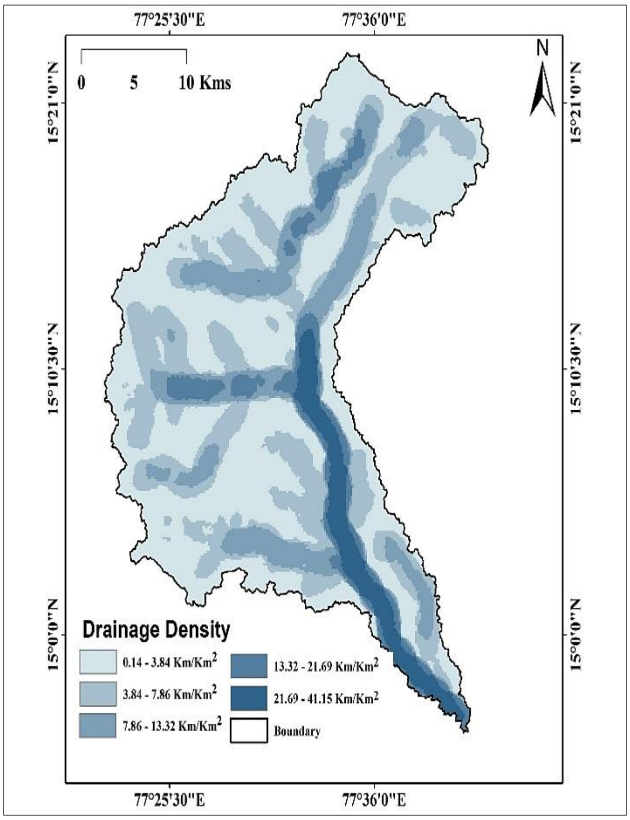

Fig 4 Drainage density of the Puliyeru River Basin, Andhra Pradesh, India

Length of overland flow (Lg)

The term length of overland flow was used by Horton [15] to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. The Lg, at an average is about half the distance between the stream channels, Horton for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density [41-42]. From the results it is observed that the Lg values of the Puliyeru River basin, Andhra Pradesh, India is 0.36.

CONCLUSION

Our understanding of the basin's geomorphic history, drainage network development, and geological control is greatly enhanced by GIS analysis. Morphometric investigation of linear and areal characteristics of the Puliyeru River basin in Andhra Pradesh finds that it is classed as a VIth order stream and displays dendritic drainage pattern. If the rocks are homogenous and resistant to horizontal erosion, this suggests that they are resistant in the vertical direction as well. In spite of this, the basin's drainage pattern is mostly determined by the basin's structure and lithology. According to the logarithmic transformation, the number of streams, order, and length of the basin's streams are in excellent accord with the observed facts, such as the basin's length is greater than its breadth. With regard to basin elevation, it is believed that most of it is in an ancient geomorphic cycle with low relief. The basin's linear and areal features suggest that it is normal, near elongated, and less disturbed in terms of geological structure. Watershed characteristics such as bifurcation ratios, drainage densities, surface textures, and relief ratios all point to high runoff, low recharge, and low rainfall intensity as the primary factors determining the main stream's discharge capacity. The basin's topography, aspect, and lithology have a significant impact on its hydrology.

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