Full Length Research Article

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Research Journal of Agricultural Sciences **14**(6): 1677–1685 (Nov-Dec 2023)
DOI: http://rjas.org/Article/Article/5666

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

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

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Received: 14 Jun 2023; Revised accepted: 20 Oct 2023; Published online: 06 Nov 2023

Abstract

This study aims to perform a comprehensive morphometric analysis of the relief aspects of the Puliyeru River Basin in Andhra Pradesh, India, utilizing remote sensing and GIS techniques. Morphometric analysis provides valuable insights into the characteristics of drainage basins, aiding in understanding their hydrological behavior, geomorphological evolution, and environmental management. Remote sensing data, including high-resolution satellite imagery, digital elevation models (DEMs), and multispectral data, were employed to extract pertinent information about the river basin. GIS tools were used for data integration, analysis, and visualization. The results of the morphometric analysis revealed the morphological characteristics of the Puliyeru River Basin. The basin exhibited dendritic to sub-dendritic drainage pattern, indicative of a homogeneous lithology and gentle slope gradient. The stream network showed variations in stream orders, signifying the hierarchical organization of the basin's drainage system. The drainage density indicated the extent of erosion and the potential for runoff in the basin. The relief ratio provided insights into the basin's surface roughness and vulnerability to erosion processes. The morphometric analysis, when integrated with ancillary data such as land use/land cover and soil information, can support effective watershed management, flood prediction, and identification of vulnerable areas within the Puliyeru River Basin. The findings of this study will aid in sustainable development planning, water resource management, and ecological conservation efforts in the region. The utilization of remote sensing and GIS techniques for morphometric analysis has proven to be a valuable approach in characterizing the relief aspects of the Puliyeru River Basin. The results obtained provide crucial information for better understanding and managing the basin's hydrological and geomorphological processes, contributing to sustainable development and environmental protection initiatives in Andhra Pradesh, India.

***Key words*:** Remote sensing, GIS, Absolute relief, Relief ratio, Watershed management

The difference in altitude, between the highest and lowest point in any given area may be defined as relief. The relief aspects of drainage basin are related to the study of dimensional features of the basins involving area, volume, and altitude of vertical dimension of landforms where in different morphometric methods are used to analyze terrain characteristics, which are the result of basin processes [1-4]. A relief aspect of a river basin describes the elevation of surface from surrounding common surface. It is always measured in terms of difference in elevation of highest and lowest elevation in an area unit. Relief is the measure of the energy head from which potential energy can be determined. Rainfall is also influenced by relief [5-7]. The potential energy of flowing water from high altitude gets converted into kinetic energy which is related to slope. Total basin relief is the difference in elevation between the highest point on the source and the mouth of the river in a basin [5-11]. For the area under study, the elevation of highest and lowest points is 707 meter and 285 meters respectively and the value of total relief is computed as 422 meters. The relief of 422 meter within a distance of 29.5 kms clearly indicates higher amount of potential energy available for water to flow in downstream reaches with high velocity, low infiltration and flashy discharge at the basin outlet [12-14]. The valley forms and their variation either with respect to space or time are greatly influenced by the relative relief and the hence the relief analysis becomes an essential part of any study regarding valley forms. The relief analysis included in following types is mainly based on the data that could be obtained from 1:50000 scale maps of S.O.I. topographical sheets [15-18]. A grid pattern with 2 cm × 2 cm as a size of square is used for obtaining data for spatial distribution of variables like relative relief, absolute relief, dissection index, amplitude of relief, slope.

The relief aspect is the third dimensional aspect of landforms lies on an Earth surface. It introduces the concept of relief. Relief disparities assume a significant role in regulating the conveyance of drizzle, an example of shell water highlights like tributaries, tanks and so on. It is likewise influenced the accessibility and stream of groundwater. Maximum sediment loss with high slope angle is found in the highest relief area [19-21]. The high relief in the basin may be associated with areas of tectonic activity. Relief aspects measure the height variation at various points in the river basin along with the channels. The several methods have been used for the calculation of relief

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Citation: Swetha K, Reddy GJ. 2023. Morphometric analysis of relief aspects of the Puliyeru River basin, Andhra Pradesh, India using remote sensing and GIS. *Res. Jr. Agril. Sci*. 14(6): 1677-1685.

aspects such as absolute relief, average relief, relative relief, relief ratio, gradient ratio, dissection index, ruggedness index, roughness index, hypsometric analysis, profiles [22-25].

MATERIALS AND METHODS

Study area

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 77º 21' 40 E to 77º 41'40 E longitudes and 14º55' 50 N to 15º24'50 N latitudes covering an area of 834.18 sq. km. 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. 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. A 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 (1945) and Strahler (1946), the basin's drainage system was analyzed (1964). In ArcGIS desktop 10.8, the WGS-84 datum and UTM zone 44N projection were used to geo reference the SOI topographic maps.

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 [26-27]. (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 [28-30]. Morphometric characteristics were analyzed and divided into three groups based on their spatial orientation. Methodology is given in (Fig 2).

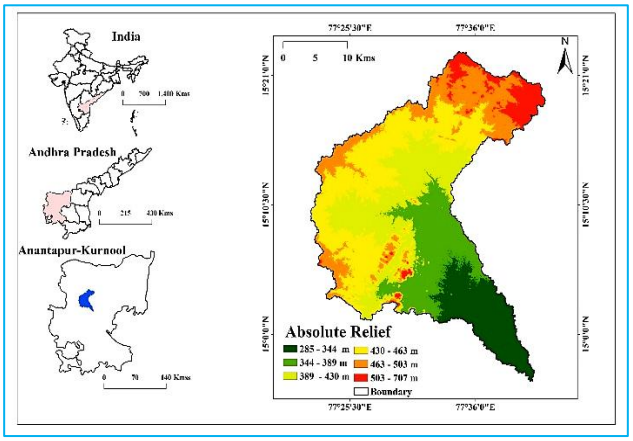

Fig 1 Location map of the Puliyeru River basin, Andhra Pradesh, India

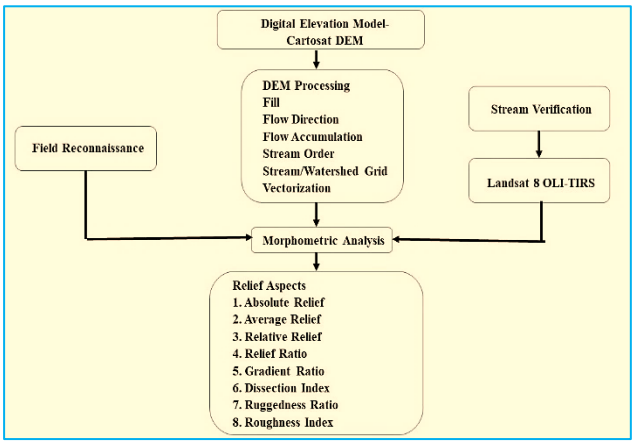

Fig 2 Methodology used for morphometric analysis of the Puliyeru River basin, Andhra Pradesh, India

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

RESULTS AND DISCUSSION

Absolute relief

The Puliyeru basin lies between Anantapur and Kurnool districts having the tributary of Penna River of Andhra Pradesh, India. Absolute relief means by which altitude of any area from sea level can be measured. Absolute relief is the maximum elevation of the basin [1], [29], [31]. It helps to calculate the information of the landform progress and structural control in the basin. The main objectives of absolute relief are to determine how much erosion has taken place in relation to the present summits of the area. Absolute relief area can be analyzed in mainly two ways. First with the help of contours and second is the different relief profiles drawn for the study area. The analysis 36588of absolute relief in morphometry is based on the pattern of contour distribution. Absolute relief can be measured by division of study area into square grid having unit area of 1 Km² and altitude measured per squared grid has been done with the help of contours. The present study helps to understand the erosional and depositional activities of landform in the river basin [32-33]. These values of absolute relief range from 300 mts to 700 mts shown in (Fig 3, Table 1). This table explains that the highest part of the basin is at 503-707 mts, while the lowest part is above 285 mts.

In this way based on different zones the basin area is divided into 4 major categories:

1. Low Absolute Relief - Below 389 mts
2. Moderate Absolute Relief - -389 - 430 mts
3. Moderate to High Absolute Relief – 430 - 500 mts
4. High Absolute Relief - Above 500 mts

Low absolute relief

The absolute relief between 285 – 344 mts and this zone covers 110.68 Km² areas out of total geographical area of the basin which is 13.27 percent. Puliyeru river joins the Penna River in this belt. Greater agriculture practices and high population density exist in this area because of availability of water. This zone includes several service centres like Peedavadugur, Pamidi and Gooty regions. 344 - 389 mts. This zone covers 135.66 Km² which is 16.26 percent of total geographical area of basin. This zone covers moderate area of basin. In this area many smaller tributaries combine to form a larger river. This relief zone is having gentle slope with good agricultural land.

Moderate absolute relief

The absolute relief between 389 - 430 mts and this zone covers 175.38 Km² areas out of total geographical area of the basin which is 21.02 percent. Puliyeru river joins the Penna River in this belt of the total basin area. The formation of V-shaped valley is the result of steep slope of river surface. This includes Gooty and Guntakal etc. as service centres.

Moderate to high absolute relief

Moderate to High absolute relief of the study area of this zone is 363.60 Km² which is 43.59 percent of total geographical area of basin. These types of relief extended in the central and northern parts of the study area. This includes Guntakal, Maddikera, Vajrakarur, and Tuggali etc. as service centres.

High absolute relief

This zone covers an area of 48.85 Km² which is 5.86 percent of the basin area. This area is the origin of main Puliyeru river and so many tributaries of Puliyeru river. This region has mainly Dhone, Papilly, and Pattikonda regions of the study area.

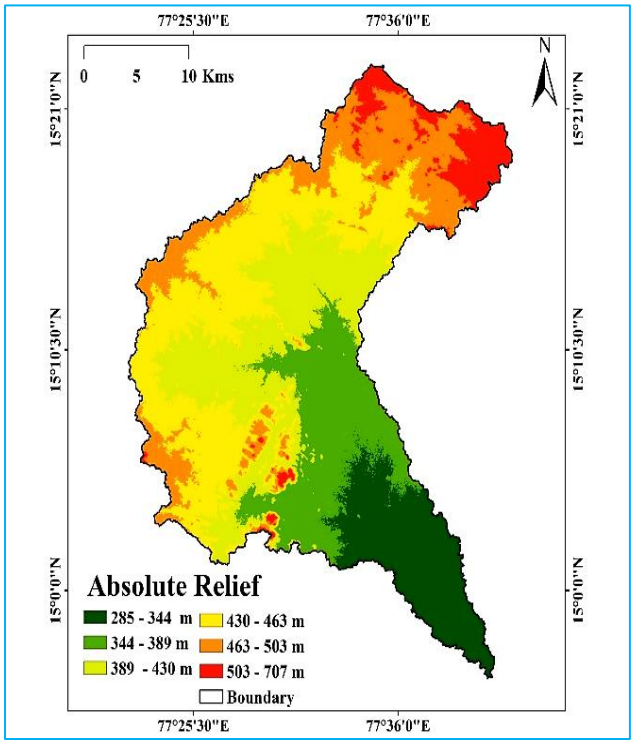

Fig 3 Absolute relief map of the study area

Table 2 Absolute relief of the Puliyeru River basin, Andhra Pradesh

Absolute relief (Mts)	Area (Km^2)	Area (%)	Major categories
285 - 344	110.68	13.27	Low
344 - 389	135.66	16.26	
389 - 430	175.38	21.02	Moderate
430 - 463	223.58	26.80	Moderate to
463 - 503	140.04	16.79	high
503 - 707	48.85	5.86	High

Average relief

Average relief is the mean value of maximum elevation and minimum elevation of a particular area. It is also called as intensity of relief. The average relief is calculated using following equation:

Average Relief = (Maximum elevation + Minimum elevation) / 2

Where, maximum elevation is the highest point in the basin and minimum elevation is the lowest point of basin. The map of average relief has been prepared with the help of 1Km² grids. In each grid maximum elevation has been calculated with the help of contours. Then mean value of maximum elevation and minimum elevation has been counted which is known as average relief. This value of average relief has been placed in each square grid [34-35]. This value varies from 285 mts to 6600 mts. The main purpose of the study of average relief is to compute level of dissection of basin. The whole basin has been divided into four different categories for average relief from below 1000 mts to above 6000 mts (Table 2, Fig 4).

Low average relief (< 351 m)

Average Relief (below 351 mts) - The area covered in this category is 134.34 Km² and 16.03 percent of total geographical area of basin. This area exists in lower part of the valley. The population density of this region is maximum among whole basin. The main part of this category is in lower part of the river basin (Fig 4).

Low to moderate average relief (351 -402 m)

Average Relief (351.20 – 402.50 mts) - The total area occupied under this category is 152.74 Km² and 18.72 percent of total area of basin. This category covers moderate area of the basin. Similar to upper category, maximum part of this category also situated in lower Puliyeru river basin (Fig 4, Table 2).

Moderate average relief (402.50 – 447.20 m)

Average relief (402.50 – 447.20 mts) - The total area occupied under this category is 251.10 Km² and 29.96 percent of total area of basin. This category covers maximum area of the basin. Like upper category, maximum part of this category also situated in central parts of the Puliyeru river basin (Fig 4, Table 2).

Moderate to high average relief (447.20 – 491.90 m)

Average relief (447.20 – 491.90 mts) - The total area occupied under this category is 224.84 Km² and 26.63 percent of total area of basin. This category covers maximum area after the moderate relief of the basin. Like upper category, maximum part of this category also situated in central parts of the Puliyeru river basin (Fig 4, Table 2).

High average relief (491.90 - 707 m)

Average relief (491.90 - 707 mts) - The total area occupied under this category is 75.12 Km² and 8.96 percent of total area of basin. This category covers minimum area of the

basin. Like upper category, maximum part of this category also situated in upper parts of the Puliyeru river basin (Fig 4, Table 2).

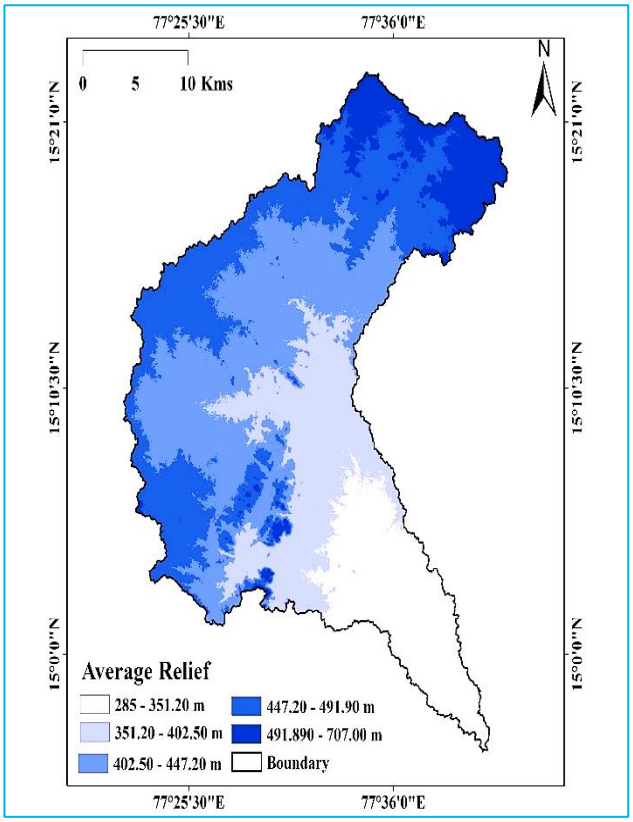

Fig 3 Average relief of the Puliyeru River basin, Andhra Pradesh, India

Relative relief

It describes the variation in altitude between lowest points and highest points covering a unit area like one Km or one mile and this is also known as "Local Relief" or "Amplitude of Relief". This concept was proposed by Portech in 1911 but Smith in 1935 used this concept for scientific study. After Smith many researchers has been generally using this concept for the study of relationship of landform and land use. Smith method has been used for the study of relative's relief of Puliyeru river basin area. The following formula is suggested for calculated of relative relief (Smith, 1935)

Relative Relief = Maximum elevation – Minimum elevation
Where, Maximum elevation is the highest point of area,
Minimum elevation is the lowest point of area

Basin area is divided into 1 Km² grid, and each grid describes the minimum and maximum altitude change. Relative relief variations occurred from minimum 16 mts to maximum 358 mts. The study area is divided into 4 major categories:

1. Low (Below 101 mts)
2. Moderate (101 – 186 mts)
3. Moderate to High (186 – 272 mts)
4. High (above 272 mts)

The relative relief pattern shown in (Fig 4, Table 3) which describes that 55.93 percent area lies in low category, 35.63 percent in under moderate category, 5.83 percent is covered by moderate to high category and 2.60 percent fall in the high category.

Low relative relief (Below 101 mts)

Relative Relief (Below 101 mts)-This category covers the area of 468.78 Km² which is 55.93 percent of total geographical area of Puliyeru river basin, Andhra Pradesh, India. The major portion of this category is located in Guntakal, Maddikera, Tuggali, Gooty, Peddavadugur, and Vajrakarur areas and minor portion of this category is in Pattikonda and Dhone regions of the study area. The conclusion of whole basin analysis reveals that the highest area of this category is in Central, South-West and South- East part of the basin (Fig 5, Table 3).

Table 3 Average relief of the Puliyeru River basin, Andhra Pradesh

Average relief (Mts)	Area (Km^2)	Area (%)	Major categories
285 - 351.20	134.34	16.03	Low
351.20 - 402.50	152.74	18.22	Low to moderate
402.50 - 447.20	251.10	29.96	Moderate
447.20 - 491.90	224.84	26.83	Moderate to high
491.90 - 707	75.12	8.96	High

Moderate relative relief (101 - 186 mts)

The area covered under this category is 298.67 Km² and 35.63 percent. This is the second largest category occupying major area of river basin. The maximum area of this category is located in upper Puliyeru river basin. Basin analysis reveals that this category is situated in northern parts of Puliyeru basin.

Moderate to high relative relief (186 – 272 mts)

The area present under this category is 48.89 Km² and 5.83 percent of total geographical area of basin. The major part of this category is located in South-West part of the Puliyeru river basin, Andhra Pradesh, India.

High relative relief (Above 272 mts)

Relative relief (Above 272 mts) - The area of this category occupies 21.82 Km² and 2.60 percent of Conclusion of basin analysis is that this category is situated in the Central parts of the Puliyeru river basin, Andhra Pradesh, India.

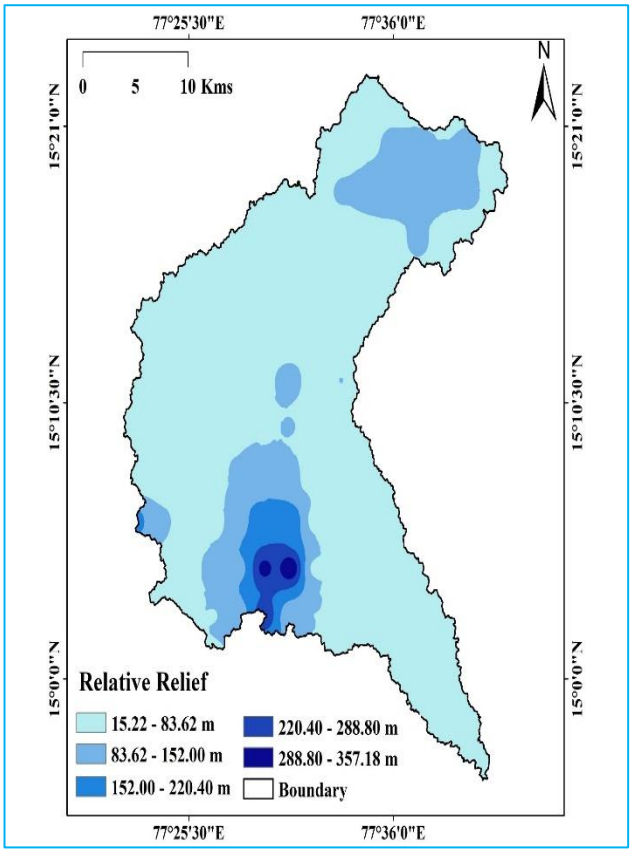

Fig 4 Average relief of the Puliyeru River basin, Andhra Pradesh

Table 4 Average relief of the Puliyeru River, Andhra Pradesh

Relative relief (Mts)	Area (Km^2)	Area (%)	Major categories
Below 101	468.78	55.93	Low
101 - 186	298.67	35.63	Moderate
186 - 272	48.89	5.83	Moderate to High
Above 272	21.82	2.60	High

Relief ratio

"The relief ratio is the ratio of the maximum relief to the horizontal distance along the longest dimension of the basin equivalent to the principal drainage line" (Schumm, 1956). It is the measurement of slope of a river basin and shows the strength of the erosion processes. The probability of a nearby relationship between help proportion and hydrologic attributes of a basin recommended by Schumm (1956), who found that silt free per unit region firmly, corresponds with relief ratio. Schumm (1956) presented this formula for calculate the relief ratio.

Relief ratio = H/Lb
Where;
H = Relative relief of the basin in meters
Lb = Basin Length

The total relief ratio of the present study is 8.38 of the basin (Table 4, Fig 5). The low relief ratio indicates that low erosion processes and resistant bedrock of the region. It's worth typically increases with diminishing drainage size and region of a given drainage basin (Fig 6).

Table 5 Relief ratio of the Puliyeru River, Andhra Pradesh

S. No	River basin	Elevation in meters		Relative relief (H-h)	Basin length (Kms)	Relief ratio (H-h/L)
		Maximum height	Minimum height			
1	Puliyeru river	707	285	422	50.38	8.38

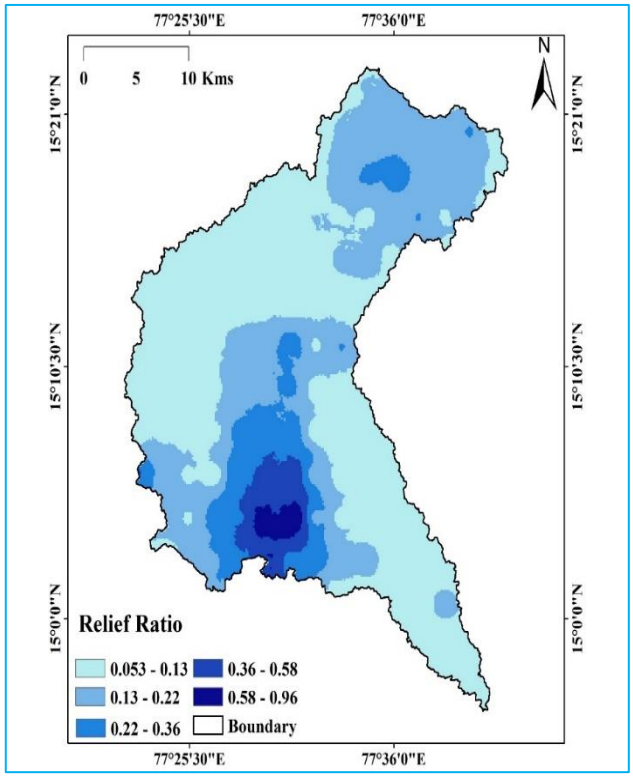

Fig 5 Relief ratio of the Puliyeru River basin, Andhra Pradesh, India

Gradient ratio

Gradient ration is the ratio between falls in height from the source to the mouth of the stream and the length of the main drainage line. It is a marker of channel slope. A high gradient ratio is found in the hilly region and low angle proportion is seen in the plain territory [30], [36]. It is figured by this equation.

Gradient ratio = (a – b) / L

Where;
a = height of river source of the basin
b = height of river mouth of the basin
L = length of the main river

In the present study zone, Puliyeru river basin has the most noteworthy gradient ratio 6.85 mts/Km (Table 5). The Gradient ratio is indicating that the slope of Puliyeru river basin is a steep slope while in lower part is gentle slope of the river basin.

Dissection index

Dissection index is important parameters for understanding the amount of dissection pattern of landforms. It is the ratio of relative relief and absolute relief. It is associated with the irregularity of plane shaped by several valleys or ravines. As a criterion of relief energy, the idea of relative dispositions is not generally had equivalent significance since their total elevations may vary [37-38]. The analysis of dissection index has given an indication to the progress of landscape in the preview of fluvial geomorphic cycle of erosion. It is also used to understand the stage of erosion as young, mature and old stages. It is also suggested that the slope regions are steep, moderate or gentle in the basin. Dov Nir (1957) computed the dissection index by the ratio between relative relief and absolute relief of an area. He presented this formula to calculate the dissection index:

Dissection Index (Di) = Relative relief / Absolute relief

Table 6 Relief ratio of the Puliyeru River, Andhra Pradesh

S. No	River basin	Elevation in meters		Fall in height (A-B)	Basin length (Kms)	Gradient ratio (H-h/L)
		Source A	Source B			
1	Puliyeru river	650	345	50.38	6.85	8.38

Dissection index explains the degree of categorization which varies between 0 (absent of dissection) to 1 (vertical cliff at sea level). The area of lower elevation may be characterized by high degree of dissection index, if the area is dissected by deep river valley or characterized by frequent and isolated hill-tops [39-40]. Grid method is used for the calculation of dissection index. The basin is divided into 1797 grids and each grid covers an area of 1 Km^2.

By using the calculation of each grid, the map and tables are prepared for the study area. The (Fig 6, Table 6) shows that the dissection index of Puliyeru river basin varies from 0 to above 0.55. The data revels that zero is the minimum value and

1 is the maximum value within an area of one Km². Thus, the river basin has been divided into four major categories. These are: - 1. Low Category (Below 0.15) 2. Moderate category (0.15-0.30) 3. Moderate to High category (0.30 – 0.55) 4. High Category (Above 0.55) (Table 6).

Table 6 Dissection index of the Puliyeru River, Andhra Pradesh

Dissection index	Area (Km^2)	Area (%)	Major categories
0.053 - 0.15	516.10	61.58	Low
0.15 - 0.30	263.71	31.46	Moderate
0.30 - 0.55	46.05	5.49	Moderate to high
0.55 - 0.96	12.29	1.47	High

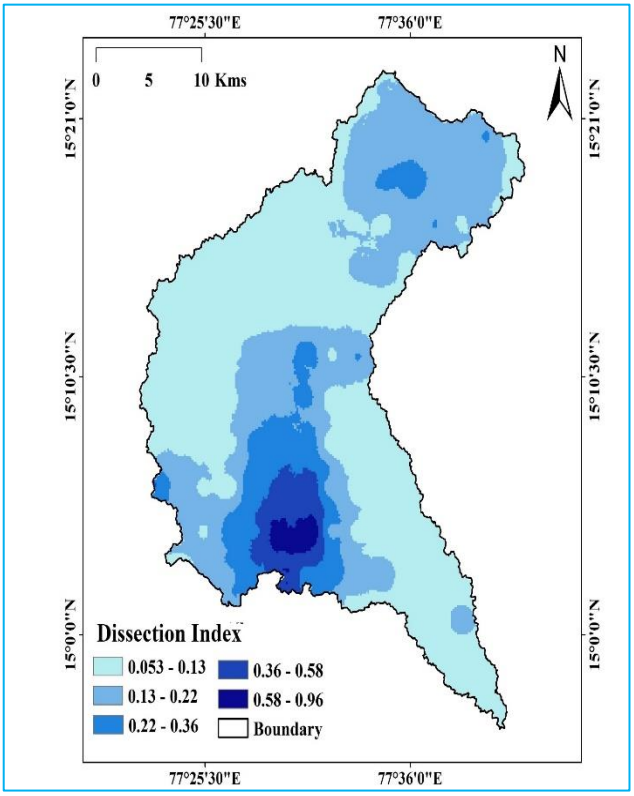

Fig 6 Dissection index of the Puliyeru River basin, Andhra Pradesh, India

Low category (below 0.15)

The low category below 0.15 includes the area of North, North- West and South-East parts of the basin. The low group of dissection index covers maximum area about 516.10 Km² which is 61.58 percent of geographical area. The highest area occupied by the Maddikera, Guntakal and Gooty Mandals followed by Peddavadugur Mandal of the study region (Fig 7).

Moderate category (0.15 – 0.30)

This is the second largest category which is covered by 263.71 Km² areas which is 31.46 percent of geographical area. The area found in Central and Northern parts of the basin. The highest area occupied by Guntakal, Tuggali and Pyapili Mandals of the study area (Fig 7).

Moderate to high category (0.3 - 0.55)

Moderate to high category of dissection index includes 46.05 Km² which is 5.49 percent of the area. This is the third highest category. A major part of this category is located in central part of the of the basin.

High category (Above 0.55)

This category is occupied by 12.29 Km² and 1.47 percent of total geographical area of basin. The main part of this category is in lowest part of basin nearby Guntakal and Vajrakarur mandals of the basin. Thus, the study reveals that the Puliyeru river basin is under the high dissection index, and the basin represents the mature stage.

Ruggedness number

"Ruggedness number is a product of relative relief and drainage density in which both the terms are expressed in the same unit of measurement" [30], [41]. It shows the degree of dissection of any region. This is important parameters for the measurement of dissection because it is caused by stream in general. It is the result of lithology, rock's structure, relative relief and climatic conditions. The value of ruggedness number is high when both relative relief and drainage density are also high which revels an area of steep slope. Ruggedness number is purposed by Strahler's (1968) but in this study we adopted the Chorley's (1972) formula. He defines this formula:

Ruggedness Number (Rn) = (Drainage Density × Relative Relief) /1000

The total ruggedness number of present study is 0.0015. (Table 7, Fig 8) shows ruggedness number varies between 0.00086 to 0.0015 (Table 7).

Table 7 Ruggedness number of the Puliyeru River, Andhra Pradesh

Ruggedness number	Area (Km^2)	Area (%)	Major categories
0.00000086 - 0.00013	598.48	71.40	Low
0.00013 - 0.00045	175.37	20.92	Moderate
0.00045 - 0.00088	37.90	4.52	Moderate to high
0.00088 - 0.0015	26.40	3.15	High

Based upon the above formula, the ruggedness number map and table have been prepared. The (Fig 7, Table 7) shows that the ruggedness number varies from below 0.00013 to above 0.0015. The data revels that zero is the minimum value and 0.0015 is the maximum value within an area of one Km². Maximum area of the basin talls in Nil category which is occupied 598.48 Km² area. The basin has been divided into four major categories. These are:

1. Low Category (below 0.00013)
2. Moderate Category (0.00013 – 0.00045)
3. Moderate to High Category (0.00045 – 0.00088)
4. High Category (above 0.00088)

Low category (below 0.00013)

Maximum area of the basin lies in low category. It is covering the area 598.48 Km², which is 71.40 percent of the basin. Highest area of this category has been found near Guntakal, Maddikera, Tuggali, Dhone and Pattikonda Mandals of the Puliyeru river basin, Andhra Pradesh. The whole basin analysis reveals that the highest area of this category is in North-West, Central and Northern parts of the basin.

Moderate category (0.00013 to 0.00045)

Moderate category of ruggedness number includes 175.37 Km² which is 20.92 percent of the basin (Table 7). A major part of this category is in Upper part of the basin followed by Central parts of the basin. This zone of ruggedness umber observed that the highest area has been found near Guntakal and Peddavadugur Mandals of the river basin.

Moderate and high category (0.00045 – 0.00088)

Moderate category of ruggedness number includes 37.90 Km² which is 4.52 percent of the basin. A major part of this category is in lower part of the basin. This zone of ruggedness umber observed that the highest area has been found near Gooty and Peddavadugur Mandals of the river basin (Fig 7).

High category (0.00045 – 0.00088)

Highest value of ruggedness number has also found where both relative relief and drainage density is high. This category is occupied by 26.40 Km² and 3.15 percent of total geographical area of basin. This zone of ruggedness umber observed that the highest area has been found near Gooty, Peddavadugur and Pamidi Mandals of the river basin. Thus, the analysis of the basin shows that ruggedness number is high. It indicates that the structural topography in association with height and drainage density of the basin have vulnerable to soil disintegration in these territories. Thus, the basin is in mature stage (Fig 7).

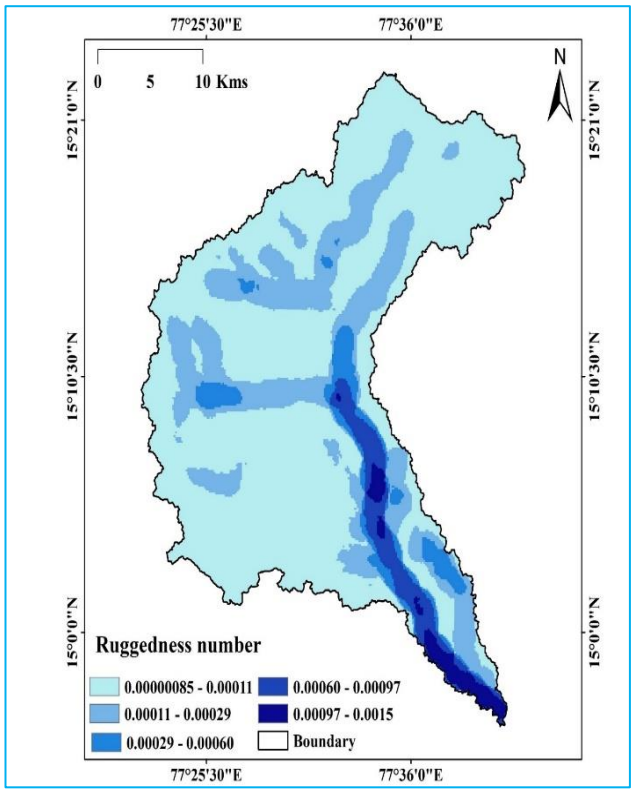

Fig 7 Ruggedness number of the Puliyeru River Basin, Andhra Pradesh, India

Roughness index

The term roughness index is utilized by many Earth researchers with the relationship of morphological examinations for the better understanding of the Earth surface formation and geomorphic processes. It expresses the individual landforms characteristics like average relief, relative relief, dissection index, average slope etc. [11], [42-43]. It is legitimately identified with the geology, water elements, and river basin improvement. The American Society for Testing and Materials (ASTM) E 867 characterizes the unpleasantness as the deviations of a pavement surface from a genuine planer surface with trademark measurements. The index reveals the combined result of evolutionary regular processes in the development of relief. A pavement profile speaks to the vertical rises of the pavement surface as a component of longitudinal separation. Roughness index is measured a degree of unevenness of the Earth surface. When the value of index will be greater with increasing number of contours intersection then the maximum values of roughness index is obtained in the hilly area or Badlands area. Hook (1955) formula has been adopted for the calculation of roughness index. The below equation is used to calculate the roughness index of the basin.

$$\text{Roughness Index} = (N \times M / 4) \times 10/4$$

Where;

N = The total number of interactions of contour lines with two sets of perpendicular grids, set as 45 constant

M = Distance in Kilometres between grid lines

10 and 4 are constant, but 4 which is denominator of M dose vary according to grid distance and scale of map

For determination of roughness index, drainage basin has been divided into 1 cm grid, each grid represents 1 Km². The (Fig 8, Table 8) show that the roughness index varies from below the low category covered by 110.52 Km² which is 13.19 percent of the total area. It is in North, North- West, and South-West. The moderate category is the intermediate of high and low category. Almost the area of the basin occupied by this category 328.21 Km² which is 39.16 percent. Because most of the part of basin is lies around hills and rocks which is almost mountain topography. The high category is covered by 108.87 Km² and 12.99 percent of total geographical area of basin. Thus, the basin is under the moderate roughness index category. Hence, the basin lies in between mature stages (Fig 8).

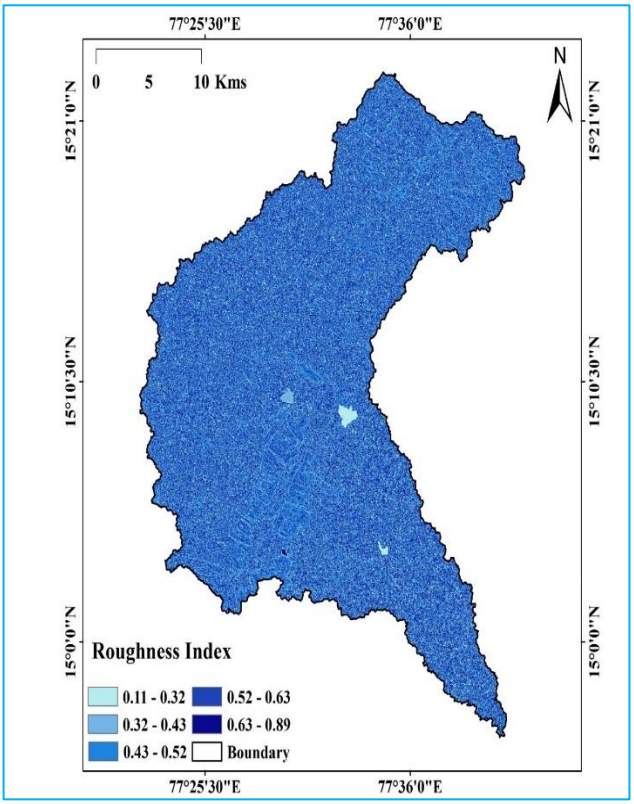

Fig 8 Roughness index of the Puliyeru River Basin, Andhra Pradesh, India

Table 8 Roughness index of the Puliyeru river, Andhra Pradesh

Roughness index	Area (Km^2)	Area (%)	Major categories
0.11 - 0.38	110.52	13.19	Low
0.38 - 0.49	290.55	34.67	Moderate
0.49 - 0.61	328.21	39.16	Moderate to high
0.61 - 0.89	108.87	12.99	High

CONCLUSION

In conclusion, this study successfully conducted a morphometric analysis of the relief aspects of the Puliyeru River Basin in Andhra Pradesh, India using remote sensing and GIS techniques. The integration of high-resolution satellite imagery, digital elevation models (DEMs), and multispectral data allowed for the extraction of pertinent information about the basin's characteristics. The morphometric parameters considered in this analysis provided valuable insights into the drainage pattern, stream network organization, erosion potential, and surface roughness of the Puliyeru River Basin. The dendritic to sub-dendritic drainage pattern indicated a homogeneous lithology and gentle slope gradient, while the variations in stream orders revealed the hierarchical arrangement of the basin's drainage system. The drainage density offered an understanding of erosion extent and runoff potential, while the relief ratio provided insights into the basin's vulnerability to erosion processes. By integrating the morphometric analysis with ancillary data such as land use/land cover and soil information, this study contributes to effective watershed management, flood prediction, and identification of vulnerable areas within the Puliyeru River Basin. The findings will support sustainable development planning, water resource management, and ecological conservation efforts in the region. The utilization of remote sensing and GIS techniques for morphometric analysis proves to be an invaluable approach for characterizing the relief aspects of river basins. The results obtained from this study enhance our understanding of the Puliyeru river Basin's hydrological behavior, geomorphological evolution, and environmental management. This knowledge will guide decision-makers and stakeholders in implementing appropriate measures for sustainable development and environmental protection in Andhra Pradesh, India.

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