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GEOSPATIAL APPROACHES FOR DELINEATING DRAINAGE POTENTIAL AREAS: A CASE STUDY IN INDIA'S INDRAVATI RIVER BASIN

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ABSTRACT

For end users who use river networks and channel branches, the geo-hydrological examination of a basin is always of utmost relevance. With the aid of a remote sensing technique and GIS tool, this study attempted to evaluate the geomorphological properties of the strategic basin situated at Indravati River, Chhattisgarh, India. The findings might provide details about the basin's structural configuration, topographic features, and current geological variation. With dendritic, parallel, and trellis drainage patterns, the Indravati watershed was dispersed over a region of 29,408 km2 in the state of Chhattisgarh. The study area was classified as a fifth-order basin based on the findings. Lower and middle order streams pre-dominate the basin, which has gentle to steep slope terrain, medium-dense vegetation, and less permeable soil. When determining the ideal locations for recharge structures, the findings from the morphometric assessment of the basin can help to more effectively assess and manage water resources.

Keywords: Geospatial Analysis, Remote Sensing, Geomorphological Characteristics, GIS

1. INTRODUCTION

For managing resources like land and water to decrease the consequences of natural disasters and encourage sustainable development, a watershed is the ideal organizational unit. With the integration of biological, topographical, geological, and cultural characteristics of the land, it offers a potent study and management unit. [2, 10] The characterization of the watershed is an essential and fundamental step in the planning and management of a watershed. [6, 13] Runoff reactions are mostly influenced by watershed characteristics, which can also offer a straightforward technique to simulate runoff responses. In order to collect and assess data for watershed management, it is helpful to define the geographic borders of watersheds and sub-watersheds. A government agency frequently only provides watershed boundaries at the "macro level," which is completely unsuitable for watershed management at the "micro level." As a result, for the watershed management programme to be effectively planned and implemented, micro watershed level watershed delineation is a crucial responsibility. Additionally, knowledge of the watershed's topographic features aids in calculating runoff and sedimentation at the watershed's outlet. It's important to depict stream networks while describing a watershed in order to know where they are and how they are connected. [6, 13] How a particular watershed responds to different hydrological processes and behaves is influenced by a variety of physiographic, hydrological, and geomorphological elements. Even if these behaviors are watershed specific and thus distinctive, the categorization of a watershed gives a notion about them. [2]

The development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks has attracted a lot of attention in the geomorphology discipline during the past few decades. [4, 5] Both hydrologists and geomorphologists have highlighted the importance of the links between runoff characteristics and the geographic and geomorphic features of drainage basin

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systems. [11] Understanding the hydrological system of the watershed more thoroughly through geomorphological studies is helpful for implementing management measures. [2] Quantitative morphometric characterization of a drainage basin is considered to be the most effective method for proper planning and management of the watershed because it enables us to compare various drainage basins that were formed under various geologic and climatic regimes and understand the relationships between various aspects of the drainage pattern of the basin. [2, 14] Horton (1945) created the technique for quantitative analysis of watersheds, and Strahler made additional modifications to it (1964). A watershed's drainage system can be quantitatively described by morphometric analysis, which is a crucial component of watershed characterization. [2, 4, 7, 9, 14] Morphometry is the measurement and quantitative analysis of the size, shape, and configuration of the landforms on the surface of the earth. [4, 7] Understanding hydrological behavior, including its structure, relief of stream networks & platforms, and topology, is aided by morphometric studies of watersheds. [3, 8, 12, 14] The most recent technology, such as GIS, can be used to analyze a basin's morphology more effectively than traditional methods, which are time-consuming and difficult to quantify. The GIS technique has the potential to be used for watershed morphometric analysis, as several previous studies have shown. [14] A morphometric analysis is conducted using remote sensing and GIS technologies to understand how water supplies can be managed and resources can be saved for a sustainable way of life. [8] It is necessary to measure a drainage basin for a variety of morphometric elements, including basin area, stream number, stream length and stream order. [7, 14]

The GIS software's watershed delineation function is now frequently used for watershed delineation, extracting stream networks, and characterizing the topography of watersheds. Digital Elevation Models (DEMs), which are grid-based GIS coverage, show the elevation of any point in a specific area at a specific spatial resolution. [2, 6, 13] In a typical DEM, the topography of a region is represented by thousands of grid cells. More thorough and precise topographic information is provided by the lower cell sizes, which reflect smaller areas. The 30-meter and 10-meter DEMs are sufficient for small watersheds. [6, 13] How well a DEM can depict the hydrologic reality of a watershed depends on the scale of capture, accuracy, and amplitude of the terrain gradient. [15] The original stream network and sub-watershed are defined using GIS software utilizing the drainage area threshold technique. [6, 13] Arc GIS is a potent programme that can analyze, visualize, update, and produce high-quality presentations using interactive mapping and analysis. [2]

The bulk of problems with land and water resource planning and management have been successfully resolved by using the fast evolving Remote Sensing, GIS, and GPS tools of Geospatial Technology (GT), which is replacing traditional data processing methods. [8, 13] The management of watersheds in all of its facets has relied heavily on the use of Geographic Information Systems (GIS) technology. GIS is an interface that can more accurately depict hydrologic systems that vary in space. To accurately estimate spatially dispersed characteristics necessary for modeling a hydrologic system, GIS can be used. [2] The technique makes it possible to quickly get a synoptic view of a vast area. GIS is utilized for spatial planning and management and provides powerful yet time-consuming capabilities for data processing and retrieval. Remote sensing and GIS have the capacity to resolve the majority of planning and management challenges connected to land and water resources due to the usage of conventional data processing techniques. [9, 12, 13] In this study, an effort has been made to evaluate the morphometric properties and features derived from topographic sheets and a DEM. The study demonstrated how RS and GIS may be utilized to supply guidelines for watershed management.

2. LOCATION AND HYDROGEOLOGICAL CONDITIONS

The Indravati River basin, which is the research area, is a sub-basin of India's Godavari River. The Indravati River rises in the Kalahandi district of Odisha's Eastern Ghats of the Dandakaranya range. It travels westward and enters Jagdalpur in the Chhattisgarh state. At the borders of three states—

Maharashtra, Chhattisgarh, and Andhra Pradesh—the river then turns south before joining the Godavari river. The sub-basin can be found between the global coordinates of 18˚ 00’ to 20˚ 00 N’ and 80˚0’ to 82˚30’E. Chhattisgarh state's Indravati basin spans a region measuring 29,408 km2. (Fig.1) The Indravati River spans 535 kilometers. The elevation is 1200 meters at its peak. Most of the rainfall in the Indravati basin occurs during the southwest monsoon season (June-September). According to IMD, this basin had 1,288 mm of annual rainfall on average from 1971 to 2013 and is located in an area with moderate temperatures.

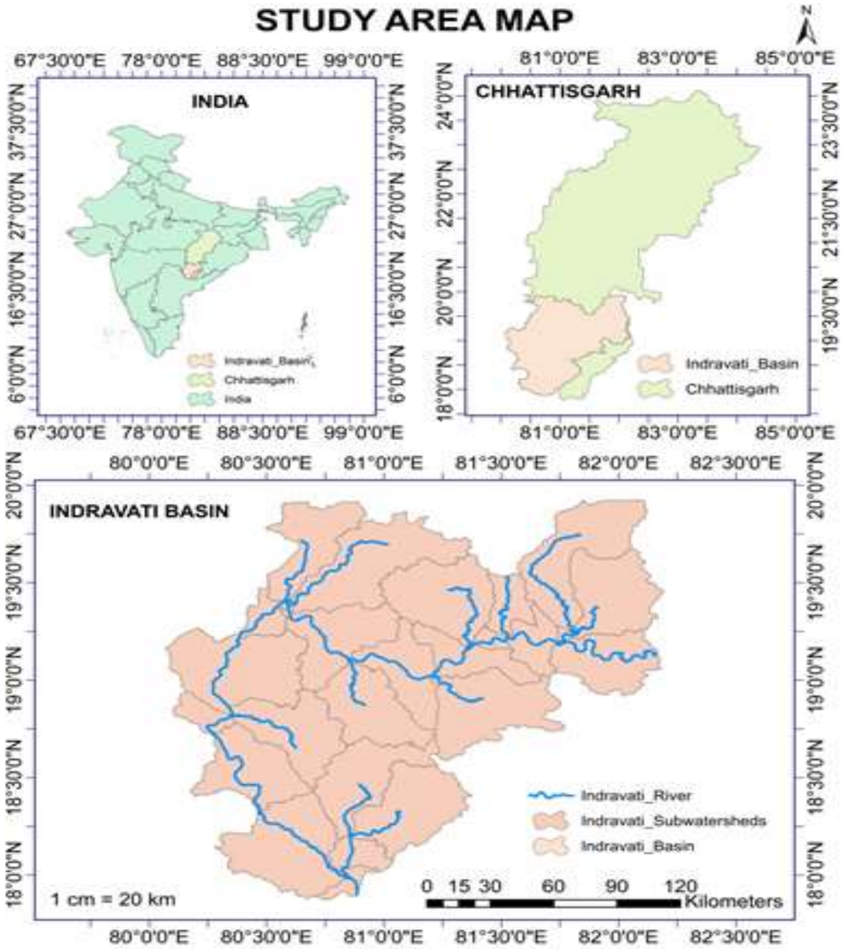

Fig 1: Study Area Map of Indravati Basin falling under Chhattisgarh State

3. MATERIALS AND METHODOLOGY

In this study, an effort has been made to analyze the morphometric features derived from a Digital Elevation Model (DEM) and topographic sheets at a scale of 1:50,000. Bhuvan (Indian Geo-Platform of ISRO) provides a DEM with a resolution of 30m x 30m which is readily available in the form of tiles for any specified area. DEM is helpful for defining watersheds, building drainage networks, and producing slope maps for a watershed. It can also be used to estimate the geomorphologic parameters of a watershed. The methodology adopted for this current research work is represented through a flowchart in Fig.2.

By using ArcHydro tool available as an add-on in ArcGIS software, watershed delineation has been done using DEM and drainage lines are extracted from topographic sheets of the concerned study area viz. Indravati basin. The topographic sheets used in the study are procured through Survey of India (SOI), Raipur. Following are the topographic sheet numbers used in the current study viz. 65A/7, 65A/8, 65A/11, 65A/12, 65A/16, 65E/3, 65E/4, 65E/7, 65E/8, 65E/11, 65E/12, 65E/15, 65 B/5, 65 B/6, 65 B/10 & 65 B/11. Watershed delineated using GIS through DEM & drainage lines are represented in Fig.1. While delineating the watershed, more emphasis has been made to cover the major streams and thus twenty-six sub-watersheds were created as represented in Fig.1. Bhuvan data was utilized to create numerous thematic maps, including DEM (Fig.3), slope (Fig.4), and slope aspect (Fig.5), for a thorough morphometric analysis.

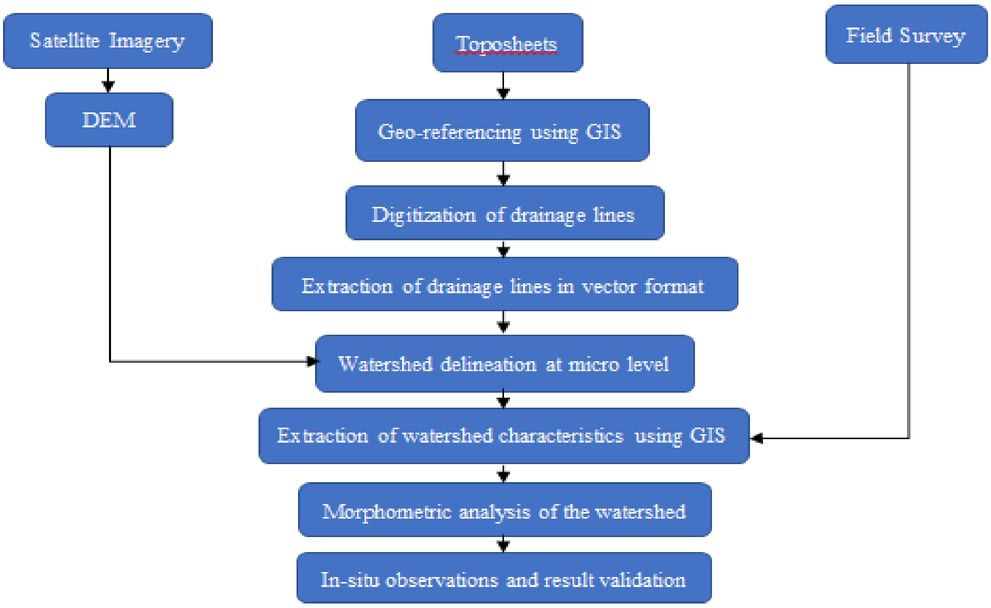

Fig 2: Methodology Flowchart

Fig. 3 DEM

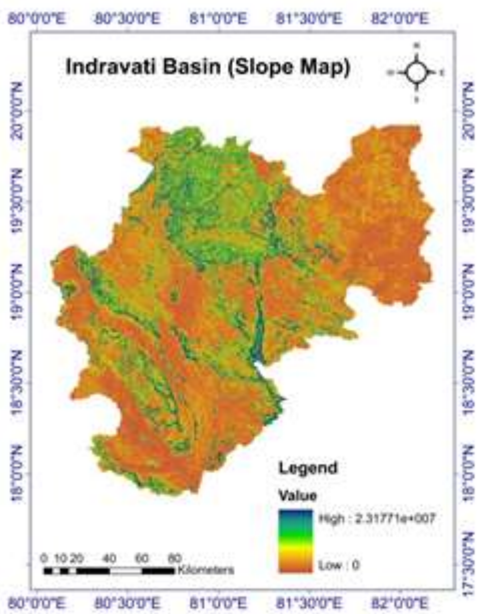

Fig. 4 Slope Map

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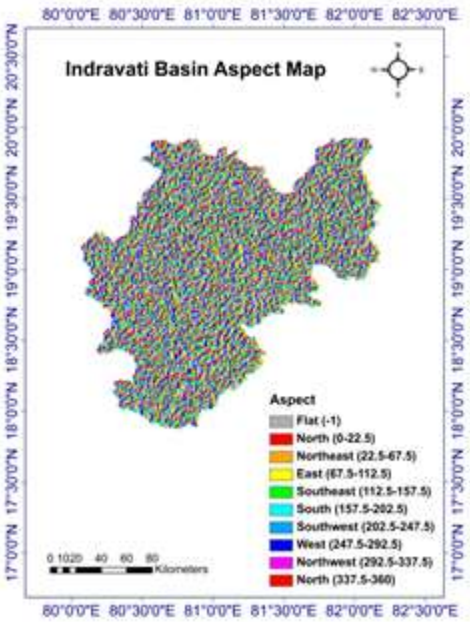

Fig. 5 Aspect Map

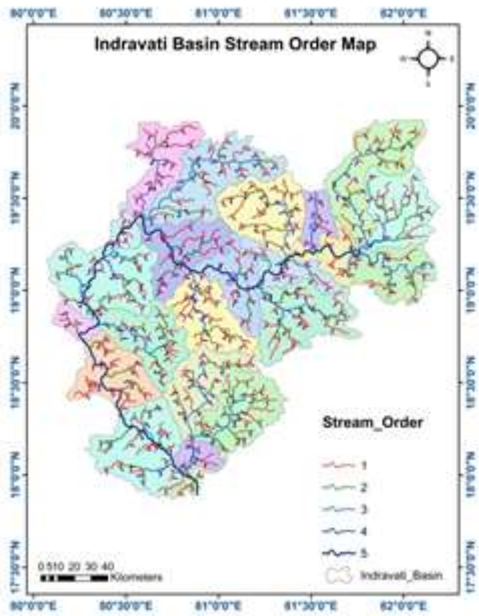

Fig. 6 Stream Order Map

4. DATA ANALYSIS AND INTERPRETATION

Morphometric Characterization

The morphometric study of a drainage basin, which provides a quantitative description of the drainage system, is a crucial part of drainage basin characterization. [2, 4, 5, 7, 9, 14] GIS was used to evaluate the linear, areal, and relief morphometric characteristics. [11] All of the sub-watersheds underwent morphometric characterization in preparation for further investigation in the GIS environment. [12] The morphometric features of stream order, stream length, and drainage density were derived using the GIS approach. The drainage map was created using the digitizing technique. [1, 12] Stream line density map is also created using GIS for representing the drainage potential in the study area. The morphological characteristics computed for all the twenty-six sub-watersheds delineated for Indravati basin is abbreviated in Table I.

TABLE I MORPHOLOGICAL CHARACTERISTICS ABBREVIATION

S.NO.	PARAMETER		ABBREVIATION
1	**Linear Aspect**	Area (A)	Area of the watershed
2		Perimeter (P)	Total length of the watershed boundary
3		Length (Lb)	Maximum length of the watershed
4		Stream Order (Nu)	Hierarchical rank
5		Stream Length (Lu)	Length of the stream
6		Stream Length Ratio(Rl)	*Rl= Lu/(Lu-1)*
7		Mean Stream Length Ratio (Lsm)	*Lsm= Lu/Nu*
8		Bifurcation ratio (Rb)	*Rb= Nu/(Nu+1)*
9	**Areal Aspect**	Drainage density (Dd)	*Dd= ∑Lu/ A*
10		Stream Frequency (Fs)	*Fs= ∑Nu/ A*
11		Texture Ratio	*T= Nu/P*

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12		Elongation ratio (Re)	$Re= 1.128\sqrt{(A/L)}$
13		Form factor (Ff)	$Ff= A/Lb^2$
14		Circularity index (Rc)	$Rc=4\pi A/P^2$
15		Length of overflow (Lg)	$Lg= 1/(2*Dd)$
16		Constant of Channel maintenance (Ccm)	$C= 1/Dd$
17		Drainage texture (T)	$T= Dd*Fs$
18	**Relief Aspect**	Basin relief (R)	$R=H-h$
19		Relief ratio (Rr)	$Rr= R/L$
20		Ruggedness number (Rn)	$Rn= R*Dd$
21		Gradient ratio (Gr)	$Gr= (H-h)/L$
22		Melton ruggedness ratio (MRn)	$MRn= (H-h)/A^{0.5}$
23		Slope (Sb)	$Sb= (H-h)/L$
24		Relative relief (Rhp)	$Rhp= (H/P)*100$
25		Shape factor (Rf)	$Rf=Lb^2/A$
26		Leminscate (K)	$K= (Lb^2/4)*A$

S. No.	Parameter		1	2	3	4	5	6	7	8	9
1	**Linear**	A	0.27	48.13	141.04	189.99	335.05	365.74	415.35	512.53	571.75

5. RESULTS & DISCUSSION

Within the state of Chhattisgarh, the total watershed area for the Indravati basin is reported to be 29,408 km2. The longest flow path is measured to be 451.94 kilometers long.

The result of the morphometric analysis for all twenty-six delineated sub-watersheds of Indravati basin is depicted in Table II, III & IV. The research area is a fifth-order basin, with the majority of the streams being of the lower and intermediate orders. Medium-density vegetation, mild to severe terrain slopes, less permeable soil, and moderate precipitation make up the drainage density of the studied region. The fifth-order drainage network and dendritic drainage pattern are shown on the stream order map for the watershed. (Fig.6)

Drainage map has been created and analyzed. The Indravati watershed has a dendritic drainage pattern. Figures 3, 4, and 5 displays a Digital Elevation Model, slope and aspect map respectively. Rainwater has slower surface runoff and more time to percolate if the slope is moderate, indicating greater infiltration. The drainage density demonstrates how closely spaced the channels are. It establishes a connection between the basin's morphometry and erosional process. The watershed also suggests a well-established drainage system and a rapid, heavy runoff that could result in flooding.

Strahler (1964) categorized every fingertip tributary as a first-order stream. A second-order stream is produced when two streams converge. The same is true for streams of the fourth, fifth, and higher orders, just as two streams of the second order combine to form a stream of the third order. [12] Fig. 6 depicts the Indravati basin stream order map.

Horton introduced the concept of drainage density in 1932, defining it as the ratio of a basin's surface area to the total length of all its channel segments across all orders. [12] Fig. 7 depicts the stream line density map for the Indravati basin.

TABLE II Morphological Characteristics of Indravati sub-watershed 1 to sub-watershed 9

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S. No.	Aspect	Parameter	10	11	12	13	14	15	16	17	18
1	Linear Aspect	A	836.70	1137.46	1253.85	1273.56	1413.97	1429.20	1444.00	1463.94	1460.45
2		P	300.84	305.58	281.94	343.90	326.75	394.56	334.03	349.52	370.74
3		Lb	28.32	22.79	14.94	27.63	20.78	32.91	38.52	29.45	24.50
4		Nu	27.00	39.00	32.00	38.00	47.00	49.00	45.00	49.00	41.00
5		Lu	182.55	218.66	238.24	221.30	303.71	263.72	284.81	250.89	305.47
6		Rl	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

S. No.	Aspect	Parameter	10	11	12	13	14	15	16	17	18
2		P	4.26	51.67	91.03	146.01	136.43	182.53	181.04	210.46	209.97
3		Lb	0.77	3.64	5.52	16.75	17.83	10.26	13.54	10.31	17.08
4		Nu	3.00	3.00	5.00	9.00	11.00	15.00	15.00	19.00	27.00
5		Lu	21.04	37.17	40.08	51.76	65.70	86.49	85.98	96.87	126.61
6		Rl	1.05	1.03	1.03	1.02	1.02	1.01	1.01	1.01	1.01
7		Lsm	7.01	12.39	8.02	5.75	5.97	5.77	5.73	5.10	4.60
8		Rb	0.75	0.75	0.83	0.90	0.92	0.94	0.94	0.95	0.96
9	Areal Aspect	Dd	77.97	0.77	0.28	0.27	0.20	0.24	0.21	0.19	0.22
10		Fs	11.12	0.06	0.04	0.05	0.03	0.04	0.04	0.04	0.05
11		Texture Ratio	0.71	0.06	0.06	0.06	0.08	0.08	0.08	0.09	0.13
12		Re	0.67	4.10	5.70	3.80	4.89	6.73	6.25	7.95	6.53
13		Ff	0.45	3.64	4.64	0.68	1.05	3.47	2.27	4.82	1.96
14		Rc	0.19	0.23	0.21	0.11	0.23	0.14	0.16	0.15	0.16
15		Lg	0.01	0.65	1.76	1.84	2.55	2.11	2.42	2.65	2.26
16		Ccm	0.01	1.30	3.52	3.67	5.10	4.23	4.83	5.29	4.52
17		T	866.80	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01
18	Relief Aspect	R	0.03	0.06	0.50	0.38	0.42	0.34	0.45	0.40	0.44
19		Rr	0.04	0.02	0.09	0.02	0.02	0.03	0.03	0.04	0.03
20		Rn	2.18	0.05	0.14	0.10	0.08	0.08	0.09	0.08	0.10
21		Gr	0.04	0.02	0.09	0.02	0.02	0.03	0.03	0.04	0.03
22		MRn	0.05	0.01	0.04	0.03	0.02	0.02	0.02	0.02	0.02
23		Sb	0.04	0.02	0.09	0.02	0.02	0.03	0.03	0.04	0.03
24		Rhp	3.78	1.01	0.85	0.26	0.32	0.24	0.25	0.35	0.38
25		Rf	2.20	0.28	0.22	1.48	0.95	0.29	0.44	0.21	0.51
26		K	0.04	159.11	1073.04	13328.08	26637.19	9631.28	19037.63	13629.96	41718.42

TABLE III Morphological Characteristics of Indravati sub-watershed 10 to sub-watershed 18

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S. No.	Parameter		19	20	21	22	23	24	25	26
1		A	1533.29	1659.92	1734.79	1860.31	1941.78	2066.10	2139.61	2179.42
2		P	323.38	345.77	327.31	386.11	435.37	373.95	472.76	392.09
3		Lb	50.91	42.61	29.12	47.25	19.99	31.50	26.26	36.88
4	Linear	Nu	33.00	51.00	53.00	55.00	51.00	81.00	60.00	83.00
5	Aspect	Lu	303.66	334.44	320.60	362.12	341.46	442.91	420.31	407.91
6		Rl	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7		Lsm	9.20	6.56	6.05	6.58	6.70	5.47	7.01	4.91
8		Rb	0.97	0.98	0.98	0.98	0.98	0.99	0.98	0.99
9	Areal	Dd	0.20	0.20	0.18	0.19	0.18	0.21	0.20	0.19
10	Aspect	Fs	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.04

7		Lsm	6.76	5.61	7.45	5.82	6.46	5.38	6.33	5.24	7.45
8		Rb	0.96	0.98	0.97	0.97	0.98	0.98	0.98	0.98	0.98
9		Dd	0.22	0.19	0.19	0.17	0.21	0.18	0.20	0.18	0.21
10		Fs	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
11		Texture Ratio	0.09	0.13	0.11	0.11	0.14	0.12	0.13	0.14	0.11
12	Areal	Re	6.13	7.97	10.34	7.66	9.31	7.43	6.91	7.95	8.71
13	Aspect	Ff	1.04	2.19	5.62	1.67	3.28	1.32	0.97	1.69	2.43
14		Rc	0.12	0.15	0.20	0.14	0.17	0.12	0.16	0.15	0.13
15		Lg	2.29	2.60	2.63	2.88	2.33	2.71	2.54	2.85	2.39
16		Ccm	4.58	5.20	5.26	5.76	4.66	5.42	5.07	5.70	4.78
17		T	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01
18		R	0.58	0.89	0.32	0.62	0.77	1.19	0.94	0.74	0.77
19		Rr	0.02	0.04	0.02	0.02	0.04	0.04	0.02	0.03	0.03
20		Rn	0.13	0.17	0.06	0.11	0.16	0.22	0.19	0.13	0.16
21		Gr	0.02	0.04	0.02	0.02	0.04	0.04	0.02	0.03	0.03
22	Relief	MRn	0.02	0.03	0.01	0.02	0.02	0.03	0.02	0.02	0.02
23	Aspect	Sb	0.02	0.04	0.02	0.02	0.04	0.04	0.02	0.03	0.03
24		Rhp	0.27	0.36	0.28	0.22	0.23	0.30	0.34	0.22	0.24
25		Rf	0.96	0.46	0.18	0.60	0.31	0.76	1.03	0.59	0.41
26		K	167709.71	147754.97	69921.97	243114.69	152571.31	387041.36	535531.75	317496.83	219088.24

TABLE IV Morphological Characteristics of Indravati sub-watershed 19 to sub-watershed 26

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11		Texture Ratio	0.10	0.15	0.16	0.14	0.12	0.22	0.13	0.21
12		Re	6.19	7.04	8.71	7.08	11.12	9.14	10.18	8.67
13		Ff	0.59	0.91	2.05	0.83	4.86	2.08	3.10	1.60
14		Rc	0.18	0.17	0.20	0.16	0.13	0.19	0.12	0.18
15		Lg	2.52	2.48	2.71	2.57	2.84	2.33	2.55	2.67
16		Ccm	5.05	4.96	5.41	5.14	5.69	4.66	5.09	5.34
17		T	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01
18	**Relief Aspect**	R	0.39	0.90	0.67	0.95	0.26	0.87	0.77	0.63
19		Rr	0.01	0.02	0.02	0.02	0.01	0.03	0.03	0.02
20		Rn	0.08	0.18	0.12	0.19	0.05	0.19	0.15	0.12
21		Gr	0.01	0.02	0.02	0.02	0.01	0.03	0.03	0.02
22		MRn	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01
23		Sb	0.01	0.02	0.02	0.02	0.01	0.03	0.03	0.02
24		Rhp	0.26	0.26	0.29	0.31	0.17	0.23	0.19	0.17
25		Rf	1.69	1.09	0.49	1.20	0.21	0.48	0.32	0.62
26		K	993582.47	753617.33	367843.81	1038306.16	193939.02	512459.05	368739.14	741173.91

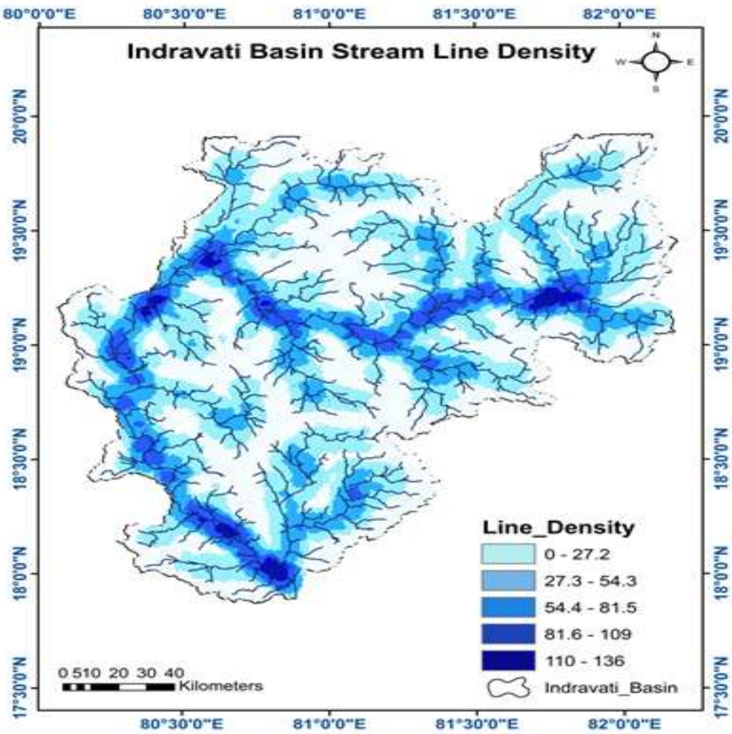

Fig.7. Stream line density map

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6. CONCLUSION

DEM is a crucial resource for hydrology spatial modeling. The DEM frequently needs to have its surface reconditioned in order to better reflect actual hydrology. But different approaches yield different outcomes, which can affect later terrain analyses. It should be noted that a watershed's mainline length and average slope values are easily obtainable from DEM using common GIS tools.

The appraisal of river basins, the management of natural resources, and the prioritization of watersheds all benefit greatly from morphometric analysis of river basins. Because it offers a more dependable and exact assessment of morphometric parameters of watersheds, GIS technique is proven to be effective for the study. The current study's objective is to produce a geomorphological analysis of the Indravati watershed in the Chhattisgarh State region. For a more thorough investigation, the watershed has been separated into twenty-six sub-watersheds.

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