



Morphometric Analysis Of Son River Basin In Sonbhadra District Of Uttar Pradesh Using Geo-Spatial Techniques

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Abstract

The Son River Basin in Sonbhadra District, Uttar Pradesh, has an important role to play in the region's environmental dynamics and hydrology. The present work presents a comprehensive analysis of different parameters of the morphometry of the Son River Basin, employing advanced geo-spatial techniques. In the present paper, digital elevation model was processed to delineate the basin's boundaries and extract various parameters of morphometry such as stream order, stream length, drainage density, basin relief, contour, slope-aspect, and watershed shape. The analysis provides important observation regarding the characteristics of morphometry of Son river basin and aids in understanding its geomorphological evolution. According to the study, the Son basin in the Sonbhadra region has a perimeter of 438.50 km and a surface area of 3214 km². The basin is 896.15 km long and contains six orders of stream. The basin's drainage density is 0.7 km/km² while stream frequency is 0.36 km², relief ratio is 9.38, mean bifurcation ratio is 4.04. Other parameters are also processed and calculated using suitable techniques.

Keywords: Morphometry, GIS, Drainage Basin, Digital Elevation Model, Son River

Introduction

The Son River is one of the main tributaries of the Ganga, spanning 784 kilometres in total length. It travels across Madhya Pradesh, Uttar Pradesh, Bihar, and Jharkhand in India and has a geographical size of 68,863 km². Drainage basin is defined as the entire region that supplies streamflow to the main stream and its tributaries. According to Clarke, 1966, "Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, and dimension of its landforms". As per the study, revealed by Strahler, 1964, morphometric analysis gives a quantitative representation of the drainage basin's geometry so that one may comprehend the geological and geomorphic history of the area, structural controls, recent diastrophism, and the drainage basin's initial slope or disparities in rock hardness.

Horton (1932, 1945) started the quantitative analysis of the basin's drainage network. Other notable academics including Strahler (1952), Miller (1953), Leopold and Miller (1956), Schumm (1956), Morisawa (1959), Shreve (1966), Scheidegger (1967), and others later refined this field of study.

Drainage basins are taken as the study unit for the morphometric investigations because they have homogeneity in terms of topographic and hydrological characteristics. The effectiveness of a quantitative morphometric study of a watershed is determined by the interplay of multiple drainage network and relief elements (Kale et al. 1986).

A basin or watershed's drainage network can be quantitatively analysed to shed light on the structure and dominant processes that exist there. This information is crucial for planning purposes related to neotectonic activities, soil erosion, surface and groundwater, hydrograph derivation, ecology, and discharge characteristics of ungauged streams. (Prabhakaran et al. 2018).

According to Horton (1932), “the factors of morphology depend on the topography of the land forms of which the drainage basin is composed and, on the form, and extent of the stream-system or drainage network within it”. As per the study of Hajam et al. (2013) understanding the geo-hydrological behaviour of the drainage basin and channel network is facilitated by the morphometric study of the basin and network, which expresses the prevalent climate, geology, geomorphology, and structural antecedents of the catchment.

Waikar et al. (2014) has observed that geospatial techniques including remote sensing and GIS have been proved an efficient tool that facilitates extraction of basin boundary and helps in the analysis of morphometric parameters of any river basin. The data in the form of satellite imageries provided by remote sensing gives a holistic picture of large areas that are used in the analysis of various parameters of morphometry of a drainage basin (Prabu et al., 2013).

In the present work, the morphometric analysis has been performed for the Son river basin in Sonbhadra district of Uttar Pradesh. All the three aspects of morphometry namely linear, aerial and relief are analysed using suitable techniques.

Study area

The Son River basin in Sonbhadra district of Uttar Pradesh geographically lies at $24^{\circ}32'6''$ N to $24^{\circ}39'54''$ N latitude and $82^{\circ}42'50''$ E to $83^{\circ}26'16''$ E longitude. This drainage basin covers an area of 3214 km^2 having perimeter of 438.50 km . Son is the main stream of the study area covering a length of 84 km in Sonbhadra district while the total length of the Son river from its source to mouth is 784 km . The major tributaries of the Son river are Rihand, Kanhar and Bijul. All these three rivers form right bank tributaries. Figure 1 shows the location map of the study area and the DEM of this drainage basin. The height of relief in the study area ranges from 140 m . to 624 m .

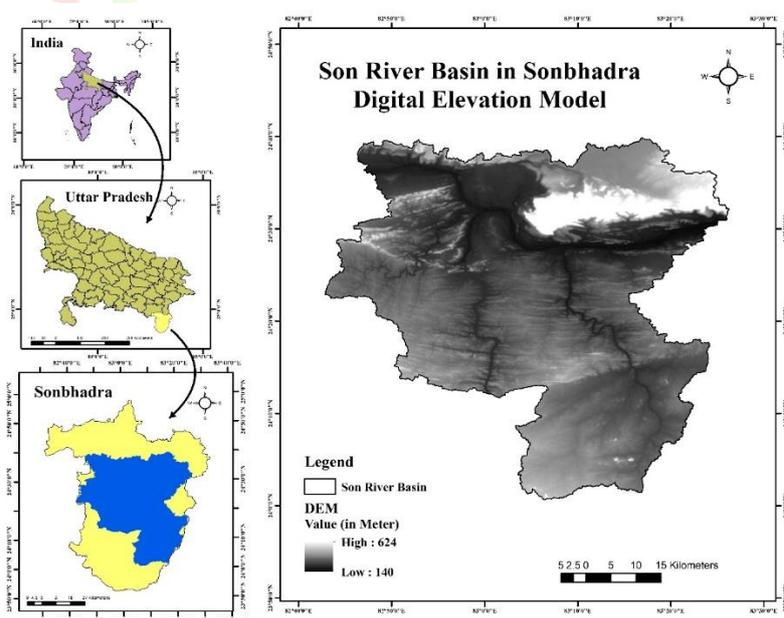


Fig. 1: Location Map of the Study Area

Research objective

The objective of this study is to do morphometric analysis of Son River basin in Sonbhadra district of the Uttar Pradesh.

Description of database

This study uses the secondary data source for the analysis of different parameters of the morphometry of Son drainage basin. SRTM Digital Elevation Model (DEM) of the study area has been downloaded from USGS Earth explorer and has been processed using ArcGIS software.

Methodology

In the present study, morphometric analysis has been processed through the integrated use of remote sensing and GIS techniques. Relevant literature from various sources was thoroughly studied to enrich and update the knowledge in the subject. The present study uses the Digital Elevation Model (DEM) for the delineation of watershed boundary and mapping of drainage network in the study area. Stream networks in the drainage basin were digitised using ArcGIS. Stream ordering in the study area was done using the popular Strahler's method of stream ordering which is also known as stream segment method. ArcGIS software was used to calculate different measures of morphometric analysis such as stream numbers, stream length, length of streams, area and length of watersheds, elevation ranges. These were used to estimate other parameters such as bifurcation ratio, length ratio (linear aspects), drainages density, stream frequency, length of overland flow etc (areal aspect) and relief, relative relief, ruggedness number etc (relief aspect). The above methodology has been summarised in the following flowchart.

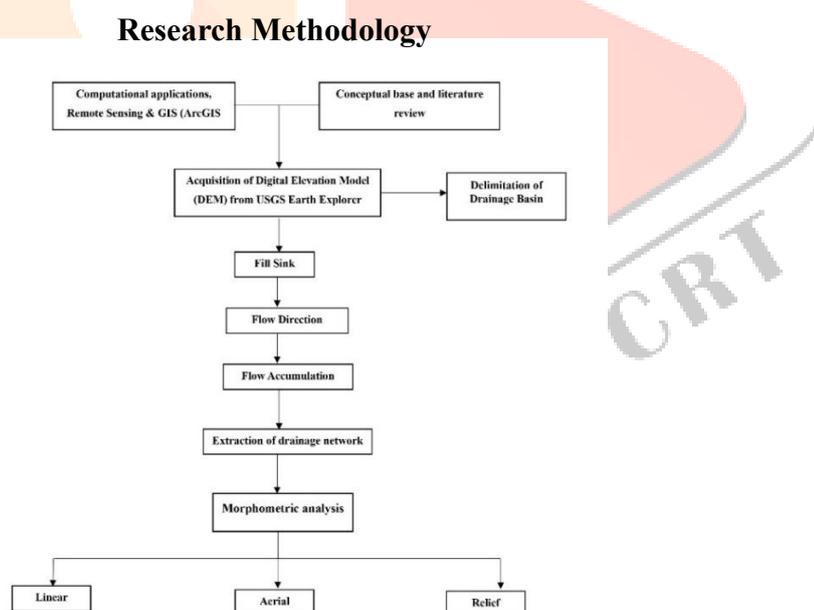


Fig. 2: Flowchart of methodology

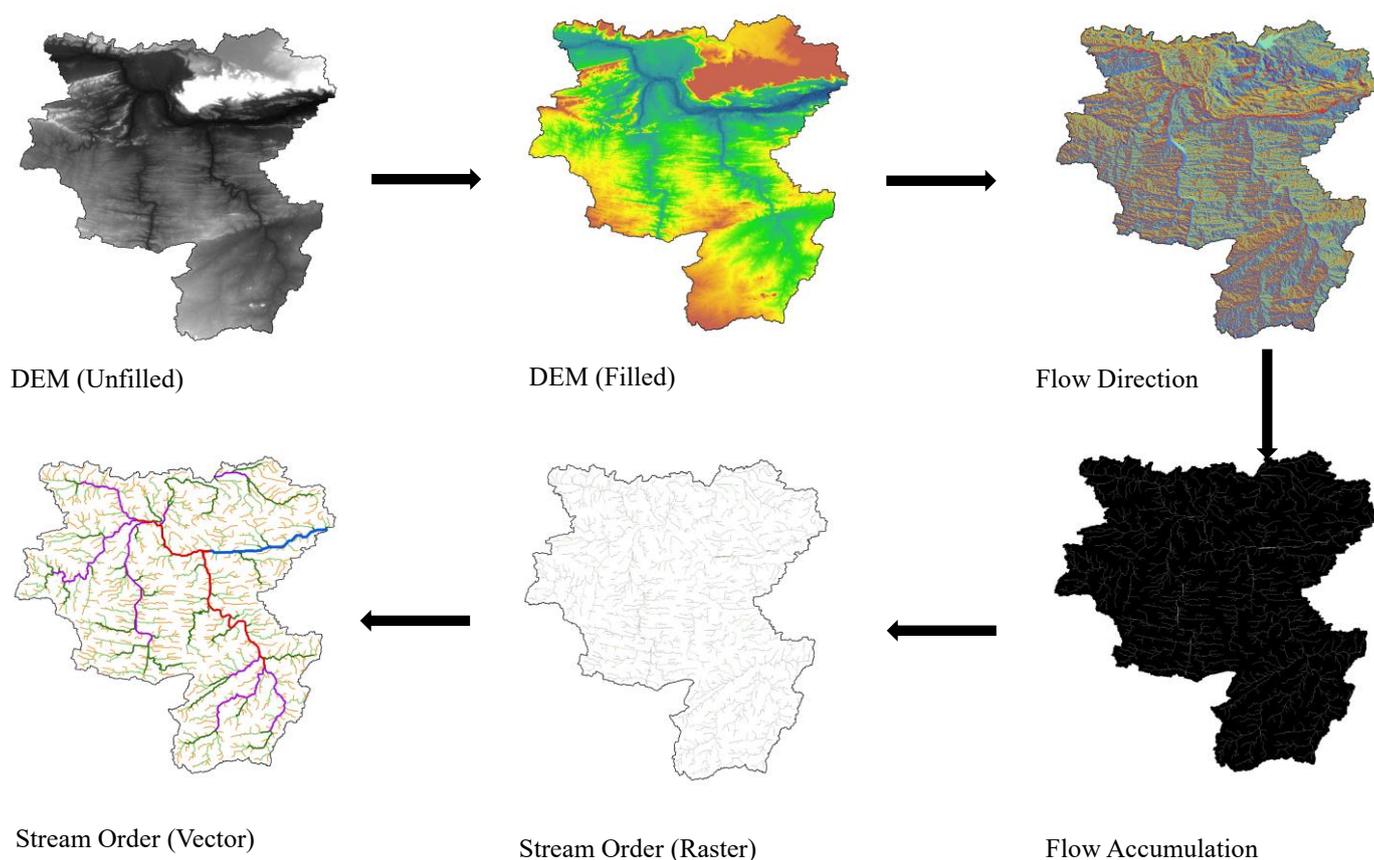


Fig 3: Methodology carried out to generate the drainage network

Formulas and references of different morphometric parameters used in this study has been presented in the following table 1:

Table 1: List of morphometric parameters and their respective formulas

Method of Calculating Morphometric Parameters of Drainage Basin			
	Morphometric Parameters	Formulas	References
Linear	Stream Order	Hierarchical order	Strahler, 1964
	Stream Length	Length of the stream	Horton, 1945
	Mean Stream Length	$L_{sm} = L_u / N_u$; Where, L_u = Mean stream length of a given order (km), N_u = Number of stream segment	Horton, 1945
	Stream Length Ratio	$R_L = L_u / L_{u-1}$ Where, L_u = Total stream length of order (u), L_{u-1} = The total stream length of its next lower order.	Horton, 1945
	Bifurcation ratio	$R_b = N_u / N_{u+1}$ Where, N_u = Number of stream segment present in the given order N_{u+1} = Number of segments of the next higher order	Schumn, 1956
Relief	Basin relief (B_h)	Vertical distance between the lowest and highest points of basin.	Schumn, 1956
	Relief Ratio (R_h)	$R_h = B_h / L_b$ Where, B_h = Basin relief, L_b = Basin length	Schumn, 1956
	Ruggedness Number (R_n)	$R_n = B_h \times D_d$ Where, B_h = Basin relief, D_d = Drainage density	Schumn, 1956

Aerial	Drainage density (D _d)	$D_d=L/A$ Where, L=Total length of stream, A= Area of basin.	Hortan, 1945
	Stream frequency (F _s)	$F_s=N/A$ Where, L=Total number of streams, A=Area of basin	Hortan, 1945
	Texture ratio (T)	$T=N_1/P$ Where, N ₁ =Total number of first order stream, P=Perimeter of basin.	Hortan, 1945
	Form factor (R _f)	$R_f=A/(Lb)^2$ Where, A=Area of basin, Lb=Basin length	Hortan, 1945
	Circulatory ratio (R _c)	$R_c=4\pi A/P^2$ Where A= Area of basin, $\pi=3.14$, P= Perimeter of basin.	Miller,1953
	Elongation ratio (R _e)	$R_e=\sqrt{(Au/\pi)}/ Lb$ Where, A=Area of basin, $\pi=3.14$, Lb=Basin length	Schumn 1956
	Length of overland flow (L _g)	$L_g=1/2D_d$ Where, Drainage density	Hortan, 1945

Source: Prepared by researcher

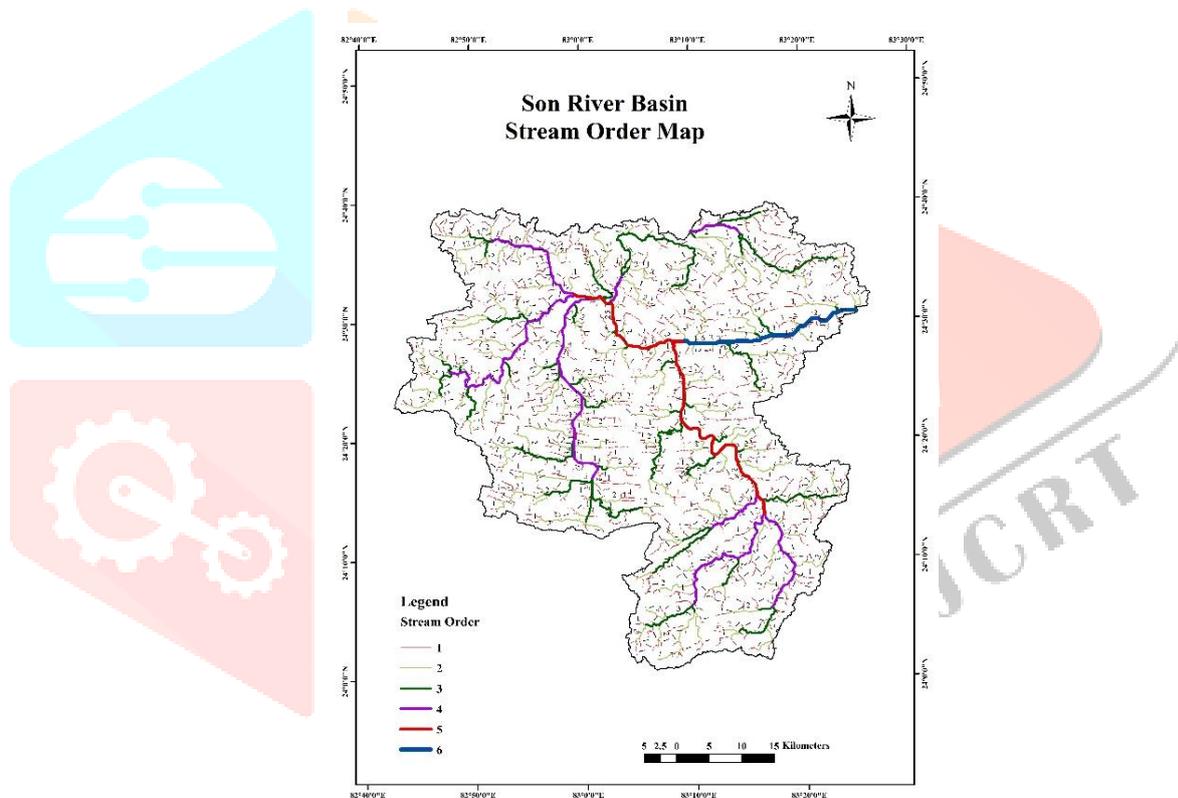


Fig 4: Stream ordering in the Son river basin
 Source: Prepared by researcher using DEM in ArcGIS

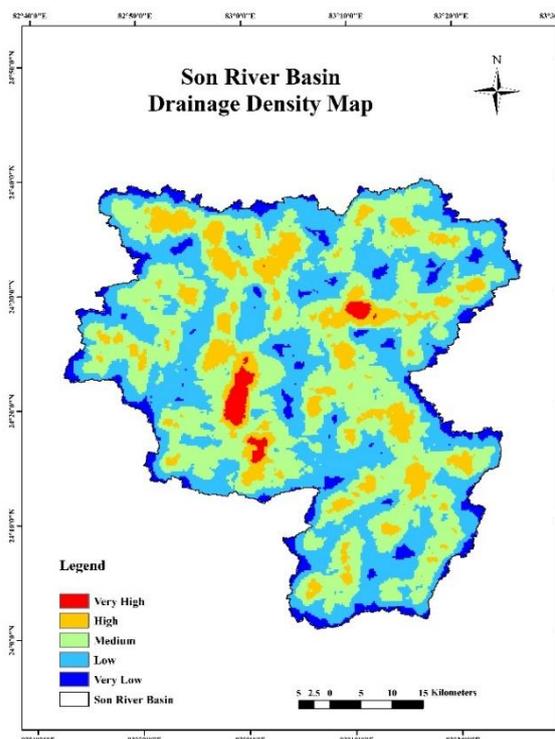


Fig 5: Drainage Density in Son river basin
Source: Prepared by researcher using DEM in ArcGIS

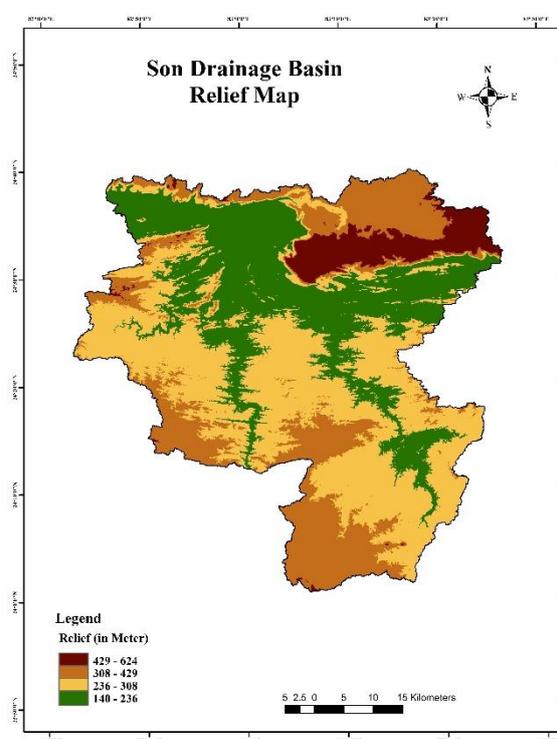


Fig 6: Relief map of Son river basin
Source: Prepared by researcher using DEM in ArcGIS

Results and discussion

According to Strahler (1964), measuring the linear, areal, and relief (gradient) features of the channel network as well as the contributing ground slopes is necessary for a systematic description of the geometry of a drainage basin and its stream channel. Using mathematical formulas for all three aspects—linear, aerial, and relief—morphometric analysis was carried out in this work with reference to factors including stream order, stream length, drainage density, stream frequency, elongation ratio, and circularity ratio, form factor, basin relief, relief ratio, and channel gradient. The formulas used for calculation of different parameters have been given in table 1.

Linear Aspect of Morphometry

The drainage network's channel patterns, which analyse the topological features of the stream segments in terms of open links within the network system, are closely related to the basins' linear features (Hajam et al. 2013). Parameters like stream order, stream numbers, bifurcation ratio, stream length, mean stream length, stream length ratio, length of overland flow, basin perimeter, sinuosity index, etc. are studied in the linear aspect of morphometric analysis. Results of different parameters for linear aspect of morphometric analysis is given in the following table 2.

Table 2: Linear morphometric parameters of the Son river basin

Stream order (U)	No. of Streams	Stream Length (L _u)	Mean Stream Length (L _{sm})	Stream Length Ratio	Bifurcation Ratio (R _b)	Mean R _b
1	897	1329.54	1.48		4.21	4.04
2	213	673.13	2.88	1.65	3.94	
3	51	308.90	6.06	2.10	6.38	
4	8	160.28	20.04	3.31	2.67	
5	3	65.31	21.77	1.09	3	
6	1	29.35	29.35	1.35		

Source: Prepared by researcher

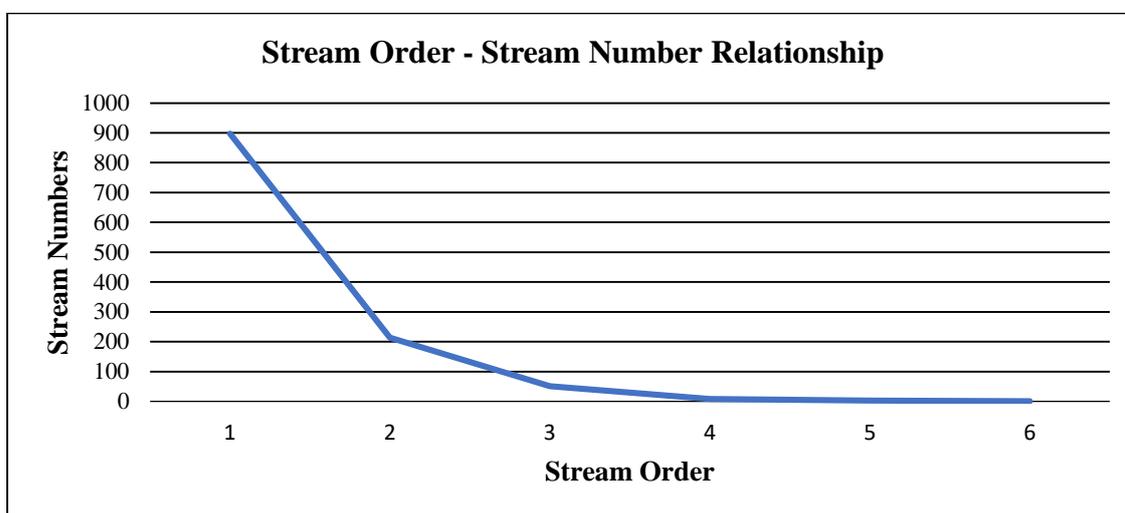


Fig 7: Relationship between stream order and stream number

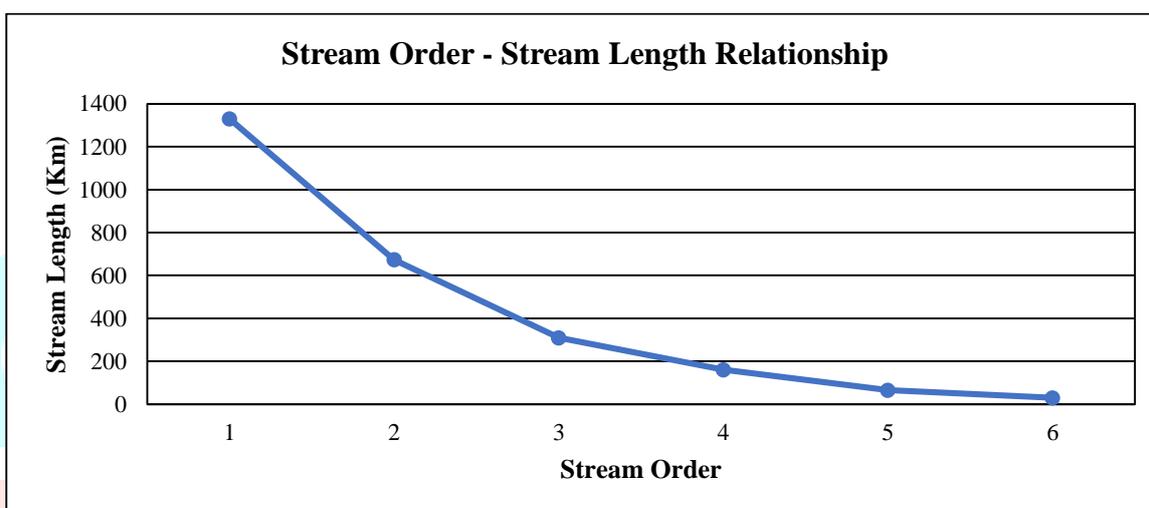


Fig 8: Relationship between stream order and stream length

Stream Order (μ)

Stream ordering is the very first step in the analysis of morphometry of a drainage basin. In this process, streams are designated different orders as per their lengths in the drainage basin. In the present study, there are 6 orders of streams in the Son drainage basin as per the Strahler's (1964) ordering scheme. In this scheme, smallest streams are designated as 1st order. Two first order streams join to form second order stream. Two second order streams join to form third order stream and the process goes on till the highest order is achieved which is the main stream of the drainage basin and is also known as the trunk stream.

Stream Numbering

Stream numbering is another important linear aspect of the morphometric analysis. Stream number is the number of stream channels in a certain order (Horton, 1940). The differences in stream numbering for each order are caused by the basin's varied geological formations (Hajam et al. 2013). An inverse relation exists between stream order and stream numbering. The number of streams decreases with increasing order of the stream. In the Son river basin, 6 order streams are having total 1173 streams. 897 streams are there in the 1st order, 213 streams in 2nd order, 51 streams in 3rd order, 8 streams in 4th order, 3 streams in second order and only 1 stream in the first order. Reduced permeability and infiltration are indicated by a larger stream count.

Stream Length (L_u)

In the present study, stream length has been calculated based on Horton's law. Stream length is indicative of the gradient of the surface. A stream with a comparatively shorter length is found in places with steeper slopes and finer textures. Streams with longer lengths typically have flatter gradients. The observations in the study area reveals that length of 1st order stream is 1329.54 km, 2nd order stream is 673.13 km long, 3rd order stream is 308.90 m long, 4th order stream is 160.28 km long, 5th order stream is 65.31 km long and the trunk stream which 1st order stream is 29.35 km long.

Mean Stream Length (L_{sm})

The mean stream length (L_{sm}) has been calculated by dividing the total stream length of order by the number of streams. The mean stream length in the study area is 1.48 for 1st order, 2.88 for 2nd order, 6.06 for 3rd order stream, 20.04 for 4th order stream, 21.77 for 5th order stream and 29.35 for 6th order stream.

Bifurcation Ratio (R_b)

According to Schumm (1956), the ratio of the number of stream segments of a particular order to the number of segments of the next higher order is known as the bifurcation ratio (R_b). It is related to the branching pattern of the drainage network. It is used to understand the geological and structural control of the drainage basin. Das et al. (2018), in their study, revealed that bifurcation ratio greater than five indicates significant structural disruptions and a significant influence of geological structures on the drainage network. Bifurcation ratio in Son river basin vary from 2.67 to 6.38. Highest bifurcation ratio is found for 3rd order stream. The mean bifurcation ratio in for this basin is 4.04.

Aereal Aspect

A drainage basin's geographical characteristics, such as its lithology, geological structure, climate, and history of depletion, are shown by aerial aspect of morphometric analysis. These factors regulate river discharge, runoff characteristics, drainage system geometry, and geographical organisation (Singh, 1998).

Drainage Density (D_d)

Drainage density is defined as the ratio between total length of all the streams and the area of the basin. Drainage density was described by Horton (1932, 1945) as the entire length of stream channels divided by the area that they occupy. It is one of the most important characteristics of aerial aspect of morphometric analysis. Valley density and channel head source area are two metrics of landscape dissection that are closely correlated with drainage density (Tucker et al., 2001). Water travel time is determined by drainage density (Schumm, 1956). According to Melton (1957), a drainage basin with a high drainage density is deeply dissected and responds to rainfall events hydrologically quite quickly, whereas a basin with a low drainage density is poorly drained and responds hydrologically more slowly. Modest drainage density readings in the sub-basin suggest that the substrata is partially permeable and that the basin relief is relatively low (Aldharab et al., 2019). The drainage density in Son river basin is 0.7 km/km² which is very low.

Stream frequency (F_s)

The total number of stream segments in all orders per unit area is the defined as the stream frequency given by Horton (1932 and 1945). In the Son river basin, stream frequency value is 0.36 which low and indicates a permeable sub-surface material and low basin relief. The drainage density and stream frequency have a positive association, meaning that when the stream frequency rises, so does the drainage density.

Texture Ratio (T)

The drainage texture ratio was established by Horton (1945) as the total number of stream segments of all kinds per area's perimeter. Climate, lithology, relief, infiltration capacity, vegetation cover, and the stage of drainage development are only a few of the variables that affect drainage texture (T) (Smith 1950). Smith

classified drainage texture into four classes as given below in the table 3. The texture ratio in Son river basin is 2.05 km which according to Smith's classification is coarse texture.

Table 3: Categories of texture

Value	Drainage texture
< 4	Coarse
4 – 10	Intermediate
10 – 15	Fine
> 15	Very fine

Source: Smith, 1950

Area and Perimeter

The son river basin covers an area of 3214 km² while the perimeter of the basin is 438.50 km.

Circulatory Ratio (R_c)

The circularity ratio (R_c), as defined by Strahler (1964), is the ratio of the drainage basin's area to the area of a circle with the same perimeter. A R_c value around 1 indicates a circular basin with a similar rate of infiltration throughout its area. Lower R_c values indicate the young stage of basin formation, during which the time it takes for surface water to flow to the basin outlet is relatively shorter (Das et al. 2018). Circulatory ratio value in Son basin is 0.16 which is low.

Form Factor (F_f)

The form factor (F_f) is defined as the ratio of the total drainage area to the square of the basin length. This component displays the basin's flow intensity within a given area (Horton, 1945). The form factor has a value of up to 0.8. Longitudinal basins exhibit a lower form factor value, whereas circular basins exhibit a value greater than 0.8. The Son River Basin has a longitudinal shape, as shown by its form factor value of 0.43.

Elongation Ratio (R_e)

According to Schumm (1956), the elongation ratio is the ratio between the drainage basin's greatest length and the diameter of a circle that spans the same area. The value of R_e in Son basin is 0.37 which is indicating that the basin is elongated.

Length of Overland Flow (L_g)

The length of overland flow (L_g) is the amount of water above the surface of the earth before it condenses into a particular stream channel (Horton, 1945). Overland flow is significantly impacted by the time- and space-varying infiltration and percolation of soil. The Son Basin's overland flow is 0.71 km long. It illustrates how the low slopes of the valleys lead to longer flow pathways and reduced surface runoff.

Relief Aspect

The analysis of different geohydrological features is facilitated by the study of three-dimensional properties, such as the area, volume, and height of vertical landform dimensions. These properties are strongly linked to the relief aspects of drainage basins. This aspect analyses things like slope, roughness number, relief ratio, and relative relief.

Relief Ratio (R_h)

The relief ratio (R_h) is the ratio of the maximum relief to the horizontal distance along the longest dimension of the basin that is parallel to the main drainage line, as defined by Schumm (1956). When the watershed size and drainage area of a drainage basin decrease, the R_h frequently rises (Gottschalk, 1964). The Son Basin's relief ratio of 9.38 suggests that the studied area is subject to a high intensity erosional mechanism.

Relative Relief

Relative relief is the height difference between an area's highest and lowest points. Amplitude of relief was first used by W. S. Glock in 1932, and he described it as the vertical distance from a horizontal, relatively flat upland down to the stream's beginning grade. Through the production of a digital elevation model, it is discovered that the elevation in the Son River basin varies between 140 and 624 metres within the current study region.

Ruggedness Number (R_n)

The product of drainage density and maximum basin relief (H) is the ruggedness number. When both factors are large—that is, when a slope is both steep and long—extreme values of the roughness number arise (Strahler, 1958). According to Aldharab et al. (2019), the ruggedness number illustrates the terrain's structural complexity and slope steepness. Elevated roughness number values inside the basin suggest a high susceptibility to erosion (Reddy et al., 2004). The Son River Basin has a ruggedness rating of 5.10, indicating a high danger of soil erosion in the area (Singh et al. 2021).

Table 4: Results of morphometric analysis

Sr. No.	Morphometric Parameters	Value
1.	Basin Area (km^2)	3214
2.	Basin perimeter (km)	438.50
3.	Basin order	6
4.	Drainage density (D_d) (Km/Km^2)	0.7
5.	Stream frequency (F_s) (km^2)	0.36
6.	Relief ratio (R_h)	9.38
7.	Texture ratio (T)	2.05
8.	Basin length (L_b) (km)	86.15
9.	Ruggedness number (R_c)	5.10
10.	Mean bifurcation ratio	4.04
11.	Form factor (F_f)	0.43
12.	Circulatory ratio (R_c)	0.16
13.	Elongation ratio (R_e)	0.37
14.	Length of overland flow (L_g) (km)	0.71

Source: Prepared by researcher

Conclusion

Using advanced Remote Sensing (RS) and Geographic Information System (GIS) techniques, the morphometric analysis of the Son River basin in Sonbhadra district has yielded invaluable insights into the hydrological dynamics and geomorphic characteristics of this important river system in the study area. This study has carefully measured morphometric parameters such drainage density, stream order, basin shape, and relief characteristics by combining digital elevation models, satellite photos, and spatial analytical tools. The drainage network and basin relief features are the basis for attributing the results of all linear, aerial, and relief parameters in this study. According to the study, the basin of the Son River has a surface area of 3214 km^2 , and its perimeter is 438.50 km. Rihand and Bijul are third order streams. The basin has moderately elongated shape. The highest point in this basin is 624 m., while the lowest point of the basin is 140 m. Low drainage

density value (0.7) in Son basin indicates that there are some extents of permeable nature in the sub-strata and the basin relief is low. Stream frequency of this basin is 0.36 km^2 , relief ratio and texture ratio are 9.38 and 2.05 respectively. Total basin length of Son river in Sonbhadra district is 86.15 km. Ruggedness number of the basin is 5.10 while mean bifurcation ratio for all the orders is 4.04. Form factor of the Son basin in Sonbhadra district is 0.43 indicating elongated basin shape. Circulatory ratio and elongation ratio is 0.16 and 0.37 respectively. Length of overland in the basin is 0.71 km.

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