Open Access

© 2023, Centre for Advanced Research in Agricultural Sciences
Research Journal of Agricultural Sciences
Volume 14; Issue 05 (Sep-Oct 2023); pp 1286–1292

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

Full Length Research Article

Morphometric Analysis of Johilla River Basin Using SRTM Data, Madhya Pradesh India

S. Siddi Raju[1] and R. Siddi Raju*[2]

[1] Department of Geology, Indira Gandhi National Tribal University in Amarkantak, Anuppur - 484 887, Madhya Pradesh, India
[2] Department of Geology, Yogi Vemana University, Kadapa - 516 005, Andhra Pradesh, India

Abstract

The present work represents the results of a quantitative morphometric analysis carried out in respect to the Johilla River Basin, M.P., India. The various morphometric parameters were calculated to represent the nature of the catchment area. Based on the field observations and the morphometric variables, favorable locations for groundwater exploration in the vicinity of present river basin could be determined. The drainage was classified based on Strhler's principle; it reveals that the river basin exhibits dendritic to sub dendritic to drainage pattern. It is a VIth order river basin and lower-order streams are mostly dominating the basin with an average drainage density of 1.06 km/km^2. The river basin area is spread over about 2887.53 sq. km and covers a part of the Annupur, Dindori and Umaria districts in M.P., India. The slope is mainly controlled by various physiographic conditions, and geologically erosion cycles. The elongation ratio is 0.46 representing the sub-watershed has an abundantly elongated with high to moderate elevation and steep slopes due to the structural disturbances. In this study, Linear, Areal, and Relief Aspects are analyzed through the SRTM Digital Elevation Model data in the Arc GIS environment.

Key words: Johilla river basin, Morphometric analysis, SRTM-30, RS, GIS

Morphometric analysis is the study of measuring and mathematically calculating the shape, size, surface area, and dimensions of the Earth's landforms [1], [9], [19], [23], [29]. A river basin is an area of land drained by a river and its tributaries. It is the area from which a river and its tributaries receive water, sediment and dissolved materials. A river basin can also be referred to as a watershed or catchment. A watershed is an area of land that drains all water to a common outlet. It is the source of water for streams, rivers, and lakes, providing drinking water, irrigation, and recreation. The Watershed approach is an effective way to maximize the use of natural resources for sustainable development and improved living standards [25]. Through the use of Remote Sensing (RS) and Geographical Information System (GIS), it is now possible to gain a better understanding of resources from larger areas in a shorter amount of time than with traditional ground surveys. Factors such as watershed size, shape, physiography, soils, soil erosion zones, land use / land cover and hydrogeological setting are all important to consider when planning and developing a watershed [10], [2], [20], [40], [41], [33]. In recent years, a number of researchers have utilized RS-GIS technologies to conduct morphometric analysis of various river basins in worldwide [21], [22], [23], [26]. These RS-GIS techniques are becoming increasingly popular and are an effective way to study the correlation between spatial variables [4], [14], [34], [35], [39]. In recent decades, the field of river geomorphology in India has been greatly advanced by the combination of traditional topographic and drainage classification studies, with field studies on the characteristics and behaviour of the river channel, as well as the development of RS and GIS. This has enabled a more comprehensive understanding of the dynamics of river systems [6], [12], [13], [17].

This paper presents a technique for assessing the morphometric analysis of the Johilla River Basin in Madhya Pradesh, India, using geospatial techniques. Mathematical computations of Linear, Aerial, and Relief Aspects were conducted, and the characteristics of various influential morphometric aspects were analyzed to facilitate planning and development of the watersheds. This technique is essential for hydrological examinations such as assessments of groundwater management, groundwater potential, environmental assessment and basin management for sustainable development.

MATERIALS AND METHODS

The Johilla River basin is covers part of the Annupur, Dindori and Umaria districts in Madhya Pradesh, Central India. The location map has shown in the figure1. The study area lies

Received: 28 May 2023; Revised accepted: 29 Aug 2023; Published online: 18 Sep 2023

Correspondence to: R. Siddi Raju, Department of Geology, Yogi Vemana University, Kadapa - 516 005, Andhra Pradesh, India, Tel: +91 879061267; E-mail: rsiddiraju@gmail.com

Citation: Raju SS, Raju RS. 2023. Morphometric analysis of Johilla River basin using SRTM Data, Madhya Pradesh India. *Res. Jr. Agril. Sci.* 14(5): 1286-1292.

between 22° 42' 0" and 23° 42' 00" N Latitudes and 80° 39' 00" and 81° 48' 00" E Longitudes and is included in the survey of India toposheets parts of 64A/(11,12,14,15,16), 64E/(2,3,4,8,12) and 64F/(1,5,9,10,13,14) having 1:50,000 scale and covers an extent of about 2887.53 sq. km. The drainage pattern of the river basin is characterized by a dendritic to sub dendritic arrangement of streams, with an uneven distribution of the network in various directions. This is a tributary of the Son River. The normal annual rainfall of the study area 1235 mm, maximum rainfall occurs during the south-west monsoon period from June to September. The normal annual means maximum and minimum temperatures of study area are 31.6º C and 18.2º C respectively [5]. The relief values range between 1153m and 355m with a median of 754m above the MSL (Mean Sea Level).

Geology

The geological map of the Johilla river basin was obtained from the Geological Survey of India (GSI) map and this area predominantly underlain by Basalts of Amarkantak group Deccan Traps, late cretaceous Palaeocene age, followed by the Granitic and granitic gneisses madan mahal granite, Archean to Palaeoproterozoic, Lower Gondwana group rocks, Lameta of late cretaceous, laterite/ Boxite of Cenozoic age.

Table 1 Data used in the present work

Type of data	Details of data	Source
DEM	SRTM-1Arc (30m)	https://earthexplorer. usgs.gov/
Geology map	District Mineral Resource Maps	Geological Society of India (GSI)

Table 2 Morphometric parameters and their formulas

S. No.	Parameters	Formula	References
1	Area	Area of the watershed	-
2	Perimeter (*P*)	Total length of the Watershed	-
3	Length (*Lb*)	Maximum length of the basin	-
4	Slope	Derived from SRTM 30 m DEM in Arc GIS 10.4	-
		I. Linear aspects	
5	Stream order (*U*)	Hierarchial rank	[41]
6	Stream number (*Nu*)	Total no of stream segments of the order ‘u’	[42]
7	Stream length (*Lu*)	Length of the stream	[41]
8	Stream length ratio (*RL*)	RL=Lu/Lu−1	[37]
9	Bifurcation ratio (*Rb*)	Rb=Nu/Nu+1	[27]
10	Mean bifurcation ratio (*Rbm*)	Rbm=Average of bifurcation Ratios of all order	[42]
		II. Aerial aspects	
11	Drainage density (Dd)	Dd=Lu/A	[11]
12	Drainage texture (T)	T=Dd×Fs	[36]
13	Stream frequency (Fs)	Fs=Nu/A	[11]
14	Circularity ratio (Rc)	$Rc= 4\pi A/P^2$	[41]
15	Elongation ratio (Re)	Re=D/L	[27]
16	Drainage texture ratio (*Rt)*	Rt=Nu/P	[11]
17	Form factor (Ff)	$Ff=A/L^2$	[11]
		III. Relief aspects	
18	Total Relief (R)	R=H−h	[27]
19	Relief ratio (Rr)	Rr = R/L	[28]
20	Ruggedness No. (Rn)	Rn=Dd*R/1000	[41]

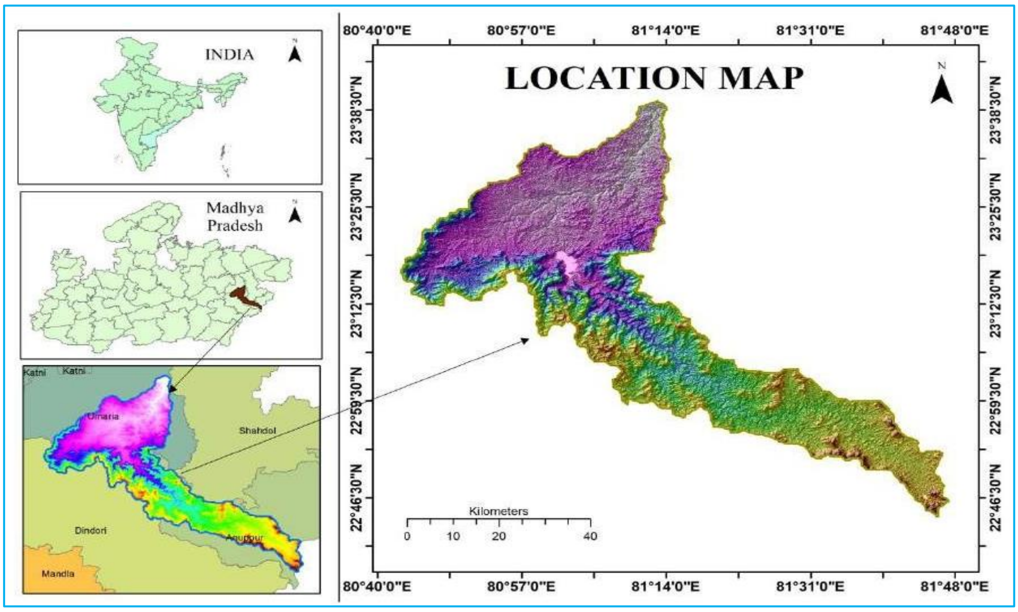

Fig 1 Location map of the Johilla River basin

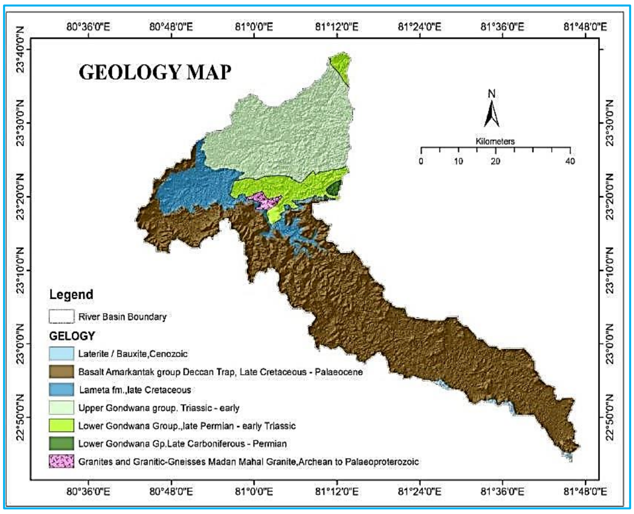

Fig 2 Geology map of the Erramsupalle sub watershed

In this study, advanced satellite datasets such as SRTM DEM-30 data were utilized to conduct a morphometric analysis. Data in (Table 1) outlines the various types of data used in the present work. Standard methodologies were applied to calculate the morphological characteristics of a sub- watershed, which are specified in (Table 2). A detailed methodology is provided in (Fig 3).

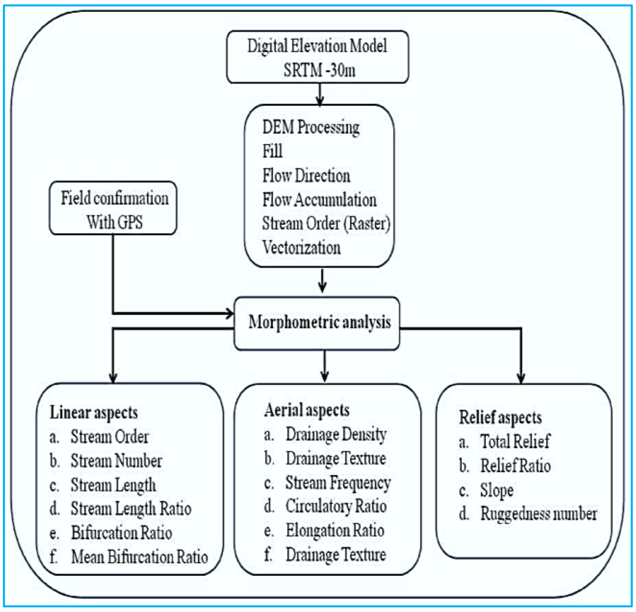

Fig 3 Detailed methodology of the study

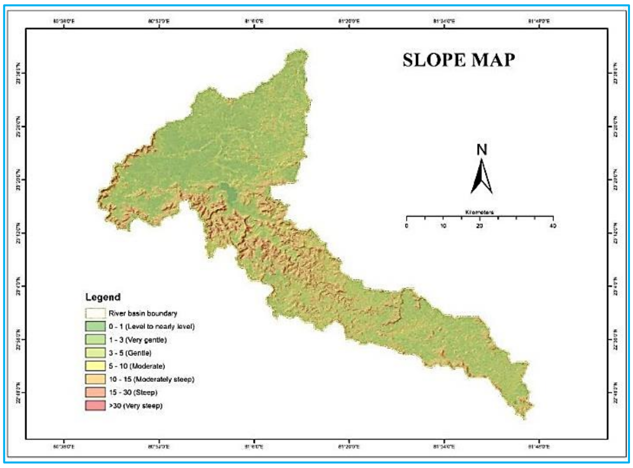

Fig 4 Slope map of the study area

The morphometric investigation was conducted using SRTM DEM data and a set of GIS tools. The drainage network of the study area was derived from this data, and morphometric parameters were analyzed (Fig 6). Slope, hill shade, and aspect maps were also prepared using the SRTM data. The morphometric parameters, such as Linear, Aerial, and Relief parameters, have been computed and evaluated by using a drainage network. Linear aspects include stream order, stream number, stream length, stream length ratio, bifurcation ratio, and mean bifurcation ratio.

The drainage system of the watershed was analyzed according to Horton's [11] law and the stream order was completed using Strahler's [41] method. The areal aspects analyzed were drainage density, drainage texture, stream frequency, circularity ratio, elongation ratio, and drainage texture ratio. Additionally, the relief aspects analyzed included total relief, relief ratio, slope, and ruggedness number. This study was successfully conducted using Arc GIS 10.4 package.

RESULTS AND DISCUSSION

The conspicuous morphometric characteristics of the Johilla River basin have been analyzed. The development of streamlines relies upon precipitation, and lithology apart from the endogenic and exogenous forces of the investigation zone. A dendritic to sub dendritic drainage pattern was observed and also it is controlled by the topography, Litho-structural, and precipitation of the area. The slope and aspect maps are prepared with the help of SRTM (30m) data. Because of the stream orders, the Johilla River is delegated as a VIth order river basin (Table 3).

Table 3 Linear aspects of Erramasupalli sub-watershed

Stream order	Stream number	Bifurcation ratio	Mean bifurcation ratio	Stream length	Stream length ratio
I	1784	-	4.48	1541.69	
II	396	4.50		753.27	2.20
III	87	4.55		392.53	2.37
IV	18	4.83		144.22	1.77
V	4	4.5		108.20	3.38
VI	1			129.72	4.79

Slope

Slope is one of the important key parameters in drainage basins geomorphological studies [30-31]. It is measure of steepness with direction. The slope values various from 0 to 39 degrees and a high degree of the slope was observed in the southwestern parts of the study area (Fig 4). Slope maps are playing an important role in planning, agriculture, Deforestation etc., [16], [29] and effects on flow direction, velocity, rate of erosion and deposition [24]. The gradient of Johill river basin was prepared through spatial analysis tools in ArcGIS 10.4 software and SRTM data.

Aspect

Angle delineate speaks to the bearing of a mountain's incline faces. The slope factor creates a major impact on its neighborhood climate as the solar rays are towards the sun's rising direction at the hottest moment in the afternoon and mainly a west-side facing gradient or slope may be hotter than the protected east side facing [15] study area aspect map was generated through the medium surface analysis tools in the Arc GIS software (Fig 5). The output raster records indicate the compass path of the aspect. Zero degrees, 90°, 180°, and 270° are showing North, East, South, and West directions respectively. Most of the range has east and northeast-facing slopes. In this manner, the examination range has high dampness and a low vanishing rate.

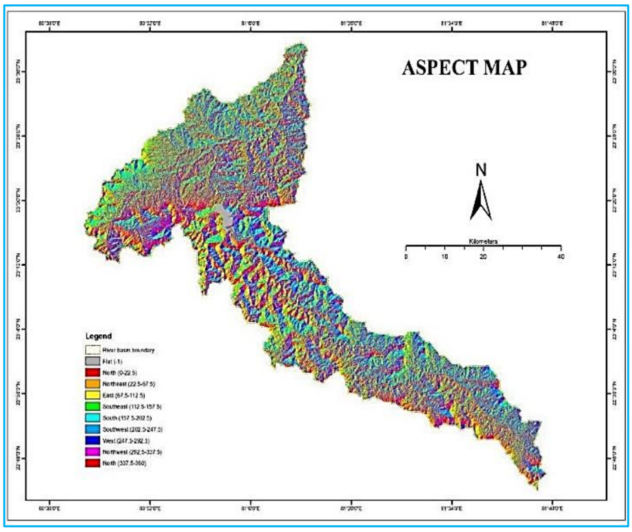

Fig 5 Aspect map of the study area

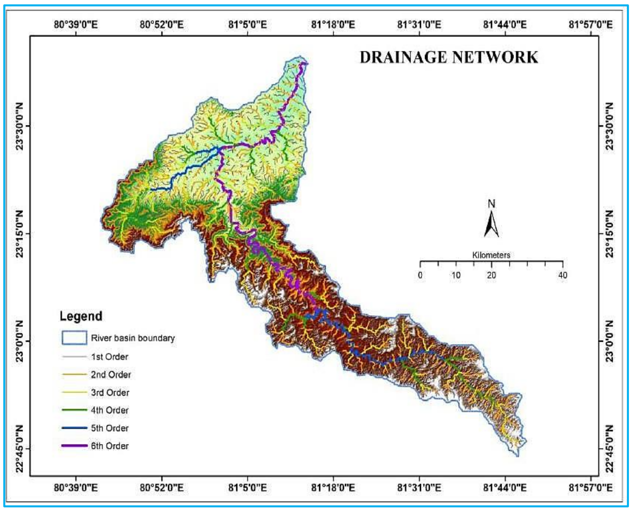

Fig 6 Drainage map of the study area showing the stream orders

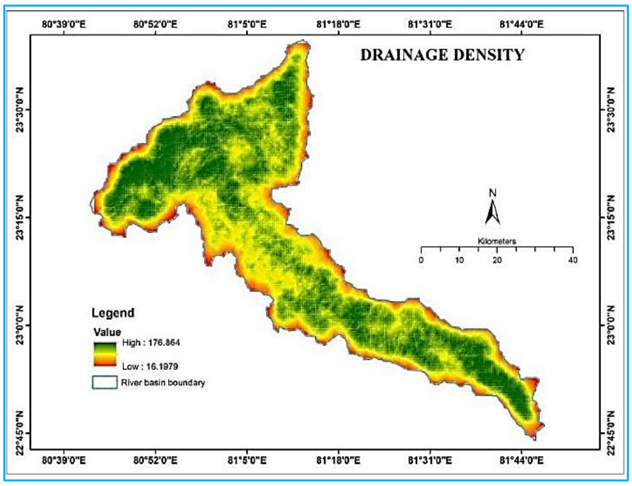

Fig 7 Drainage density map of the study area

Area (A)

Area of the Johilla River Basin is 2887.53 sq. km. Based on Area, River Basins is classified in to two categories, they are (I) Large River Basins (>20,000 sq.km) and (II) Small River Basin (2000-20,000 sq. km.) [3]. Hence, Johill river basin comes under second category. It is calculated with the help of a geometry tool in the Arc GIS environment.

Perimeter (P)

It's a boundary extent of the total drainage area. The perimeter of the Johilla river basin is about 439.1 km. The perimeter value was derived for the sub-watershed with the help of the calculating geometry tool in the Arc Toolbox within ArcGIS 10.4.

Basin length (BL)

The length of a basin is the greatest length of a sub-basin or basin and it must correspond to the major drainage lines. The total basin length is 132.69 km. Based on the results it is concluded that the shape of the basin influences the stream hydrographs as well as peak flows.

1. *Linear aspects*

Stream order (U)

In detailed watershed analysis stream ordering is the primary action. According to Straheler (1964) stream network has been ranked and it is shown in (Table 3). After analyzing the stream orders, it is noticed that the present research area falls into the VIth order basin obviously, the aggregate number of streams steadily decreases along with the increase of the stream order. The stream characteristics are verified with Horton's first law i.e., "The Law of stream numbers", it is showing that the inverse geometric ratio of drainage basins.

Stream length (Lu)

According to Horton [11], the stream length, Stream length ratio, as well as Average stream length, has had been calculated by using ArcGIS 10.4 for the study area. The Johilla river basin total stream length is 308.03 sq. km. In general, the stream length is inversely related to its stream order (Table 3). Short lengths of stream segments specify steep slopes and fine texture plus lengthy streams indicate low inclined. The Law of stream length was proposed by Horton, it is well known as Horton's second law. It expresses that the average distance end to end of stream segments of every one of the different orders within the watershed be inclined closely to approximate a straight geometric ratio**.** Most of the drainage systems demonstrate a linear relationship with a little divergence as in a straight line [8].

Mean stream length (Lsm)

It is one of the main characteristic properties of the drainage system in addition it is related to the surfaces of the basin [41]. It could be evaluated by dividing the sum of Lu of specified orders by the no. of streams of segments in the specified order. Lsm of Johilla river basin is represented in (Table 3).

Stream length ratio (RL)

Stream length ratio (RL) is an important parameter to examine the hydrological behavior of the river basin for the reason that of the permeability of the geological structure within the basin. It additionally indicates if there may be a primary variant within the hydrological behavior of the basic rock surfaces inside the basin [32]. The stream length ratio is calculated by applying the formula presented in (Table 2) and results are shown in (Table 3) which represents the value Stream length ratio varies from 1.77 to 4.79.

Bifurcation ratio (Rb)

The bifurcation ratio is the ratio of the number of streams of any given order to the number of segments of the higher stream order [11]. Rb is getting from the formula given in Table 3 and its mean bifurcation ratio is 4.48. It demonstrates a little scope of variation for various provinces or else for various conditions except for where the capable lithology and structural control overwhelm [40]. In the Johilla river basin, greater values of Rb specify a rigid structurally controlled drainage system while the lesser values point out that the sub-watersheds are slightly affected by geological conflict [7], [38], [41].

Aerial aspects drainage density (Dd)

The drainage density system in a watershed is a measure of the amount of water that is drained from the watershed over a given area [18]. It is calculated by dividing the total length of streams and rivers in the watershed by the total area of the watershed. This measure helps to identify areas of high runoff potential, which can be used to inform land management decisions. The closeness of channel spacings in a basin area is a reflection of the differential weathering of various formations, relief, and rainfall. Smith (1950) and Strahler (1957) classified drainage density as coarse (≤5), medium (5-13.7), fine (13.7-155.3) and ultra fine (>155.3). Chow (1964) suggested low drainage density in regions of highly permeable sub-soil & dense drainage density in regions of weak/impermeable sub-soil, sparse vegetation and mountain relief. Horton proposed that the Drainage Density (Dd) of a basin can be characterized by the ratio of the total length of streams of all orders to the total area of the basin. The Johilla River basin has a low drainage density of 1.06 km/km^2, as computed by Horton's formula (Table 3). This is likely due to the presence of permeable sub-surface strata, dense vegetation, and low relief. Dd values of Johilla river basin is specified in Low to High density 16.19 and 176 respectively (Fig 7).

Drainage texture (T)

In basic terms, drainage texture (T) is the outcome of drainage texture and Fs. The drainage texture is 0.846 which demonstrated that the T is course drainage texture. The Drainage Texture of the present study is influenced by various natural factors, for example, rainfall, climate, vegetation, soil type, rock type, relief, and infiltration capacity in addition to the stage of development that are responsible for drainage texture [36]. The fine texture is accountable where the soft rocks are defenseless with vegetation while hard or resistant rocks cause coarse texture. The T is classified as coarse, intermediate, fine, and ultrafine if the ranges from <4, 4-10, 10-15, and >15 respectively [36].

Stream frequency (Fs)

As per Horton (1945), the Fs is the sum of stream segments of all orders per unit area. Fs values demonstrate an optimistic relationship with the Dd of the basin proposed that the increase in stream population take place with reverence to the rising in drainage density [31]. The Stream frequency (Fs) of the study area is 0.79 (Table 4).

Table 4 Aerial aspects of Johilla River basin

Drainage density	Drainage texture	Stream frequency	Circularity ratio	Elongation ratio	Drainage texture ratio	Form factor
1.06	0.846	0.79	0.188	0.46	5.215	0.16

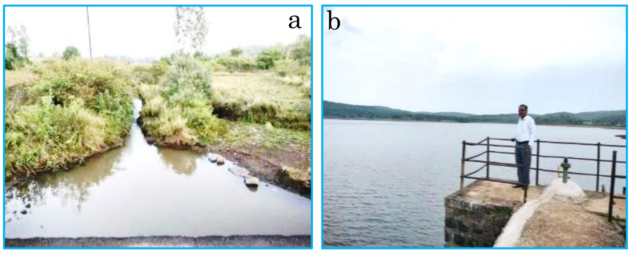

Fig 8 (a) Johillla river starting point at Amarkantak

(b) Amarkantak Reservoir, Madhya Pradesh, India

Form factor (Ff)

It is a significant character to know the outline of the basin and also predict the flow intensity. As per Horton 1945, the Ff could be the ratio of area (A) of the basin and the square of basin length (L^2). The form factor (Ff) of the study area is 0.16, If the watershed or subbasin is a circular basin the value is >0.78 else more elongated.

Circularity ratio (Rc)

As per Strahler's (1964) definition, the Circularity ratio (Rc) of the basin is the ratio of basin area (Au) to the area of a circle (Ac) including a similar perimeter as the basin. Rc has been subjective by the stream length, structures, frequency, climate, relief, slope, and LU/LC (Land use and land cover), of the watershed. The Rc is the most important proportion, which shows the parallel to sub-parallel drainage pattern. Its high, medium and low values are indicated the old, mature, and youth stages of the basin life cycle respectively. The Rc value of the study area is about 0.188 and the Rc value is 0.5 and over designate as they are relatively circular furthermore are characterized through high to moderate relief and drainage network be structurally controlled. The Johilla river basin encompasses an index of <0.50 specifying that the sub-watershed is strongly elongated in addition to impermeable homogeneous geologic materials, and has a high discharge of more runoff.

Elongation ratio (Re)

The elongation ratio (*Re*) is the fraction of the diameter of a circle of the same area as the basin and the maximum basin length [27]. According to Strahlar (1964) *Re* value ranged from 0.6 to 1.0 for various geologic and climatic conditions. The value of *Re* close to 1 is determined as areas extremely low in relief, while values ranging from 0.6–0.8 are normally related to high elevation and sharp ground slope. These values are subdivided into three modules that are (I) circular (>0.9), (ii) oval (0.9–0.8), and (iii) elongated (<0.7). The Elongation ratio of Johilla river basin is 0.46, which means that the watershed is strongly elongated and the *Re* value has been represented in (Table 4).

Table 5 Relief aspects of Erramasupalli sub-watershed

Maximum elevation of sub-watershed	Minimum elevation of sub-watershed	Total relief	Relief ratio	Ruggedness number
599	119	480	20.04	0.95

Relief aspects

Relief or elevation is one of the key parameters for drainage basin studies. Assessment of a few of the relief aspects of the basins is mentioned below.

Total relief (R)

Total relief (R) is the variance height between the highest and the lowest points of the basin it is a significant variable for understanding the denudation property of the basin analysis. The relief map is prepared with the help of SRTM 30m it shows that 1153m maximum and 355m lowest elevations in this connection the total relief of Johilla river basin is 798m (Table 5). The high relief rate is observed in the southern and western parts of the study area and here in which indicates the magnitude of water flow, high runoff, and low infiltration rate conditions.

Relief ratio (Rr)

As per Schuman [28], the Rr is the dimensionless height-length ratio equivalent to the tangent of the angle produced through two flat surfaces interconnecting at the mouth of the basin, one exhibiting the horizontal and another one by way of the highest spot of the basin. It is also the main indicator of the strength of the erosion cycle development on the slope of the watershed. The Relief ratio of the study area is 6.01.

CONCLUSION

Geospatial technology with high-resolution satellite data involves detailed watershed management efficiently with less time and low cost. In this study we evaluated through the measurement of i) Linear ii) Aerial and iii) Relief aspects of watersheds. The morphometric analysis of the study area discloses that it is designated as a VIth Order River and exhibits dendritic to sub dendritic and parallel to sub-parallel drainage pattern which indicates the drainage has been highly controlled by the Lithology and structures. Naturally, lower-order streams are dominant. The geometrical relation of linear aspects of stream order, number, and length observed with logarithmic function as good relation. The mean Bifurcation ratio of the sub-watershed is 4.48. It demonstrates a little scope of variation for various provinces or else for various conditions except where the capable lithology and structural control overwhelm. The aerial and relief aspects of a sub-watershed are drainage density, stream frequency, and relief ratio indicating less rainfall and rapid runoff. Moreover, these aspects influence the sediment yield, runoff pattern, and different hydrological parameters. The Dd of the sub- watershed is 1.06 which is extremely coarse with high relief. The topography, aspect, and lithology of the basin have an important bearing on its hydrological characteristics of the basin. The sub-watershed is highly elongated (0.46), and the basin slope is moderate to steep. Morphometric analysis of a watershed is important for planning and management, locating the artificial recharge sites for augmenting the groundwater. The river basin originates from the steep slope area. Mostly 2nd order and 3td order streams are favorable locations for constructing artificial recharge statures such as check dams, Nalabunds.

Abbreviations

DEM- Digital Elevation Model

GIS- Geographical Information System GSI- Geological Society of India

IRS- Indian Remote Sensing Satellite RS- Remote Sensing

SOI- Survey of India

SRTM-Shuttle Radar Topography Mission

Acknowledgments

The authors are deeply grateful to the Department of Geology, Yogi Vemana University, the Geological Society of India (GSI), Survey of India (SOI), and the United States Geological Survey (USGS) for providing the necessary facilities, base geology maps, topographical maps, and SRTM satellite data, respectively.

LITERATURE CITED

1. Agarwal CS. 1998. Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P. *Jr. Indian Soc. Remote Sensing* 26: 169-175.
2. Avinash K, Jayappa KS, Deepika B. 2011. Prioritization of sub-basins based on geomorphology and morphometricanalysis using remote sensing and geographic information system (GIS) techniques. *Geocarto Int*. 26(7): 569-592.
3. Bali YP. 1980. Selection of implementation area/ catchment, watershed delineation, classification and priority determination. National Seminar on Watershed Management- Rainfed and Himalayan Development. New Delhi, India.
4. Burrough PA. 1986. *Principles of Geographical Information Systems for Land Resources Assessment.* Oxford: Oxford University Press, 1986.
5. CGWB. 2013. *District Groundwater Information Booklet*. Anupur District, Madya Pradesh, India
6. Chandrashekar H, Lokesh KV, Sameena M, Roopa J, Ranganna G. 2015. GIS–based morphometric analysis of two reservoir catchments of Arkavati River, Ramanagaram district, Karnataka. *Aquatic Procedia* 4: 1345-1353.

7 Chopra R, Dhiman RD, Sharma PK. 2005. Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing* 33(4): 531-539. doi:10.1007/bf02990738.

8. Chow Ven T. 1964. *Handbook of Applied Hydrology*. McGraw Hill Inc., New York.
9. Clarke JI. 1996. Morphometry from Maps. Essays in geomorphology. Elsevier publication. 1996, Co., New York. pp 235-274.
10. El-Tahan AHMH, Elhanafy HEM. 2016. Statistical analysis of morphometric and hydrologic parameters in arid regions, case study of Wadi Hadramaut. *Arabian Journal of Geosciences* 9(2): doi:10.1007/s12517-015-2195-7.
11. Horton RE. 1945. Erosional development of streams and their drainage basins: Hydro physical approach to quantitative morphology. *Bull. Geo. Soc. Am*. 56: 275-370.
12. John Wilson JS, Chandrasekar N, Magesh NS. 2012. Morphometric analysis of major Sub Watersheds in Aiyar & Karai Pottanar Basin, Central Tamil Nadu, India using Remote Sensing & GISTechniques. *Bonfring Int. Jr. Ind. Eng. Manag. Science* 2(Special issue 1): 8-15.
13. Kale VS, Shejwalkar N. 2007. Western Ghat escarpment evolution in the Deccan Basalt Province: geomorphic observations based on DEM analysis. *Jr. Geol. Soc. India* 70(3): 459.

14. Kim JB, Saunders P, Finn JT. 2005. Rapid assessment of soil erosion in the rio lempa basin, central america, using the universal soil loss equation and geographic information systems. *Environmental Management* 36(6): 872-885. doi:10.1007/s00267-002-0065-z.
15. Magesh NS, Chandrasekar N, Soundranayagam JP. 2010. Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. *Environmental Earth Sciences* 64(2): 373-381. doi:10.1007/s12665-010-0860-4.
16. Magesh NS, Jitheshlal KV, Chandrasekar N, Jini KV. 2013. Geographical information system-based morphometric analysis of Bharathapuzha river basin, Kerala, India. *Applied Water Science* 3(2): 467-477.doi:10.1007/s13201-013-0095-0.
17. Mesa LM. 2006. Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina). *Environ Geology* 50(8): 1235-1242.
18. Moglen GE, Eltahir EAB, Bras RL. 1998. On the sensitivity of drainage density to climate change. *Water Resources Research* 34(4): 855-862. doi:10.1029/97wr02709.
19. Obi Reddy GE, Maji AK, Gajbhiye KS. 2012. GIS for morphometric analysis of drainage basins. *GIS India* 4(11): 9-14.
20. Patel DP, Dholakia MB, Naresh N, Srivastava PK. 2012. Water harvesting structure positioning by using geo-visualization concept and prioritization of mini- watersheds through morphometric analysis in the Lower Tapi *Basin. Jr. Indian Soc. Remote Sens*. 40(2): 299-312.
21. Prabu P, Baskaran R. 2013. Drainage morphometry of upper Vaigai river sub-basin, Western Ghats, South India using remote sensing and GIS. *Journal of the Geological Society of India* 82(5): 519-528. doi:10.1007/s12594-013-0183-7.
22. Prasannakumar V, Vijith H, Geetha N. 2011. Terrain evaluation through the assessment of geomorphometric parameters using DEM and GIS: A case study of two major sub- watersheds in Attapady, South India. *Arabian Journal of Geosciences* 6(4): 1141-1151. doi:10.1007/s12517-011-0408-2.
23. Rai PK, Mohan K, Mishra S, Ahmad A, Mishra VNA. 2014. GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. *Applied Water Science* 7(1): 217-232. doi:10.1007/s13201-014-0238-y.
24. Rajasekhar M, Raju GS, Raju RS. 2020. Morphometric analysis of the Jilledubanderu river basin, Anantapur District, Andhra Pradesh, India, using geospatial technologies. *Groundwater for Sustainable Development* 11: 100434.
25. Rastogi RA, Sharma TC. 1976. Quantitative analysis of drainage basin characteristics. *Jr. Soil Water Conservation India* 26(1/4): 18-25.
26. Roy PS, Dwivedi RS, Vijayan D. 2010. *Remote Sensing Applications*. RS & GIS applications area NRSC-ISRO.
27. Schumm SA. 1956. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Bulletin Geol. Soc. Am*. 67: 597-646.
28. Schumm SA. 1963. Sinuosity of alluvial rivers in the Great Plains. *Bulletin Geol. Soc. Am*. 74: 1089-1100.
29. Siddi Raju R, Sudarsana Raju G, Rajasekhar M. 2020. Morphometric analysis of Mandavi River Basin in Rayalaseema region of Andhra Pradesh (South India), using remote sensing and GIS. *Jr. Ind. Geophys. Union* 24(1): 54-67.
30. Siddi Raju R, Sudarsana Raju, Rajasekhar M. 2018. Estimation of rainfall-runoff using SCS-CN techniques for Mandavi Basin in YSR Kadapa district of Andhra Pradesh, India. *Hydrospatial Analysis* 2(1): 1-15. http://dx.doi.org/10.21523/gcj3.
31. Singh P, Gupta A, Singh M. 2014. Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques. *The Egyptian Journal of Remote Sensing and Space Science* 17(2): 111-121. doi:10.1016/j.ejrs.2014.09.003.
32. Singh S. 1995. Quantitative analysis of watershed geomorphology using remote sensing techniques. *Annuals of Arid Zone* 34(4): 243-251.
33. Singh S, Kanhaiya S. 2015. Morphometry of the Barakar river basin, India: a remote sensing and GIS approach. *Int. Jr. Curr. Research* 7(7): 17948-17955.
34. Singh S, Kumar S, Mittal P, Kanhaiya S, Prakash P, Kumar R. 2018. drainage basin parameters of Bagh River, a sub-basin of Narmada River, Central India: Analysis and implications. *Jr. Appl. Geochem.* 20(1): 91-102.
35. Singh S, Srivastava R. 1974. A morphometric study of tributary basins of the upper reaches of the Belan River. *Natl. Geogr*. 11(2): 123-131.
36. Smith KG. 1950. Standards for grading texture of erosional topography. *American Journal of Science* 248(9): 655-668. doi:10.2475/ajs.248.9.65 5.
37. Sreedevi PD, Sreekanth PD, Khan HH, Ahmed S. 2012. Drainage morphometry and its influence on hydrology in a semi-arid region: using SRTM data and GIS. *Environmental Earth Sciences* 70(2): 839-848. doi:10.1007/s12665-012-2172-3.
38. Srinivasa Vittala S, Govindaiah S, Honne Gowda H. 2004. Morphometric analysis of sub- watersheds in the Pavagada area of Tumkur district, South India using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing* 32(4): 351-362. doi:10.1007/bf03030860.
39. Srivastava PK, Gupta M, Mukherjee S. 2012. Mapping spatial distribution of pollutants in groundwater of a tropical area of India using remote sensing and GIS. *Appl. Geomat*. 4(1): 21-32.
40. Strahler AN. 1957. Quantitative analysis of watershed geomorphology. *Trans. Am. Geophys. Union* 38: 913-920.
41. Strahler AN. 1964. Quantitative geomorphology of drainage basins and channel networks. *In*: (Eds) Chow V.T. Handbook of Applied Hydrology. McGraw Hill, New York (NY). pp 39-76.
42. Strahler AN. 1957. Quantitative analysis of watershed geomorphology. *Trans. Am. Geophys. Union* 38: 913-920.