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Morphometric Analysis Using Remote Sensing and Geographical Information System: A Case Study of Nawagarh Watershed of Chhattisgarh, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The study highlights the suitability of a GIS-based approach for evaluating morphometric parameters. It focuses on the quantitative analysis of morphometric characteristics within thirteen sub-watersheds of the Nawagarh watershed, which originates from the Seonath river catchment in the Mahanadi basin in Chhattisgarh, India. The Nawagarh watershed spans an area of 2647.27 km^2. Its outlet is located at 21°46'10" N Latitude and 81° 48'43" E Longitude. The Nawagarh watershed covers four districts in Chhattisgarh - Kabirdham, Bemetara, Baloda Bazar, and Mungeli. The analysis reveals the relative qualities of the sub-watersheds in terms of hydrological response. The Nawagarh watershed features a dendritic drainage network with 2760 streams of different orders. The slope of the land directly affects water absorption and drainage. High relief ratio 0.032 in SWD1 and SWD3 indicates rapid concentration, rapid stream flow, and greater susceptibility to erosion than other sub watersheds. The drainage density is 0.80 km^{-1}, which is close to 1 km^{-1},

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indicating that the basin has a nearly high drainage density, which demonstrate that the location with impermeable weak subsurface material and has high relief. The elongated shape with the values of form factor (0.39), circulatory ratio (0.28) and elongation ratio (0.69), indicated that the Nawagarh watershed is more elongated with lower peak flow of long duration having low permeability. The drainage density in the basin is relatively high, suggesting a significant drainage network. The study emphasizes the need for effective erosion control methods in the Nawagarh watershed to protect the land.

Keywords: Remote sensing; geographical information system; watershed management; land degradation.

1. INTRODUCTION

Watershed management is the practice of using land and water resources in a way that maximizes productivity while minimizing harm to the natural environment within a specific area called a "watershed." This involves conserving soil and water within the watershed, based on rainfall. Therefore, it is crucial to understand the morphometric characteristics at the watershed or basin level in order to estimate groundwater replenishment. These characteristics are influenced by various factors, including structural components, geomorphology, geology, soil, and vegetation. Physiographic data, such as the location of the drainage divide, channel length, channel network layout, slope, and geomorphology, play a vital role in effective watershed management.

The preservation of natural resources such as land and water are essential because these resources play the significant role in sustaining life on earth. It is imperative to reduce the ever-increasing demand for these resources, which can be achieved through their conservation. The depletion of land is a serious concern with around 146.82 million hectares being affected by various forms of land degradation [1]. The surging population of India is pressuring the nation's natural resources, which necessitates the careful use and protection of land and water for the survival and prosperity of humans. To ensure sustainable development, it is vital to exploit natural resources wisely. As a result, the management and development of land resources are essential tools (Pawar, 2003); [2].

The Digital Elevation Model (DEM), RS, and GIS can be used to quickly parameterize runoff models. However, in developing countries where there is limited information available, DEM-based runoff modeling is more challenging. Garg,[3] developed a DEM from topographic maps to calculate slope and catchment area in order to generate flow direction, network flow pattern, and drainage network in a watershed, which was then used to develop runoff models. Various algorithms for automating the extraction of watershed characteristics from DEM have been developed [4], Martz and Garbrecht [5], and Agestino et al. [6]. Incorporating G1S into hydrologic modeling offers greater evaluation detail and minimizes the user's bias in parameter selection, resulting in significant time savings and cost reduction [7]. "Stream tube" approach and contour- based DEM to divide the catchment into interconnected elements [8].

Morphometry refers to the examination of the size and structure of Earth's landforms using mathematical methods. Analyzing basins in hydrology, including linear, areal, and relief aspects. Morphometric data is valuable for a variety of applications, including determining regional flood frequency, modeling hydrological processes, prioritizing watersheds, managing natural resources, evaluating drainage basins, and more [9,10] Morphometric studies assess streams through the examination of various stream parameters. Multiple drainage metrics are analyzed, which include stream ordering, perimeter, basin area, drainage frequency, bifurcation ratio, circulation ratio, and texturing ratio, alongside drainage density and frequency. The drainage features of several river basins and sub-basins across the globe have been studied through conventional techniques by Horton, [9]; Strahler,[10]; Krishnamurthy et al. [11].

Many studies have utilized remote sensing and GIS in the morphometric analysis of river basins. These analyses have demonstrated the effectiveness of these tools in understanding the geomorphology of the study area and analyzing drainage patterns [12,13,14] provide evidence for the comprehensive knowledge that can be obtained through these techniques. The objective of the present study is to determine morphometric parameters (linear, areal and relief aspects) of the Nawagarh watershed using the remote sensing and GIS technology.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The Nawagarh watershed originated from Seonath river catchment in Mahanadi basin at Chhattisgarh state in India. This watershed covers the four districts (Kabirdham, Bemetara, Baloda Bazar and Mungeli) of Chhattisgarh. However, the major part covers under Kabirdham district of Chhattisgarh. The study watershed lies between 21°43’ to 22°30’ N latitude to 81°00’ to 81°48’ E longitude. The Nawagarh watershed has its outlet at 21° 46' 10" N Latitude and 81° 48’43” E Longitude. The location of Nawagarh watershed in India and Chhattisgarh is shown in Fig. 1. The drainage outlet situated in Nandghat (Nawagarh block) of Bemetara district, it is the part of Seonath river Sub-basin of Mahanadi basin, Seonath is the major tributary of Mahanadi River. Study watershed covers 2647.27 Km^2 geographical area. The annual average rainfall of the area is 1035.9 mm. The overall climate of the area can be classified as sub-tropical. Nawagarh watershed has two major rivers Sakri and Hamp, they both are tributaries of Seonath river. The general elevation of the area ranges from 262 to 277 m above mean sea level (MSL). Location map of Nawagarh watershed was shown in the Fig. 1.

2.2 Database and Methodology

The topography features of the Nawagarh Watershed were analyzed using the topographic sheet of the Indian survey. Nawagarh watershed is covered by topographic map No. (64G/1, 64G/5, 64G/9, 64G/10, 64G/13, 64G/14, 64F/3, 64F/4, 64F/7, 64F/8, 64F/12) of 1: 50,000 scale having 10 m contour interval. These topographic maps were collected from Survey of India, Raipur, Chhattisgarh (www.surveyofindia.gov.in). Arc GIS 10.5 software was used to georeferenced the topographical maps. Arc-GIS 10.5 was used to delineate the entire study region while assigning the projection coordinate system (WGS 1984, UTM zone 44 N). The Digital Elevation Model (DEM) shown in Fig. 2 was created using information from the Shuttle Radar Topography Mission (SRTM). The DEM, which had a ground resolution of 30 m and was in the Tagged Information File Format (TIFF) format, was downloaded from the United States Geological Survey (USGS) website. Drainage channels were extracted using the ArcGIS 10.5 Hydrology tool, which is part of the Spatial Analyst Tools section, the drainage map of Nawagarh watershed shown in Fig. 3. These procedures included DEM, fill, flow accumulation, stream order, and drainage network. In morphometric analysis, the determination of the stream order is the first step based on the hierarchical stream rendering suggested by Strahler [10], which was used in the present study. The fundamental morphometric parameters, including stream length, number of streams, area, and basin length, were calculated using the ArcGIS 10.5. Morphometric study was performed on each of the thirteen sub-watersheds separately Fig. 4 shows the sub-watershed map of Nawagarh Watershed. Table 1 shows the formulas for calculating the morphometric parameters.

3. RESULTS AND DISCUSSION

The geographical area of Nawagarh watershed covers 2647.27 km^2. The drainage network and topography of the research region were used to create the sub watershed maps. Sub-watershed wise area and perimeter are given in Table 2. This table shows that SWD7 has the largest area (332.94 km^2) while SWD10 has the 54 smallest area (114.62 km^2). The elevations of the sub-watersheds vary from 230 m to 975 m above mean sea level (MSL). The slope was divided into several categories. The slope map of the Nawagarh watershed shown in Fig. 5. The watershed features a section with strong to severe slope, which does not allow surface water to penetrate through the soil surface. The various morphometric parameters of the Nawagarh watershed were determined and are reported in Tables 2-6.

3.1 Linear Aspects

The linear aspects parameters were computed, and the results are given in Table 4.

3.2 Stream Order (u)

The initial step in studying the geomorphology of a drainage basin is to establish the stream order, which was done in this study by utilizing the stream ordering method proposed by Strahler in [10]. The drainage map revealed that the Nawagarh watershed is classified as a 5th order basin, characterized by a drainage pattern that ranges from dendritic to sub-dendritic. Whenever two first order streams combine, they form a stream of second order, and this pattern continues. In terms of stream frequency, first order streams have the highest occurrence rate, followed by second order streams. The stream orders of the Nawagarh watershed presented in Fig. 6.

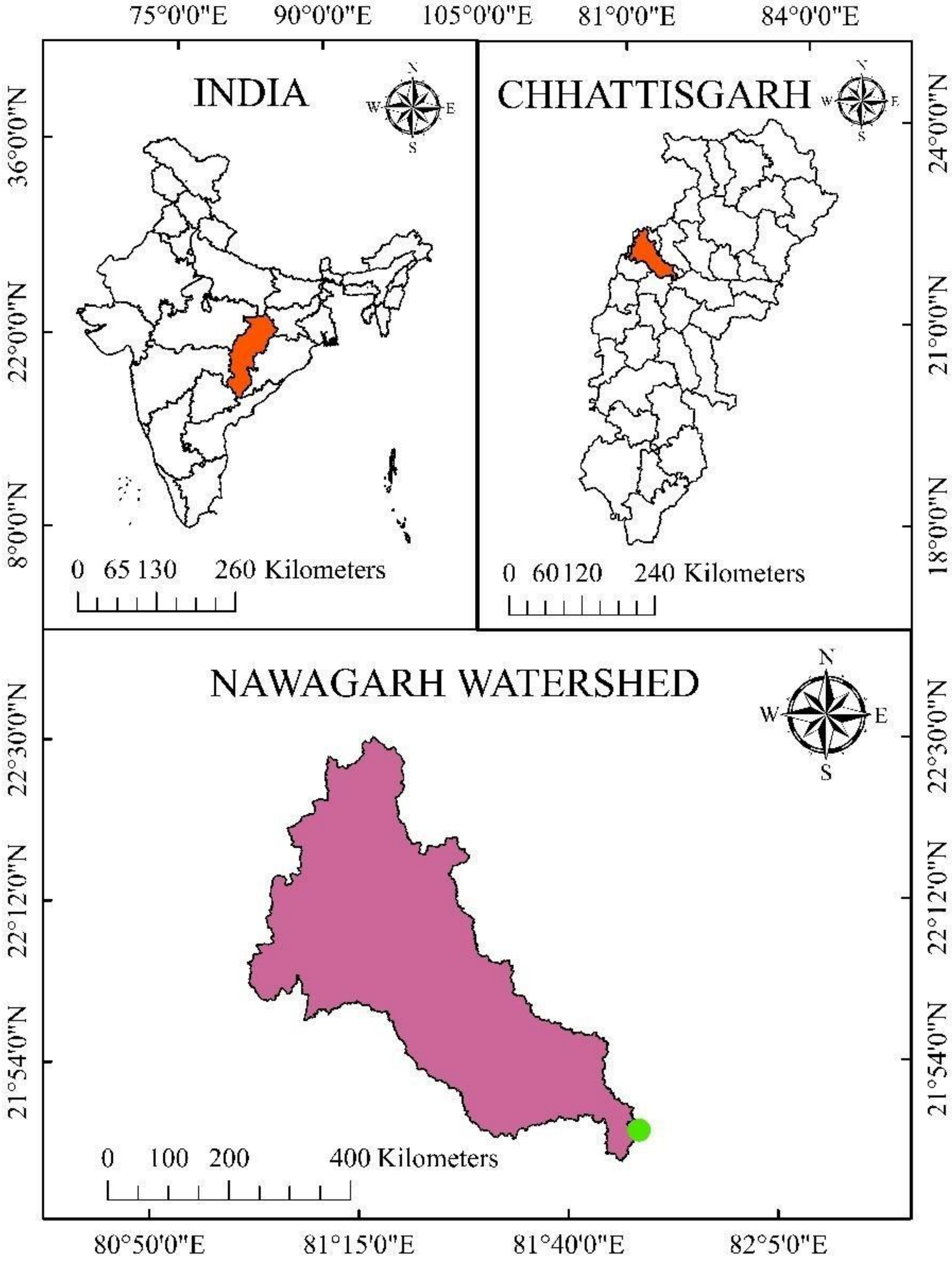

Fig. 1. Location of nawagarh watershed

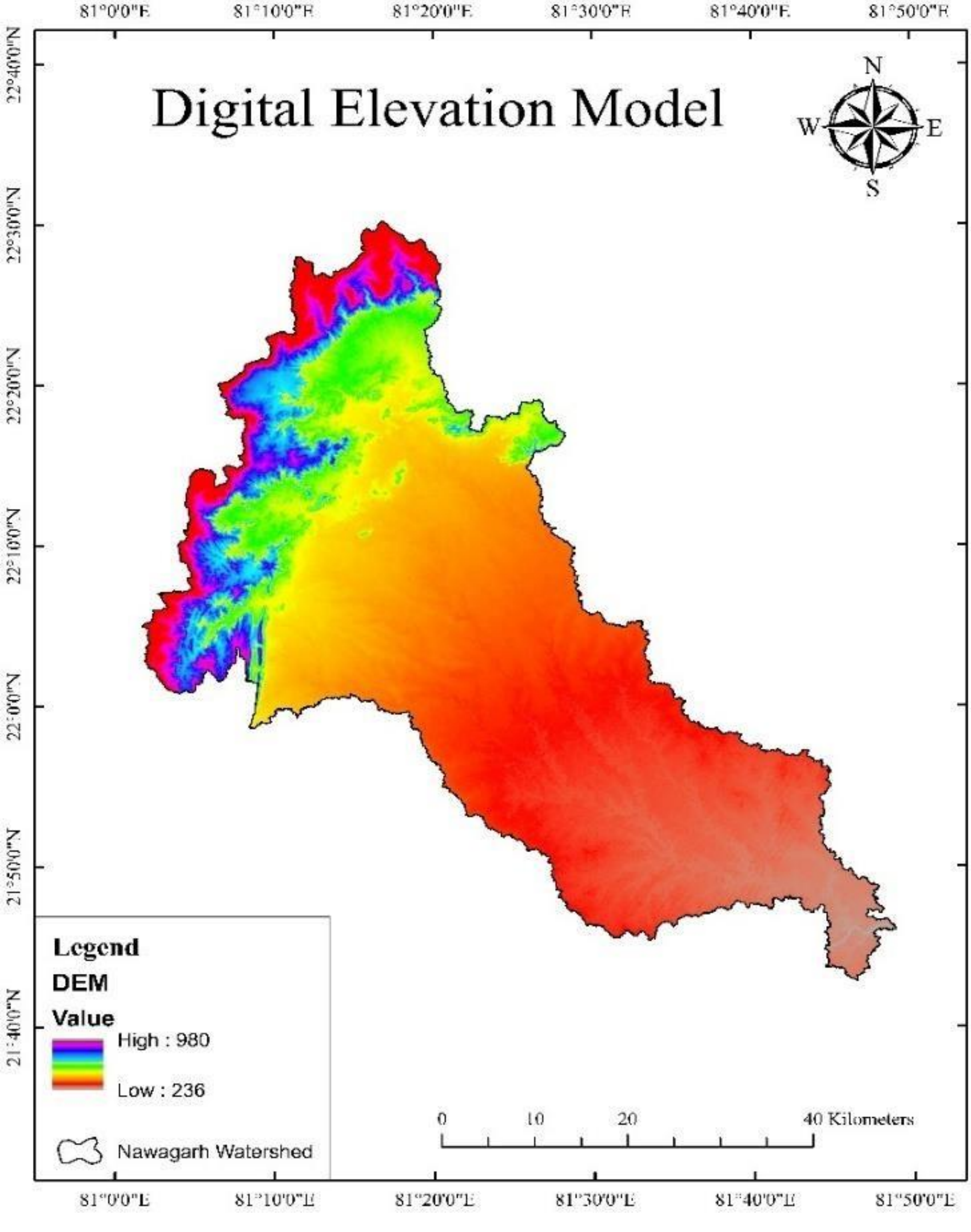

Fig. 2. DEM of nawagarh watershed

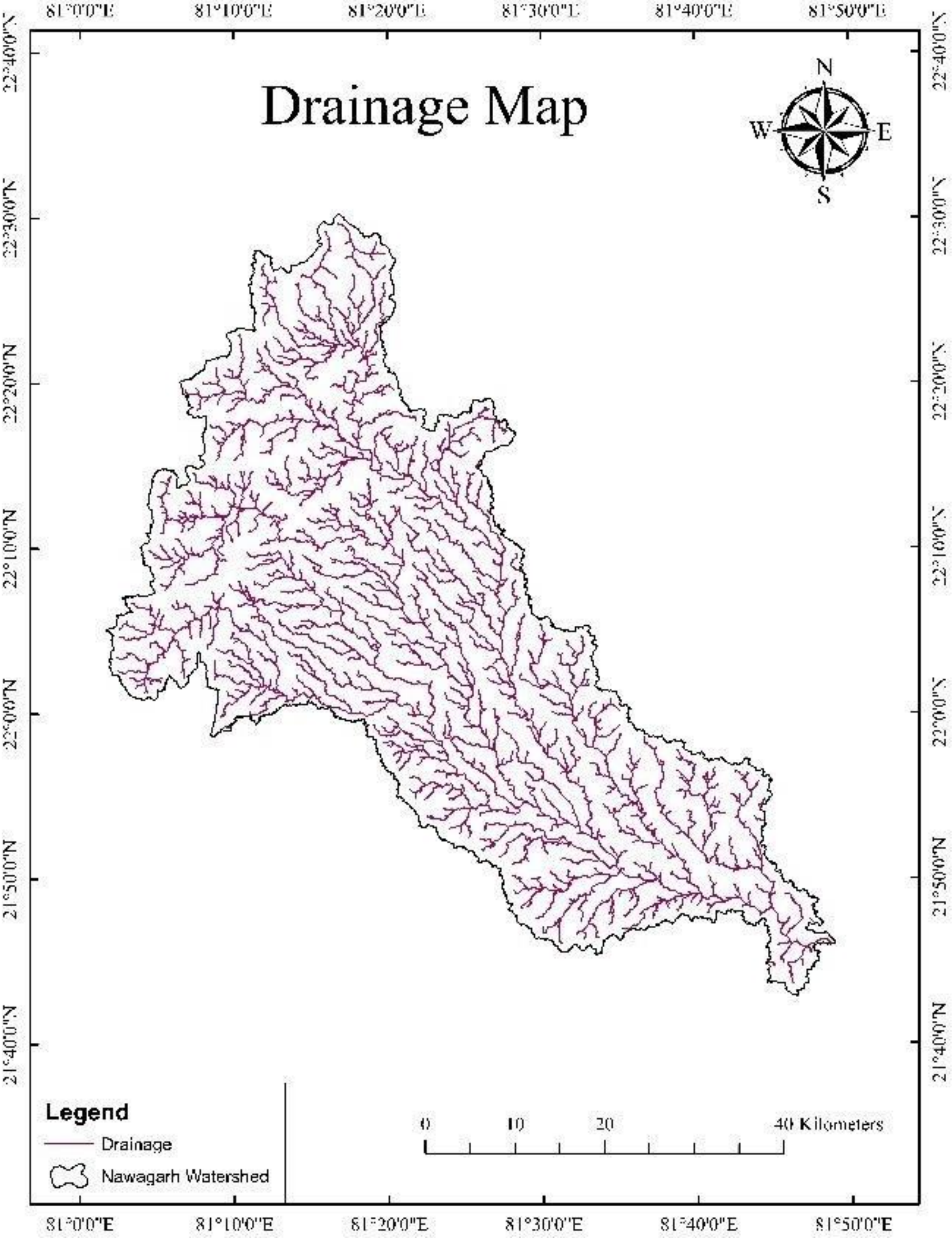

Fig. 3. Drainage map of the Nawagarh watershed

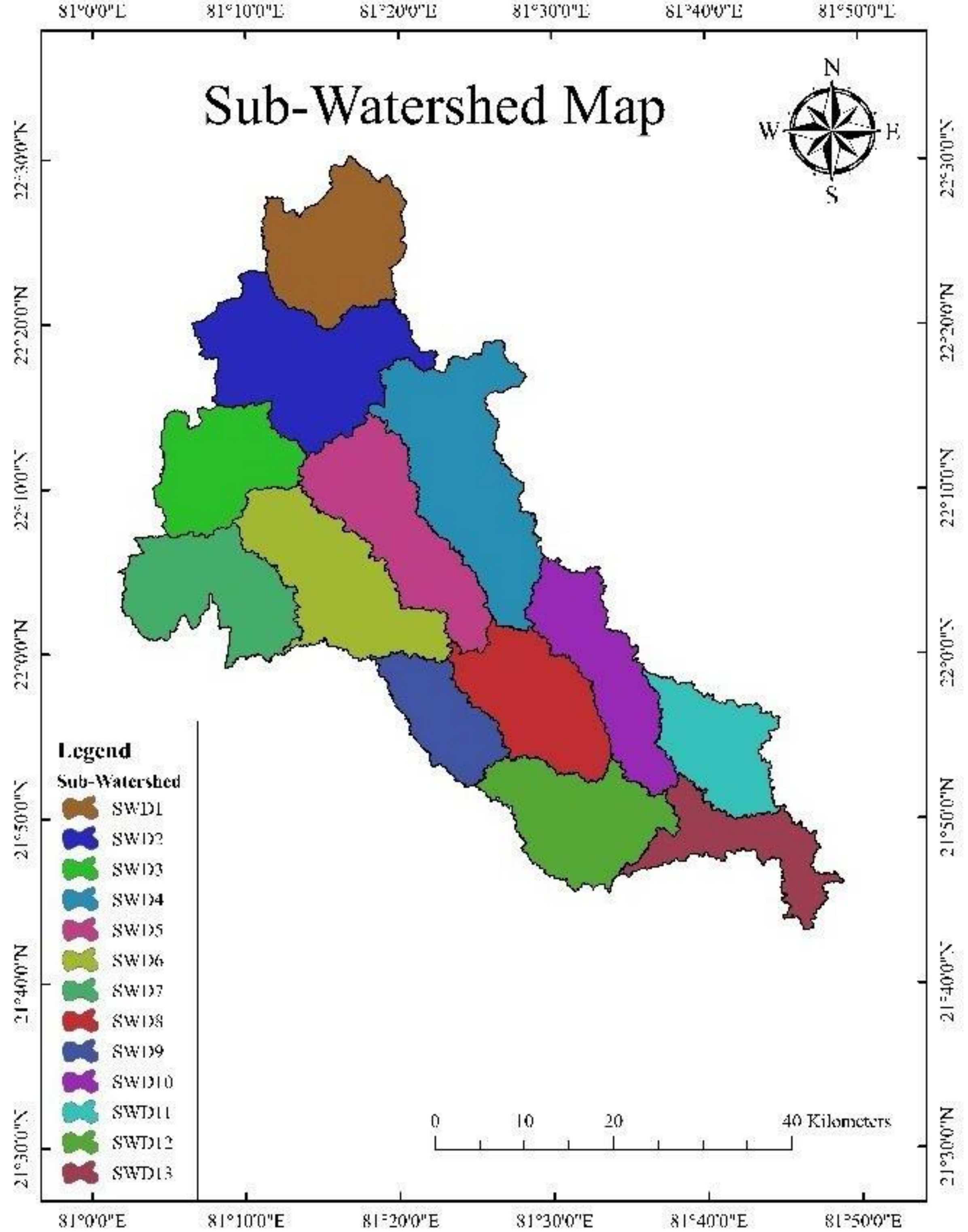

Fig. 4. Sub-watershed map of Nawagarh watershed

Table 1. Formulae for computation of morphometric parameters

Category of parameter	Name and Notation of Morphometric Parameters	Equation	References
Linear parameters	Stream Order	Hierarchical Rank	Strahler (1964)
	Stream number (Nu)	$Nu = N1 + N2 + \ldots + Nn$	Horton (1945)
	Total stream Length (Km)	Obtained from Arc Map	
	Basin length (Km)	Obtained from Arc Map	
	Mean Bifurcation Ratio (Rbm)	Rbm = Average of bifurcation	Strahler (1957)
	Bifurcation ratio (Rb)	$Rb = Nu/Nu+1$	Schumm (1956)
Areal parameters	Area of the basin (A) (Km^2)	Obtained from Arc Map	
	Basin Perimeter (P) (Km)	Obtained from Arc Map	
	Drainage Density (Dd) (km/Km^2)	$D_d = Lu / A$	Horton (1945)
	Stream Frequency (Fu)	$Fu = Nu / A$	Horton (1945)
	Circularity Ratio (Rc)	$Rc = 4\pi * A / P^2$	Strahler (1964)
	Elongation Ratio (Re)	$Re = (2/L_b)*2\sqrt{(A/\pi)}$	Schumm (1956)
	Form factor Ratio (F_f)	$F_f = A / L_b^2$	Horton (1945)
	Texture ratio (T)	$T = Nu / P$	Horton (1945)
	Shape index (Sw)	$Sw = L_b^2 / A$	Horton (1945)
	Constant of channel maintenance (C)	$C = 1/D_d$	Horton (1945)
	Length of overland flow (Lo)	$Lo = \frac{1}{2} D_d$	Horton (1945)
	Compactness constant (Cc)	$Cc = 0.2824 * p / \sqrt{A}$	Horton (1945)
Relief parameters	Drainage factor (D_f)	$D_f = Fu/D_d^2$	Keshri and Rao (2018)
	Maximum Basin Height (m)	GIS software analysis	
	Minimum Basin Height (m)	GIS software analysis	
	Relief Ratio (Rr)	$Rr = R / Lb$	Schumm (1956)
	Basin Relief (R) (m	$R = \text{Max } H - \text{Min } H$	Schumm (1956)
	Relative Relief Ratio (Rhp)	$Rhp = H * 100/P$	Schumm (1956)
	Ruggedness Number (Rn)	$Rn = D_d * (H / 1000)$	Patton and Baker (1976)

3.3 Stream Number (Nu)

The number of streams of different orders is directly related to stream order. When stream order increases, the number of streams in that order decreases, indicating lower permeability and infiltration. In the ArcGIS platform, the total number of streams and stream segments in the basin is determined by counting and calculating the number of streams of each order. The total number of streams in the Nawagarh watershed was determined to be 2760. Table 4 provides the total number of streams, which is the sum of stream numbers for each order in the respective sub-watershed. The highest number of streams, 324, was found in SWD7, while the lowest, 87, was found in SWD10.

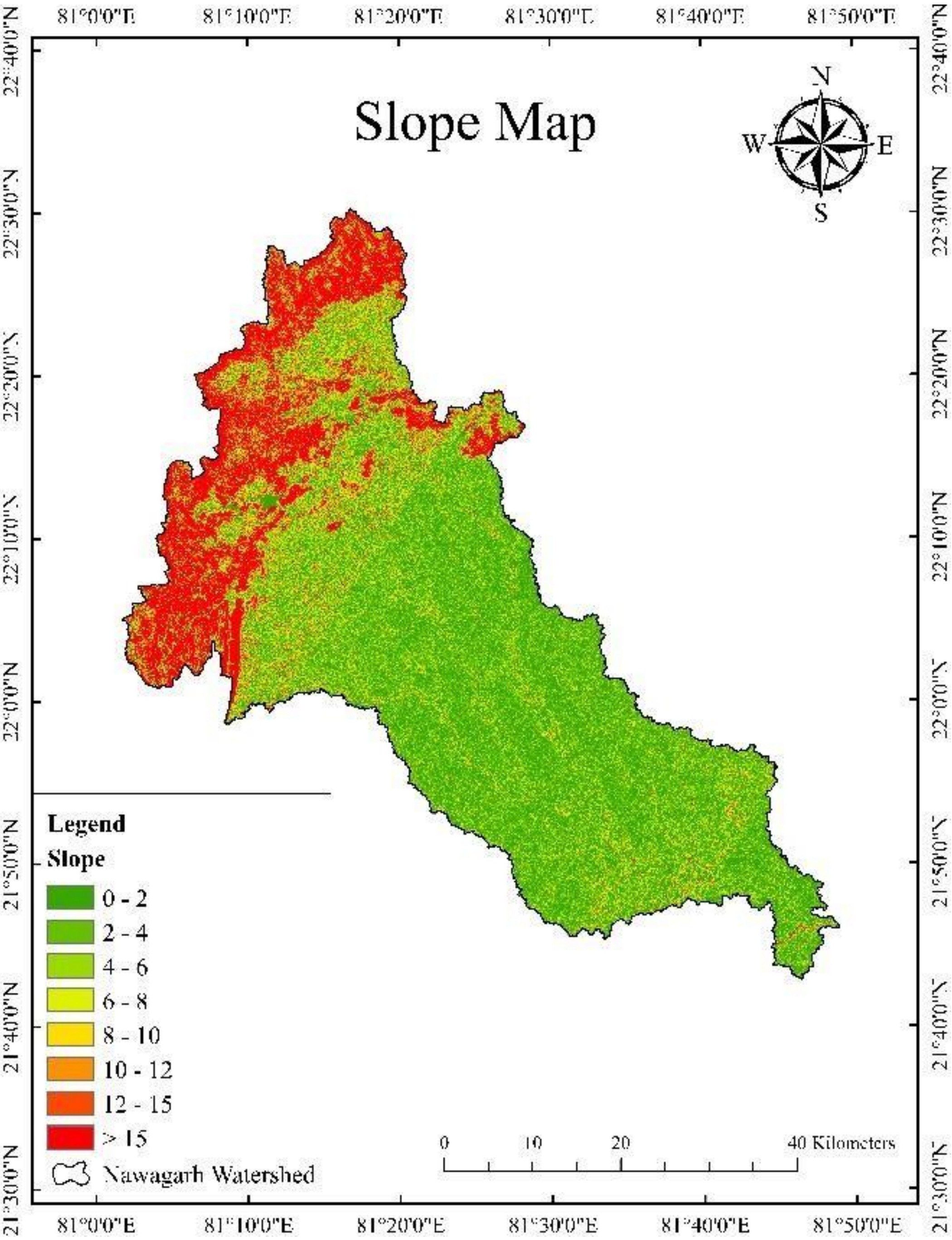

Fig. 5. Slope map of the Nawagarh Watershed

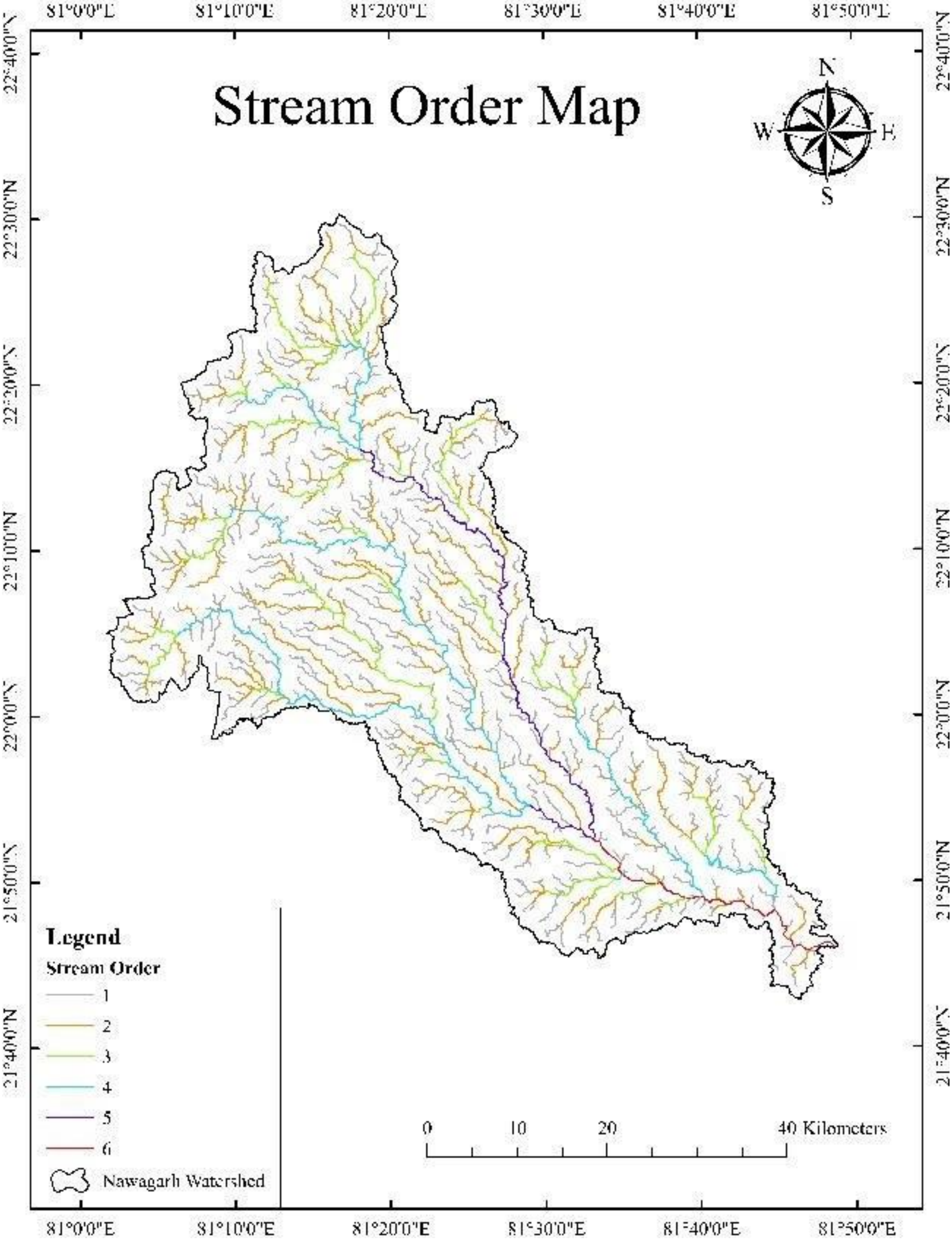

Fig. 6. Stream order map of theNawagarh Watershed

Table 2. Sub-watershed wise area and perimeter

S. no.	Sub-watershed	Area (km^2)	Perimeter (P) (km)	Area (%)
1	SWD1	205.11	77.77	7.75
2	SWD2	289.40	110.76	10.93
3	SWD3	171.95	72.77	6.50
4	SWD4	212.06	96.88	8.01
5	SWD5	237.29	113.98	8.96
6	SWD6	227.57	112.48	8.60
7	SWD7	332.94	130.91	12.58
8	SWD8	179.65	104.96	6.79
9	SWD9	187.77	87.78	7.09
10	SWD10	114.62	66.78	4.33
11	SWD11	197.92	95.35	7.48
12	SWD12	147.56	84.26	5.57
13	SWD13	143.42	120.48	5.42
14	Nawagarh watershed	2647.27	1274.96	100

Table 3. Stream order and Stream length (km) according to stream order

		Stream Number (Nu)					Stream Length (km)				
Watershed	**Area (Km^2)**	**I**	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**
SWD1	205.114	81	58	28	19	-	75.97	49.10	38.66	6.13	-
SWD2	289.4012	139	80	63	57	-	107.22	62.15	42.93	24.23	-
SWD3	171.9455	98	48	21	13	-	71.48	42.74	13.78	11.95	-
SWD4	212.059	93	55	23	19	-	80.34	46.75	17.30	18.38	-
SWD5	237.2914	103	56	33	-	-	113.93	55.70	39.56	-	-
SWD6	227.5704	130	51	17	22	-	99.44	62.47	23.24	19.68	-
SWD7	332.9373	153	101	49	21	-	120.99	85.80	42.83	26.57	-
SWD8	179.6532	118	53	22	27	-	72.12	22.60	15.98	24.23	-
SWD9	187.7716	65	24	41	1	-	73.95	36.59	36.92	0.23	-
SWD10	114.6188	40	27	10	10	-	50.26	29.00	9.95	11.18	-
SWD11	197.9239	162	78	60	3	19	78.13	42.77	32.43	2.09	6.52
SWD12	147.562	68	31	34	-	-	45.90	29.61	30.09	-	-
SWD13	143.4217	174	18	44	-	-	44.94	18.06	25.10	-	-
Total	2647.27	1424	680	445	192	19	1034.68	583.35	368.77	144.66	6.52

3.4 Total Stream Length (Lu)

The stream length characteristics observed in these sub basins provide support for Horton's second law [9], which suggests that the average length of streams in a drainage basin tends to follow a direct geometric ratio. To calculate the lengths of different segments of streams, GIS software is utilized. Across all 13 sub-watersheds, the overall stream length is highest for first-order streams and decreases as the stream orders increase. The total stream length shown in Table 4 represents the combined length of streams for each order in their respective sub-watershed. The largest stream length was recorded in sub-watershed SWD7, measuring 276.20 km, while the shortest stream length was found in sub-watershed SWD13, measuring 88.10 km.

3.5 Basin Length (Lb)

The length of the basin is calculated by measuring the distance from where the water flows out of the catchment to a distant point on the catchment's boundary. Moving upstream from the mouth of the basin allows us to determine the location of the main stream. If there is a point where the stream splits into two streams of the same order, the stream with the larger catchment area is considered to be the main stream. The longest basin length of 33.89 km was discovered in sub watershed SWD7.

3.6 Bifurcation Ratio (Rb)

The bifurcation ratio, which is a dimensionless quantity, represents the ratio of the number of streams at a particular order "u" to the sum of the streams at the next higher order "u+1" (Schumn 1956). A lower value of Rb indicates a watershed that has experienced slight disturbances without causing a distortion in the drainage pattern [12]. On the other hand, a high Rb value implies a sub-watershed with limited recharge and excessive overland flow. The shape of the basin also influences the Rb value. Except for areas with significant geological effects, the bifurcation ratio suggests a relatively narrow range of variation across different locations or ecosystems. The average bifurcation ratio of each watershed is referred to as the mean bifurcation ratio (Rbm). Table 4 in the study indicates variations in the mean bifurcation ratio. Usually, when the 'Rb' value is low, the basin produces a rapid discharge peak, whereas when the Rb value is high, the basin produces a slow but continuous peak flow. Circular basins have a low Rbm means SWD2, SWD12, and SWD11 have rapid discharge peak, while elongated basins have a high Rbm means SWD9, SWD11, and SWD13 have slow continuous discharge peak. The range of Rbm values in the study watershed is between 1.37 and 14.76 Table 4.

3.7 Areal Aspect

The values of the areal parameters were calculated, and the results for all 13 sub-watersheds are given in Table 5.

3.8 Stream Frequency / Drainage Frequency (Fu)

The stream frequency, also known as drainage frequency (Fu), refers to the collective number of stream segments per unit area as stated by Horton (1932). It serves as an indicator of the texture and patterns of the drainage network and is primarily influenced by the geological characteristics of the basin. A higher value of drainage frequency suggests a greater runoff. In this particular study, SWD13 demonstrated a higher runoff compared to other sub-watersheds. Nevertheless, the Fu values ranged from 0.69 (SWD9) to 1.64 (SWD13).

3.9 Drainage Density (Dd)

Drainage density refers to the measure of total stream length in relation to the area covered by a drainage basin. It is influenced by both the climate and physical characteristics of the basins. Various factors contribute to drainage density, including the resistance of rocks to erosion, the capacity of land to absorb water, and climate conditions. Regions with a high drainage density typically have weak and impermeable sub-surface material, sparse vegetation, and significant relief. On the other hand, areas with low drainage density tend to have dense vegetation, gentle relief, and resistant and permeable sub-soil materials. The density of drainage is controlled by several elements, such as relief, rainfall, terrain infiltration capacity, and land erosion resistance. In the specific research area, the sub-watershed SWD6 has the highest drainage density of 0.90, while the sub-watershed SWD13 has the lowest drainage density of 0.61.

3.10 Form Factor (Ff)

The form factor, as defined by Horton (1932), is a dimensionless ratio of the basin area to the square of the basin length. It serves as a numerical representation of the shape of a catchment area. A higher form factor value indicates that the basin is more elongated. In practical terms, a high form factor value indicates that peak flows occur quickly or in a short amount of time, while catchments with lower form factor values tend to have smaller peak flows that last longer. The form factor values range from 0.20 to 0.66, and Table 5 shows the form factor values for various sub-watersheds.

3.11 Circulatory Ratio (Rc)

In 1953, Miller introduced the concept of the dimensionless circularity ratio (Rc) as a means to describe the shape of a catchment area. Rc is determined by comparing the catchment area to the area of a circle with the same perimeter. Numerous factors play a role in influencing the value of Rc, such as stream length, drainage frequency, geology, land use, land cover, relief, basin climate, and slope. A low Rc value suggests an elongated catchment, while a value close to 1 indicates a circular shape where water is evenly absorbed. Consequently, excess water takes a longer time to reach the basin's outlet. In Table 5, the circulatory ratio is provided for all sub-watersheds, with sub-watershed SWD13 having the smallest Rc value of 0.12, contrasting sub-watershed SWD1 with the highest value of 0.42.

3.12 Elongation Ratio (Re)

The Re, represented by the elongation ratio, calculates the relationship between the diameter of a circle with the same area as the catchment and the average length of the basin. This

Table 4. Linear aspects of Nawagarh watershed

Sub Watershed	Total no. of stream (Nu)	Total stream length (Lu)	Basin Length(Lb)	Bifurcation Ratio (Rbm)
SWD1	186	169.87	17.62	1.65
SWD2	339	236.52	23.38	1.37
SWD3	180	139.95	16.87	1.98
SWD4	190	162.77	21.54	1.76
SWD5	192	209.19	28.86	1.77
SWD6	220	204.83	29.52	2.11
SWD7	324	276.20	33.89	1.97
SWD8	220	134.94	29.69	1.82
SWD9	131	147.69	21.70	14.76
SWD10	87	100.39	18.84	1.73
SWD11	322	161.93	23.45	5.88
SWD12	133	105.60	21.88	1.55
SWD13	236	88.10	19.82	5.04

parameter typically falls within the range of 0.6 to 1.0 under various climatic and geological conditions. Re values close to 1.0 indicate areas with low relief, while values ranging from 0.6 to 0.8 suggest high relief and steep slopes. Re values can be categorized into three types: circular (Re > 0.9), oval (0.9–0.8), and elongated (Re < 0.8). The analysis of catchment shape heavily relies on this index, as it provides valuable information regarding the hydrological characteristics of a drainage basin. Circular-shaped catchments are more efficient in discharging runoff compared to elongated ones. Among all sub-watersheds, SWD1 stands out with the highest elongation ratio at 0.92. The Re values for 13 sub-watersheds are detailed in Table 5.

3.13 Length of Overland Flow (Lo)

The term "Lo" is used to describe the movement of water from a point on the boundary of a catchment to a nearby stream. This movement is roughly half of the inverse of the Dd value, according to Horton [9]. Lo is a variable that has an impact on the hydrological and physiographic development of a watershed, affecting both the runoff process and flooding. Overland flow refers to water that flows over the surface of the earth and reaches the streams, while surface runoff refers to water that reaches the outlet of the catchment. In smaller watersheds, overland flow is more significant, whereas in larger watersheds, surface runoff is dominant. The Lo values are lower in the sub-watersheds SWD13, which have a length of 0.30 km. On the other hand, among the 13 sub-watersheds, sub-watersheds SWD6 have higher Lo values with a length of 0.45 km, as indicated in Table 5.

3.14 Constant of Channel Maintenance (C)

The constant inversely related to Dd is utilized to upkeep channels, as mentioned by Horton in 1945. This constant calculates the surface area of a river catchment necessary to sustain a single section of a stream channel. In regions with flat terrain, a larger basin surface area is required to maintain an equivalent channel compared to regions with hilly terrain. The sub-watershed area of lower-order streams is greater in sub-watersheds where C values are higher, with the highest C value being 0.020 in sub-watershed SWD1 and the lowest being 0.009 in sub-watershed SWD11, according to Table 5. Sub-watersheds with lower C values exhibit rapid water discharge due to the presence of minimal vegetative cover and facilitate channel flow, thereby minimizing Lo.

3.15 Texture Ratio (T)

The texture ratio plays a significant role in evaluating the characteristics of the terrain and is influenced by various factors like the lithology properties of the basin, soil infiltration capacity, underlying geology, and relief aspects of the catchment. This measurement is determined by dividing the total number of streams by the perimeter of the catchment. The texture ratios differ among the sub-watersheds, with SWD11 having the highest value of 1.69 and SWD10 having the lowest value of 0.60. Table 5 provides the values for all sub-watersheds.

Table 5. Sub watershed wise areal aspect of Nawagarh watershed

Sub Watershed	Drainage density (Dd)	Stream frequency (Fu)	Length of overland flow (Lo)	Texture ratio (T)	Circulatory ratio (Rc)	Form factor (Rf)	Shape factor (Bs)	Elongation ratio (Re)	Constant of channel mainte-nance (C)	Compac-tness constant (Cc)
SWD1	0.83	0.91	0.41	1.04	0.43	0.66	1.51	0.92	1.21	0.01
SWD2	0.82	1.17	0.41	1.25	0.30	0.53	1.89	0.82	1.22	0.01
SWD3	0.81	1.05	0.41	1.35	0.41	0.60	1.66	0.88	1.23	0.01
SWD4	0.77	0.90	0.38	0.96	0.28	0.46	2.19	0.76	1.30	0.01
SWD5	0.88	0.81	0.44	0.90	0.23	0.28	3.51	0.60	1.13	0.01
SWD6	0.90	0.97	0.45	1.16	0.23	0.26	3.83	0.58	1.11	0.01
SWD7	0.83	0.97	0.41	1.17	0.24	0.29	3.45	0.61	1.21	0.01
SWD8	0.75	1.22	0.38	1.12	0.20	0.20	4.91	0.51	1.33	0.02
SWD9	0.79	0.70	0.39	0.74	0.31	0.40	2.51	0.71	1.27	0.01
SWD10	0.88	0.76	0.44	0.60	0.33	0.32	3.10	0.64	1.14	0.02
SWD11	0.82	1.63	0.41	1.70	0.27	0.36	2.78	0.68	1.22	0.01
SWD12	0.72	0.90	0.36	0.81	0.26	0.31	3.24	0.63	1.40	0.02
SWD13	0.61	1.65	0.31	1.44	0.12	0.36	2.74	0.68	1.63	0.02

3.16 Compactness Constant (Cc)

The compactness coefficients in the sub-watersheds varied, with the highest value of 2.13 found in SWS-5 and the lowest value of 3.10 found in SWS-9. Table 5 provides an overview of the significant variances in compactness coefficient throughout the sub-watersheds**.**

3.17 Shape Index (Sw)

The shape index of the catchment is determined using Horton's method from 1932, where the basin length is squared and divided by the catchment area. The flow of water and sediment yield in a drainage basin is influenced by its Sw, which is determined by the length and relief of the basin. Among the sub-watersheds, SWD8 has the highest Sw value of 4.90, while SWD1 has the lowest value of 1.51. Table 5 provides the shape index values for all thirteen sub-watersheds.

3.18 Relief Aspects

The elevations of the sub-watersheds in the present study ranges from 187 m to 1145 m (MSL). The Relief aspects parameters have been computed and results were tabulated in Table 6.

3.19 Basin relief (R)

The Basin relief or R, which refers to the maximum vertical distance between the highest and lowest point of a catchment, plays a crucial role in determining the gradient of the stream channel. This, in turn, affects the patterns of floods and the amount of sediment carried by the stream. The elevation of the catchment provides the potential energy for the drainage system, and the R value can range from 57 m to 589 m. An increase in relief leads to steeper hill slopes, higher stream gradients, and a shorter time of concentration. As a result, the flood peak is elevated. Patton and Baker suggested this in 1976, and the Table 6 provides the sub watershed-wise values of basin relief for the Nawagarh Watershed [15,16].

3.20 Relative Relief (Rhp)

Schumm (1956) defined Relative Relief as the proportion of the maximum elevation difference within a catchment to its perimeter. Table 6 presents the Rhp values for 13 sub-watersheds, with sub-watershed SWD13 having the smallest Rhp value of 0.56 and sub- watershed SWD2 having the highest Rhp value of 8.09.

3.21 Relief Ratio (Rr)

The relief ratio was defined by Schumm in 1956 and is a measure of the ratio between the relief of a basin and the longest dimension of the catchment that runs parallel to the primary drainage line. In catchment areas, relief ratio values typically range from 0.01 to 0.04. Regions with high relief and steep slopes tend to have higher relief ratio values, while areas with low relief ratio values are usually attributed to less permeable basement rocks and low slope degrees. The relief ratio is an important indicator of erosion strength resulting from slope, as it measures the overall steepness of the catchment. Sub-watersheds with high relief ratios, like sub-watershed SWD1 and SWD3 with a value of 0.032, have shorter time of

Table 6. Relief Aspect of Nawagarh watershed

Sub Watershed	Max Basin height	Min Basin height	Basin relief(R)	Ruggdness No. (Rn)	Relative relief (Rhp)	Reliefratio (Rr)	Drainage Factor (Df)
SWD1	975	406	569	0.47	5.14	0.032	1.32
SWD2	942	353	589	0.48	8.09	0.025	1.75
SWD3	924	376	548	0.45	5.66	0.032	1.58
SWD4	908	327	581	0.45	5.10	0.027	1.52
SWD5	694	293	401	0.35	3.56	0.014	1.04
SWD6	509	290	219	0.20	1.67	0.007	1.19
SWD7	622	284	338	0.28	3.22	0.010	1.41
SWD8	325	253	72	0.05	0.82	0.002	2.17
SWD9	316	259	57	0.04	0.86	0.003	1.13
SWD10	335	270	65	0.06	0.68	0.003	0.99
SWD11	315	237	78	0.06	0.93	0.003	2.43
SWD12	310	240	70	0.05	0.58	0.003	1.76
SWD13	298	230	68	0.04	0.56	0.003	4.36

concentration and higher stream flow rates, making them more susceptible to erosion compared to other sub- watersheds shown in Table 6.

3.22 Ruggedness Number (Rn)

The ruggedness number is a dimensionless value that can be calculated by multiplying R and Dd, both of which have the same unit (Patton and Baker, 1976). A high ruggedness number indicates a steep and long slope, suggesting a complex landscape structure that is prone to erosion. Rough areas with high relief and low Dd values are associated with high ruggedness numbers, while smooth areas with low relief and high Dd values have low ruggedness numbers. A high ruggedness number can lead to a sudden increase in the hydrograph. In the Nawagarh watershed area, the ruggedness number ranges from 0.04 to 0.48, as shown in Table 6. Sub-watersheds 9 and 13 have low ruggedness numbers, while the other sub-watersheds have highvalues [17,18].

3.23 Drainage Factor (Df)

Drainage factor (Df) refers to the relationship between Fu and the square of Dd. In the current study area, the Df value ranges from 0.99 to 4.36. The Table 6 presents the specific values of the Drainage factor for each sub-watershed within the Nawagarh watershed [19,20].

4. CONCLUSIONS

The study demonstrated that utilizing a GIS-based approach is more suitable for evaluating morphometric parameters. The research conducted for quantitative analysis of morphometric characteristics within thirteen sub-watersheds of the Nawagarh watershed. The morphometric analysis of several sub-watersheds shows their relative qualities in terms of the watershed's hydrological response. The Nawagarh watershed contains a dendritic drainage network consisting of a total of 2760 streams of different orders, ranging from the first to the fifth order. The slope of the land is an analytical factor that directly impacts the rate at which the ground absorbs water and the speed at which it drains. As the slope increases, the amount of water runoff also increases, while the rate of water infiltration decreases. The Nawagarh watershed exhibits an almost flat and undulating landscape, ranging from mild (0-2) to severe (>15) slopes. The elongated shape of the catchment is indicated by various values, such as the form factor (0.39), circulatory ratio (0.28), and elongation ratio (0.69). These values suggest that the Nawagarh watershed has a more elongated shape, with lower peak flow durations and a lower permeability. Sub watersheds SWD1 and SWD3, which have a relief ratio of 0.032, indicates the rapid concentration, rapid stream flow, and a greater vulnerability to erosion compared to other sub watersheds. The basin has a reasonably high drainage density, as seen by the drainage density of approximately 0.80 km-1, or close to one km-1. which show the location's steep relief and poor, impermeable underlying material. The Nawagarh watershed, which has an elongated shape and a lowered peak flow with poor permeability over an extended period of time, was discovered to have a dendritic drainage network. Soil erosion must be stopped in these sub-watersheds by using efficient techniques; only then will the land be spared from further erosion. This research is important for managing watersheds, planning for land and water resources, preventing erosion, and investigating possible uses in runoff studies in thefuture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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