# Drainage basin analysis of the Sarayan River, Ganga Plain, India

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## ABSTRACT

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The Sarayan River is a groundwater fed meandering river, originating near Gola Gokaran Nath Town in Lakhimpur Kheri District of Uttar Pradesh in the Ganga Plain. It flows around 170 km before joining the Gomti River at Kaintain hamlet, Sidhauli Tehsil, Sitapur District, Uttar Pradesh. The morphometric analysis of the Sarayan River Basin is explained in the present paper by using Geographical Information System (GIS) technique and Survey of India topographical sheets to integrate basic, shape and derived characteristics. It shows a dendritic drainage pattern, with a surface area of about 2535 km². The basic parameters identified are, perimeter 383 km, length 112 km and slope 0.80 m/km. The derived parameters such as the relief–ratio (Rr) 0.30 m/km, bifurcation ratio (Rb) 8.82 and RHO coefficient 0.02, describe a gently undulating topography, influencing sediment transport and the formation of extensive alluvial plain. The form factor (Ff) 0.20, circularity index (Rc) 0.22, and elongation ratio (Re) 0.51 indicate the elongated shape of the basin. The Sarayan River Basin is a fourth order river basin with mature topography and dendritic behaviour of the drainage network.

Key–words—Ganga Plain, Sarayan River, Morphometry, Geomorphology, Landscape.

## INTRODUCTION

SIGNIFICANT sediment transportation, redistribution and deposition caused by river action characterize the Indo–Gangetic foreland basin, which is an active peripheral foreland basin (Sen, 2019). The region exhibits diverse and persistent geomorphic surfaces and landscape resulting from the interaction of climatic fluctuations and tectonic influences. The Ganga Plain exhibits a dual slope orientation, pointing north in the southern part and south in the northern part due to its gradual regional slope towards the southeast. Two significant morpho–stratigraphic units that have been discovered by previous researchers are the older alluvium, known as Bhangar and the newer alluvium, known as Khadar (Oldham, 1917; Pascoe, 1917; Pilgrim, 1919; Geddes, 1960; Mukherji, 1963; Das Gupta, 1975). The younger alluvium is found in small river channels and valleys, while the older alluvium occupies elevated interchannel areas. The Bhangar surface (Mukherji, 1963) is a depositional terrace which originate due to shifting climate and sea level fluctuations. The Ganga Plain's current appearance was developed during the Late Pleistocene–Holocene tectonic dynamism and climate change (Srivastava *et al*., 2003). The Ganga Plain is divided into four areas: the Bhabar belt, Terai belt, Central Alluvial Plain and Marginal Alluvial Plain, arranged from north to south (Pathak, 1966). Geddes (1960) identified the fan and the interfan zones in the northern section of the Ganga Plain and the Geological Survey of India (GSI) mapped and named various geomorphic units as part of their Quaternary mapping program. Singh (1996) recognized and detailed six primary geomorphic sub divisions, including the surface of upland terraces, marginal plain upland surfaces, megafan surfaces, river valley terrace surfaces, piedmont fan surfaces and active flood plain surfaces. Ganga Plain is characterized by many river basins such as Ganga, Ghaghara, Yamuna and Gomti, etc. (Singh, 2018). Gomti is a tributary of Ganga River and the Sarayan River is the tributary of Gomti River. After conducting the morphometric analysis for Yamuna River (Nishat & Singh, 2018), Chhoti Gandak (Singh & Awasthi, 2011) , Baghain River (Gautam *et al*., 2022), Ghaghara River (Singh *et al*., 2020), Kalyani River (Kumar *et al*., 2018) and Gomti River (Tangri *et al*., 2018), the present study has been carried in the Sarayan River. The current study aims to analyze the morphometric analysis of the Sarayan River, as it

remains still unexplored. Because they have significant role in the basin hydrological response, the geomorphological parameters of a river basin must be taken into account in the flood study. An evaluation of the drainage parameters and basin characteristics, which directly affect flood mechanism and groundwater recharge, was conducted in this work using morphometric analysis.

## STUDY AREA

### REGIONAL SETTING

The Sarayan River, a left bank tributary of the Gomti River, is the main subject of the study, which covers the Lakhimpur Kheri and Sitapur districts of Uttar Pradesh. Beginning its journey near Gola Gokaran Nath Town in Lakhimpur Kheri District, the river bends southward until it converges with the Gomti River in Kaintain Village, Sidhauli Tehsil of Sitapur District (Fig. 1). It covers a distance of about 170 kilometers from its origin in Gola Gokaran Nath Town, Lakhimpur Kheri to its confluence with Gomti River in Sitapur District. The basin exhibits a north–south trending topography, situated between the Gomti and Ghaghara rivers with well developed river terraces; T2, T1 and T0 (Fig. 2) The study area is located between 27°11'–28°06' latitude and 80°25'–80°52' longitude. The Sarayan River is characterized by cut–off meander, palaeo–channel and oxbow–lake (Fig. 3a–d).

### GEOLOGY OF THE AREA

Geologically, the study area is mainly characterised by Quaternary sediments, of two groups: older alluvium, also known as Varanasi alluvium, dating back to the mid to late Pleistocene Period and younger alluvium of Holocene age (Sinha *et al*., 2005). The older alluvium consists of oxidized, brown, yellow and khaki colour, with a polycyclic sequence of silt, clay and calcrete. Silt, clay and grey micaceous sand sequences (Fig. 4) are interbedded in the younger alluvium.
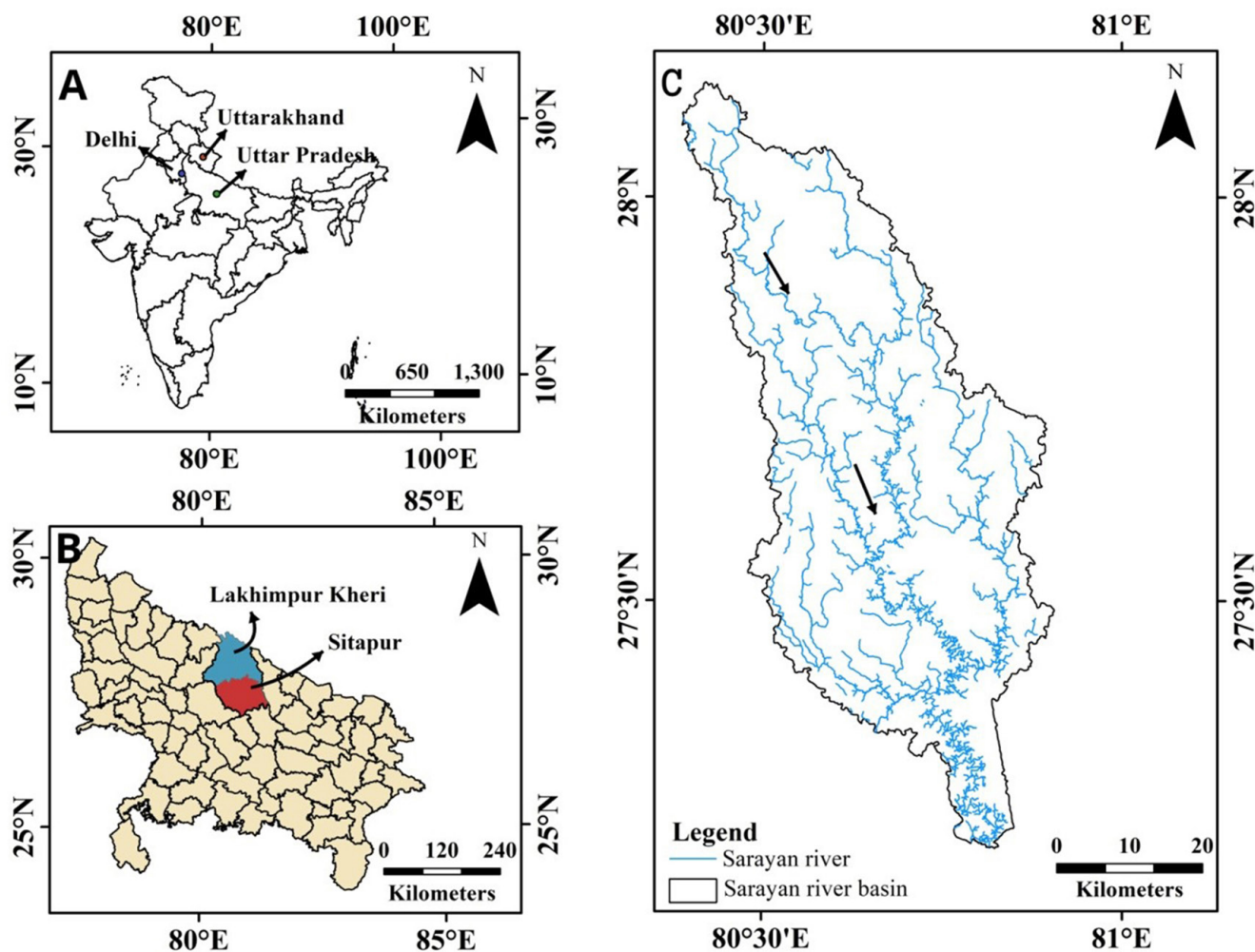


Fig. 1—Location map showing Sarayan River Basin covering Lakhimpur Kheri and Sitapur districts of Uttar Pradesh.

Fig. 2—Active river channel of Sarayan River in Rahimadabad Village showing T0, T1 and T2 surfaces.

Alluvium, which is mostly composed of sediment deposited by Himalayan, groundwater–fed and peninsular rivers, mostly makes up the study area, which is a portion of the Great Northern Indian Plains.

## METHODOLOGY

In this study area , twelve toposheets (62 D/8, 62 D/12, 63 A/5, 63 A/6, 63 A/8, 63 A/9, 63 A/10, 63 A/11, 63 A/13, 63 A/14, 63 A/15, 63 A/16) were selected. Georeferencing was conducted using the Projected Coordinate System (PCS) on WGS 84, 44 North zone, ensuring precision in real–world correlation. Mosaicking followed, combining georeferenced sheets into a single banded image using Arc Map 10.4.1. Subsequently, drainage extraction involved digitizing streams and branches individually on the GIS platform, creating a shape file with line features. These methodical procedures, carried out with Arc Map 10.4.1, thorough GIS–based analysis. The GIS platform or numerical methods are used to compute morphometric parameters. Strahler's (1964) approach was utilized to build stream orders and calculate

the basic, derived and shape parameters (Kale & Gupta, 2001; Reddy *et al*., 2004; Sreedevi *et al*., 2004; Garde, 2006) in addition to Horton's laws (Horton, 1945) for the analysis of the drainage network.

## RESULTS

Three distinct categories—basic parameters, derived parameters and shape parameters—were used to generate the morphometric parameters. When combined, these categories offer details about the characteristics of the river and its basin.

## BASIC PARAMETERS

### Features of the basin

**Basin Area:** The basin area encompasses both sub– and inter–basin areas as well as the entire area between the division line and the outfall. It depends on the drainage basin and affects the structure (Garde, 2006). The basin's total area is 2535 square kilometers, as determined in a GIS environment with Arc Map 10.4.1.

**Perimeter:** GIS techniques were used to calculate the perimeter, which is the whole length of the drainage basin boundary. The Sarayan River Basin has a perimeter of 383 kilometers.

**Basin Length:** Using the Gregory and Walling (1973) approach, the longest diameter from the basin mouth to the most conspicuous point on the perimeter was determined. The length of the Sarayan River Basin is determined to be 112 kilometers based on GIS estimates.

**Stream Order (Nu):** This method clarifies the drainage basin stream hierarchical position (Fig. 5). It is based on Strahler (1952); stream segment method. It offers vital details about each stream's dimensions, area of discharge and drainage capacity (Strahler, 1957). Here, there are 552 number of $1^{st}$ order streams, 117 number of $2^{nd}$ order streams, 12 number of $3^{rd}$ order streams and one $4^{th}$ order stream (Table 1).

**Stream Length (Lu):** It was measured using GIS tools, especially Arc Map 10.4.1, it is necessary to measure both the overall stream length (Lt) and the stream length for a particular order (Lu). $1^{st}$ order streams bear a total length of 618.57 km; $2^{nd}$ order streams bear a total length of 255.86 km ; $3^{rd}$ order streams bear a total length of 210.54 km and $4^{th}$ order streams equal to 2.25 km (Table 1).

**Slope (Sb):** This hydrologically significant morphometric parameter measures the basin's slope angle. Higher surface runoff and lower infiltration rates are frequently associated with steeper slopes. In this case, the computed slope is 0.80 m/km, (Table 2) which was obtained by applying the formula Sb = (H–h) / L', where H stands for the maximum height, h for the minimum height and L' for the basin's horizontal length.
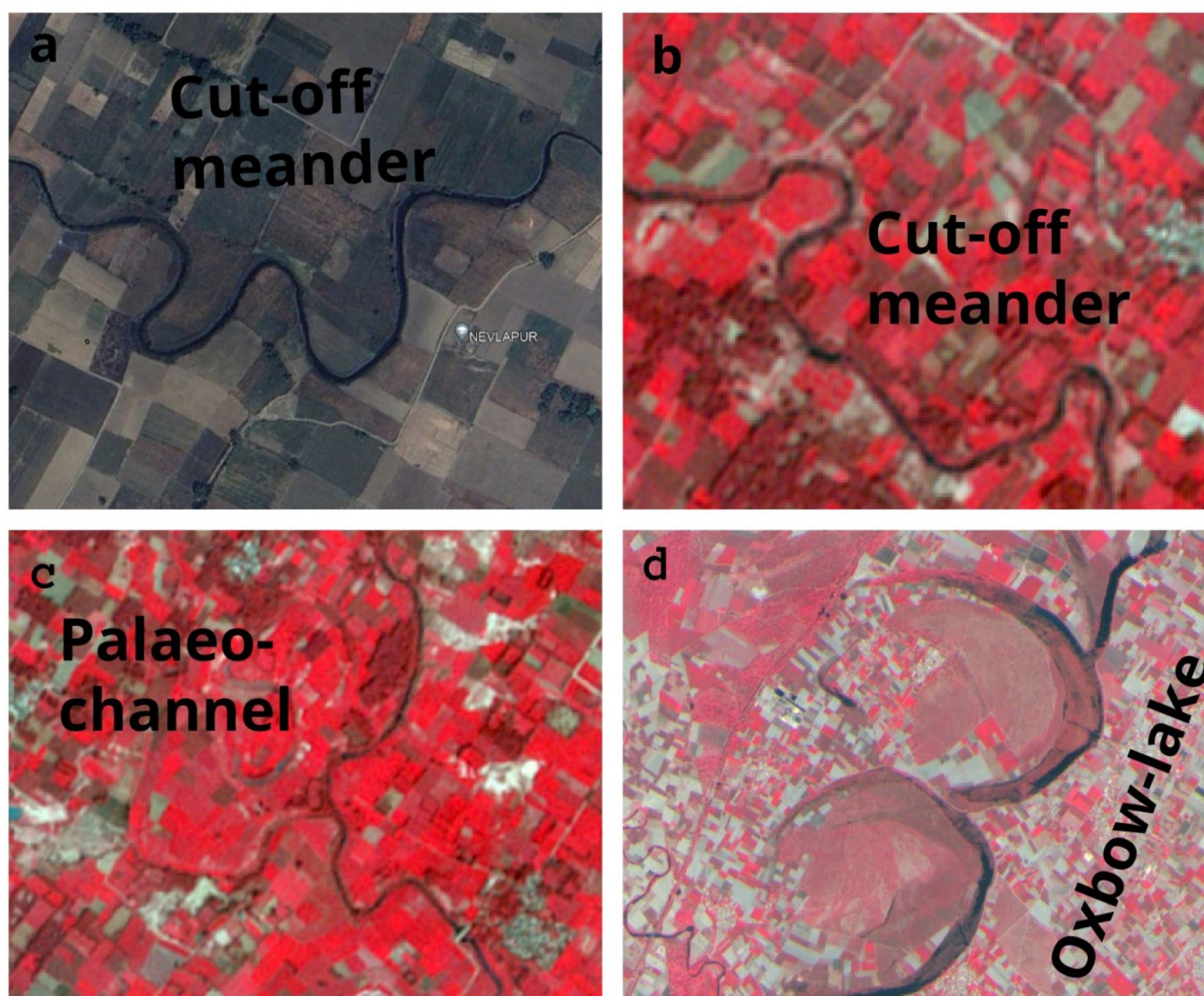
Fig. 3—Various geomorphic features shown by the river: (a) cut–off meander, (b) cut–off meander, (c) palaeo–channel, (d) oxbow lake.

## DERIVED PARAMETERS

**Basin Relief (R):** Basin relief is a basin elevation dynamics, represented by the letter R, characterize difference in altitude amongst highest and lowest points in the basin. According to Schumm and Hadley (1961); this dynamic component is essential in forming stream gradients, affecting flood pattern and figuring out the basin's capacity for sediment transport. The relief that has been calculated is 32 metres above mean sea level (Table 2).

**Relief–ratio (Rr):** The relationship between basin length (L) and relief (R) is quantified by the relief–ratio (Rr), a dimensionless parameter that was introduced by Schumm in 1963. With respect to erosion potential, Rr values provide information about the amount of material that is available for erosion. A relief–ratio of 0.30 m/km has been computed (Table 2).

**Bifurcation Ratio:** The bifurcation ratio (Rb), first introduced by Horton in 1945, shows the relationship between the number of streams in a particular order (Nu) and those of higher orders (Nu+1) (Table 1). The computed value of Rb, a quantitative indication of the degree of ramification in a drainage network, is 8.82.

**Stream length ratio (Rl):** There is a clear correlation between the erosional stage of the basin, the surface flow discharge and the stream length ratio (Rl). Changes in terrain and slope between stream orders have an effect on Rl (Sreedevi *et al*., 2004). The stream length of order "u" is Lu, while the stream segment length of the previous lower order is Lu–1. The stream length ratio, or Rl, is used in this equation. It can be expressed quantitatively as Rl = Lu / Lu–1 = 0.13 Rl. The average stream length ratio (Rl) in the Sarayan River Basin is 0.13.

**RHO Coefficient (RHO):** The RHO coefficient, which clarifies drainage density, physiographic evolution and the drainage network's storage capacity, is first introduced by Horton in 1945. The definition of this coefficient is the stream length ratio (Rl) divided by the bifurcation ratio (Rb). It is
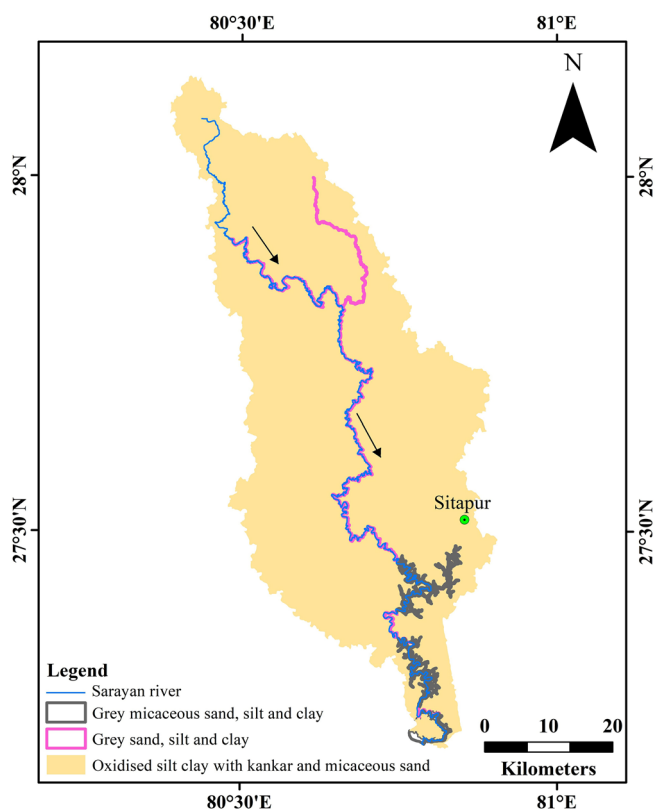
Fig. 4—Sediment texture map of the study area.



Fig. 5—River basin showing streams of various order.

an important indicator that is impacted by both natural and man–made elements when trying to understand how water is stored during floods and how erosion occurs.

$$RHO = Rl / Rb = 0.02$$

**Stream frequency (Fs):** In 1945, Horton coined the term "stream frequency," which he defined as the ratio of the total area of the basin to the total number of stream segments in all of its orders. This equation represents the basin size, A and the total number of stream segments, Nu. This formula is

$$Fs: \sum Nu /A = 0.27.$$

**Drainage density (Dd):** The total length of streams per unit area of a drainage basin is measured by drainage density (Dd), according to Horton (1945) definition. As Verstappen (1983) pointed out, this metric measures the amount of the
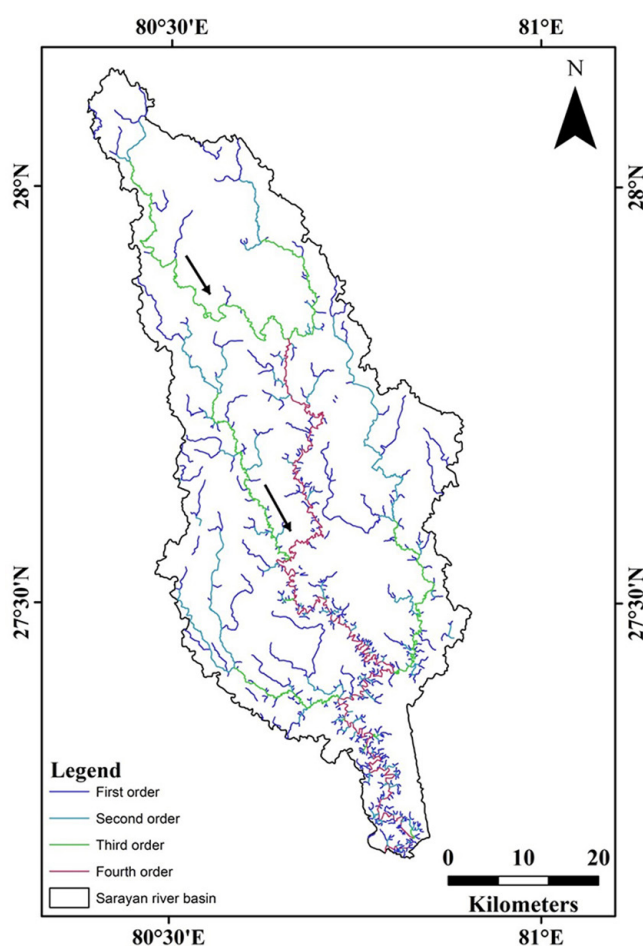
fluvial dissection and is directly proportional to a number of factors, including the resistance of rocks to erosion, the ability of land to infiltrate and the current climate. With Lt amounting to the total length of all the ordered streams and A amounts to the basin's area, Dd = $\sum$Lt/A = 1264.21 / 2535.088 = 0.50 (Table 2).

**Drainage Texture (T):** Smith defined drainage texture (T) in 1950 and it shows the relative distances between channels in a fluvial dissected terrain. Numerous natural

Table 1—Drainage geometry of Sarayan River Basin.

| Stream Order | Stream no. | Length of stream (km) | Log (stream length) | Log (stream number) | Stream length ratio (Rl) | Bifurcation ratio (Rb) |
|---|---|---|---|---|---|---|
| 1st | 552 | 618.57 | 2.79 | 2.74 | | 4.72 |
| 2nd | 117 | 255.86 | 2.41 | 2.07 | 0.21 | 9.75 |
| 3rd | 12 | 210.54 | 2.32 | 1.08 | 0.10 | 12 |
| 4th | 1 | 179.24 | 2.25 | 0.00 | 0.08 | |
| Total | | | | | | |
| 4 | 682 | 1264.21 | 9.77 | 5.89 | 0.13 | 8.82 |

Fig. 6—Graphical plot between order of stream versus logarithmic of stream length.
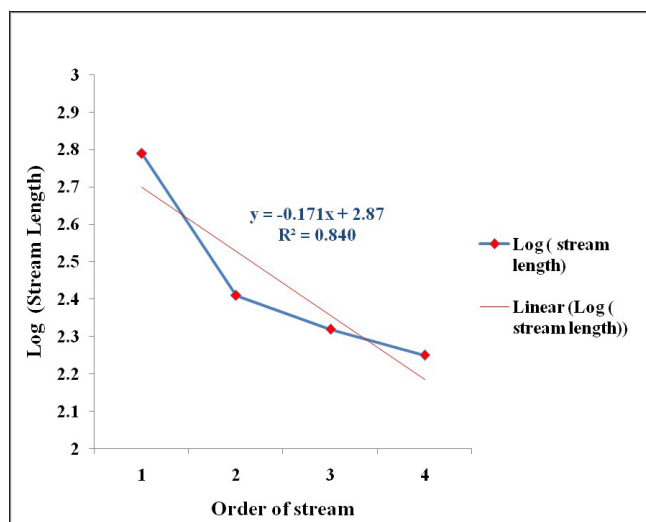


Fig. 7—Graphical plot between order of stream versus logarithmic of stream number.

variables, including vegetation, rainfall patterns, climate, relief and basin development stage, influence the value of this parameter. For drainage density (Dd) and stream frequency (Fs), T is equal to Dd × Fs, or 0.50 * 0.27 = 0.14 (Table 2).

**Constant of channel maintenance (Cc):** The constant of channel maintenance, denoted as Cc and introduced by Schumm (1956), is the inverse of drainage density (Dd). These two hydrological parameters seem to be reciprocally related.

$$Cc = 1 / Dd = 2$$

**Length of the Overland Flow (Lg):** Horton (1945) characterizes the length of overland flow (Lg) as being equivalent to half of the inverse of drainage density (Dd) (Table 2). This relationship is expressed as Lg = 1 / ( 2 Dd ) = 1

**Ruggedness number (Rn):** Basin relief (R) multiplied by drainage density (Dd) yields the ruggedness number, according to Strahler (1968) nomenclature.

$$Rn = R × Dd = 17$$

## SHAPE PARAMETERS

**Ratio of Elongation (Re):** The ratio of the diameter (D) of a circle whose area equals the basin to the basin length (L) is known as the elongation ratio (Re), according to Schumm (1956). Where A is the basin's size, L is its length and 1.128 is a constant, we get Re = D/L = 1.128 √Basin size / Basin Length = 0.51 (Table 2).

**Circularity index (Rc):** As per the explanations provided by Miller (1953) and Strahler (1964), the circularity index (Rc) is determined by dividing the area of the basin (A) by the area of a circle whose perimeter equals the basin (P). Let P represent the basin's perimeter, A its area, Rc its circularity and 4 a constant, to simplify the calculation. As a result, Rc = 4 ∏A / P2, = 0.22 (Table 2).
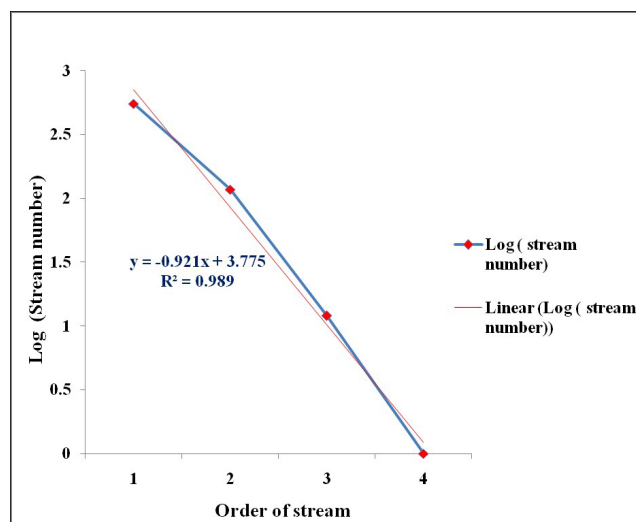
**Form factor (Ff):** Horton developed this parameter in 1945 as a method of predicting the intensity of flow in a specific area of a basin. To calculate the form factor (Ff) of a drainage basin, divide its area (A) by its length squared (L^2). According to Gregory and Walling's (1973) study, the Ff index has an inverse relationship with the square of the axial length and a direct relationship with peak discharge. $Ff = A/L^2 = 0.20$ (Table 2), signifying elongated basin shape (Nautiyal, 1994) .

**Elipticity index (E):** An essential shape parameter that shows the overall shape of the drainage basin is the elipticity index. $E = ∏ L^2/4A = 3.89$ (Table 2).

## DISCUSSION

The basic features defining drainage basin is in close association with the configuration and organisation of the drainage pattern. In particular, as suggested by Kale and Gupta (2001), the dendritic pattern, which is a sign of a consistent lithological composition and a gradual regional slope, illustrates how climate and drainage basin size interact to affect the total amount of water received and the amount of runoff. The useful measure incorporating stream size, discharge and drainage area is stream order (Nu), which is determined by the quantity and kind of tributary junctions in accordance with Strahler's recommendations (1957, 1964). Stream number (Nu) follows an inverse geometric ratio supported by stream parameters, which is consistent with Horton's laws.

Plotting 'log Nu' against stream order in Fig. 6 provides a visual representation of this geometric relationship. Fig. 7 also depicts Horton's law of stream length, which is supported by the relationship between the stream length (Lu) of a specific order (u) and the overall stream length of the basin (Lt). The comprehensive morphometric analysis helps to quantify the

Table 2—Basic, Derived and Shape parameters.

| Basic | | Derived | | Shape | |
|---|---|---|---|---|---|
| No. of first order streams | 552 | Rb$_{1-2}$ (Bifurcation ratio of 1 with respect to 2) | 4.72 | Elongation ratio, E | 0.51 |
| No. of second order streams | 117 | Rb$_{2-3}$ (Bifurcation ratio of 2 with respect to 3) | 9.75 | Circularity Index, Rc | 0.22 |
| No. of third order streams | 12 | Rb$_{3-4}$ (Bifurcation ratio of 3 with respect to 4) | 12 | Form factor, F | 0.20 |
| No. of fourth order streams | 1 | Rb (Mean) | 8.82 | Elipticity Index, E | 3.89 |
| Total no. of streams | 682 | Rl$_{2-1}$ (Stream length ratio of 1 with respect to 2) | 0.21 | | |
| Length of first order streams | 618.57 km | Rl$_{3-2}$ (Stream length ratio of 2 with respect to 3 ) | 0.10 | | |
| Length of second order streams | 255.86 km | Rl$_{4-3}$ (Stream length ratio of 3 with respect to 4) | 0.08 | | |
| Length of third order streams | 210.54 km | Rl (Mean ) | 0.13 | | |
| Length of fourth order streams | 179.24 km | RHO | 0.02 | | |
| Total length of streams (Lt) | 1264.21 km | Stream Frequency, Fs ( km$^{-2}$) | 0.27 | | |
| H (Maximum elevation) | 174 m | Drainage density, Dd (km$^{-1}$) | 0.50 | | |
| h (Minimum elevation) | 142 m | Drainage texture, T (km$^{-1}$) | 0.14 | | |
| Slope Sb (m/km) | 0.80 m/km | Relief, R (m) | 32 | | |
| | | Relief ratio, Rr ( m/km) | 0.30 | | |
| | | Circularity ratio, Cc (km) | 2 | | |
| | | Length of overland flow, Lg (km) q | 1 | | |
| | | Ruggedness Number, Rn (m/km) | 17 | | |

landscape structure of the drainage basin. It demonstrates how the morphology has adapted to specific environmental elements like rainfall, lithology and climate. The primary factor influencing the decline in water discharge is climate change, highlighting the critical function of morphometric analysis.

The region's mature topography, which is indicated by a high number of first–order streams, supported by the favourable slope (Sb) that facilitates groundwater recharge. A low relief value suggests restricted sediment transport and limited water spreading within the basin. Basin relief (R) influences stream gradient, flood pattern and sediment transport. The presence of highly degradable alluvium is suggested by the relief ratio (Rr), which is directly correlated with surface runoff and intensity of erosion. The average Rl value and bifurcation ratio (Rb) highlight structural and lithological control, signifying a mature stage of landscape evolution with little surface runoff. An elevated value of the RHO Coefficient (RHO) indicates a greater capacity for water storage within the drainage network. Reduced water storage capacity and higher erosion

during high discharge are indicated by a low RHO value. Stream frequency (Fs), drainage density (Dd) and drainage texture (T) in the Sarayan River Basin collectively indicate a mature stage of erosion. This stage is distinguished by the presence of easily erodible lithology and the occurrence of widely spaced channels. Numerous additional morphometric parameters, such as the form factor (Ff), ellipticity index (E), length of overland flow (Lg), ruggedness number (Rn), elongation ratio (Re) and circularity index (Rc), help us to understand the shape features of the basin. The compacted and extended form of the basin, as shown by the basin map, causes the river's peak discharge to occur downstream. A high Ruggedness number (Rn) indicates resistance to erosion. It is important to understand how the basin has changed over time through fluvial dynamics and responses to outside influence. The drainage pattern is efficiently ensured by the dendritic network, which is shaped by complex processes such as climate and hydrology. The basin is characterized by its mature landscape evolution, dominance of lower–order stream and peak discharge. The elongated shape of the basin

and skewness towards southeast, combined with smaller flood peaks and longer flooding durations, emphasise the complex reactions to physical processes such as hydrology and climate. The drainage network in the Ganga Plain may cross tectonic lineaments even though it is not the result of tectonic activity. In order to increase water storage capacity and successfully reduce flooding, forward–thinking planning should include techniques like desiltation, the creation of new lakes and strategic settlement zoning.

## CONCLUSIONS

The study area exhibits diverse geomorphic features, such as meandering pattern, oxbow lakes, point bars, natural levee and river terrace surfaces (T0, T1, T2). Understanding the Sarayan River Basin is improved by a detailed evaluation of basic, derived and shape factors. The Sarayan River Basin shows high number of first–order streams with a total stream length of 1265 km. This shows intense weathering within the watershed region and enhances drainage efficiency and sediment transport. The bifurcation complexity and drainage pattern analysis reveal high bifurcation ratio, signifying a well–branched river system, with the transition from 2nd to 3rd order streams contributing to a dense network with distributaries.

In terms of hydrological density and spatial distribution, a high stream frequency and drainage density indicate a dense and spatially distributed river network, facilitating efficient landscape drainage and sediment transport. Topographic characteristics, including a moderate relief of 32 m and a relief ratio of 0.30 m/km, suggest a gently undulating topography, influencing sediment transport and contributing to the formation of extensive alluvial plains.

Analyzing the shape and geomorphic features, the study points to moderately elongated shape, non–circular pattern and ellipticity index, suggesting a river with pronounced elongation influencing its meandering course and overall geomorphic features. The assessment of ruggedness and overland flow reveals a terrain that is moderately rugged with an overland flow length of one kilometer. This highlights the river capacity to sculpt its path through a variety of topographies. In general, the results provide significant understanding of the geomorphological features and morphometric parameters of the Sarayan River.

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