Original Research Article

IntegratedMorphometric and Hypsometric Analysis of NiragantipalliMicro Watershed Using Remote Sensing and Geographical Information System Techniques

ABSTRACT

Employing Remote sensing (RS) and geographic information system (GIS) for the morphometric parameters analysis are discovered to be tremendous usefulness in the prioritization of watersheds for soil, water conservation and natural resource management at micro watershed level. The analysis of morphometric parameters plays a crucial role for understanding and managing watersheds. In current study an, attempt was to determine the morphological parameters of Niragantipallimicro-watershed in Chikkaballapura District of Karnataka, India.For detail study, Google earth pro, GPS visualizer conversion toll and Arc GIS were used for preparation of DEM and delineation of the watershed boundary. GIS was used for evaluation of basic, linear, areal and relief aspects of morphometric parameters. The Niragantipalli micro-watershed occupies an area of 632 ha with third order stream (truck order) and dendritic drainagepattern. The mean bifurcation ratio of the micro-watershed is 2.5 it suggests that the drainage system formed on homogeneous rock when the influences of geologic structures on the network of streams were negligible and generate sharp peak flow.With a drainage density of 1.31 km/km2, the drainage network is extremely coarse. The watershed is elongated, as shown by the form factor of 0.27 and elongation ratio of 0.58.

The results from the morphometric analysis of the watershed are very beneficial for developing and designing conservation structures of soil and watershed management measures. The hypsometric curves' structure as well as estimated hypsometric integral results reflects the Niragantipalli Micro Watershed erosional stages. As a result, the study concludes that morphometric and hypsometric analysis findings may be useful to stakeholders participating in catchment development and management projects.

Key words: Niragantipalli micro-watershed, Dendritic Pattern, Morphometric evaluation, RS and GIS

1. INTRODUCTION

Water stands as the cornerstone among natural resources, playing a pivotal role in both human welfare and the economic advancement of nationsabdeta*et al.,* 2020. Its judicious utilization becomes imperative to meet the needs of future generations.Watershed is an area enclosed by a well defined boundary or ridge line and draining ultimately to a specific outlet. The morphometric evaluation of the basin gives a detailed overview of a drainage network system and is a significant feature in watershed characterization (Strahler, 1964 and 1957). The morphometry is the branch of mathematics that specifically focuses on describing the terrain data such as studies of ground water projection, relief, lithology, hydrology, and watershed variances. Through quantitative analysis, these can be investigated and clarified (Pande*et al.,* 2018 and Shivaswamy*et al.,* 2019).

A watershed's morphometric analysis is a is aimportant aspect of hydrological extensive research,offering insightful details regarding thewatershed's physical characteristics and hydrological behaviour (Rekha*et al.,* 2011). This analysis involves the quantitative evaluation of the watershed's morphology, which includes factors such as stream order, bifurcation ratio,drainage density and relief aspects. Digital delineation techniques have revolutionized morphometric analysis by enabling precise and efficient extraction of these parameters using geospatial tools (Dhabal*et al.,* 2014 and Sukristiyant*et al.,* 2018).

In this investigation, we utilized digital elevation models (DEMs) prepared using Google Earth Pro, GPS Visualizer, and ArcGIS to carry out a comprehensive morphometric analysis of the selected watershed. Google Earth Pro provided high-resolution elevation data, while GPS Visualizer was used to convert coordinate data into geospatial formats compatible with ArcGIS. ArcGIS, with its advanced spatial analysis capabilities, was employed for DEM processing and the subsequent extraction of morphometric parameters (Kumar *et al.,* 2021). This coordinated strategy not only ensures accuracy but also enhances the understanding of the watershed’s terrain, which is necessary forefficient management of watershed and planning. Morphometric parameters are very usefull in watershed evaluation, setting priorities, soil and water conservation and protecting natural resource management (Ashwini *et al.,* 2021).

Recently, a large number of scholars have access to have discovered that remote sensing and GIS are vital techniques for drainage network analysis of parameters from different data sources(Guptha et al., 2021). The foremost advantage of the remote sensing and GIS method for drainage network analysis over conventional method,RS and GIS is capable of managing and processing spatial information in large amounts, efficiently and accurately (Sreedevi *et al*., 2009 and Singh *et al.,* 2024). In the current investigation, an integrated application of RS and GIS was utilized for the analysis of drainage network parameters of the Niragantipallimicro-watershed of Chikkaballapura District, Karnataka, India. The determined values were plotted and evaluated by utilizing GIS and statistical approaches to recognize the drainage basin and stream network systems.

The primary goal of this paper was the demarcation of the Niragantipallimicro-watershed and determination of morphological feature utilizing remote sensing and GIS technique. Specifically, we focused on drainage network analysis to provide knowledge to further appreciate the hydrological features of a study area and conceptual foundations.Give an example of how spatial mapping approaches can be used to produce morphological information related to basin, flow directions, flow accumulation, upstream and downstream, stream link, stream network, stream order, and DEM.

2. MATERIALS AND METHOD

2.1 Location

The Niragantipalli micro-watershed (WS-Code:4C3G8d05) is situated in Gollapallisub-watershed, of Chikkaballapura district in South-east part of Karnataka, India. It covers a total geographical area of 632 ha, which is part of theand situated within the Eastern dry Agro climatic zone of Karnataka and lies between 13˚46' 17.36" N latitude and 77˚51′ 56.44" E longitudes to 13˚44′ 51.06" N latitude and 77˚53′ 19.97" E longitudes with an typical elevation of 915 m above mean sea level (MSL). The study area's average annual rainfall is 615mm. The area of micro-watershed is predominantly under the influence of southwest monsoon with 90per cent of the rainfall falling from June to September, August being the wettest month. Temperatures range from 18°C to 36°C.The research area's location map can be foundin Fig. 1.

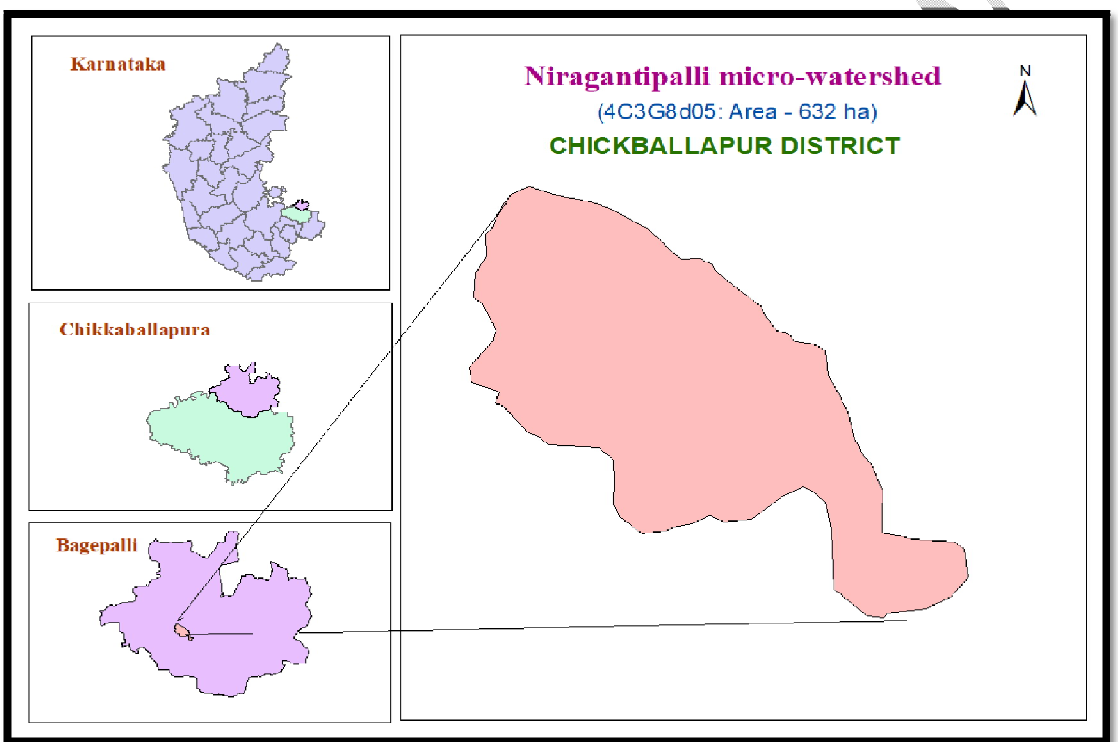

Fig.1 Location map of Niragantipalli micro-watershed

2.2 Software used

The development of GIS data in the desired format is complex in nature particularly, for hydrological analysis. ArcGIS 10.8.1 version was used to prepare the map layout and to get good output, which was easy to work and integrate the different feature class maps in a single layer. Using spatial analyst tools present in the software, several thematic maps required for the study were prepared. The whole investigation was completed in ArcGIS 10.8.1 version in the REWARD Project.

Google Earth Pro is a valuable tool for watershed studies. It provides a user-friendly platform to visualize, analyse, and understand watersheds. It offers high-resolution satellite imagery and topographic data, allowing to visualize the entire watershed, including streams, rivers, lakes, and land cover. It is used to measure distances, areas, and slopes within the watershed. This information is crucial for calculating drainage patterns, runoff rates, and potential erosion risks. This software facilitates DEM map creation for the Niraganipalli micro-watershed by enabling the extraction of elevation points.

2.3 Geomorphological analysis

Geomorphological analysis is the methodicalstudy of the geometry and its stream channel system of the watershed in order to quantify the (I) Linear aspects of drainage network (II) Areal aspects of watershed and (III) Relief aspects of channel network. The watershed's hydrological features and rock formation are revealed by the morphological parameters, either directly or indirectly (Patel *et al.,* 2019). Topographic maps were obtained and used as foundation for the creation of many GIS data maps to establish an effective information platform to systematically proceed with the calculation of morphometric parameters.

Firstly, Google Earth Pro is employed to recognize and extract elevation data of the field of study. This data can then be converted into a compatible format using GPS Visualizer, which translates the Google Earth coordinates into a DEM file. In ArcGIS, the DEM is imported and further processed and projection to the desired coordinate system (e.g., UTM / Kriging) (Prithiviraj andVekateswaran, 2019). The DEM is then refined using spatial analyst tools for applications such as watershed analysis in ArcGIS 10.8.1 environment. The complete procedure of morphological investigation is illustrated in Fig. 2.

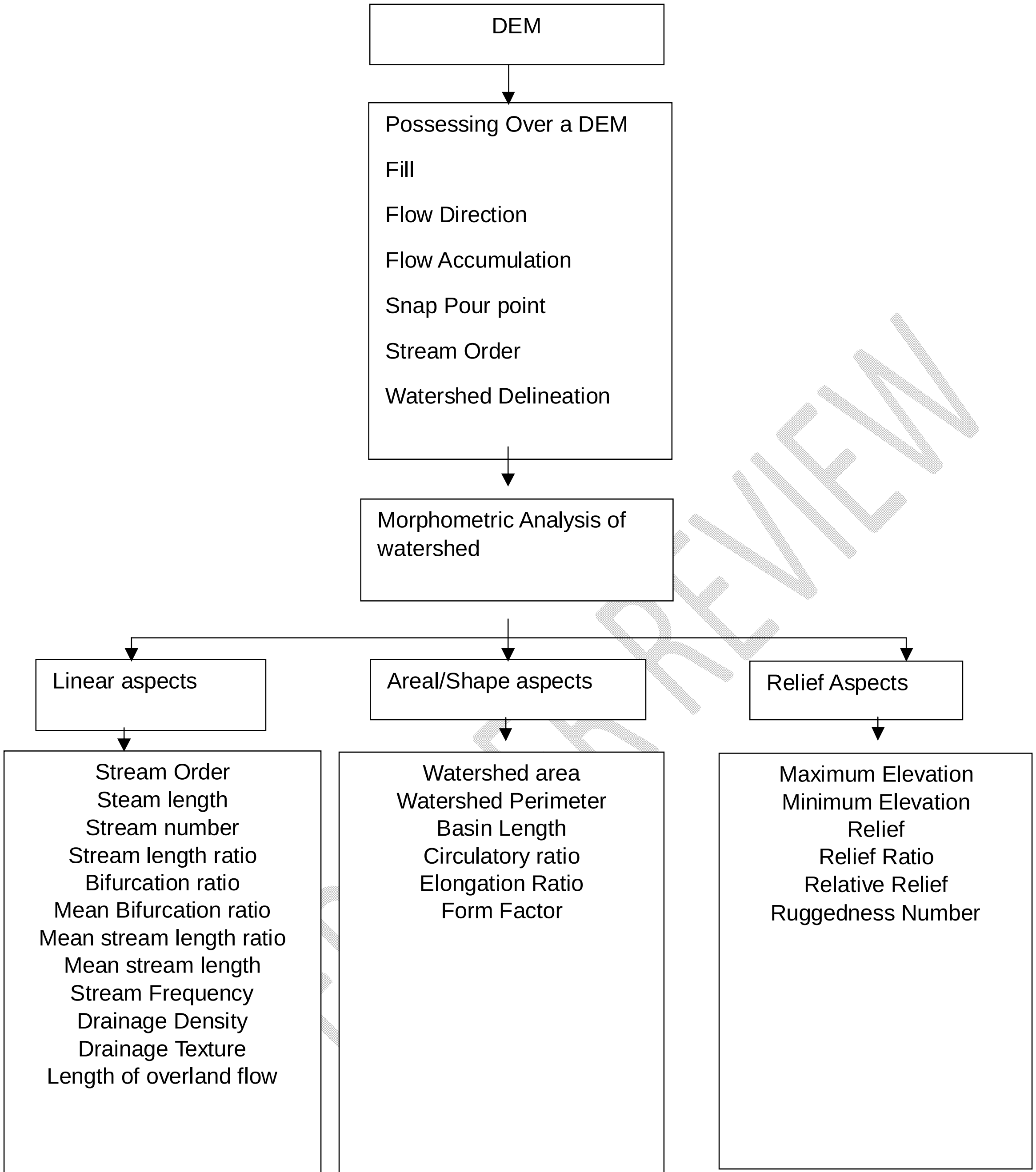

Fig. 2. Flow chart representing procedure for morphometric analysis of Niragantipallimicro-watershed.

2.4 Linear aspects of drainage network

2.4.1 Stream order : First order stream are the tiniest fingertip tributaries without branches; where two first order streams converge, a second order channel segment is created and so on. The maximum order segment carries the sediment flow of water at the outlet of the watershed.

2.4.2 Mean stream length : It is the length ($\bar{L}_u$) of all order streams by dividing total number of segments of that order (N_u). It is computed using the equation that follows.

$$\bar{L}_u = \frac{\sum_{i=1}^{N} L_u}{N_u}$$

Where,

$\bar{L}_u$= Mean stream length, km

L_u = Cumulative length of all streams of order u, km

N_u = Number of streams of the given order u.

2.4.3 Stream length ratio (R_L)

The stream length ratio is the ratio of the mean stream length of a given order to the mean stream of the next lower order (Harton 1945). As stated this ratio increase as we move from lower stream order to higher stream order and iscalculated using following formula.

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}}$$

Where,

R_L**=** Stream length ratio

$\bar{L}_u$ **=** Mean stream length, km

$\bar{L}_{u-1}$= Mean stream length of next lower order, km

2.4.4 Bifurcation ratio (R) : The number of streams of any order divided by the number of streams of the next higher order is knows as the bifurcation ratio. It can be calculated using the following formula.

$$R_b = \frac{N_u}{N_{u+1}}$$

Where,

R_b = Bifurcation ratio

N_u = Number of stream segments of order ‘u’ and

N_{u+1} = Number of stream segments of next higher order

(E) Areal aspects of watershed

2.4.5 Form factor (R_f)

It is the proportion of the square of the watershed area to that of watershed length and it is dimensionless ratio. It is used asa quantitative expression of the shape of watershed.

$$R_f = \frac{A}{(L_b)^2}$$

Where,

R_f = Form factor

A = Area of watershed(km^2)

L_b = Length of basin (km)

2.4.6 Drainage density (D_d)

It is defined as the proportion of cumulative length of all stream order per drainage area and is expressed in km km^{-2}.

$$D_d = \frac{L}{A}$$

Where,

D_d = Drainage density, km km^{-2}

L = Total length of streams of all order, km

A = Total area of watershed, km^2

2.4.7 Drainage texture (D_t)

It is the proportion of all stream segments of all orders to the perimeter of that area (Harton, 1932). The drainage texture is expressed as.

$$D_t = \frac{N}{P}$$

Where,

D_t = Drainage texture, per km

N = Total number of stream segments of all orders

P = Perimeter of the watershed, km

2.4.8 Circulatory ratio (R_c)

Miller (1953) defined circulatory ratio (R_c) is the ratio of watershed area to the area of a circumference of circle having the same perimeter as the watershed.

$$R_c = \frac{4\pi A}{(A_c)^2}$$

Where,

R_c = Circulatory ratio

A = Area of watershed, km^2

A_c = Perimeter of the watershed, km

2.4.9 Elongation ratio (R_e)

Schumm (1954) The diameter of circle with the same area as the basin divided by the maximum basin length is known as the elongation ratio.

$$R_e = \frac{D_c}{L_b} = \frac{2 \times \sqrt{A/\pi}}{L_b}$$

Where,

R_e = Elongation ratio

D_c = Diameter of the circle having same area as that of the basin, km

L_b = Basin length, km

A = Basin area, km^2

2.4.10 Texture ratio (R_t)

It is computed using the following formula and represents the number of first order streams per unit perimeter of the drainage basin (Horton, 1932).

$$R_t = \frac{N_1}{P}$$

Where,

R_t = Texture ratio

N_1 = Number of first order streams

P = Basin perimeter, km

2.5 Relief aspects of drainage network

2.5.1 Maximum watershed relief (H)

The elevation difference between the basin outflow (discharge point) and the three highest points on the basin perimeter is known as maximum watershed relief (H).

2.5.2 Relative relief (R_R)

It is the ratio of maximum watershed relief to the length of perimeter. It is an indicator of general steepness of the basin from peak to outlet. It is computed by using following expression.

$$R_R = \frac{H}{L_p} \times 100$$

Where,

R_R = Relative relief, per cent

H = Watershed relief, m

L_p = Length of perimeter, m

2.5.3 Relief ratio (R_r)

It is the highest watershed relief divided by the length of the basin. The drainage basin's overall sharpness 11 is increased by the relief ratio, which can be calculated using the formula below.

$$R_r = \frac{H}{L_b}$$

Where,

R_r = Relief ratio

H = Maximum watershed relief, m

L_b = basin length, km

2.5.4 Ruggedness number (R_n)

Its definition is the result of the drainage density and the maximum watershed relief. A location with high relief and a high density of streams experiences an abnormally high ruggedness number. It gives a sense of a watershed's general roughness.

$$R_n = \frac{H\,D_d}{1000}$$

Where,

R_n = Ruggedness number

H = Maximum watershed relief, m

D_d = Drainage density, km km^{-2}

2.5.5 Time of concentration (T_c)

The following expression provides the amount of time needed for runoff water to travel from the watershed's most remote point to its outflow.

$$T_c = 0.0195 L^{0.77}\, S^{-0.385}$$

Where,

T_c = Time of concentration, min

L = Length of watershed from remote point to outlet, m

S = Slope of the catchment, per cent

The hypsometric curve serves as a crucial tool for understanding the overall slope and geomorphology of the area. It represents the proportion of the micro-watersheds area that lies above a particular elevation, providing insight into the erosional stages of the landscape. The curve's shape can reveal whether the micro-watershed is in a youthful stage, indicated by a convex upward curve, a mature stage, characterized by an S-shaped curve that is convex downward at lower elevations and concave upward at higher elevations marked by a concave upward curve (Shekar*et al.,* 2023). These stages, as defined by Strahler (1952), reflect the micro-watershed's susceptibility to erosion and its stabilization over time. The hypsometric integral (HI) further quantifies this, with values greater than 0.6 indicating a young, erosion-prone micro-watershed, values between 0.3 and 0.6 suggesting a mature stage and values below 0.3 representing a stabilized, monadnock or old landscape as shown in Fig.2. Understanding these characteristics is essential for effective catchment treatment, basin planning and identifying potential sites for rainfall harvesting within the micro-watershed(Markose and Jayappa, 2019).

For the research area, the hypsometric analysis was examined by utilizing RS and GIS approaches as shown in Fig. 3. The contours were created in ArcGIS 10.8.1 software using the line feature class and then processed with the spatial analyst's hydrology tool. The contours elevation, length, area and perimeter values, were stored in the attribute tables of the geo-referenced feature classes that represented the contours and their enclosed area with the watershed boundary (Aravinda and Balakrishna, 2013). The micro-watershed's hypsometric curve was plotted using attribute feature classes that contained these values. In this investigation, the HI was determined using the elevation-relief ratio approach (Shekar and Mathew, 2022) as exhibited inTable. 2.

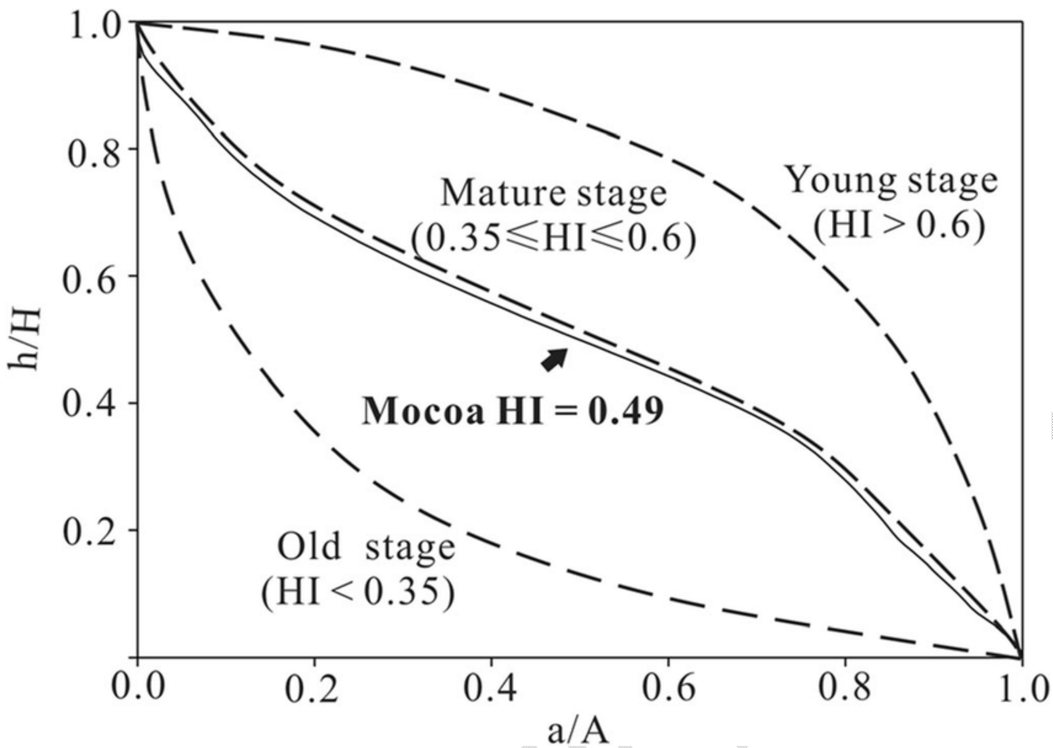

Fig.3. Stages of Hypsometric curve

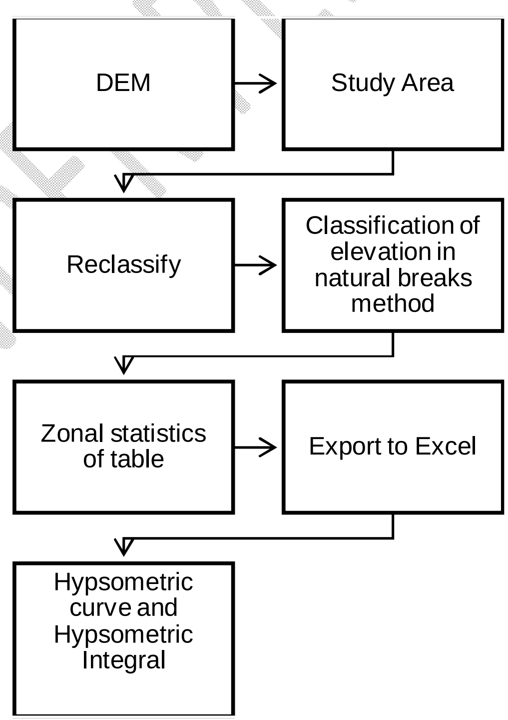

Fig. 4.Flow chart representing procedure for hypsometric analysis

3. RESULT AND DISCUSSION

Morphology is the quantification and statistical study of surface, shape and structure measurement of the earth (Stahler 1957). This research stressed the utilization of RS & GIS towards morphological assessment and the outcomes are addressed below. Using formulas, the values of the various geomorphological parameters were determined. The values that were computed are shown in Table 1.

3.1 Morphological Characteristics

The morphological characteristics of the researcharea was represented in the Table 1.

3.1.1 Linear aspect of the Watershed

The examination of the bifurcation ratio, stream length ratio, stream order, and stream number is referred to. Following examination, it was discovered that the watershed is of 3rd order stream with dendrite drainage pattern. The numbers of stream of 1st, 2nd, and 3rd, order is 6, 2 and 1 correspondingly, and their matching length are 5574.36, 2666.2 and 40.2 m respectively. The values of stream length ratio (R_L) for 2nd to 1st and 3rd to 2nd order streams wasdiscovered to be 0.478 and 0.0076 respectively. The ratio of stream length varies according to the change in geography and slope. Typically, thestream length ratio valuetends to increase as we move from lower stream orders to higher stream orders (Horton 1932). But in this study area a declining trend in the mean stream length ratio indicates that the terrain is undulating and such areas, higher-order streams are relatively shorter compared to lower-order streams, resulting in a higher value for this ratio at the higher stream orders. (Shekar *et al.* 2022). The mean bifurcation ratio was found to be 2.5 indicates a more elongated and undistorted geologic structure. (Premanand *et al.*, 2018 and Manoj *et al.,* 2022)

3.1.1.1Relation between stream number and stream order

This graph, which was plotted for the watershed in the current study, satisfies Horton's law by showing a straight line. It is clear that the straight line fit for the watershed has a correlation coefficient of 0.98, which is pretty excellent.

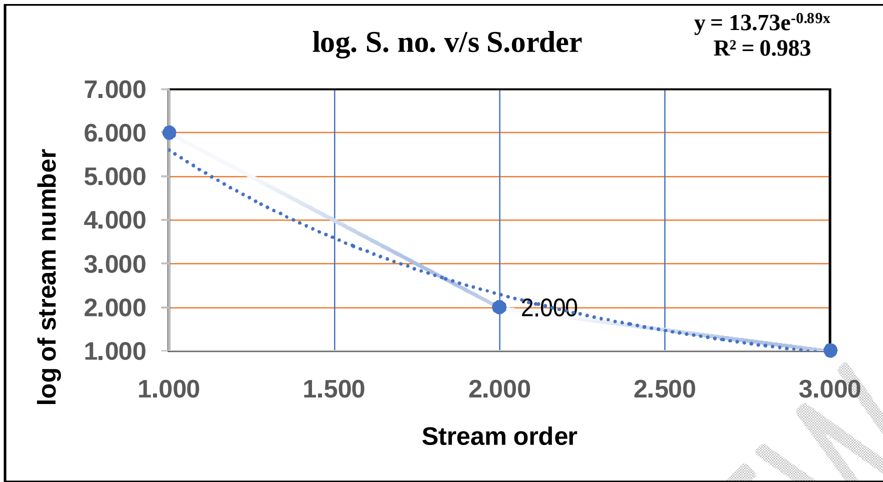

Fig. 5. Regression of logarithm of stream number and stream order

3.1.1.2 Relation between cumulative stream length and stream order

As seen in Fig. 6, the watershed's logarithm of cumulative stream length along the ordinate and stream order along the abscissa are plotted in a straight line. The straight line implies that geometrical resemblance is maintained in basins of rising order and shows that the ratio between cumulative stream lengths is consistent throughout a basin's consecutive order (Kumar 2001 and Gupta, 2003). It is also clear that the straight line fit for the watershed has a correlation coefficient of 0.86, which is very excellent.

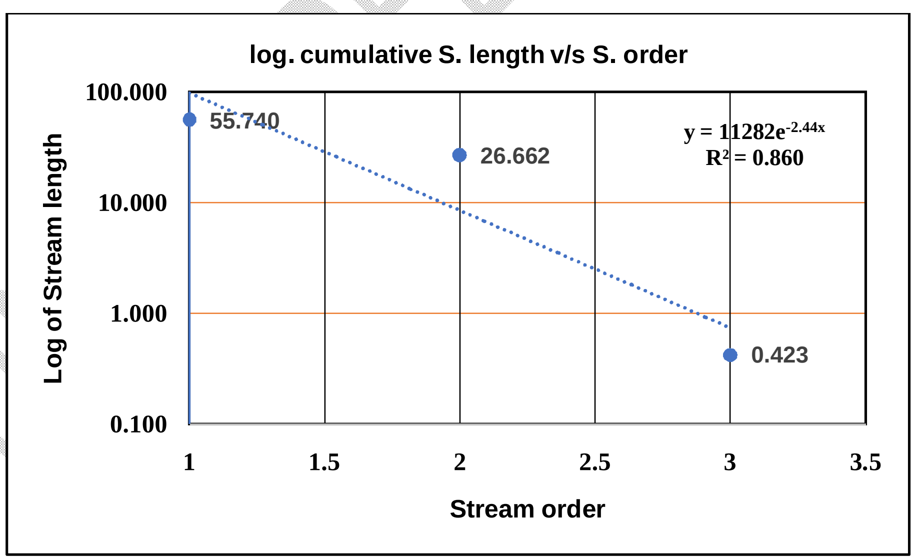

Fig. 6.Regression of logarithm of cumulative stream length and stream order

3.1.2 Areal aspects of Watershed

Referring Table 1, it demonstrates that the value of form factor (Rf), circulatory ratio (Rc) and elongation ratio (Re) are 0.27, 0.46 and 0.58 respectively. The high value of Re compare to

Rcsuggests that the watershed is elongated shape. The value of drainage density (D_d) and stream frequency (F) were 1.31 km km^{-2} and 0.014 no ha^{-1}.These values indicates that, Coarse textured watershed with gentle slope to moderate slope,sub-surface strata is porous and a less interconnected drainage network. A similar result was also reported by Premanand *et al.,* (2018) and Ananad *et al.,* (2020). The length of over land flow (L_g) and compactness coefficient (C_c) for the micro-watershed were 0.36 km km^{-2} and 1.47 respectively, as shown in Table 1. (Vinoth *et al*. 2014 and Praveen Kumar Rai *et al.*, 2017).

3.1.3 Relief aspects of drainage network

The calculated relief value (H) was 296.30 m, based on which relief ratio (R_r) and relative relief (R_R) were found to be 0.072 and 0.26 respectively. This was an indication of erosion and reflects that the watershed is to be treated with soil and water conservation measures. Addition to these characteristics, Ruggedness number (R_N) and geometric number were computed and values were 0.67 and 0.47, respectively, as shown in Table 1. With high value of Ruggedness number 0.67 is obvious that watershed is having high slope in some parts of the watershed. (Manoj *et al*., 2022).

Table. 1 Morphological characteristics and results of Niragantipalli micro-watershed

Sl.No.	Morphological Characteristics	Estimated values
	Liner Aspects Parameter	
1	Area, ha	632
2	Perimeter, m	13107.85
3	Basin length (L_b), m	4835.14
4	Avg. basin width, m	2626.35
5	Stream Order	
	I	6
	II	2
	III	1
6	Stream length (L_u), m	
	I	5574.36
	II	2666.2
	III	42.33
7	mean stream length, m	
	I	929
	II	1333.10
	III	40.33
8	Bifurcation ratio (R_b)	
	I	3
	II	2
	mean	2.5

9	Stream length ratio (L_u)	
	R1	0.47
	R2	0.015
	The areal aspects parameters	
10	Drainage density (D_d), km km^{-2}	1.31
11	Stream frequency (F), no.ha^{-1}	0.014
12	Drainage Texture (D_t), no.km^{-1}	1.068
13	Form factor (R_f)	0.27
14	Shape factor (S_b)	3.70
15	Circulatory ratio (R_c)	0.46
16	Elongation ratio (Re)	0.58
17	Length of overland flow (L_g), km km^2	0.36
18	Compactness coefficient (C_c)	1.47
	The relief aspects parameters	
17	Total relief (H), m	296.30
20	Relief ratio (R_r), km^2	0.06
21	Relative relief	0.023
22	Ruggedness no. (R_N)	0.67
23	Geometric No.	0.47
24	Constant of channel maintenance (C)	0.40
25	Time of concentration (T_c)	37.43

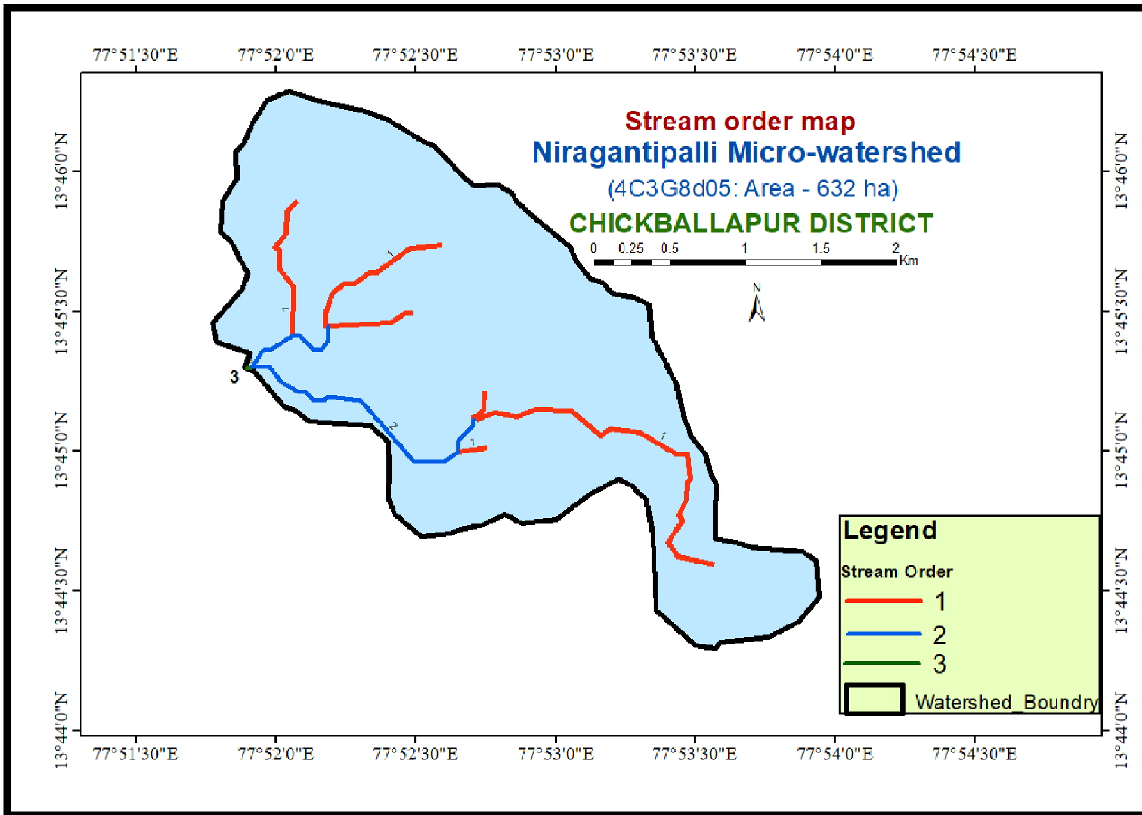

Fig. 7. Stream order map of Niragantipalli micro-watershed

3.2 Hypsometric analysis of Niragantipalli micro-watershed

Hypsometric curve (HC) is representation of relative heights and relative surface area. A young basin is indicated by a convex upward hypsometric curve, whereas a mature basin is indicated by an S-shaped HC and an old or eroded basin is indicated by a concave curve. The hypsometric curves for the Niragantipalli micro-watershedwere found to be a mix of convex and concave and S shapes (Fig. 8), which could be attributed to soil erosion caused by washout of the soil mass and stream cutting. HC is used to determine the result of the HI for the current study areas listed in Table 2. The hypsometric integral was calculated using Pike and Wilson's relation and the value of hypsometric integral was determined to be 0.49, suggesting that the soil was mature or at equilibrium. Comparable findings were reported by Kadlag*et al.,* 2022, Ashwini *et al.,* 2021 and Shekar *et al.,* 2022.

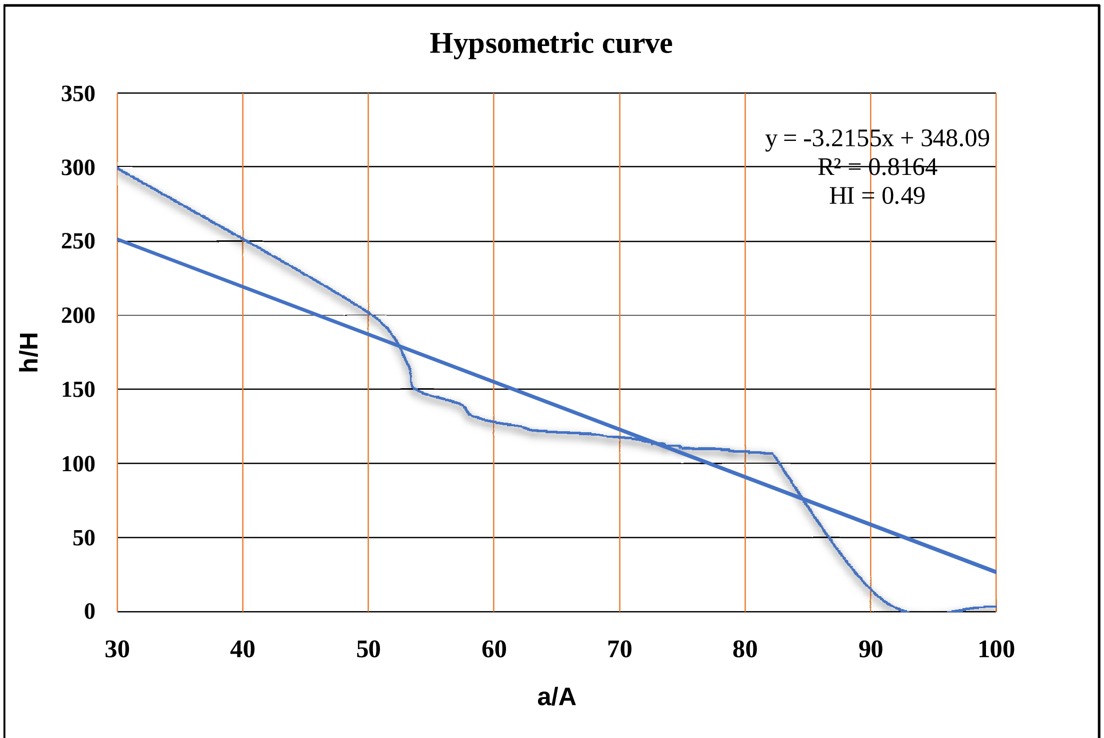

Fig. 8. Hypsometric curve of the Niragantipalli micro-watershed

Sl. Nor	MIN	MAX	MEAN	RANGE	MEAN - MIN	A(km^2)	h	a	a/A	h/H	HI	Hypsometric Integral (HI)	Geological Stage
1	763.0414	792.6661	780.1959	29.6247	17.15443	2.968207	29.6247	6.32858	0.223807	1234.992	0.579058	0.49	Mature stage
2	792.6766	822.2672	804.3507	29.59064	11.674132	1.588463	59.21533	3.36037	0.279986	882.201	0.394521		
3	822.3144	851.9017	835.2511	29.58734	12.936677	0.617919	88.80267	1.77191	0.210376	783.9162	0.437237		
4	851.9494	881.5269	865.7428	29.57745	13.793378	0.323515	118.3801	1.15399	0.182347	588.3558	0.466348		
5	881.775	911.1076	896.5104	29.33258	14.73536	0.236182	147.7127	0.83048	0.077634	0.375427	0.502355		
6	911.2949	940.7814	925.8649	29.48651	14.570004	0.197734	177.1992	0.59430	0.176855	0.301177	0.494124		
7	940.7977	970.3813	954.3981	29.58362	13.600339	0.153793	206.7828	0.39656	0.151455	0.214511	0.459725		
8	970.7157	1000.03	985.1905	29.3147	14.474794	0.116993	236.0975	0.24277	0.530984	0.201205	0.493773		
9	1000.077	1028.898	1011.455	28.82178	11.378015	0.079643	264.9193	0.12578	0.131227	0.167437	0.394771		
10	1029.911	1059.296	1044.616	29.38416	14.704904	0.046138	294.3035	0.04613	1	0.10066	0.500437		
					H 294.303	A 632.0(ha)					0.49		

Table 2. Hypsometric curve and Hypsometric Integral Calculations of Niragantipalli Micro-watershed

4. CONCLUSION

The goal of this research is to exibit how Geographic Information System (GIS)andRemote Sensing (RS) data can be effectively utilized for both morphometric and hypsometric analysis. The study reveals that the drainage network in the Niragantipalli micro-watershed exhibits a dendritic pattern, as confirmed by analysing morphometric parameters related to the watershed'slinear, areal, and relief characteristics. The indices elongation ratio (Re)**,** circularity ratio (Rc)**,** andform factor (Ff) indicate that the basin has an elongated shape**.**

Through hypsometric analysis, the catchment is discovered to be in an equilibrium or mature stage, with a hypsometric integral value of 0.49**.** Furthermore, the statistical examination of the data highlights a noteworthy connection between stream order and both stream length and stream number**.** These results are essential for guiding the implementation of soil and water conservation measuresthat will support the catchment's long-term sustainability.

Highlights

- Demarcation of Niragantipalli micro-watershed was done using DEM with spatial resolution of 25m×25m.
- Analysis of drainage network characteristics of Niragantipalli micro-watershed using remote sensing and GIS technique.
- Morphological investigation of linear, aerial and relief drainage aspects.

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REFERENCE

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