Drainage network characteristics of the Ghaghghar River Basin (GRB), Son Valley, India

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ABSTRACT
The present study helps to understand the relation between the different morphometric parameters to delineate the drainage characteristics of the Ghaghghar River Basin (GRB), Son Valley, India. Shuttle Radar Topographic Mission (SRTM) data were used to prepare the Digital Elevation Model (DEM), Aspect, Drainage, and Slope maps by using ArcGIS 10 software. The Ghaghghar River is third-order stream that exhibits dendritic to sub-dendritic pattern. The trails drainage patterns are also observed in some areas of the basin which may be due to the effect of regional tectonics. The mean bifurcation ratio is 5.1 showing normal basin which is somehow controlled by structural disturbances. High bifurcation ratio (>10) determines that the region is subjected to strong structural control on the drainage. Drainage density (0.36) shows very coarse drainage texture also having positive correlation with stream frequency. The elongation ratio is 0.64 along with circulatory ratio (0.6) shows elongated nature of the basin. The low values of drainage density and stream frequency imply that surface run-off is not quickly removed from the basin, making it susceptible to flooding and gully have very little effect on the extent to which the surface has been lowered by agents of denudation.

1. Introduction
The characteristic of drainage basins depends upon the slope, regional tectonics, geology of the catchment area, and aerial climate. The method of quantitative analysis of drainage basins was developed by Horton (1945) and modified by Strahler (1964) to evaluate the nature of the drainage basins, relationship with character of the terrain, for deriving means to safeguard and manage the natural resources and combating natural hazards.

Morphometry is the measurement and mathematical analysis of the formation of the earth’s surface, shape, and dimension of its landforms. Morphometric studies involve area, altitude, shape, size, slope, and profiles of watershed (Kanhaiya, Singh, Singh, Mittal, & Srivastava, 2018; Rai, Chandel, Mishra, & Singh, 2018; Singh & Kanhaiya, 2015; Sreedevi, Subrahmanyam, & Ahmed, 2004, 2005; Thomas, Joseph, & Thrivikramai, 2010). Morphometric analysis could be used for prioritization of sub-watersheds by studying different linear and aerial parameters of the watershed (Biswas et al., 1999). Morphometric characteristics of many river basins and sub-basins in different parts of the world have been studied using conventional methods (Horton, 1945; Krishnamurthy, Srinivas, Jayaraman, & Chandrashekar, 1996; Strahler, 1957, 1964). To assess and organize the basin for soil and water preservation, quantitative examination of morphometric attributes is of tremendous significance. Morphometric analysis of a watershed gives a quantitative depiction of the seepage framework which is a vital part of the portrayal of watersheds (Strahler, 1964). Different researchers have completed morphometric investigation of river basin by utilizing remote-sensing and GIS methods. The geographic and geomorphic attributes of a drainage basin are utilized in hydrological examinations including appraisal of groundwater potential (Sreedevi et al., 2005) and watershed prioritization (Patel, Gajjar, & Srivastava, 2013). Morphometric appraisal explains an essential hydrological finding all together to anticipate surmised conduct of a watershed assuming accurately combined with geomorphology and geography (Esper Angiliieri, 2008). A number of researchers have carried out morphometric analysis of various river basins of India by using remote-sensing and GIS techniques in recent decades (Kanhaiya et al., 2018; Nag, 1998; Nag & Chakraborty, 2003, 2018, 2017; Rai at al., 2014; Magesh and Chandrasekar, 2014; Singh & Kanhaiya, 2015; Prakash et al., 2016, 2017; Singh et al., 2018; Sreedevi et al., 2004, 2005; Thomas et al., 2010).

In this work, we focuses on drainage network characterization and effect of regional tectonics on the Ghaghghar River Basin (GRB), Son Valley, India using remote-sensing and GIS technique. The valuable outcome of the present work will be very useful for the...
construction, flood mitigation, and groundwater management in the river catchment and adjoining areas. Present study connects the association between surface morphometry and subsurface geography of the basin to deliver compelling data as a piece of basin management. So the target of the present research is to consider the morphometric parameters of GRB and to recognize the impact of the regional topography on the morphometric parameters of the basin lastly to create a considerable information base with respect to the connection between surface morphometry and subsurface lithology for incorporated watershed management.

2. Study area

The Ghaghar River start its journey from Soma village (Lat. 24°32'58.02" N Long. 83°23'19.02" E) flowing in E-W direction and makes a major boundary between Bijaigarah shale and Scarp sandstone. Due to Markundi Fault striking ENE-WSW direction, the river is changing its course abruptly and starts following N-S trend before interning in the Rohtas limestone and after that in glauconitic sandstone before confluence with river Son near Patwadh village (Lat. 24°31'43.14" N Long. 83°2'47.42" E) (Figure 1).

The study area lies over the Vindhyan supergroup of rocks, the largest Proterozoic sedimentary basin of the Indian subcontinent (Figure 2). The Vindhyan Basin is one of the thickest (~ 4.5 km) Proterozoic sedimentary succession in India (Auden, 1933; Bhattacharya, 1996). The basin overlies the stable Bundelkhand Craton of Archean to Early Proterozoic age (Acharyya, 2003). Vindhyan sedimentation commenced in an intracratonic rift setting that later transformed into a sag basin during Upper Vindhyan time (Bose, Sarkar, Chakrabarty, & Banerjee, 2001; Charkrabarti et al., 2007). The generalized stratigraphy of the Vindhyan Supergroup is given in Table 1.

3. Materials and methods

The morphometric parameters broadly divided into three categories, i.e., linear aspect, relief aspect, and aerial aspect of the river basin (Mesa, 2006). These includes basin area, perimeter, basin length, stream order and stream length, mean stream length, stream length ratio, bifurcation ratio, basin relief, relief ratio, ruggedness number, drainage density, stream frequency, drainage texture, form factor, circulatory ratio, elongation ratio, length of overland flow, and constant channel maintenance.

The extraction of drainage has been done from Shuttle Radar Topographic Mission (SRTM) Digital Elevation Show (DEM) (90 m) information utilizing
ArcGIS 10. The generation of depression less DEM is dependably the preliminary advances for morphometric investigation of a basin. Depressions are information mistakes or result from the averaging associated with relegating rise estems to cells (pixels) of limited zone. These fake melancholies meddle with the right directing of flow paths amid the watershed examination, particularly in zones of low elevation. The Watershed progression solves this error by first locating and filling the depressions. This DEM is utilized to compute the flow direction and flow accumulation raster. Facilitate recreation of these two raster delivers the standard flow paths and sub watersheds. The flow chart of detailed methodology is also given in Figure 3. The standard and formulae adopted for the analysis of different parameters and their calculated values are listed in Table 2. We also characterized the field site using macro- and micro-scale analyses, and the different structure and outcrops along the course of the river and its catchment area are also investigated and given in Figure 4.

4. Result and discussions

4.1 Aspect, slope, and relative relief of the basin

The aspect of topography is the direction to which it faces (Magesh, Jitheshlal, Chandrasekar, & Jini, 2013). The vegetation and precipitation is more or less affected by aspect of the topography. The compass direction of the aspect is calculated from the output raster data value following Magesh, Chandrasekar, & Soundranayagam (2011). The aspect of the Ghaghghar River is shown in Figure 5a, which clearly indicating north, northwest, south, and southwest facing slope of the basin. These major slopes reflect the higher moisture content and low evaporation that the other parts of the basin which plays an important role to conserve vegetation, forests, and bio-diversity in the study area.

The slope of the basin is dependent of rock type of its catchment area having varying resistance (Magesh et al., 2011). The slope elements are highly related to run-off of the water, so that affecting the required time for rain water to enter in the river beds that make up the network of the river basin (Villela & Mattos, 1975). The degree of slope in the GRB varies from <1.62 to >46.08 (Figure 5b). The slope map is very useful.

Table 1. The generalized stratigraphy of Vindhyan Supergroup (Modified after Auden, 1933; Banerjee, Dutta, Paikaray, & Mann, 2006).

| Group       | Formation                               | Formation       |
|-------------|-----------------------------------------|-----------------|
| Upper Vindhyan | Upper Bhandar Sandstone Formation       | Sirbu Shale Formation |
|             | Lower Bhandar Sandstone Formation       | Lower Bhandar Sandstone Formation |
|             | Bhandar Limestone Formation             | Ganurgarh Shale Formation |
| Rewa group  | Rewa Sandstone Formation                | Rewa Shale Formation |
| Kaimur group| Upper Kaimur Sandstone Formation        | Bijaigarh Shale Formation |
|             | Lower Kaimur Sandstone Formation        | Lower Kaimur Sandstone Formation |
| Lower Vindhyan | Rohtas Limestone                        | Kheinjua Shale |
| Semri group  | Porcellanite Formation                  | Kajrahat Formation |
|             | Deoland Formation                       | Deoland Formation |
to delineate watershed planning, agriculture, deforestation/afforestation, water harvesting, civil engineering purpose, and morpho-conservation practices (Sreedevi et al., 2005).

The topographical characteristic of a basin is determined using the relative relief of its catchment area (Gayen, Bhunia, & Shi, 2013). The GRB is having highest relief as 618 m, while the lowest value is measured as 169 m (Figure 5c). The low relief designated in the SW side suggests that this area of the basin is flat to gentle slope type (Figure 5c). So the SW area is more prone to water accessibility and also suitable for agriculture activities.

4.2. Linear aspect

The linear aspects include the stream order (U), stream length (Lu), mean stream length (Lsm),

| Parameters                     | Methods                                      | References                  | Observed Values |
|--------------------------------|----------------------------------------------|-----------------------------|-----------------|
| Stream Order (U)               | Hierarchical order                           | Strahler, 1964              | 1–3             |
| Stream Length (Lu)             | Length of the stream                         | Horton, 1945                | 162.57 km       |
| Mean Stream Length (Lsm)       | Lsm = Lu/Nu, where Lu = Stream length of order "U" | Horton, 1945                | 5.08 km         |
| Stream Length Ratio (Rl)       | Rl = Lu/Lu-1, where Lu = total Stream length of order "U" | Horton, 1945                | 0.79            |
| Bifurcation Ratio (Rb)         | Rb = Nu/Nu + 1, where Nu = total number of stream segments of order "U," Nu + 1 = Number of stream segments of next higher order | Schumm, 1956                | 5.1             |
| Basin Relief (Bh)              | Vertical distance between the lowest and highest points of watershed | Schumm, 1956                | 169 m           |
| Relief Ratio (Rh)              | Rh = Bh/Lb, where Bh = Basin Relief; Lb = Basin Length | Schumm, 1956                | 4.67 m/km       |
| Ruggedness Number (Rn)         | Rn = Bh × Dd, where Bh = Basin Relief; Dd = Drainage density | Schumm, 1956                | 0.16            |
| Drainage Density (Dd)          | Dd = L/A, where L = Total length of streams; A = Area of watershed | Horton, 1945                | 0.36            |
| Stream Frequency (Fs)          | Fs = N/A, where N = Total number of streams; A = Area of watershed | Horton, 1945                | 0.07            |
| Drainage Texture (T)           | T = Fs/Dd, where Fs = Stream frequency; Dd = Drainage density | Horton, 1945                | 0.025           |
| Form Factor (Rf)               | Rf = A/Lb, where A = Area of watershed; Lb = Basin Length | Horton, 1945                | 0.32            |
| Circularity Ratio (Rc)         | Rc = 4πA/P2, where A = Area of watershed; P = Perimeter of watershed | Miller, 1953                | 0.60            |
| Elongation Ratio (Re)          | Re = 2√(A/π)/Lb, where A = Area of watershed; Lb = Basin Length | Schumm, 1956                | 0.64            |
| Length of Overland Flow (Lof)  | Lof = 1/(2Dd), where Dd = Drainage density | Horton, 1945                | 1.38            |
| Constant Channel Maintenance (C)| C = 1/Dd, where Dd = Drainage density | Horton, 1945                | 2.77            |
stream length ratio (RL), and bifurcation ratio (Rbm), which are determined and results have been presented in Table 2.

### 4.2.1. Stream order (U), stream length (Lu), and mean stream length (Lsm)

The designated stream order (Nu) is the first step in the drainage basin analysis. In the present study, ranking of the stream has been carried out following Strahler (1964). The order-wise stream numbers, stream length, and mean stream length of the GRBs are given in Table 1. The GRBs have 26 first-order streams, 5 second-order streams, and 1 third-order streams with total length of 95.98, 29.08, and 37.51 km, respectively (Figure 6). The mean stream length of the basin is 5.08 km as in Table 1. In general, there is a decrease in stream frequency as the stream order increases in the present study.

### 4.2.2. Stream length ratio (Rl)

The stream length ratio (Rl) is the resultant of mean stream length of a given order (Lu) to the mean stream length of next higher order (Lu + 1). It is somehow controlled by the slop and regional topography, and thus controls the discharge and erosional activity of the particular watershed or basin (Sreedevi et al., 2004; Thomas et al., 2010). The stream length ratio values are calculated following Horton (1945). The mean values of stream length ratio for the GRB is 0.79 (ranging from 1.28 for third/second order to 0.30 for second/first order). Increase in the stream length ratio from lower to higher orders successively reveals geomorphic maturity of the basin (Kanhaiya et al., 2018; Rai et al., 2018; Thomas et al., 2010).

### 4.2.3. Bifurcation ratio (Rb)

Bifurcation ratio (Rb) is the ratio between the numbers of stream segments of any given order (Nu) to the number of stream segments of next higher order (Nu + 1). The bifurcation ratio for third to second order is 5 and second to first order is 5.2 with a mean value of 5.1 which shows very small structural control and elongated shape of the basin. The medium Rb ratio of the studied basin shows the structural and lithological control on the ongoing drainage development in the study area. The formula, reference, and calculated values are listed in Table 2.

### 4.3. Relief aspects

The relief aspect includes the study of basin relief (Bh), relief ratio (Rh), and Ruggedness number (Rn), respectively. The formulae with references and calculated values are listed in Table 2.
Figure 5. Showing (a) Aspect map (b) Slope Map and (c) Elevation map of the Ghaghghar River Basin, Son Valley, India.

Figure 6. Map showing different stream orders of the Ghaghghar River Basin, Son Valley, India.
4.3.1. Basin relief (Bh)
The height of the mouth of the catchment is 449 m from the sea level. The relief of catchment varies in between 618 m from the height of the catchment mouth. The calculate relief of the GBR is 169 m as given in Table 2. The generalized relief map of the basin is given in Figure 4c.

4.3.2. Relief ratio (Rh)
Relief ratio (Rh) is the response of horizontal distance between two points (H) to the vertical difference between the same two points (Lb). The calculated value of relief ratio for the GBR is 4.67 m/km as in Table 2.

4.3.3. Ruggedness number (Rn)
Strahler (1958) expressed ruggedness number (Rn) as the product of basin relief and drainage density. The Rn reflects the slope and relief variation in the basin. The low value of Rn (= 0.16) implies that the basin area is less prone to soil erosion and having lack of intrinsic structural complexity in association with the basin relief and drainage density (Vijith and Satheesh, 2006; Thomas et al., 2010) (Table 2).

4.4. Aerial aspect

4.4.1. Drainage density (Dn)
Drainage density (Dn) is defined as the length of streams (L) per unit of drainage area (A) and measured by dividing the total length of stream by the area of a drainage basin (Horton, 1945). It reflects the interaction between climate and the geological setup. There is a high correlation among drainage density, precipitation, and evaporation (Horton, 1932). Drainage density describes the spacing of the drainage ways. Higher this number means closer together are the channels. Coarse drainage density occurs in regions of highly permeable subsoil material, under dense vegetative cover, and where relief is low. The low drainage density values (0.36 km/km²) of the GBR reveal coarse drainage texture, permeable subsurface/subsoil, and dense vegetation in the study area.

4.4.2. Stream frequency (Fs)
The ratio between total number of streams (N) and area of a basin (A) is known as stream frequency (Fs) as given by Horton (1945). It is dimensionless and is a measure of texture of the drainage basin in geomorphologic terms (Thomas et al., 2010). The ratio >3 shows the very rough texture and high run-off on medium-to-high relief of low permeability (Reddy, 2002). The calculated value of stream frequency (Fs) is 0.07/km² (<3) showing smooth texture and low run-off on low-to-medium relief of high permeability. The low value of stream frequency (Fs) indicates permeable subsoil and gentler gradient of the catchment area (Kanhaiya et al., 2018; Rai et al., 2018; Thomas et al., 2010).

4.4.3. Drainage texture (T)
The drainage texture is defined as the total number of stream segments of all order in a basin per perimeter of the basin (Horton, 1945). In general, the drainage texture is a measure of relative channel spacing in a fluvial-dissected terrain, which is greatly influenced by the climate, vegetation, lithology, soil type, relief, and stage of development of a watershed (Smith, 1950). In case of the Ghaghghar River, the calculated value of the drainage texture is 0.025 showing all drainage are texturally very coarse in nature.

4.4.4. Form factor (Rf)
Horton (1945) defined the form factor (Rf) as the ratio between basin area (A) and the square of basin length (Lb²). This ratio deals with shape of basin and also related to drainage texture and relief of the basin. The zero value indicates highly elongated shape and one indicates circular shape of the basin. Low form factor ratio will be for basins of flatter peak flow for longer duration (Biswas, 1999) with less side flow for shorter duration and main flow for longer duration (Reddy et al., 2002; Reddy, Maji, & Gajbhiye, 2004), and vice versa for high ratio. The calculated value for the studied basin catchments is 0.32 which confirms flatter peak flow for longer duration in moderately elongated shape.

4.4.5. Circularity ratio (Rc)
It is the ratio of area of basin (A) to the area of the circle having the same perimeter of the same basin (Miller, 1953). Similar to form factor, value nearer to one means more circular shape (Strahler, 1964). Run-off in circular shape basins gets more time to stay. Therefore, circular-to-elongate basin is inversely related to their character of movement (rapid or slow) of run-off to outlet and infiltration. These are further subjected to lithology, slope, and land cover of the basins or sub catchments. The calculated value of the circulatory ratio is 0.60, which indicates elongated shape of the studied river basin.

4.4.6. Elongation ratio (Re)
According to Schumm (1956), the ratio between diameter of the circle having same area as of the basin and the length of the same basin is defined as elongation ratio (Re) of a river basin. The higher value of the Re indicates high infiltration capacity and low run-off conditions and vice versa (Reddy et al., 2002, 2004). The observed value of the elongation ratio for the Ghaghghar River is 0.64 which indicates high run-off and elongated shape of the basin.
4.4.7. Length of overland flow (Lof)
As per Horton (1945), the length of overland flow (Lof) is the length of water over the ground before it gets concentrated into definite stream channels which affect both the hydrological and physiographic characteristics of the basin. In the present studied basin, the Lof value is 1.38 showing relatively mature stage of the drainage development.

4.4.8. Constant of channel maintenance (C)
It is the inverse of drainage density and expressed with dimension of square per unit (Horton, 1945). It is also defined as the area of the basin needed to develop and sustain a unit length of stream channel (Schumm, 1956). Permeability, rock type, relief, vegetation, and duration of rainfall are the affecting factors of the constant of channel maintenance (C). The high value (= 2.77) of constant of channel maintenance for the studied river basin indicates high permeability of subsoil, gentle-to-moderate slope, and high surface run-off.

5. Conclusions
Based on detailed investigation of the GRB using remote sensing and GIS, and field survey, the following conclusions have been made:

1. The Ghaghghar River is third-order basing, elongated in nature having basin area 447.67 km², perimeter 96.06 km, and maximum length of the basin is 37.14 km.
2. The river initially flowing E-W direction and due to Markundi Fault (ENE-WSW striking same as Son-Narmada Lineament), its course abruptly changed to N-S direction. This reveals that drainage of the river basin is somehow affected by the regional tectonics which is possibly due to activation of Son-Narmada Lineament or secondary tectonics associated with it. The Bifurcation ratio (>5) and trellis drainage patterns in some part of the basin also confirm the same.
3. The basin have low drainage density and coarse drainage texture suggests permeable subsurface/subsoil, dense vegetation cover in the study area.
4. The low value of stream frequency indicates permeable subsoil and gradual slope of the catchment area, while the form factor value confirms flatter peak flow for longer duration in moderately elongated shape of the basin.
5. The high value of constant of channel maintenance of the basin indicates high permeability of subsoil, gentle-to-moderate slope, and high surface run-off showing relatively mature stage of the drainage development confirmed by length of overland flow.

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No potential conflict of interest was reported by the authors.

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