International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

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GIS-based morphometric analysis of sub-watersheds and their prioritization in the Upper Yamuna Basin up to Kalsi, Uttarakhand, India

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International Journal of Science and Research Archive, 2025, 14(02), 1691-1708

Publication history: Received on 14 January 2025; revised on 22 February 2025; accepted on 24 February 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.14.2.0548

Abstract

This paper is aimed to study the viability of GIS data in Upper Yamuna basin for morphometric analysis and their prioritization. For the study upper Yamuna basin upto Kalsi has been selected. The Horton and Strahler methodshas been used to delineate the areal, linear and relief parameters of watersheds. Morphometry of watershed analysis helps to reduce time and is also beneficial for water conservation, planning, and development. The remote sesnsing and toposheets based data is used, processed in GIS, and verified at field. The study shows morphometric characteristics of the upper Yamuna basin. The procedure includes accurate quantitative measurements and mathematical studies of drainage basins, which successfully disclose the complex interrelationships between the basin's geomorphologic features and hydraulic parameters. The total watershed area is 2340.3 sq. Km. is grouped into nine sub-watersheds (SW1 to SW9), ranging from 161.28 to 457.28 sq. Km, mean bifurcation ratio ranges from 3.57(SW7) to 5.07(SW6), drainage density ranges from 2.36(SW8) to 5.49(SW1), sub-watersheds are sub-dendritic to dendritic in nature and form factor, circulatory and elongation ratio indicate that sub-watersheds are sub-elongated to elongated in nature. Taking all parameters, compound values are analyzed, and finally, prioritization, i.e., arranging sub-watersheds in hierarchy order is done based on compound value. The lowest compound value (2.84; SW1)has given priority, which indicates maximal soil erosion and increased susceptibility to natural hazards.

Keywords: Morphometric Analysis; GIS; Sub-Watersheds; Prioritization; Upper Yamuna Basin

1. Introduction

Himalayan Rivers vary in size depending on source, slope and season. The hydrologic system is governed by the interaction of climate and landscape (Sivakumar & Sivakumar, 2017); this affects the hydrologic characteristics of rivers. The Yamuna River is highly used for drinking and agriculture purposes. Yamuna is also considered a significant tributary of Ganga and meets Ganga at Prayagraj. Various sub-tributaries join the Yamuna at multiple places and change its characteristics.

Soil erosion is the primary factor in the Himalayas, causing land degradation; these materials are deposited in the river bed, disturb the river depth and cause flooding in the monsoon season. One of the major natural disasters that affects the Himalayas virtually yearly is flooding. As the watershed is a fundamental unit of fluvial systems, various studies are based on the characteristics of the basin. To know about the drainage network, erosional stage, slope, relief, altitude, and runoff characteristics morphometric analysis is essential(Sarkar et al., 2020). As a result, morphometric parameters like relief, areal, and linear must be calculated. The morphometric analysis given by Horton(Horton, 1932, 1945) indicates the relationship between natural agents like hydrology, soil, vegetation, geology and climate. To further understand this, it was studied in detail by Strahler(Strahler, 1952, 1957, 1958, 1964).The characteristics of these parameters can be used in various studies, such as the assessment of environmental changes and water conservation

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planning and development(Obeidat et al., 2021). These analyses also help to predict the behaviour of sub-watersheds in rainfall. The watersheds are divided into nine sub-watersheds, and their prioritization is done based on morphometric analysis. Sub-watersheds are prioritized by rating them according to the necessity of the necessary treatment(Farhan, 2017; Krishnan & Ramasamy, 2022; Mallick et al., 2022; Obeidat et al., 2021; Shekar & Mathew, 2022).

Traditional methods are used in several parts of the world for morphometric analysis, but Remote sensing technology is one of the most optimum method for morphometric analysis along with GPS and GIS is highly used nowadays because satellite images provide larger area view. DEM data from USGS is downloaded and processed by GIS. These techniques are used by(Biswas et al., 2014; Rai et al., 2018; Sharma & Mohanty, 2018; Sreedevi et al., 2005). Geospatial tools are highly used to know the characteristics of sub-watersheds, and it has excellent precision because of freely available high-quality resolution DEM. I have taken mainly two objectives for the research paper: 1) Analyzing morphometric properties and 2) Prioritizing the sub-watersheds.

2. Study Area

Yamuna is the largest tributary of the Ganga. The Yamuna emerges from the higher Himalayas, passes through lesser than outer, and finally meets the Ganga at TriveniSangam (confluence of three rivers, Ganga, Yamuna and Saraswati) in Prayagraj. Study area is located in the Uttarkashi and Dehradun districts, Uttarakhand i.e., Upper Yamuna basin up to Kalsi of coordinates 31° 0'5.62"N, 78°33'21.02"E to 30°30'45.62"N, 77°50'52.48"E in fig 1, covering the area of 2340.3 sq. km of watershed and lies in the lesser and higher Himalaya.

This basin comprises HHC (Higher himalayan crystalline) lies between MCT and MBTwhich is high grade metamorphic of Neoproterozoic age, LHMS(Lesser Himalayan Meta-Sedimentary) of palaeoproterozoic to paleozoic age, outer Himalayan and Indo-Gangetic alluvium.

Study area lies in the tropical environment receiving NE monsoon (October –December) and SW monsoon (June-September).

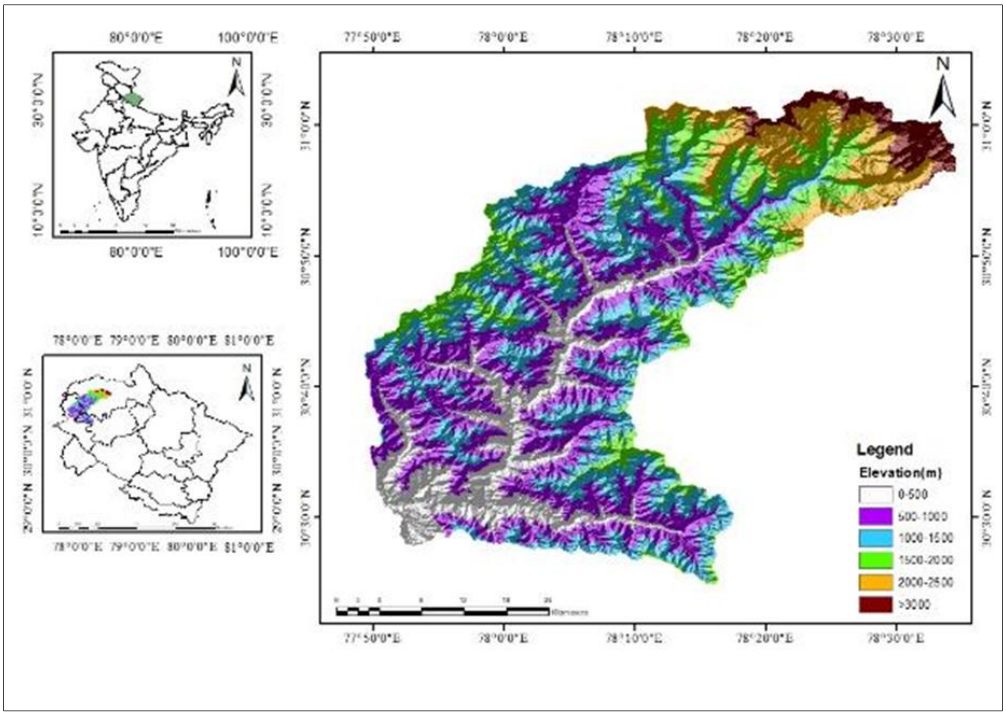

Figure 1 General map of study region

3. Materials and Methods

3.1 Data collection

The study regions are included in several toposheets of the 1:50,000 scale, which are derived from a survey of India. Following that, ArcGIS 10.6 was used to georeference, crop, and combine all toposheets into a single sheet. Shuttle Radar Topography Mission (SRTM) data are downloaded from USGS Earth Explorer of 30m resolutionfor morphometric analysis.

Table 1 Data collected from the following

Data	Details of Data	Source
Toposheets	Toposheet no.53I4, 53I8, 53I12, 53F10, 53F11, 53F13, 53F14, 53F15, 53J1, 53J2, 53J3, 53J5, 53J6, 53J7, 53J9 from Survey of India	https://onlinemaps.surveyofindia.gov.in/FreeMapSpecification.aspx
DEM	USGS Earth Explorer of 30 m resolution.	https://earthexplorer.usgs.gov/
Subbasins / Sub-watersheds	Asian Hydrosheds	

3.2 Delineate the drainage

Sub-watersheds, along with streams, are delineated from GIS and verified by overlaying them in Google Earth and the toposheet. The ArcGIS 10.3 spatial analyst tool measures metrics such as basin perimeter and area, stream order, and length. Other characteristics that aid in the measurement of two-dimensional linear, areal, and three-dimensional relief aspects are computed using mathematical procedures. Table 2 displays these parameters as well as the formula and citations**.**

Table 2 Formulae Used

S.No.	*Morphometric Parameters*	*Formulae*	*Citations*
Basic Parameters			
1	*Basin area/ watershed area(A)*	*Area measured by ArcGIS*	(SCHUMM, 1956)
2	*Basin Perimeter (P)*	*Measurement of periphery of basin by GIS*	(SCHUMM, 1956)
3	*Basin/ Watershed length(L_b)*	*GIS analysis or* $L_b = 1.312\ A^{0.568}$	(Nooka Ratnam et al., 2005; SCHUMM, 1956; Sreedevi et al., 2005)
4	*Basin width (W_b)*	$W_b=A/ L_b$	(Horton, 1945; Munoth & Goyal, 2020; Radwan et al., 2020)
Linear Aspect			
5	*Stream order (U)*	*Hierarchical order*	(Munoth & Goyal, 2020; Strahler, 1957)
6	*Stream number (N_u)*	$N_u=N_1+N_2+N_3$+--	(Horton, 1945; Potter, 1957)
7	*Stream length (L_u)*	$L_u=L_1+L_2+L_3$+--	(Horton, 1945; Jaiswal et al., 2015; Strahler, 1964)
8	*Mean stream length (L_m)*	$L_m= L_u/ N_u$	(Horton, 1945; Jaiswal et al., 2015)
9	*Stream length ratio (R_u)*	$R_u = L_u/ L_{u-1}$	(Horton, 1945; Jaiswal et al., 2015)
10	*Bifurcation ratio (Rb)*	$Rb= N_u/ N_{u+1}$	(Horton, 1945; Jaiswal et al., 2015; Strahler, 1964)

11	*Mean Bifurcation ratio (Rbm)*	*Rbm = Rb/n*	(Munoth & Goyal, 2020; Strahler, 1964)
12	*Rho coefficient (ρ)*	$\rho = R_u / Rb$	(Horton, 1945; Potter, 1957)
Aerial aspect			
13	*Drainage density (D_d)*	$D_d = L_u / A$	(Horton, 1932, 1945)
14	*Stream frequency (F_s)*	$F_s = N_u / A$	(Horton, 1932, 1945)
15	*Drainage texture (R_t)*	$R_t = N_u / P$	(Horton, 1945)
16	*Drainage intensity (D_i)*	$D_i = F_s / D_d$	(Farhan, 2017; Strahler, 1957)
17	*Form factor (R_f)*	$R_f = A / L_b^2$	(Horton, 1945)
18	*Circulatory ratio (R_c)*	$R_c = 4\pi A / P^2$	(Miller, 1953; MUELLER, 1968)
19	*Elongation ratio (R_e)*	$(R_e) = 2 / L_b * (A/\pi)^{0.5}$	(SCHUMM, 1956)
20	*Infiltration number*	$D_d * F_s$	(Horton, 1945)
21	*Length of overland flow (L_g)*	$L_g = 1/2D_d$	(Horton, 1945)
22	*Constant channel maintenance (C)*	$C = 1/D_d$	(Horton, 1945; SCHUMM, 1956)
23	*Compactness coefficient (Cc)*	$Cc = 0.28418 * P / A^{0.5}$	(Potter, 1957)
24	*Lemniscate's ratio(k)*	$k = L_b^2 / 4A$	(Jothimani et al., 2020)
Relief aspect			
25	*Basin relief (H)*	*H=Z-z, Z=Maximum height z= Minimum height*	(SCHUMM, 1956; Strahler, 1952)
26	*Ruggedness number (Rn)*	$Rn = H * D_d$	(SCHUMM, 1956; Strahler, 1958)
27	*Relief ratio (R)*	$R = H / L_b$	(SCHUMM, 1956)
28	*Hypsometric integral(HI)*	$HI = E_{mean} - E_{min} / E_{max} - E_{min}$"	(PIKE & WILSON, 1971)

3.3 Flowchart of Methodology

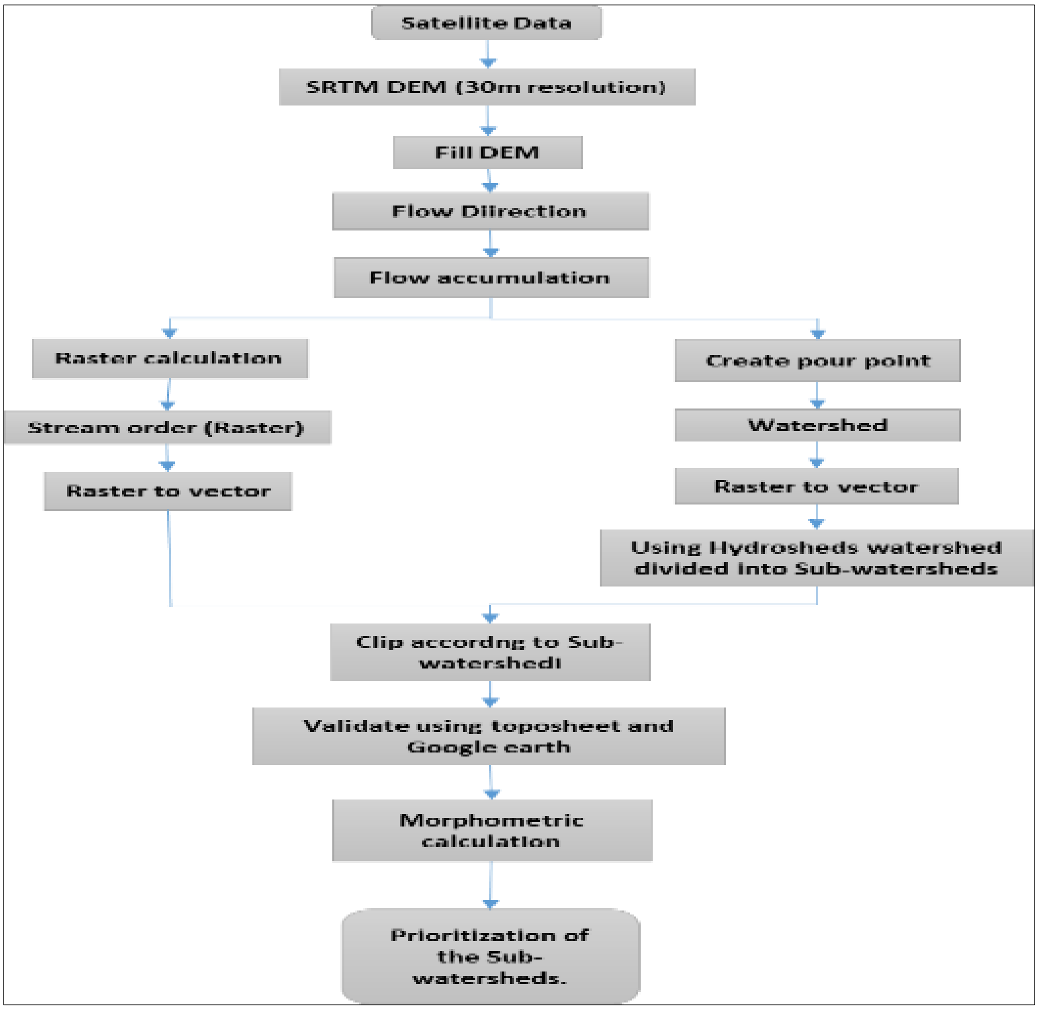

Figure 2 Showing flowchart of the methodology

4. Result and discussion

Using DEM data and ArcGIS, watersheds are delineated and divided into nine sub-watersheds (SW1 to SW-9) display in Figure 3. Morphometry is calculated mathematically using methods given in Table 2. The drainage is delineated into seven-order streams Figure3 and is of dendritic to sub-dendritic pattern.

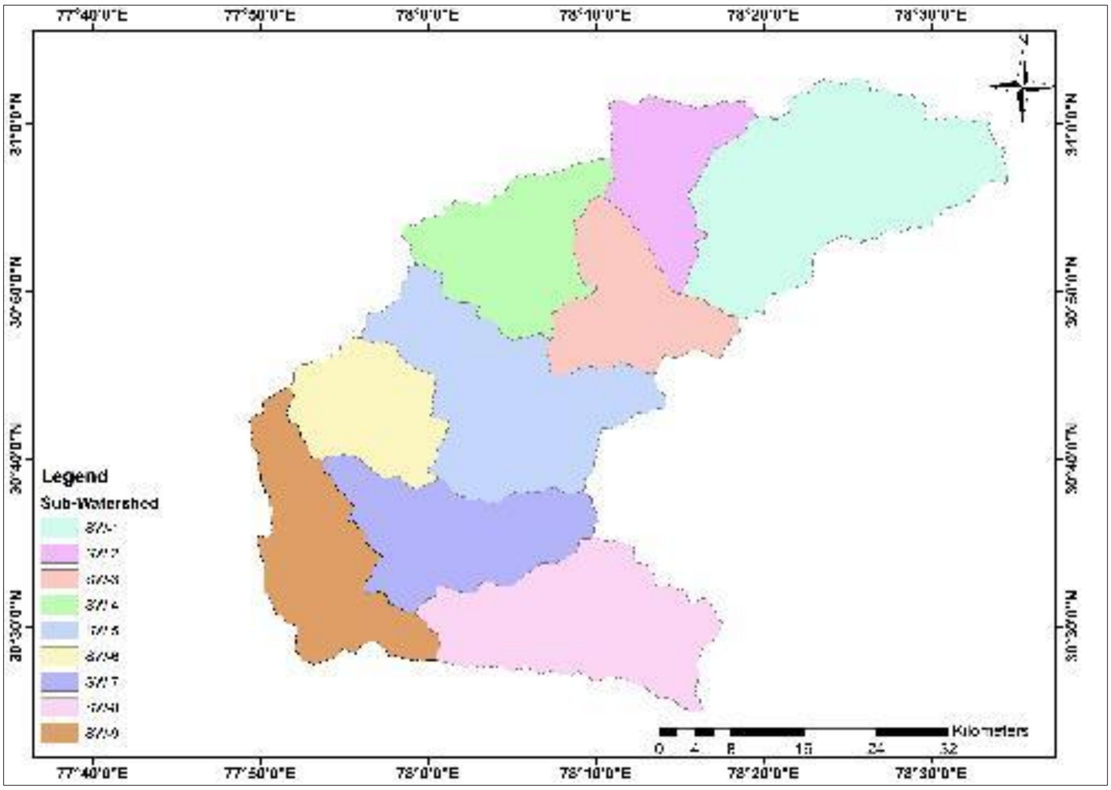

Figure 3 Sub-Watersheds of study area

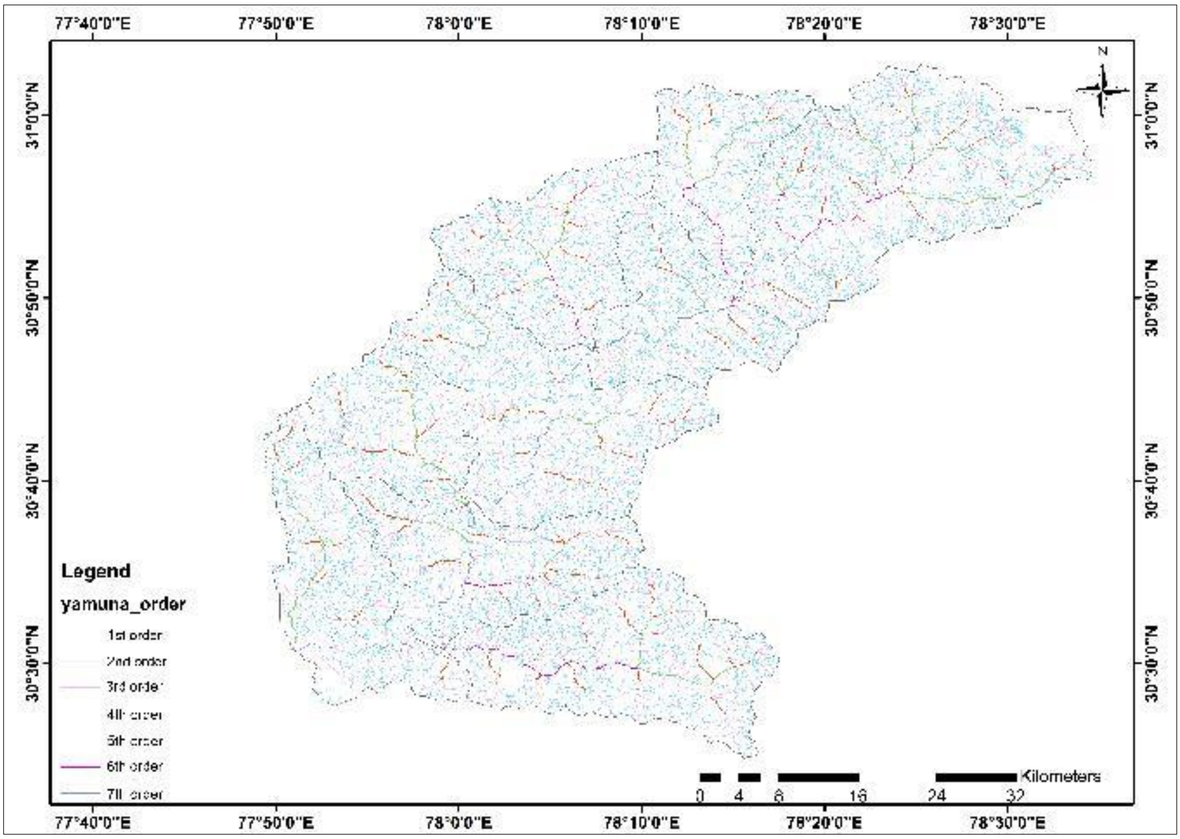

Figure 4 Streams of study area

4.1 Figure4a,4b,4c and 4d shows contour, hillshade , slope and aspect of study area

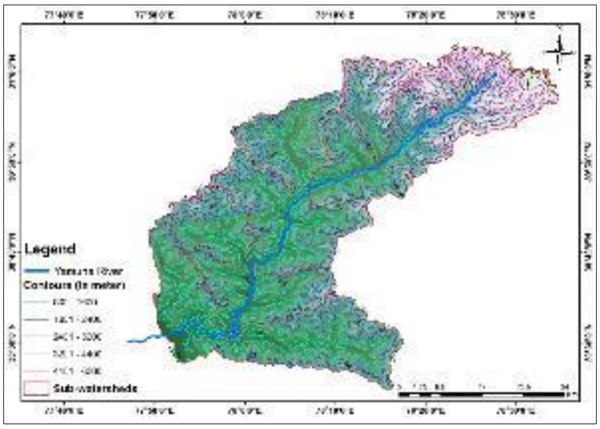

Figure 5a Contour

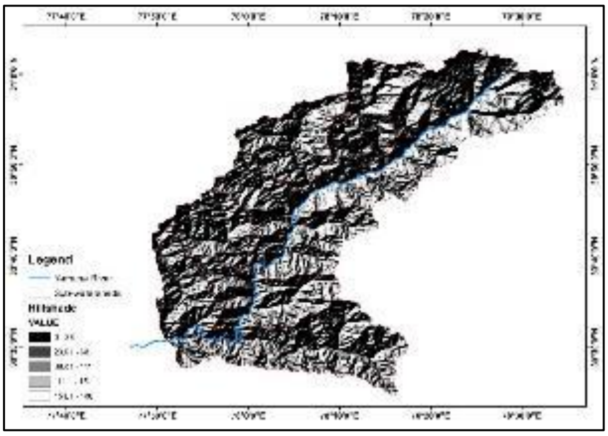

Figure 5b Hillshade

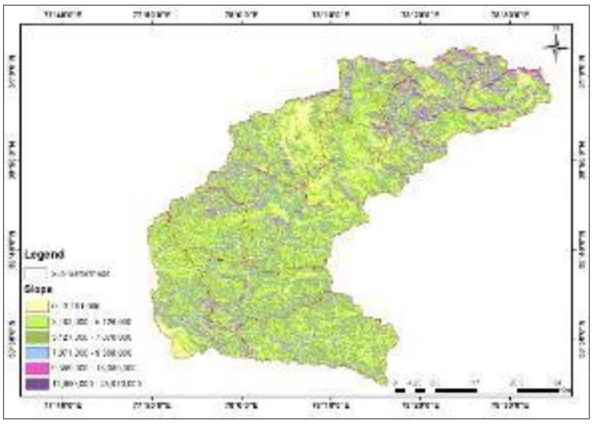

Figure 5c Slope

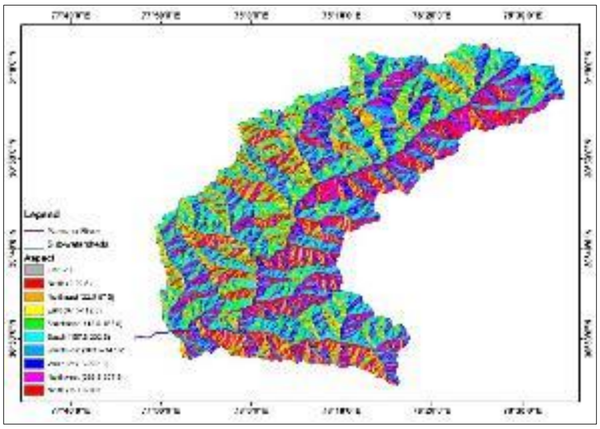

Figure 5d Aspect

Morphometry is one of the best methods to delineate linear, areal and relief aspects using Horton and Sthaler method:

4.2 Basic Parameters

4.2.1 Basin area/watershed area(A):

"It is defined as total area of watershed", which indicates storage capacity of watershed; the total area is 2340.3km^2, it ranges from 161.28(SW-2) to 457.28(SW-1).

4.2.2 Perimeter(P)

"Length of the peripheral part of basin", total perimeter of Upper Yamuna basin is 767 km, it ranges from 59(SW-6) to 108(SW-1).

4.2.3 Basin/ Watershed length (L_b)

Length along main water resources from basin to divide(SCHUMM, 1956). Values are shown in the Table 3.

4.2.4 Basin/ Watershed Width (W_b)

Distance of line perpendicular to basin length, Table 3 displays values.

Table 3 Basic Parameters

	Sub-Watershed								
	SW1	***SW2***	***SW3***	***SW4***	***SW5***	***SW6***	***SW7***	***SW8***	***SW9***
Basin area/watershed area(A): Sq. km	457.28	161.28	190.68	219.72	349.66	168.62	239.50	308.92	244.66
Perimeter(P):in Km	108	68	73	77	107	59	86	92	97
Basin/ Watershed length (L_b):	42.55	23.54	25.90	28.06	36.54	24.14	29.47	34.05	29.83
Basin/ Watershed Width (W_b):\	10.75	6.85	7.37	7.83	9.57	6.99	8.13	9.07	8.20

4.3 Linear Parameters:

These factors directly impact soil erodibility by affecting the amount and extent of flow(Verma et al., 2022). Table 4 displays every parameter that has a value.

4.3.1 Stream order (U)

"It defines as positioning of streams and their intersection". It is assigned according Strahler, outer stream is given as 1st order stream, two 1st order streams intersect makes 2nd order and so on(Strahler, 1957). Upper Yamuna Basin is the 7th order stream, and the basin is divided into nine sub-watersheds with different orders ranging from 5th order to 7th order.

4.3.2 Stream number (N_u)

It shows number of stream branching(Horton, 1945) N_u=N_1+N_2+N_3+--. Table no. 4 displays the total number of streams for all orders. Stream number is inversely proportional to stream order, first order being the maximum number of streams.

4.3.3 Stream length (Lu)

Length of all streams, i.e., the sum of the length of all streams(Horton, 1945)". A longer channel indicates a gentler slope and softer strata, allowing water to flow farther and therefore cut through its banks and beds and, therefore, cause more erosion, whereas, shorter channel represent steep slopes, hard impermeable rocks, and water flow with greater velocity, but cause less erosion because of resistant rock(Verma et al., 2022). Watersheds with decreasing stream length is as follows 2507.99(SW-1), 1092.63(SW-5), 979.97(SW-8), 812.55(SW-7), 728.01(SW-9), 711.64(SW-4), 665.75(SW-3), 498.02(SW-6), 468.81(SW-2).

4.3.4 Mean stream length (Lm)

Ratio of total stream length to total stream number".

Stream length ratio: "Ratio of total stream length of a particular order to total stream length of a previous order(Potter, 1957)". This varies with slope and topographic conditions and is related to surface flow discharge and erosional stage of the basin(Sreedevi et al., 2005). The stream length ratio of sub-watershed varies between 1.46 to 5.28.

4.3.5 Bifurcation ratio:

The ratio is the total number of streams of given order to total number of streams of next order(Jaiswal et al., 2015; Strahler, 1964)".Stronger geological control is indicated by higher values. If Rb<3, the basin is considered flat and lacks structural influence. If Rb between 3 to 5, the basin has some geological structure but has minimal impact on the drainage pattern. If the Rb>5, the basin has terrain and is controlled by both lithology and structure(A. P. Singh et al., 2020). It has a direct impact on soil erosion(Verma et al., 2022). While the 9-sub watersheds have a mean bifurcation ratio ranging between 3.57 to 5.07, the basin mean bifurcation ratio is 4.17, but all. According to the data, the watershed experienced fewer structural disturbances(Prieto-Amparán et al., 2019; Strahler, 1958; Verma et al., 2022).

4.3.6 Rho coefficient

"The proportion of stream length ratio to bifurcation ratio; it is an important parameter that controls the storage capacity of the stream network and the level of drainage development(Horton, 1945; Potter, 1957)". The Mean Rho of the basin is 0.13, whereas the Rho of sub-watershed lies from 0.06 to 0.25. Those with higher Rho have excellent water storage during periods of flood and reduced erosive effects during periods of high discharge(Mesa, 2006)

Table 4 Calculation of linear Parameters

	Sub-Watershed								
	SW1	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	**SW7**	**SW8**	**SW9**
Stream number (Nu)									
1storder(N1)	1948	522	737	789	1369	606	1076	1311	857
2ndorder(N2)	467	107	156	172	297	143	233	268	188
3rdorder(N3)	113	28	27	40	67	30	51	62	37
4thorder(N4)	27	5	8	12	11	7	12	15	8
5thorder(N5)	8	2	1	5	3	1	3	2	1
6thorder(N6)	2	1	-	1	1	-	1	1	-
7thorder(N7)	1	-	1	-	1	-	1	-	1
Nu= N1+N2+N3+----	2566	665	930	1019	1749	787	1377	1659	1092
Stream length (Lu): in Km									
1storder(L1)	1051.34	316.91	470.96	475.77	712.89	321.22	517.80	607.10	463.96
2ndorder(L2)	1211.28	73.84	115.04	120.22	197.56	92.38	146.91	195.34	136.04
3rdorder(L3)	118.92	33.73	47.11	55.75	102.90	48.85	67.93	90.71	59.30
4thorder(L4)	59.30	11.35	26.85	32.16	35.25	27.04	38.66	51.48	24.78
5thorder(L5)	47.48	17.32	5.64	16.15	20.90	8.53	10.71	15.37	22.91
6thorder(L6)	18.91	15.66	-	11.59	0.01	-	7.69	19.97	-
7thorder(L7)	0.76	-	0.15	-	23.12	-	22.85	-	21.02
(Lu= L1+L2+L3+----)	2507.99	468.81	665.75	711.64	1092.63	498.02	812.55	979.97	728.01
Mean stream length (Lm = Lu/ Nu)	0.98	0.71	0.72	0.70	0.63	0.63	0.60	0.60	0.67
Bifurcation ratio (Rb= Nu/ Nu+1)									
Rb1= N1/ N2	4.17	4.88	4.72	4.59	4.61	4.24	4.62	4.90	4.56
Rb2= 2/ N3 N	4.13	3.82	5.78	4.3	4.43	4.77	4.57	4.32	5.08
Rb3= N3/ N4	4.19	5.6	3.38	3.33	6.10	4.29	4.25	4.13	4.63
Rb4= N4/ N5	3.38	2.5	8	2.4	3.67	7	4	7.5	8
Rb5= N5/ N6	4	2	1	5	3	-	3	2	1
Rb6= N6/ N7	2	-	-	-	1	-	1	-	-
Mean bifurcation ratio (Rbm): Rbm= Rb/n	3.64	3.76	4.58	3.92	3.80	5.07	3.57	4.57	4.65
Stream length ratio (Ru = Lu+1/ Lu)									

R1= L2/ L1	1.15	0.23	0.24	0.25	0.28	0.29	0.28	0.32	0.29
R2= L3/ L2	0.10	0.46	0.41	0.46	0.51	0.53	0.46	0.46	0.44
R3= L4/ L3	0.50	0.34	0.57	0.58	0.34	0.55	0.57	0.57	0.42
R4= L5/ L4	0.80	1.53	0.21	0.50	0.60	0.32	0.28	0.30	0.92
R5= L6/ L5	0.40	0.90	-	0.72	0.001	-	0.72	1.30	-
R6= L7/ L6	0.04	-	0.03	-	-	-	2.97	-	0.92
Ru	2.99	3.46	1.46	2.51	1.73	1.69	5.28	2.95	2.99
Rho coefficient (ρ = Ru / Rb)	0.14	0.18	0.06	0.13	0.08	0.08	0.25	0.13	0.13

4.4 Aerial Parameter

Drainage density: "The ratio of total stream length to basin is drainage density(Potter, 1957)". Drainage density of sub-watershed varies between 2.36 to 5.49 km^{-1}. Drainage density defines how many streams are there i.e., how dense is the watershed. It is usually affected by lithology, climate, soil and rock type, relief, landscape, runoff intensity, infiltration capacity, surface roughness, vegetation, and stream source. Higher the drainage density finer will be drainage texture(Strahler, 1964). Low drainage density shows the area of high resistant, permeable, low relief and dense vegetation however, high drainage density show impermeable, high relief and sparse vegetation (Nag, 1998). The amount and type of precipitation have an impact on quantity and nature of surface runoff(Bali et al., 2012).

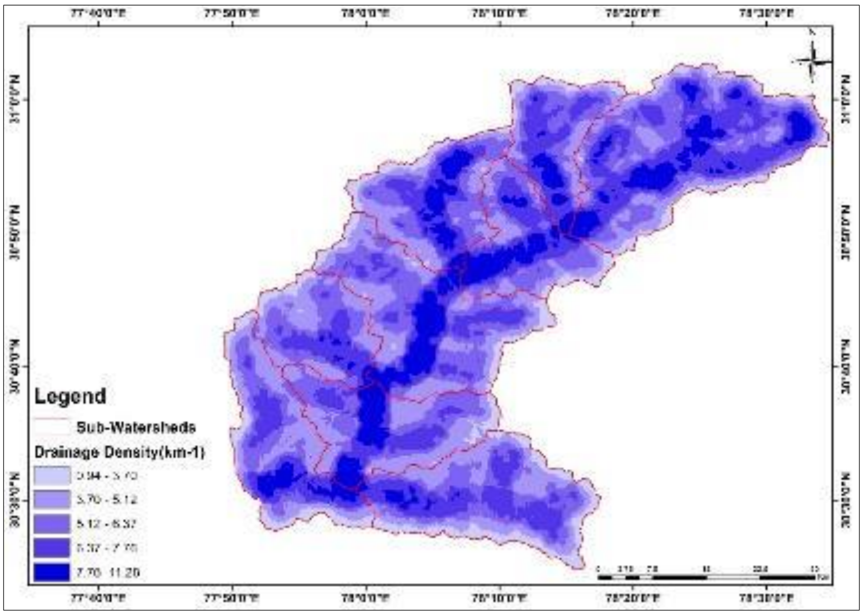

Figure 6 Drainage Density

- **Stream frequency:** "Number of streams present in a particular area". A variety of factors contribute to it, including rock composition, permeability, and amount of precipitation in the landscape."It is related to lithological character(Kumar & Chaudhary, 2016) ,permeability, infiltration capacity and basin relief(Vijith & Satheesh, 2006). The higher the stream frequency higher will be the relief, lower infiltration capacity and more soil erosion. It is characterized in 5 classes(A. P. Singh et al., 2020), i.e., 0-5 for low, 5-10 for moderate, 10-15 for moderately high, 15-20 for high, and 20-25 for very high. The sub-watershed's mean stream frequency ranges from 3.54 to 6.78 Km^{-2}, whereas the basin's mean stream frequency is"5 Km^{-2}.
- **Drainage texture:** "Ratio of total number of streams to the basin's perimeter(Horton, 1945)". Surface runoff is determined by infiltration capacity and vegetation density, which also impact the area's drainage texture(Chopra et al., 2005) Together with these factors, it also depends on the kind of soil and rock, climate, precipitation, relief, and basin development stage(Smith, 1950). Smith(Smith, 1950) also classified drainage

texture into the following classes 4-6 for intermediate, <2 for extremely coarse, 2-4 for coarse, 6-8 for fine, >8 for ultra fine. The sub-watersheds exhibits a fine drainage texture, with a range of 9.78 to 23.76 in length.

- **Drainage intensity:** "Ratio of stream frequency to drainage density (Faniran, 1968; Strahler, 1957)", lower will be the drainage density higher will be drainage intensity.
- **Infiltration number:** "Product of drainage density and stream frequency (Strahler, 1957)**".** It indicate the infiltration and surface runoff rate. Infiltration number is inversely proportional to infiltration and is directly proportional to runoff(Rawat et al., 2022).
- **Length of overland flow:** "Generally half of drainage density(Potter, 1957)**".** It is the length covered by precipitation. It is inversely proportional to slope and relief(Yadav et al., 2014). The more the L_g the more chance of erosion. Here is the value with decreasing order and hence with the decreasing capacity to erosion :2.74(SW1), 2.00(SW9), 1.75(SW3), 1.70(SW7), 1.62(SW4), 1.56(SW5), 1.48(SW6), 1.45(SW2), 1.18(SW8).
- **Lemniscate's ratio:** helpful in governing the gradient of the basin(Jothimani et al., 2020)**.**
- **Constant channel maintenance:** "Reciprocal to drainage density(Munoth & Goyal, 2020)". The value ranges from 0.18 to 0.42.
- **Compactness coefficient:** "Ratio of basin perimeter to circumference of a circle having same area to basin(Potter, 1957)**"**. It depends on slope, not on watershed size. It directly affects erosion risk assessment factors(Verma et al., 2022).
- **Shape factor:** Shape of basin influenced by drainage pattern, geological structure, lithology slope, weathering, erosion, etc.
- **Form factor:** "Ratio of basin's area to the square of basin length(Horton, 1945)". It ranges from 0 to 1; smaller the value elongated is basin. 0 stands for elongated shape, whereas 1 represent circular shape. A low form factor displays an extended low peak flow over a longer period of time, and a high form factor displays a high peak flow of short duration(Chopra et al., 2005). It ranges for sub-watersheds from 0.25 to 0.30.
- **Circulatory ratio:**"Ratio of basin area to an area of a circle having same circumference as of basin perimeter(Miller, 1953; MR et al., 2019; Strahler, 1964)". It varies between 0(line) to 1(circle). >0.5 shows basin is more circular and more homogeneous, whereas <0.5 shows the basin is elongated. Length, stream frequency, geological structure, climate, land use/cover, relief, and slope all have an impact. It indicates stage of basin development(Sreedevi et al., 2005). The sub-watersheds' varying circulatory ratios, which range from 0.33 to 0.61, suggest that they are somewhat circular.
- **Elongation ratio:** "ratio of a circle's diameter with the same area as a watershed to a basin's length(Munoth & Goyal, 2020)**".** It ranges from 0(highly elongated) to 1(circular). "R_e between 0.9-1 is circular, 0.8-0.9 is oval, 0.7-0.8 is less elongated, 0.5-0.7 is elongated and <0.5 is more elongated(Rawat et al., 2022; SCHUMM, 1956)". Closer to 1 is low relief (Strahler, 1964)**.** Elongation ratio of sub-watershed varies from 0.57 to 0.61, indicate that the sub-watersheds are sub-elongated to elongated.

5. R_f, R_c, and R_e show the watersheds are sub-elongated to elongated

Table 5 "Calculation of Aerial Parameters

	Sub-Watershed								
	SW1	*SW2*	*SW3*	*SW4*	*SW5*	*SW6*	*SW7*	*SW8*	*SW9*
"Drainage density (D_d) in Km^{-1}	5.49	2.91	3.49	3.24	3.13	2.95	3.39	2.36	4.01
Stream frequency (F_s) in Km^{-2}	5.61	4.12	4.88	4.64	5.00	4.67	5.75	3.54	6.78
Drainage texture (R_t) in Km^{-1}	23.76	9.78	12.74	13.23	16.35	13.34	16.01	11.87	17.10
Drainage intensity (D_i) in Km^{-1}	1.02	1.42	1.40	1.43	1.60	1.58	1.70	1.50	1.69
Form factor (R_f)	0.25	0.30	0.29	0.28	0.26	0.29	0.28	0.27	0.28
Circulatory ratio (R_c)	0.49	0.44	0.45	0.47	0.38	0.61	0.41	0.46	0.33
Elongation ratio (R_e)"	0.57	0.61	0.60	0.60	0.58	0.61	0.59	0.58	0.59
*Infiltration number (I_f=D_d*F_s):*	30.78	11.99	17.03	15.02	15.63	13.79	19.51	8.33	27.16
Length of overland flow (L_g)	2.74	1.45	1.75	1.62	1.56	1.48	1.70	1.18	2.00
Lemniscate'sratio(k=L_b^2/4A)	0.99	0.86	0.88	0.90	0.95	0.86	0.91	0.94	0.91

Constant channel maintenance (C)	0.18	0.34	0.29	0.31	0.32	0.34	0.30	0.42	0.25
Compactness coefficient (Cc)	1.44	1.52	1.50	1.48	1.63	1.29	1.58	1.49	1.76

5.1 Relief Parameters:

Basin relief : The slope and erosion of the area are affected by it. As the value increases, erosion increases, and the slope becomes steeper, flood risk increases.

Ruggedness number: "product of the basin's relief and drainage density", it represent the structural complexity of the terrain, the higher the value, the more rugged will be the topography and drainage density, lesser the value the lower the surface. High ruggedness indicates more erosion and flooding.

Relief ratio: "It is the ratio between relief of basin to basin length(SCHUMM, 1956)". It represents steepness and degree of erosion. The relief ratio is directly proportional to erosional power. It varies from 68.95 to 138.14 m/km.

Relative relief: “Ratio of basin relief to perimeter(Munoth & Goyal, 2020)”. Higher the value more susceptible to erosion.

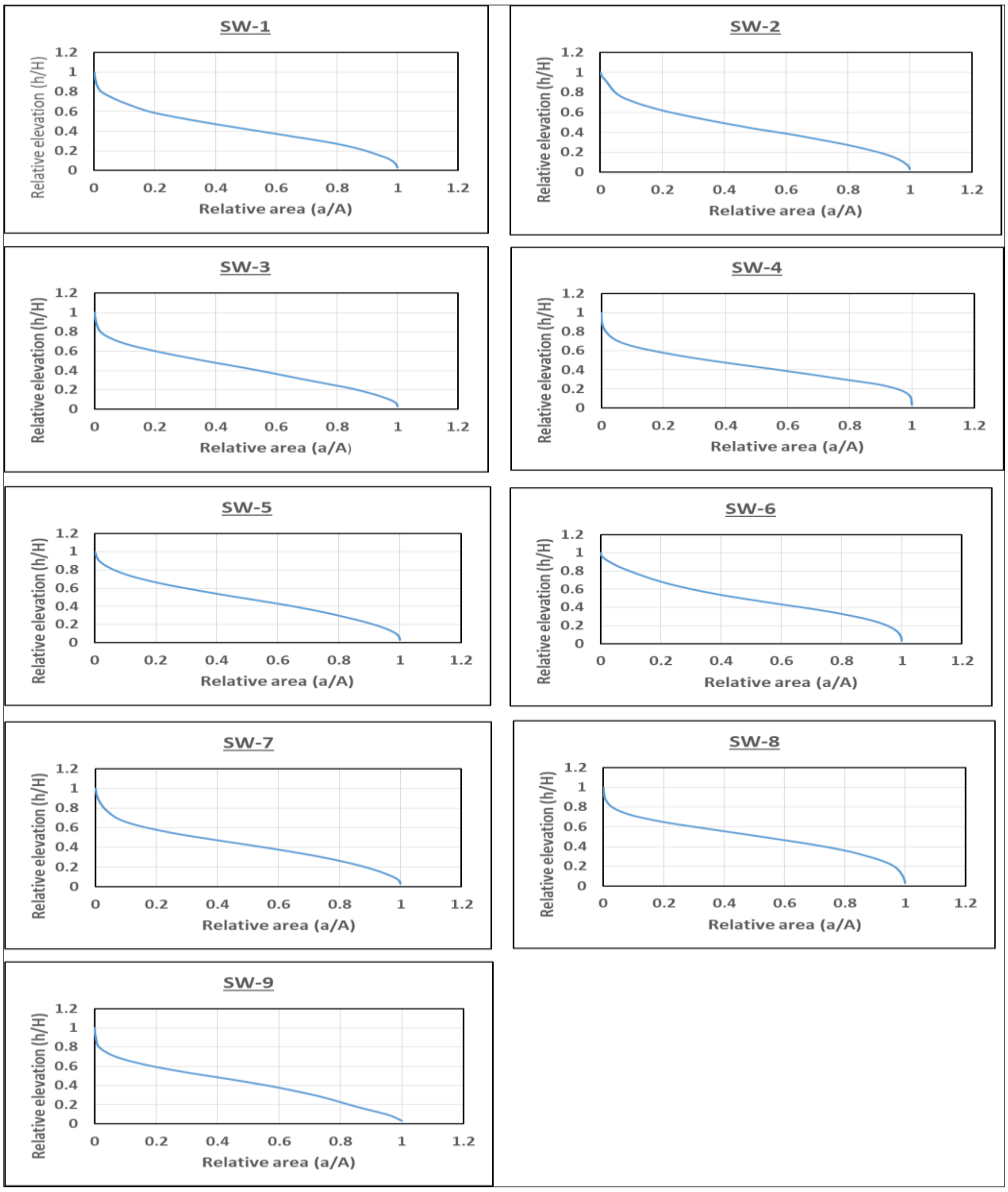

Figure 7 Hypsometric curves

Hypsometric curve (HC) and Hypsometric integral ($HI=E_{mean}-E_{min}/ E_{max}-E_{min}$):Hypsometric analysis include HC and HI (Langbein, 1947). It shows elevation distribution of drainage areas at various levels(Pérez-Peña et al., 2010). HI indicates the "cycle of erosion(Strahler, 1952)" HI is $E_{mean}-E_{min}/ E_{max}-E_{min}$(PIKE & WILSON, 1971), where E is the elevation. HI is divided into 3 classes ≤0.35 for old stage or monadnock, 0.35-0.6 for mature and ≥0.6 for youth stage(Strahler, 1952). HC is a hypsometric curve plotted by relative height(h/H) vs relative area(a/A) (Miller, 1953). According to(Strahler, 1957, 1964), HC is divided into three classes: Convex upward shape for youth stage, S-shape(concave upward toward high elevation and convex downward toward lower elevation) for mature stage and concave upward for old stage, i.e., peneplain and distorted. HI of the sub-watersheds is 0.5 and the HC of all watersheds are slightly different but almost they all form an S-shape curve, HC and HI show that the sub-watersheds are of mature stage.

5.1.1 Dissection Index (Di)

It is used to know the degree of dissection of landforms, i.e., "degree of vertical erosion and phase of landform development(S. Singh & Dubey, 1994)". "It defines as ratio of basin relief to highest elevation of the relief". The DI value varies from 0 to 1, with 0 indicate the dissection is absent, i.e., it has horizontal topography whereas 1 for the cliff, development of landform, i.e., presence of vertical erosion and steep slope. DI values of sub-watersheds ranges from 0.67 to 0.84, which means vertical erosion is present in the area.

Table 6"Calculation of Relief Parameters

	Sub-Watershed								
	SW1	*SW2*	*SW3*	*SW4*	*SW5*	*SW6*	*SW7*	*SW8*	*SW9*
Z=Maximum height of the basin (in meter)	5989	4461	2998	3130	2946	2956	2978	2978	2657
z=Minimum height of the basin (in meter)	1219	1209	984	979	774	765	612	630	438
Basin relief H=Z-z (in meter)	4770	3252	2014	2151	2172	2191	2366	2348	2219
Ruggedness number ($Rn=H D_d$): (in m/km)*	26.16	9.45	7.03	6.97	6.79	6.47	8.03	5.53	8.89
Relief ratio ($R=H/ L_b$)	112.10	138.14	77.79	76.65	59.45	90.75	80.29	68.95	74.39
Relative ratio (Rr=H/ P)	44.17	47.82	27.59	27.94	20.30	37.14	27.51	25.52	22.88
"HypsometricIntegral (HI):$HI=E_{mean}-E_{min}/ E_{max}-E_{min}$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Dissection Index (Di)"	0.80	0.73	0.67	0.69	0.74	0.74	0.80	0.79	0.84

6. Prioritization of the Sub-Watersheds

Setting priorities involves placing the most important watersheds at the top of the hierarchy according to how urgently they need to be treated for conservation(Rahaman et al., 2015), i.e., a watershed that requires the highest maintenance is given top ranking. The evaluation of erosion determines the ranking for many metrics. The risk of soil erosion is directly related with linear and relief parameters, meaning that the higher the value assigned to rank 1, the higher the danger of erosion. These parameters include Rbm, Lm, ρ, Dd, Fs, Rt, Di, If, Lg, H, Rn, R, and Rr. Alternatively, the shape factor is inversely proportional, meaning that the higher the C, k, Cc, Rf, Rc, and Re, the lower the likelihood of erosion; the lowest value is assigned rank 1(Bharath et al., 2020; Sangma & Guru, 2020; A. P. Singh et al., 2020). The watershed is grouped into nine smaller watersheds, and Table No. 7 provides the computed compound value. As seen in Figure 8, the lowest compound value is assigned the most priority. *SW1> SW9> SW7> SW3> SW2> SW6> SW4> SW5> SW8* is the priority order. Due to its higher flow, increased danger of soil erosion, and increased susceptibility to natural disasters, SW1 should receive the highest priority when it comes to planning and conservation measures.

Table 7 Priority ranking table

	Sub-Watershed																	
Parameters	***"SW1***		***SW2***		***SW3***		***SW4***		***SW5***		***SW6***		***SW7***		***SW8***		***SW9"***	
Rbm	3.64	8	3.76	7	4.58	3	3.92	5	3.80	6	5.07	1	3.57	9	4.57	4	4.65	2
L_m	0.98	1	0.71	3	0.72	2	0.70	4	0.63	6	0.63	6	0.60	7	0.60	7	0.67	5
ρ	0.14	3	0.18	2	0.06	6	0.13	4	0.08	5	0.08	5	0.25	1	0.13	4	0.13	4
D_d	5.49	1	2.91	8	3.49	3	3.24	5	3.13	6	2.95	7	3.39	4	2.36	9	4.01	2
F_s	5.61	3	4.12	8	4.88	5	4.64	7	5.00	4	4.67	6	5.75	2	3.54	9	6.78	1
R_t	23.76	1	9.78	9	12.74	7	13.23	6	16.35	3	13.34	5	16.01	4	11.87	8	17.10	2
D_i	1.02	9	1.42	7	1.40	8	1.43	6	1.60	3	1.58	4	1.70	1	1.50	5	1.69	2
I_f	30.78	1	11.99	8	17.03	4	15.02	6	15.63	5	13.79	7	19.51	3	8.33	9	27.16	2
L_g	2.74	1	1.45	8	1.75	3	1.62	5	1.56	6	1.48	7	1.70	4	1.18	9	2.00	2
H	4770	1	3252	2	2014	9	2151	8	2172	7	2191	6	2366	3	2348	4	2219	5
Rn	26.16	1	9.45	2	7.03	5	6.97	6	6.79	7	6.47	8	8.03	4	5.53	9	8.89	3
R	112.10	2	138.14	1	77.79	5	76.65	6	59.45	9	90.75	3	80.29	4	68.95	8	74.39	7
Rr	44.17	2	47.82	1	27.59	5	27.94	4	20.30	9	37.14	3	27.51	7	25.52	6	22.88	8
C	0.18	1	0.34	6	0.29	3	0.31	4	0.32	5	0.34	6	0.30	3	0.42	7	0.25	2
k	0.99	7	0.86	1	0.88	2	0.90	3	0.95	6	0.86	1	0.91	4	0.94	5	0.91	4
Cc	1.44	2	1.52	6	1.50	5	1.48	3	1.63	8	1.29	1	1.58	7	1.49	4	1.76	9
R_f	0.25	1	0.30	6	0.29	5	0.28	4	0.26	2	0.29	5	0.28	4	0.27	3	0.28	4
Rc	0.49	8	0.44	4	0.45	5	0.47	7	0.38	2	0.61	9	0.41	3	0.46	6	0.33	1
Re	0.57	1	0.61	5	0.60	4	0.60	4	0.58	2	0.61	5	0.59	3	0.58	2	0.59	3
Compound value	2.84		4.95		4.68		5.11		5.32		5		4.05		6.21		3.58	
Rank	I		V		IV		VII		VIII		VI		III		IX		II	

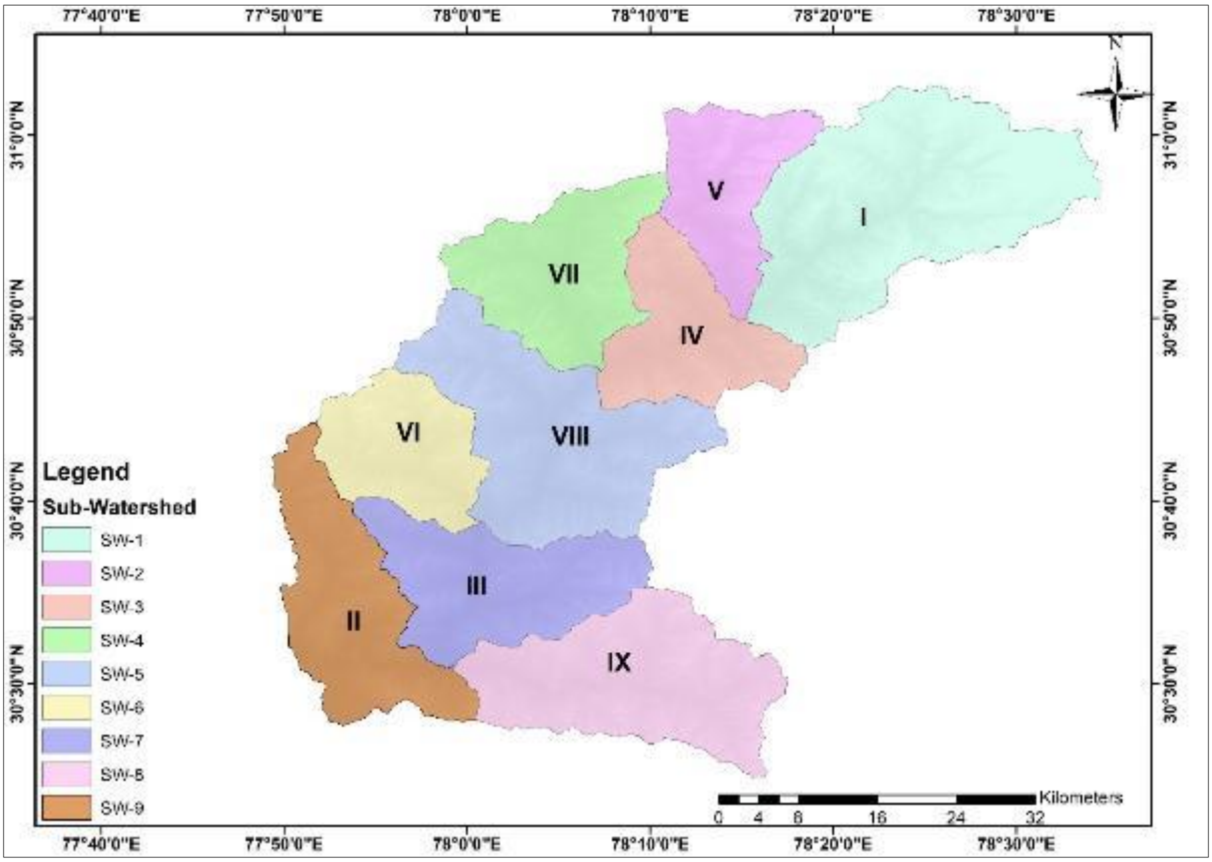

Figure 8 Prioritization of the Sub-watersheds

7. Conclusion

Watershed morphometry is an essential tool in the sustainable management of water resources. Its precise measurements and analyses contribute significantly to water conservation efforts, enabling better planning and development strategies. ArcGIS, remote sensing, and other technology are used for the morphometric study of the Upper Yamuna basin sub-basins, which are grouped into nine sub-watersheds; the watershed is seventh order. Stream patterns are sub-dendritic to dendritic. The bifurcation ratio indicates that the basin has a geological structure but less influence on drainage patterns. Rf, Rc, and Re show the watersheds are sub-elongated to elongated. High drainage density shows impermeable, sparse vegetation and high relief. The higher the stream frequency, the higher the relief and the lower the infiltration capacity. Hypsometric analysis shows that the sub-watersheds are in mature stage, and the dissection index shows that vertical erosion is present. Compound value helps in ranking the watershed based on erosion susceptibility. It shows the highest priority sub-watersheds, SW1, SW9 has a high risk of erosion which is directly related to greater risk of flooding during monsoon, SW2, SW3, and SW7 have medium risk and the lowest priority sub-watersheds SW4, SW5, SW6, SW8 have low risk of erosion and therefore has low chance of erosion. The result can be helpful for planning and development strategies.

Compliance with ethical standards

Acknowledgments

The authors are grateful to my supervisor and co-supervisor, Dept. of Geology, HNB Garhwal University, Srinagar and the National Institute of Hydrology, Roorkee, for the research facilities. I'm thankful to Dr. Aakash Mohan Rawat, Dr. Raman Patel and Mr.Sumit for helping me.

Disclosure of conflict of interest

Authors declare that there is no conflict of interest

Statement of ethical approval

All authors of manuscript agree to publish the article to your journal.

Funding sources

The researcher is self funded. The authors received no financial support for the research

Author Contributions

Pooja sample collection and draft of manuscript. Pooja, SK for analysis. DSB and SK for reviewed and edited the manuscript

Data availability Statement

Manuscript incorporates all datasets produced or examined throughout this research study

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