



## SRTM and GIS-Based Geomorphic Analysis of Tons River Basin: A Geographical Case Study

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DOI: <https://doi.org/10.59436/jsiane.421.2583-2093>

### Abstract

Tons River Basin is approximately 16,860 sqkm in extent and 264 km in length; It is situated in the Kaimur Range (Upper Vindhyan) at an elevation of 610 meters. The morphometric features were used to conduct a quantitative analysis of the Tons River basin's evolution. Data from SRTM, DEM, and Lands are used to generate the drainage network. Upstream in the drainage basin, the trellis pattern is more prominent, whereas in the middle and downstream, the dendritic pattern is more prevalent. Based on the drainage density, it appears that the basin has a subsurface that is permeable and is covered in dense vegetation. With a smaller drainage area, a larger form factor value indicates a higher flow peak. Results from the Tons River Basin's relief ratio and roughness number show that the soil is easily washed away. According to the results of the present investigation, the Tons River Basin has a low risk of flooding, a low rate of soil erosion, and an abundant supply of surface water. This study has the potential to improve water resource use and pave the way for future growth in the Tons River basin. Finding a connection between the hydrologic characteristics of the basin and morphometric drainage parameters was the goal of these GIS-based studies. Therefore, the present investigation aims to hydrologically characterise the Tons River Basin and quantify its morphometric features (linear, areal, and relief aspects). Basin management, soil and water resource planning, and other related fields can benefit from this helpful data.

**Keywords:** Quantitative Approach, Morphometric Analysis, Drainage Pattern, Basin Management, GIS, Tons River Basin

Received 07.06.2025

Revised 15.07.2025

Accepted 06.09.2025

Online Available 20.09.2025

### Introduction

Countries with rapidly expanding populations, like India, must make heavy use of their limited land and water resources. To manage natural resources, the most basic administrative entities are drainage basins, catchments, and sub-catchments. The mathematical and computational study of the shape, structure, and form of the Earth is known as morphometry (Clarke, 1996; Agarwal, 1998). The geology, structural elements, geomorphology, soil composition, and vegetation of the region traversed by a river are significant factors that affect the development of a drainage system and the river's flow pattern over time and distance. GIS provides a flexible platform and robust tools for the manipulation and analysis of spatial data, particularly for future data extraction and identification, and has been employed to assess the morphometric and topographical parameters of drainage basins and watersheds (Vijith, 2006). Conducting a morphometric analysis of the drainage basin and channel network is crucial for understanding the geo-hydrological dynamics of the drainage basin and for articulating the prevailing climatic, geological, geomorphological, structural, and other antecedent factors of the catchment. According to Nag (1998) and Kanth *et al.* (2012), watershed management is all about maximising output with little impact on natural resources. It involves making the most efficient use of land and water. The drainage network's linear and geometric dimensions can be used to conduct morphometric analysis (Biswas *et al.*, 1999; Javed *et al.*, 2011; Patel *et al.*, 2012). (2013).

For morphometric analysis, theme layers are created using remote sensing. By analysing morphometric data, one can learn more about the geological and geometric history of a drainage basin and its geometry (Strahler, 1957). The primary goals of this work were to conduct a morphometric investigation of the Tons River Basin and determine its various characteristics using various parameters such as show in below;

**Table: Morphometric Parameters of the Drainage Basin**

| Parameter Name                  | Symbol | Unit               | Formula / Definition                                              |
|---------------------------------|--------|--------------------|-------------------------------------------------------------------|
| Total Number of Streams         | Nu     | —                  | Total number of streams of all orders                             |
| Basin Length                    | Lb     | Km                 | Maximum length of the basin measured along the principal drainage |
| Basin Perimeter                 | P      | Km                 | Outer boundary length of the basin                                |
| Basin Area                      | A      | Km <sup>2</sup>    | Total area enclosed by the basin bound                            |
| Basin Width                     | Wb     | Km                 | $A / L_b$                                                         |
| Elongation Ratio                | Re     | —                  | $Re = 2\sqrt{A/\pi} / L_b$                                        |
| Form Factor                     | Rf     | —                  | $Rf = A / L_b^2$                                                  |
| Circulatory Ratio               | Rc     | —                  | $Rc = 4\pi A / P$                                                 |
| Compactness Constant            | Cc     | —                  | $Cc = 0.2821 P$                                                   |
| Drainage Density                | D      | Km/Km <sup>2</sup> | $D = \Sigma L / A$                                                |
| Stream Frequency                | Fs     | No./Km             | $Fs = Nu / A$                                                     |
| Texture Ratio                   | Rt     | —                  | $Rt = Nu / P$                                                     |
| Mean Bifurcation Ratio          | Rbrm   | Km/ Km             | Average of bifurcation ratios of all stream orders                |
| Constant of Channel Maintenance | C      | Km                 | —                                                                 |
| Length of Overland Flow         | L      | m                  | $Lg = 1/D$                                                        |
| Basin Relief                    | Rh     | —                  | $Rn = D \times (H/1000)$                                          |

### Objective of the Research

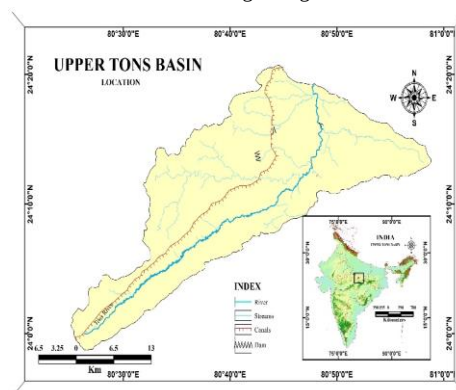
- The goal of this research is to better understand the hydrologic characteristics of the basin as it relates to the morphometric drainage parameters.
- Define the Tons River Basin hydrologically and quantify its morphometric features (linear, areal, and relief parts)..

### Data and Methodology

A topographical map was used to construct the Study Area map, and the scale is 1:7,17,036. In order to delineate the entire research region in GIS, topographical maps were georeferenced and masked. The World Geodetic System and Arc-GIS 10.4.1 software were utilised (WGS 1984). The drainage network and morphometric parameters were extracted from SRTM (30 m)/DEM data in this investigation. An array of operations were performed on the drainage channels using the Hydrology tool in ArcGIS 10.4.1. These operations included drainage network, DEM, fill, flow accumulation, relief, aspect ratio, stream order, stream direction, and flow accumulation. The several morphometric parameters used in the Study Area are defined below.

### Study Area

The Tones River Basin is situated between the latitudes of 23°58'36.14" N and 24°20'41.38" N, and the longitudes of 80°25'7.32" E and 80°58'47.07" E, inside the Madhya Pradesh districts of Satna, Panna, and Katni (Fig. 1). The Tons River Basin encompasses an area of 797.93 km<sup>2</sup>. The Tons River Basin comprises five sub-basins. The river basin has a perimeter of 171 kilometres and has 59 streams, totalling a length of 303.97 kilometres.



## Results and Conclusions

**Morphometric characteristics-** The following morphometric variables were computed: the bifurcation ratio, the stream frequency, the form factor, the drainage density, the circularity ratio, the elongation ratio, the stream length, and the compactness constant.

### Linear aspects of the basin

**Stream order** - An initial step in the process of carrying out a quantitative analysis of the Basin is the ordering of the streams. When it comes to drainage studies, the first step is to develop stream orders, which is a methodical classification of streams. This study employs the methodologies provided by Strahler (1964) in order to conduct an analysis of the streams. The highest level in the hierarchy of the basin is represented by the apex stream. In this case study, a watershed of the fourth order is investigated. In the fifth map, it was shown that the frequency increased as the stream order became more ascending.

**Stream number (Nu)** - The stream number represents the total number of distinct types of stream segments among all of the streams. It increases in a manner that is directly proportional to the order of the stream. ArcGIS 10.4.1 is implemented in order to ascertain the stream number. Among the 59 streams that were found, there were eight streams of the first order, twenty-five streams of the second order, twenty-four streams of the third order, and one stream of the fourth order. According to Strahler (1964), an increase in stream order results in a decrease in both permeability and infiltration measures.

**Bifurcation ratio (Rb)** - Horton (1945) defines the bifurcation ratio as a dimensionless statistic that compares streams of Nth order to those of (N+1)th order. It is a crucial characteristic for defining the stages of a river's evolution. Decreased Rb levels indicate basins that have seen modest structural disruptions (Strahler, 1964). The Tons River Basin demonstrates a bifurcation ratio of 8.45.

**Stream length (Lu)** - A single cumulative stream length is reached by all streams of order Lu, which converge to this length. This particular region exemplifies the basin's contribution to the ecosystem under question. Horton's law (1945) was utilised in order to arrive at an estimate of the lengths of streams belonging to different orders. 303.97 km is the total length of the stream that makes up the research region.

**Length of overland flow (Lg)** - Runoff water must travel a certain distance after entering the catchment before it can no longer be directed to the outflow due to the fact that it has reached its destination. According to Horton (1945), the relationship between the length of overland flow (Lg) and drainage density is approximately half of the inverse of the former. The length of the overland flow in the Tons River Basin is specified to be 0.19 km.

### Aerial aspect of drainage basin

**Basin area (A)** - The dimensions of a basin are determined by the changes occurring within its drainage system. Geographical characteristics and terrain influence runoff velocity. The lesser the runoff, the larger the area, and vice versa. The basin's surface area is 797.93 km<sup>2</sup>.

**Perimeter (P)** - The length of a basin has a perimeter that is defined along its length. There is a relationship between the basin parameter and the elongation and circulation ratios. There are 171 km that make up the whole perimeter of the basin.

**Drainage density (Dd)** - The drainage density of a basin is calculated by dividing its area by the total length of all its streams. Horton (1932) introduced the term "drainage density" to characterise the closeness of channel spacing. Chorley et al. (1957) assert that Dd serves as a crucial quantitative metric for landscape segmentation and runoff potential. Regions characterised by low Dd values generally consist of highly permeable soils with minimal topographical variation and limited vegetation, while areas with elevated Dd values are primarily covered by vegetation (Nautiyal, 1994). The drainage density of the Tons River Basin is 0.38 km per km<sup>2</sup>.

**Stream frequency (Fs)** - Stream frequency refers to the ratio of the number of streams to the basin's area. It denotes the configuration of the drainage network, mostly influenced by the lithology of the basin. When employed correctly, it may accurately forecast water drainage patterns. The basin's overall stream frequency (Fs) was established at 0.07.

**Texture ratio (Rt)** - According to Horton (1945), the sum of all stream segments for each regional boundary, regardless of the chronology in which they occur. Horton achieved his definition of drainage texture by taking into account both the density and the frequency of drainage. He came to the conclusion that the infiltration capacity was the most important factor that influenced the Texture ratio (Rt). In accordance with the findings presented in Table 2, the texture ratio (Rt) for the area under investigation was found to be 0.34.

**Circularity ratio (Rc)** - Miller (1953) calculated that it was the ratio of the area of the basin to the area of a circle with a diameter that was equal to the basin's perimeter (P). It has been found that a low circularity ratio is associated with efficient channel storage and a reduced sediment yield-delivery ratio, whereas a high ratio indicates rapid discharge in watersheds

(Singh, 1992). The Tons River Basin was the location where the 4.66 was reported.

**Form factor (Rf)** - The proportion of the basin's area to the square of its length (Horton, 1932). The basin's form factor ratio is only 0.027, signifying inadequate performance.

**Elongation ratio (Re)** - The ratio of a circle's diameter to the basin's maximum length yields the elongation ratio (Schumm, 1964). A 'Re' value of 1.91 was assigned to the Tons River Basin. The three classes of Re values are: less elongated (0.7), oval (0.8-0.9), and round (>0.9). Chopra et al. (2005) assert that the basin is circular, according to the data. Areas with negligible topographical variation are indicated by values nearing 1.0 (Strahler, 1964).

**Aspects of drainage basin Maximum watershed relief (H)** - The maximum vertical elevation difference between the Basin's lowest and tallest peaks is represented by this value. A value of 353 is assigned to it, and it is generally referred to as complete relief (H).

**Relief ratio (Rh)** - For the purpose of determining it, the maximum basin length (Lb) is measured and then divided by the total relief (H) of the watershed. It is a representation of the potential energy that is available for the transportation of water and silt down any slope. It is common for the Rh to grow when the size of watersheds and the area of the drainage basin both decrease (Gottschalk, 1964). According to Schumm (1956), the relief ratio is a ratio that measures the entire steepness of a drainage basin. This ratio also serves as an indicator of the intensity of the erosion process that is influencing the slope of the drainage basin. In the Tons River Basin, a relief ratio of 2.06 has been registered as having been recorded.

**Ruggedness number (Rn)** - It is possible to determine the roughness number by multiplying the drainage density (Dd) by the basin relief (H). It exemplifies the general harshness of the watershed as a whole. In the Tons River Basin, soil erosion is a common occurrence. This is due to the region's inherent structural complexity, which is connected with drainage density and terrain. This is demonstrated by the region's hardness Number of 0.78, which indicates that the basin has a moderate level of harshness.

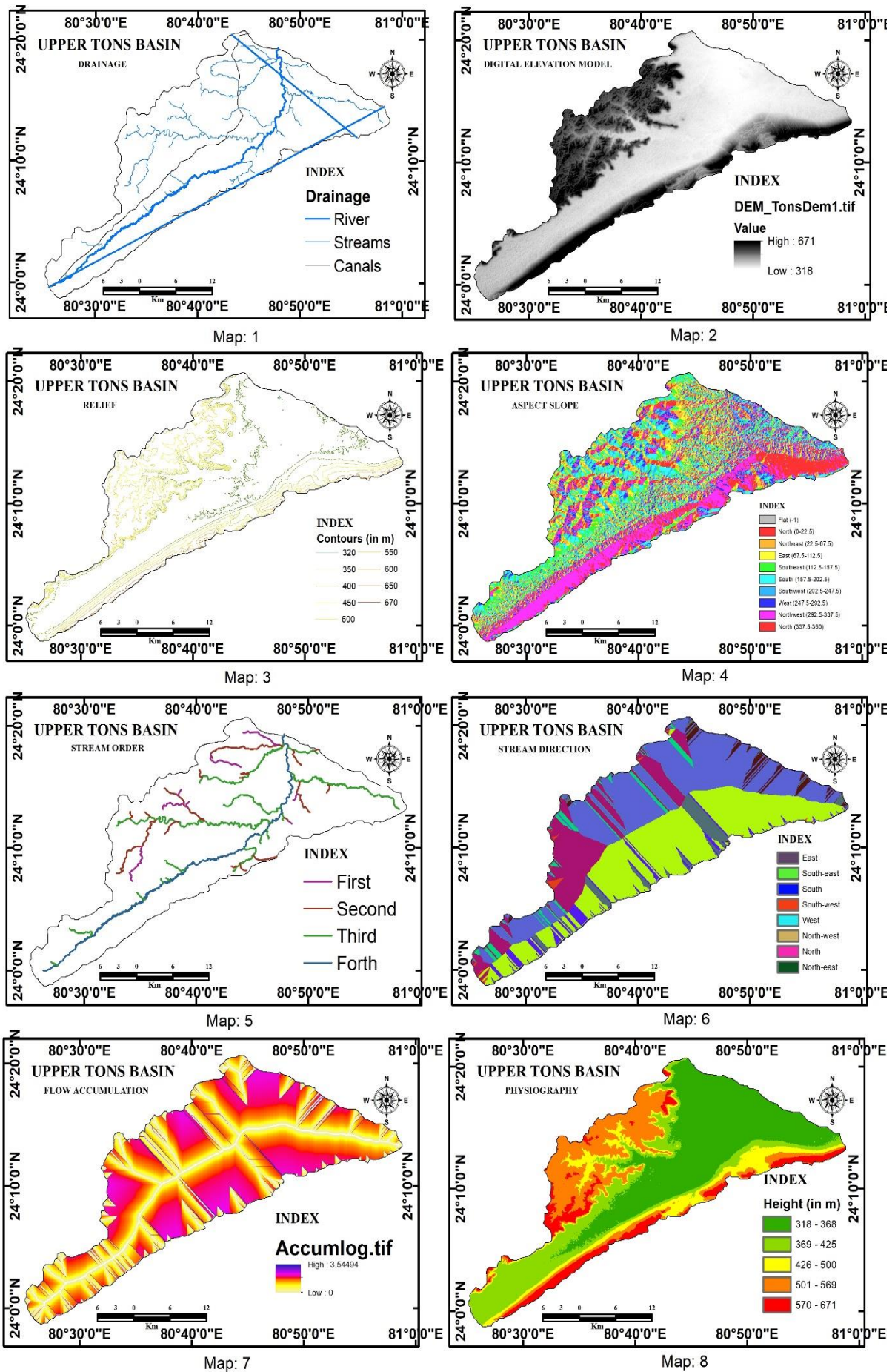
**Relative relief (Rr)** - The ratio of the circle of the watershed to its relief is the most important issue to consider. From the topographical map and geographic information system (GIS) of the Basin, the morphological components of a watershed were painstakingly collected. It was determined that the area under investigation had a relief ratio of 3.92.

**Compactness constant (Cc)** - The ratio of the watershed perimeter to the circumference of the circular region that corresponds to it is the definition of the compactness coefficient, also known as Cc. However, the Cc is not reliant on the size of the basin; rather, it is solely determined by the form of the basin. 2.35 was determined to be the value of the compactness coefficient for the area under investigation.

**Constant of channel maintenance (C)** - According to Schumm (1956), the channel maintenance constant can be seen as the reciprocal of drainage density. The relative relief of the basin, the lithology of the basin, the climate, and other factors all have an impact on the channel maintenance constant. This constant is related to drainage density. When the erodibility of the material increases, it decreases (Schumm, 1956). A value of 0.59 was determined to be the channel maintenance constant (C) for the Tons River Basin. A decreased number implies that there is less percolation and infiltration, which contributes to an increase in surface runoff (Bhagwat et al., 2011).

**In conclusion**, Techniques involving geographic information systems (GIS) and remote sensing have shown to be accurate and efficient in drainage delineation and its updates. The morphometric parameters of the Maniari sub-watershed are going to be determined through the use of GIS interpretation skills, which is the purpose of this study. Remote sensing techniques are considered suitable for the timely and cost-effective generation of updated drainage maps. Furthermore, these techniques should be prioritised in soil erosion studies for the purpose of acquiring input data since they are deemed appropriate. The investigation of morphometric parameters within a river basin sheds light on the interrelationships that exist between several drainage patterns and the impact that these patterns have on geomorphological processes, drainage characteristics, and the quality of land erosion. In order to properly classify drainage basins according to their morphometric characteristics, the drainage density and stream frequency are the most important factors to consider. The flow pattern, sediment discharge, and other hydrological factors of the drainage basin are laid out in detail by these features. A fourth-order stream network is present in the River Basin. The total length of the streams in the basin is 303.97 kilometres, and the drainage density is 0.38 kilometres per square kilometre. This indicates that the drainage density in the basin is rather low. As a consequence of this, these findings are extremely useful for planning and the management of watersheds.

Figure.2, Morphometric Analysis in the Study





**Table.1 Utilising empirical connections to analyse morphometric parameters and formulas**

| Morphometric Parameters      | Formula                                                                                                                                                                      | Reference          |
|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| <b>Linear Aspects</b>        |                                                                                                                                                                              |                    |
| Stream order                 | Hierarchical rank                                                                                                                                                            | Strahler (1964)    |
| Stream length (Lu)           | Length of stream                                                                                                                                                             | Horton (1945)      |
| Mean stream length (Lsm)     | $L_{sm} = L_u / N_u$<br>where, $L_{sm}$ = mean stream length<br>$L_u$ = Total stream length of order „u“<br>$N_u$ = Total no. of stream segments of order „u“                | Strahler, 1964)    |
| Stream length ratio (Lur)    | $L_{ur} = L_u / L_{u-1}$<br>where, $L_{ur}$ = stream length ratio<br>$L_u$ = mean of stream length of order „u“<br>$L_{u-1}$ = mean of stream length of its next lower order | Horton (1945)      |
| Bifurcation ratio (Rb)       | $R_b = N_u / N_{u+1} + 1$<br>$R_b$ = Bifurcation ratio<br>$N_u$ = Total no. of stream segments of order „u“<br>$N_{u+1}$ = no. of stream segments of the next higher order   | Schumm (1956)      |
| Mean bifurcation ratio (Rbm) | $R_{bm}$ = Average of bifurcation ratios of all orders                                                                                                                       | Strahler (1957)    |
| Length of overland flow (Lg) | $L_g = 1 / 2 D_d$<br>where, $L_g$ = Length of overland flow<br>$D_d$ = Drainage density                                                                                      | Horton (1945)      |
| Basin length (Lb)            | $L_b = 1.321 A^{0.568}$<br>where, $A$ = Area of the basin                                                                                                                    | Nookaratnam (2005) |
| Basin Perimeter (P)          | Outer boundary of drainage basin measured in kilometers. (GIS software analysis)                                                                                             | Schumm (1956)      |
| <b>Areal Aspects</b>         |                                                                                                                                                                              |                    |
| Drainage density (Dd)        | $D_d = L_u / A$<br>where, $D_d$ = Drainage density<br>$L_u$ = Total stream length of all orders<br>$A$ = Area of basin (km <sup>2</sup> )                                    | Horton (1945)      |
| Basin Area (A)               | Area from which water drains to a common stream.                                                                                                                             | Strahler (1964)    |

**Table.2, Morphometric Parameters of the Study Area**

| Morphometric parameters                     | Value  |
|---------------------------------------------|--------|
| Basin Area (Km <sup>2</sup> )               | 797.93 |
| Total Number of Stream (Nu)                 | 59     |
| Perimeter(P), (Km.)                         | 171    |
| Basin Length (Lb), (Km.)                    | 61.95  |
| Basin Width (Wb), (Km)                      | 25.94  |
| Elongation Ratio (Re)                       | 1.91   |
| Texture Ratio (Rt)                          | 0.34   |
| Mean Bifurcation Ratio (Rbm)                | 8.45   |
| Drainage density (D), (Km/Km <sup>2</sup> ) | 0.38   |
| Stream frequency(Fs)                        | 0.07   |
| Form factor(Rf)                             | 0.027  |
| Circulatory ratio(Rc)                       | 4.66   |
| Length of overland flow (Lg), (Km.)         | 0.19   |
| Constant channel maintenance(C)             | 0.38   |
| Compactness constant (Cc)                   | 2.35   |
| Ruggedness Number                           | 0.78   |
| Basin Relief (H), (m.)                      | 353    |
| Relief Ratio (Rh)                           | 2.06   |

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