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# Spatial regionalisation of morphometric characteristics of mini watershed of Northern Foreland of Peninsular India

Sandeep Kumar Yadav[1] · Alok Dubey[1] · Sudhir Kumar Singh[2] · Diwakar Yadav[1]

## Abstract

The morphometric (geomorphic) parameters are reconnaissance tools used to analyse and evaluate the different aspects of a river basin (watershed) such as lithological characteristics, geomorphic landforms, and hydrological behaviour. In this study, a recurrent drought-affected Barua watershed of Tons river basin has been selected for detailed analysis of spatial regionalisation of morphometric characteristics. This mini watershed has been studied using topographic maps (1:50,000 scale), satellite images (CARTOSAT DEM of 1″ or ~ 32-m resolution), extensive field surveys, and generated isopleth maps of morphometric parameters in GIS environment using ArcGIS 10.2.2. The areal parameters indicate elongated shape of the basin, hilly region, and moderate-to-steeper ground slope. More than 85% of the area have gentle-to-moderate slope (2–10°); steep slope found along the escarpment of the Bhander Plateau; more than half of the area has above 30 m of basin relief. Hypsometric integral (HI) is 0.47, and the shape of hypsometric curve is sigmoidal; it indicate equilibrium stage of the watershed. The correlation matrix enables that the correlation coefficient between drainage attributes (as drainage density, stream frequency, and drainage texture) are reflecting very strong positive correlation and ranges from 0.83 to 0.91, and the basin relief showing very strong positive correlation with dissection index (0.99), moderately positive correlation with average slope and ruggedness number. The HI and length of overland flow ($L_o$) are show weak correlation with the other variables. It means the high drainage density, stream frequency, and drainage texture are associated with moderately hilly region, less permeable rock, and high run-off, giving less time for infiltration. Hence, hilly and rocky surfaces of the region are identified as poor groundwater-potential zones, while the areas of alluvial valley plain are characterised as better groundwater-potential zones.

**Keywords** Morphometric analysis · Hypsometric curve · Mini watershed · Isopleths · Spatial regionalisation

✉ Sudhir Kumar Singh
   sudhirinjnu@gmail.com

   Sandeep Kumar Yadav
   sandeepkalld15@gmail.com

   Alok Dubey
   alokdubey59@yahoo.co.in

   Diwakar Yadav
   diwakaryadav444@gmail.com

[1] Department of Geography, University of Allahabad,
   Prayagraj, U.P. 211002, India

[2] K. Banerjee Centre of Atmospheric and Ocean Studies, IIDS, Nehru
   Science Centre, University of Allahabad, Prayagraj, U.P. 211002,
   India

## Introduction

The term 'spatial regionalisation' refers to the interpretation of spatial variability and areal coverage of geomorphic characteristics in the watershed through commonly used morphometric variables, related isopleth maps, and bar diagrams (Dubey 1990; Kayamkhani 1990; Choudhary 2002). The study of the spatial regionalisation of drainage characteristics and relief aspect of the region within the broad framework of morphometric analysis has become essential to determine the present topographic make-up of the face of the study region and the evolution of the various dynamic environmental processes instrumental in causing altimetric and planimetric variations in the region (Choudhary 2002).

The morphometric analysis of a drainage basin is considered the most satisfactory method; this method enable us to find interrelationship among different aspects of the drainage pattern of the basin (Biswas et al. 1999), facilitate a

comparative evaluation of different drainage basins developed in various geologic and climatic regimes, and define certain useful variables of drainage basins in numerical terms (Nag and Chakraborty 2003). In a well-defined spatial boundaries, rivers are the medium of energy exchange from one place to another place in external environment (Patel et al. 2012; Yadav et al. 2014). River basins have a defined morphologic region and have special relevance to drainage pattern and geomorphology (Doornkamp and Cuchlaine 1971; Strahler 1957; Reddy et al. 2004). Morphometric analysis is a strong way to evaluate and understand the behaviour of hydrological system and hydrological nature of rocks (Singh et al. 2013; Banerjee et al. 2017); it provides quantitative specification of basin geometry to understand initial slope or inconsistencies in rock hardness, structural controls, recent diastrophism, and geological and geomorphic history of drainage basin (Strahler 1964; Esper Angillieri 2008; Kumar et al. 2011; Singh et al. 2013, 2014; Yadav et al. 2014; Banerjee et al. 2017).

The quantitative measurements have a crucial role in the analysis of morphometric characteristics; in recent time, many authors have discussed the role of morphometric parameters in their literature as follows: check dam positioning (Ratnam et al. 2005); flood hazard mapping (Patton and Baker 1976; Angilli 2008; Bajabaa et al. 2014; Bhatt and Ahmed 2014); sustainable land use planning (Kar et al. 2009), erosion-prone area (Pradhan et al. 2020; Edon and Singh 2019; Gajbhiye et al. 2014), geo-environmental hazards (Arnous et al. 2011), landslides (Elmahdy et al. 2016), rainwater harvesting (Yousif and Bubenzer 2015), groundwater-potential zones (Sreedevi et al. 2005; Singh et al. 2010; Adham et al. 2010; Sinha et al. 2012; Kumar et al. 2014; Yadav et al. 2016; Kumar et al. 2018; Pande et al. 2020; Murmu et al. 2019;36. Choudhari et al. 2018; Kaliraj et al. 2015).

A number of papers have been written and published on the study of morphometric analysis of river basin especially on the river system of Peninsular India, spatio-temporal variations in gully rills frequency and drainage density of Deoghat area (Dubey 1990; Singh and Dubey 1997; Kale 2002), and morphometric analysis of Upper Tons basin from Northern Foreland of Peninsular India (Yadav et al. 2014). Prioritisation of sub-watersheds based on earth observation data of agriculturally dominated northern river basin of India (Yadav et al. 2016). In the last few decades, field-based studies of the river channel characteristics and behaviour, together with developments in the field of remote sensing, geographic information system (GIS), and computer techniques, have strengthened the study of fluvial geomorphology in India and changed the traditionally approach that was based on study of topographical sheet (Kale and Shejwalkar 2007; Yadav et al. 2014).

After the advent of digital elevation models (DEMs), it is very easy to calculate the morphometric parameters more accurately and timely with the support of GIS software; many

scientific research workers have evaluated DEM (Szabó et al. 2015; Rawat et al. 2019) and morphometric parameters derived from ASTER and SRTM DEM (Grohmann et al. 2007; Singh et al. 2013, 2014; Kaliraj et al. 2015; Elmahdy et al. 2016; Yadav et al. 2016). However, the detailed knowledge of morphometric properties of basins, scale effects, and hydrological response helps in managing resources and planning.

The study is based on application of remote sensing and GIS techniques. The objectives of the current study are (i) to determine how lithology is associated with hydraulic characteristics of a watershed and (ii) to delineate and analyse the multivariate morphological regional classes of the Barua watershed through generating various layers of morphometric parameters.

## Study area

The Barua is a consequent bed rock stream of Tons (Tamas) basin of northern foreland of Peninsular India (Fig. 1), where hydraulic activities have been playing a dominating role and hence signify the importance of fluvial morphometric studies (Yadav et al. 2014), developed upon north-eastern corner of the Bhander Plateau upland. The Barua watershed has been divided into two parts: first, Upper hilly and plateau region and, second, Lower Barua watershed. The area of the basin is about 170 km$^2$. The western and middle parts (three-fourth area of the region) have been covered with the Bhander Plateau uplands and its hillocks.

## Physiographic setting

The DEM of the region gives good overview about relief distribution in the Barua basin (Fig. 2). On the basis of physiography in the Barua watershed, two well-defined units can be delineated, viz. the Bhander Plateau upland with steeper escarpment (Fig. 3) and plain valley region. The average height of the plateau is 503 m above mean sea level (M.S.L.) surrounded by an extensive plain area which is 303 m above M.S.L. Over this plateau again occur several smaller flat-topped hillocks either isolated or in clusters. The closely spaced clusters of hills in the south-western corner of the plateau gave rise to a very rugged topography. Some of the flat-topped hillocks, particularly those near Parsowania, Barura, and Gunjhir, are quite extensive and can be regarded as miniature plateaus (Rao and Lal 1974).

The region experiences subtropical climate marked by moderate rainfall and moderate humidity, mean annual rainfall (1255.61 mm); more than 85% of rainfall is received during south-west monsoon (July–September), mean annual temperature (25.36 °C), mean max (33.17 °C), and mean min temperature (17.57 °C), respectively (Singh and Srivastava 1974; Yadav et al. 2014). The Bhander Plateau upland is covered by mainly monsoon-mixed deciduous forest and
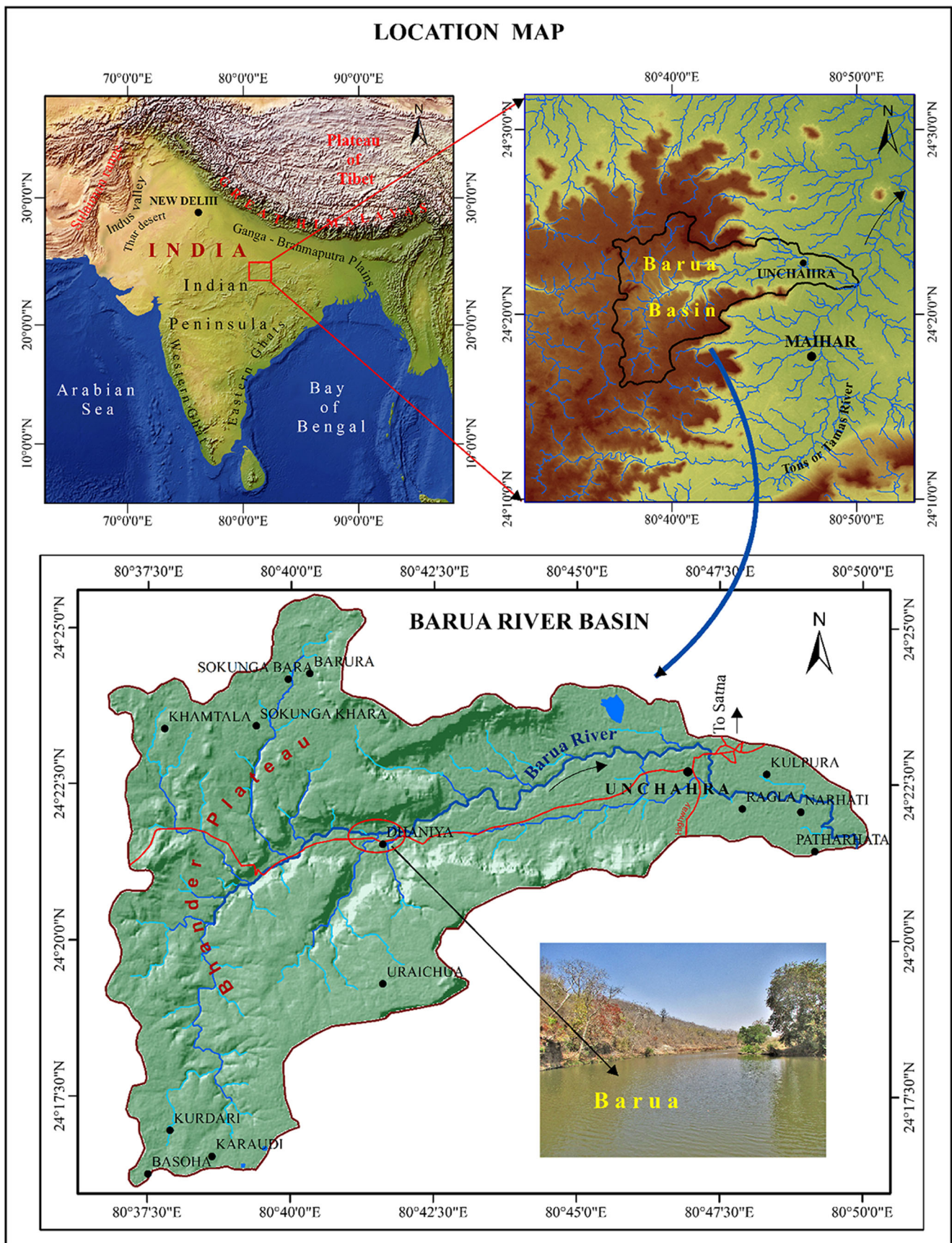
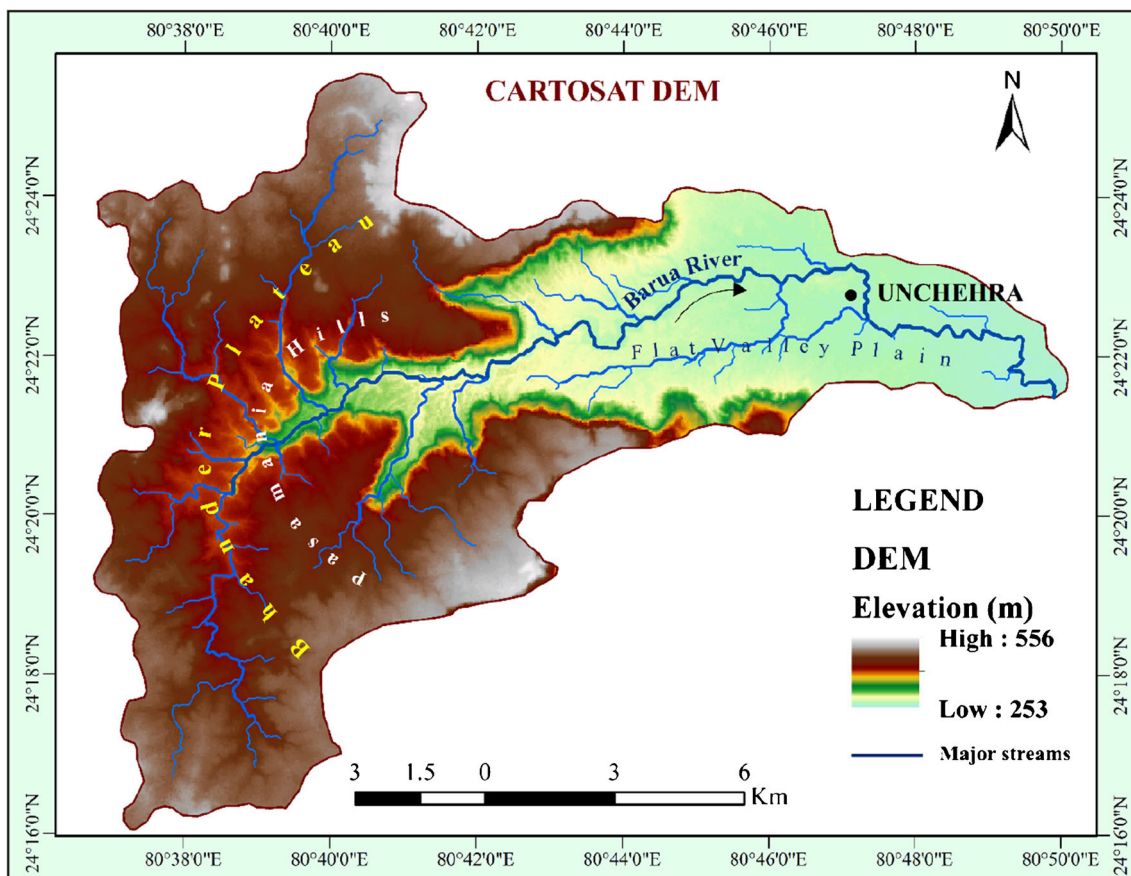**Fig. 1** Location map of the study region

**Fig. 2** The CARTOSAT DEM image of the Barua watershed

bamboo forest. Teek, Sal, and other plantations have been taken up by Forest Department on the plateau (Sanyal and Sanyal 1987). More than 70% percent of the area in the region is covered with open-mixed jungle mainly bamboo.

## Geological setting

Mallet (1969) was the first to present a comprehensive account of the geology of the Vindhyan basin. The area examined forms the north-eastern part of the Bhander Plateau which occurs in the central part of the basin. No geological mapping of this area was carried out in recent times. Chowdhury (1958) recorded the occurrences of bauxite on the Raja Saha Hill near Parsowania. According to him, the bauxite is of superficial boulder nature and is of no economic importance (Rao and Lal 1974; Yadav et al. 2014; Yadav et al. 2016). The Bhander group includes various rock formation, i.e. Upper Bhander (Maihar) sandstone, Sirbu shale, Lower
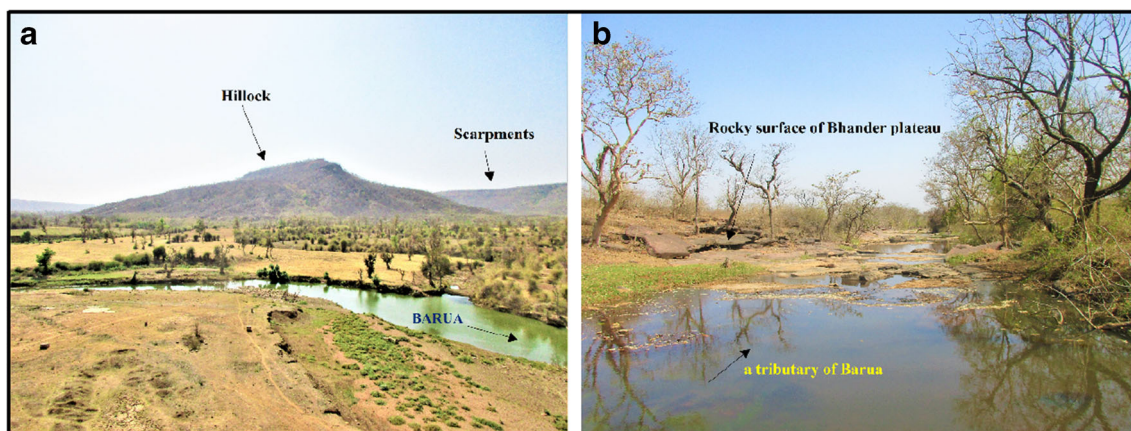


**Fig. 3** The geospatial features of the study region. **a** Barua along the escarpment of Bhander Plateau with a hillock. **b** Rocky bottom of a tributary of Barua over the Bhander Plateau with exposed sandstones in surrounding, near Parsowania hill (photos captured during field survey)

Bhander sandstone, Bhander limestone, and Ganurgarh shale. The Rewa group includes Upper Rewa sandstone, Jhiri shale, Lower Rewa sandstone, and Panna shale (Wadia 1975; Sanyal and Sanyal 1987).

The examined area consists of Sirbu shale overlain by Maihar sandstone both belonging to the Bhander group of the Vindhyan supergroup. The Maihar sandstone has detached capping of lateritised clay at several places. Isolated bodies of basic rock (trap rock) occur over the Maihar sandstone (Rao and Lal 1974). In the study region, two major rock out crops were found; the first is the hard Upper Bhander sandstone formation occupying the Bhander Plateau and the second is Sirbu shale spreading just below the alluvium valley pain of Barua (Fig. 3).

# Methodology

The present study is based on detailed morphometric analysis of the Barua basin using remote sensing and geographic information system (GIS). The CARTOSAT DEM images (1″ or ~ 32-m spatial resolution) are used for delineating the watershed boundary and extracting streams and for relief aspects with the help of the ArcGIS 10.2.2 software tools. The digital elevation model (DEM) is fast and less cumbersome in extracting geospatial features and calculating morphometric parameters (Farr and Kobrick 2000; Grohmann 2004; Joshi et al. 2013). The CARTOSAT DEM images have been downloaded from BHUVAN-ISRO'S Geoportal/Gateway to Indian Earth Observation available at http://bhuvan-noeda.nrsc.gov.in (Fig. 2). Some basic information related to geological setting were extracted from quadrate sheet (the geological survey of India map, no. 63D of scale 1:250,000) of the region. The Survey of India (SOI) topographical maps (nos. 63D/11 and 63D/15 of 1:50,000 scale) have been also used for digitising other significance geospatial features (such as settlements and roads).

For computing and analysis of morphometric characteristics, mathematical methods and formulae have been used. The isopleth maps (or layers) of morphometric parameters have been generated, applying grid square (Fishnet) method (one grid being 1 km$^2$) (Singh 1976) and using inverse distance weighting (IDW) interpolation technique of spatial analysis tool in the ArcGIS environment. The quantitative amount of spatial distribution of morphometric parameters (such as drainage density, stream frequency, drainage texture, basin relief, dissection index, average slope, ruggedness number, and hypsometric integral) in the study region have been represented through bar diagrams (Fig. 6). The elevation and other characteristics of study region are also verified during extensive field observation with Global Positioning System (GARMIN etrex-10 GPS).

## Drainage pattern and stream ordering

The spatial arrangement and form of natural drainage system in terms of geometrical shapes are known as drainage patterns, e.g. dendritic pattern, trellis pattern, and parallel pattern. Joining with nearly right angle indicate low slope of the region while acute joining of stream indicate steep slope fault and joint system (Al Saud 2009; Yadav et al. 2014) The selection or determination of the hierarchal position of a stream segments within that basin is known as stream ordering (Yadav et al. 2014). After the study of different schemes (Horton 1932, 1945; Shreve 1966; Scheidegger 1965) of stream ordering comparatively, it becomes apparent that scheme of Strahler is simple, easy, and relevant for application. In the present study, stream ordering follows Strahler's method (Fig. 4a).

## Bifurcation ratio ($R_b$)

It is the ratio of number of streams ($N_\mu$) of given order to the number of stream segments of the next higher order ($N_{\mu + 1}$). Mathematically, it is expressed as (Schumm 1956; Yadav et al. 2014):

$$R_b = N_\mu / N_{\mu+1},$$

where $\mu$ is the order of the stream

The theoretically minimum bifurcation ratio is 2.0 and the value of $R_b$ of a natural drainage system varies from 3.0 to 5.0 (Strahler 1964). Lower $R_b$ values between 2.0 to 3.0 indicate gentle slope of terrain, permeable, and soft bed rock which facilitate sufficient time for infiltration and produce a better groundwater recharge potential zone (Yadav et al. 2014). Strahler (1957) has discussed about bifurcation ratio; one supposed that the bifurcation ratio would constitute a useful dimensionless number for expressing the form of a drainage system. It is more emphasised that actually the number is highly stable and shows a small variation from region to region or environment to environment, except where powerful geologic controls dominate.

## Drainage density ($D_d$)

The drainage density is a measure of the length of total streams per unit area of drainage basin. It can be expressed as follows (Horton 1932):

$$D_d = \frac{\sum L_\mu \text{ (Total length of all stream) km}}{A \text{ (Area of the basin) km}^2}$$

The Drainage density analysis is useful in a numerical measurement of landscape dissection and run-off potential (Reddy et al. 2004; Yadav et al. 2014). Lower $D_d$ values (nearly zero) indicate permeable nature of rocks with very high infiltration
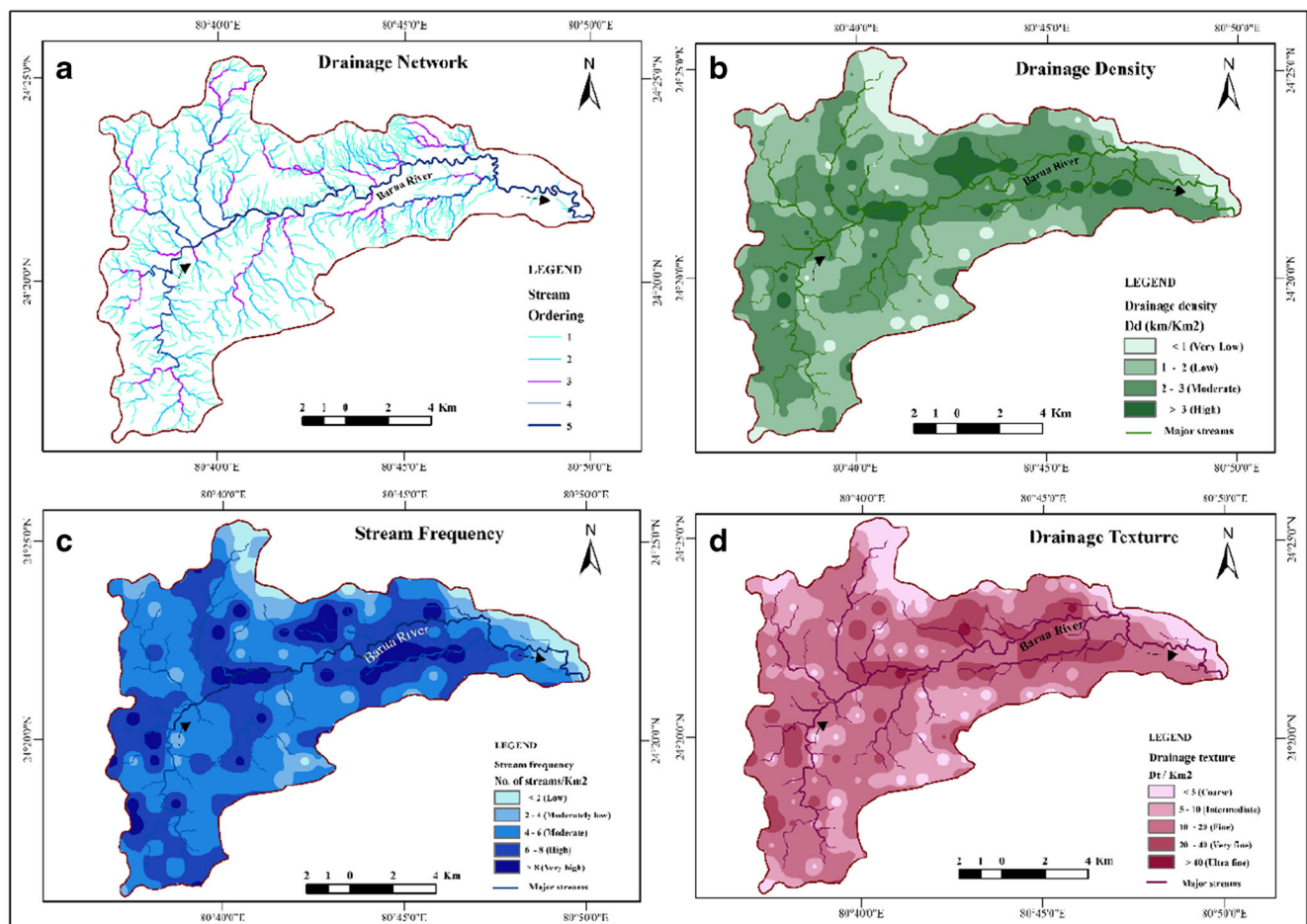
**Fig. 4** A comparative representation of the spatial regionalisation of drainage characteristics in the study region. **a** Drainage map with stream ordering. **b** Distribution of drainage density. **c** Distribution of stream frequency. **d** Distribution of drainage texture

rates and high groundwater potential while high $D_d$ indicate impermeable rocks under spare vegetation and hilly relief region (Horton 1945). The drainage density of the study region has been categorised into four classes: very low (< 1), low (1–2), moderate (2–3), and high (> 3).

## Stream length ratio ($R_l$)

The stream length ratio is the ratio of the mean length ($L_\mu$) of all stream segments of a given order ($\mu$) to the mean length of all stream of the next lowest order ($L_{\mu-1}$); with the help of stream length ratio, we can determine discharge of surface flow and erosional stage of the basin (Horton 1945; Yadav et al. 2014).

## Stream frequency ($F_s$)

It is the ratio of number of streams ($N_\mu$) to the area ($A$) of the basin; higher values of stream frequency indicate steep ground slope, greater surface run-off, and low infiltration (Horton 1932, 1945).

## Drainage texture ($D_t$)

Drainage texture refers relative spacing of drainage lines (Smith 1950). Mathematically, drainage texture is defined as the product of drainage density ($D_d$) and stream frequency ($S_f$) (Horton 1945; Yadav et al. 2014). The term drainage texture must be used to indicate relative spacing of the streams in a unit area along a linear direction (Singh 1976; 1978). Drainage texture of any drainage basin depends on climate, rainfall, vegetation, soil and rock types, infiltration rate, relief, and the stage of development (Horton 1945; Smith 1950; Yadav et al. 2014). We have adopted the method proposed by Smith (1950) which is the classification of texture of a basin as coarse (< 4 per km), intermediate (4–10 per km), fine (10–15 per km), and ultrafine (> 15 per km) (Fig. 4d).

## The parameters related to shape of the watershed

There are some morphometric (geomorphic) parameters commonly used to determine the shape of the basin (watershed) such as the form factor ($F_f$), elongated ratio ($R_e$), circularity

ratio ($R_c$), and shape factor ($B_S$); these were calculated for the Barua watershed.

## Form factor ($F_f$)

The form factor is a ratio between the area of the basin ($A$) and the squared value of the basin length ($L^2$) (Horton 1945). It is expressed as:

$$F_f = A/L^2$$

Numerically, the value of this index lies between '0' and '1' (circular shape). The higher $F_f$ value indicates high peak flow in shorter duration, whereas lower values of form factor reflect lower peak flow in longer duration in the drainage basin (Chopra et al. 2005; Yadav et al. 2014).

## The elongation ratio ($R_e$)

The elongation ratio is another shape parameter expressed as the ratio of diameter ($D$) of a circle of the same area as the basin ($A$) to basin length ($L$) (Schumm 1956). It is mathematically expressed as:

$$R_e = D/L = \frac{1.128\sqrt{A}}{L}$$

The $R_e$ values range from '0' to '1'; lower $R_e$ values are related to highly elongated shape, while higher value (close to 1) is associated to circular shape of the watershed (Bali et al. 2012; Yadav et al. 2014; Yadav 2018). Circular shape of a basin shows active denudational activities, high infiltration rate, and low run-off, while elongated shape of the watershed is related to the areas having higher relief, steep slope, and susceptibility to high headward erosion along tectonic lineaments (Strahler 1964; Reddy et al. 2004; Kumar et al. 2011; Yadav et al. 2014; Yadav 2018).

## Circularity ratio ($R_c$)

It is the ratio of the basin area ($A$) to the area of a circle having the same perimeter ($P$) as the basin (Miller 1953; Strahler 1964) and is expressed as:

$$R_c = 4\pi A/P^2$$

The value of $R_c$ is found between zero and one; the values closer to zero indicate highly elongated shape ($R_c = 0$ reflect a line), while higher values nearer to '1' are associated with circular shape (Bali et al. 2012; Yadav et al. 2014; Yadav 2018). The circularity ratio is influenced by drainage density, stream frequency, rock's nature, land cover, climate, and morphology of the basin. It is an important morphometric variable, which indicates the stage of the basin. Its low value indicates younger stage, medium value shows mature/equilibrium stage, and high value is associated to older stages of the tributaries in the basin (Sreedevi et al. 2005; Horton 1945; Yadav 2018).

## The shape factor ($B_S$)

The shape factor is another parameter related to the shape of the watershed. Mathematically, it is defined as:

$$B_s = L^2/A$$

where $L$ is the basin length and $A$ is the area of the watershed (or basin) (Horton 1932). Some scholars (Cannon 1976; El Hamdouni et al. 2008) calculate shape factor ($B_s$) in another way such as:

$$B_s = \left(\frac{L}{B_w}\right)$$

where $L$ is the length of the basin and $B_w$ is the width of the basin measured at its widest point. We have applied Horton's (1932) method in the present study.

## Constant of channel maintenance (C)

The constant of channel maintenance is the inverse of drainage density ($D_d$) (Schumm 1956). It is expressed as:

$$C = 1/D_d$$

This parameter refers to the area required to maintain one linear kilometre of stream channel (Yadav et al. 2014). Constant of channel maintenance ($C$) depends on slope of basin, geological setting, and vegetation cover and the duration of erosion. Generally, the higher $C$ values are associated to the higher permeability of rocks and vice versa (Pakhmode et al. 2003; Rao 2009; Kumar et al. 2011; Yadav et al. 2014).

## Length of overland flow ($L_o$)

The length of overland flow ($L_o$) is defined as half of the reciprocal of the drainage density (Horton 1945). It is characterised as the length of flow of water on the surface before it becomes concentrated into a definite stream channel (Yadav et al. 2014; Yadav 2018). Higher $L_o$ values are associated to gentle ground slope, long flow paths, and high groundwater recharge potentiality (Yadav et al. 2014).

## Relief aspect

We have conducted relief analyses with the help of the DEM. There are some significant relief parameters we extracted such as basin relief ($R$), relief ratio ($R_r$), gradient ratio ($G_r$),

dissection index, average slope, ruggedness number ($R_n$), hypsometric curve, and hypsometric integral (HI).

## The basin relief (R)

The basin relief can be defined as the difference in elevation between the highest and the lowest points of the watershed. It is a very important variable which assists to understand the denudational characteristics of that drainage basin, which influences the slope of the ground, surface run-off, amount of sediment, and the flood pattern in the basin (Hadley and Schumm 1961; Yadav et al. 2014). We have regionalised the basin relief values in the study region through the isopleth map and classified them in five categories, viz. (i) extremely low (< 15 m), (ii) low (15–30 m), (iii) moderately low (30–60 m), (iv) moderate (60–120 m), and (v) moderately high relief (120–240 m) (Fig. 5a).

## Relief ratio (R_r)

The relief ratio is the ratio of the basin or relative relief ($R$) to the basin length ($L$). Geology and slope of the basin influence the relief ratio. Higher values of $R_r$ are associated with a hilly region, whereas lower values of relief ratio indicate pediplain and valley zone (Kumar et al. 2011; Yadav et al. 2014; Yadav 2018). It is expressed as (Schumm 1956):

$$R_r = \frac{R}{L}$$

Relief ratio is directly associated to length of overland flow and time to peak. It is easy to derive and can often be obtained where detailed information about the topography is lacking (Strahler 1957; Yadav 2018).

## Gradient ratio (G_r)

The gradient ratio is a ratio of difference of source elevation and mouth elevation of major stream of basin to channel length ($L$) of major stream of that basin (Sreedevi et al. 2005; Yadav et al. 2014). It is expressed as:

$$G_r = \frac{(a-b)}{L}$$

where $a$ is the elevation of source and $b$ is the elevation at the mouth of the river. The high value of $G_r$ indicates steep slope and high run-off, while the low value indicates less surface run-off and better possibility of infiltration, which produces better groundwater recharge potential zone.

## Dissection index (D_i)

The dissection index is a ratio of the basin relief to the maximum absolute relief (Singh 1972). It is expressed as:

$$D_i = \frac{R}{(\text{max. elev.})}$$

where $D_i$ is the dissection index, $R$ is the basin relief, and max. elev. means elevation of the highest point in the watershed. It is an important morphometric indicator of the nature and magnitude of dissection of terrain. If in a unit area the variation in amplitude of local relief is highly variable through the process of land sculpturing by the erosion and weathering, the region is said to be called highly dissected (Choudhary 2002). The values of dissection index derived for each grid of 1 km$^2$ dimension are classified into four categories: extremely low (< 0.1), low (0.1–0.2), moderate (0.2–0.3), and high dissection index (> 0.3), and an isopleth map is prepared for the study of spatial variation (Fig. 5b).

## Average slope (A_s)

The analysis of the angular properties of the earth's deformities, formed by various tectonic, erosional, and depositional processes, has been made necessary to the systematic study of landforms which has drawn the attention of curious geomorphologists towards the significance of slope in terrain analysis and determination of landform characteristics on the basis of angular properties (Choudhary 2002). The average slope of the watershed has been calculated by the method as suggested by Wentworth (1930). Then, the slope angles have been categorised into four classes, namely level (< 2°), gentle (2–5°), moderate (5–10°), and moderately steep (10–20°) (Fig. 5c).
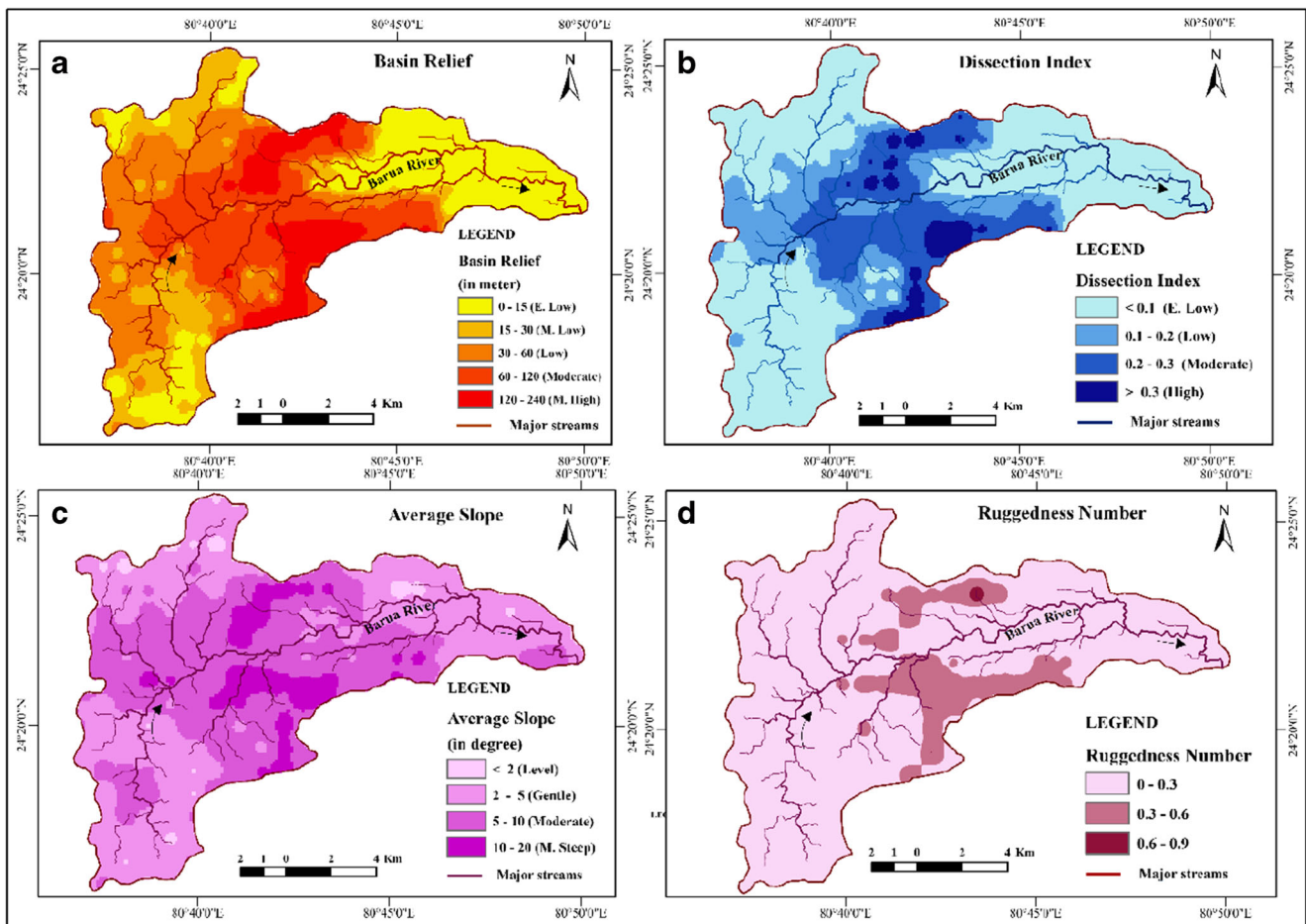
## Ruggedness number (R_n)

The ruggedness number of the basin is associated with the structural complexity of the terrain (Schumm 1956; Kumar et al. 2011). It is defined as"

$$R_n = R \times D_d$$

where $R$ is the basin relief and $D_d$ is the drainage density of the watershed (basin). The higher values of $R_n$ are usually expected in a mountainous region of tropical climate with higher rainfall. The spatial distribution and categorisation of ruggedness number values are shown in related figure (Fig. 5d) and diagram (Fig. 6g).

**Fig. 5** The spatial regionalisation of relief aspects in the study region. **a** Distribution of basin relief. **b** Distribution of dissection index. **c** Distribution of average slope. **d** Distribution of ruggedness number

## The hypsometric curve and hypsometric integral

Hypsometric analysis describes the distribution of ground surface area, or horizontal cross-sectional area, of a landmass at different elevations (Strahler 1952; Schumm 1956; Pérez-Peña et al. 2009a). The hypsometric curve or hypsometric integral facilitate estimation of hypsometric characteristics of the region/basin (Pérez-Peña et al. 2009a).

Hypsometric integral is equivalent to the ratio of area under the hypsometric curve to the area of the entire square (Strahler 1952) and expresses the landmass of a basin that has not been eroded (Singh and Singh 2018); therefore, hypsometric integral is correlated with the shape of this curve (Pike and Wilson 1971; Strahler 1952; Pérez-Peña et al. 2009a). The hypsometric integral can be calculated, using the following equation (Pike and Wilson 1971; Mayer 1990; Singh and Singh 2018; Keller and Pinter 2002):

$$HI = \frac{mean\ elevation - minimum\ elevation}{maximum\ elevation - minimum\ elevation}$$

The convex shape of the curve associated with youthful stage and sigmoidal shape indicates mature stage and concave shape of the curve associated with Monadnock phase of the basin (Strahler 1952; Keller and Pinter 2002; Pérez-Peña et al. 2009). In this work, we categorise HI values in four categories (Fig. 7a, b) as young stage (> 0.60), mature (0.50–0.60), Monadnock to mature (0.40–0.50), and Monadnock phase (old stage) (< 0.40) for the analysis of erosional stage and lithological setup of the watershed (Sharma et al. 2018). The hypsometric curve of the Barua watershed has been created by using the DEM and the tool of CalHypso, a GIS extension which is developed and applied by Pérez-Peña et al. 2009a. We used Quantum GIS (QGIS) environment instead of the ArcGIS for creating the curve. The hypsometric integral has been computed and mapped (Fig. 7b) using zonal statistics as table, a spatial analysis tool in the ArcGIS 10.2.2 software.

**Fig. 6** The bar diagrams of spatial distribution of morphometric parameters. **a** Drainage density. **b** Stream frequency. **c** Drainage texture. **d** Basin relief. **e** Dissection index. **f** Average slope. **g** Ruggedness number. **h** Hypsometric integral
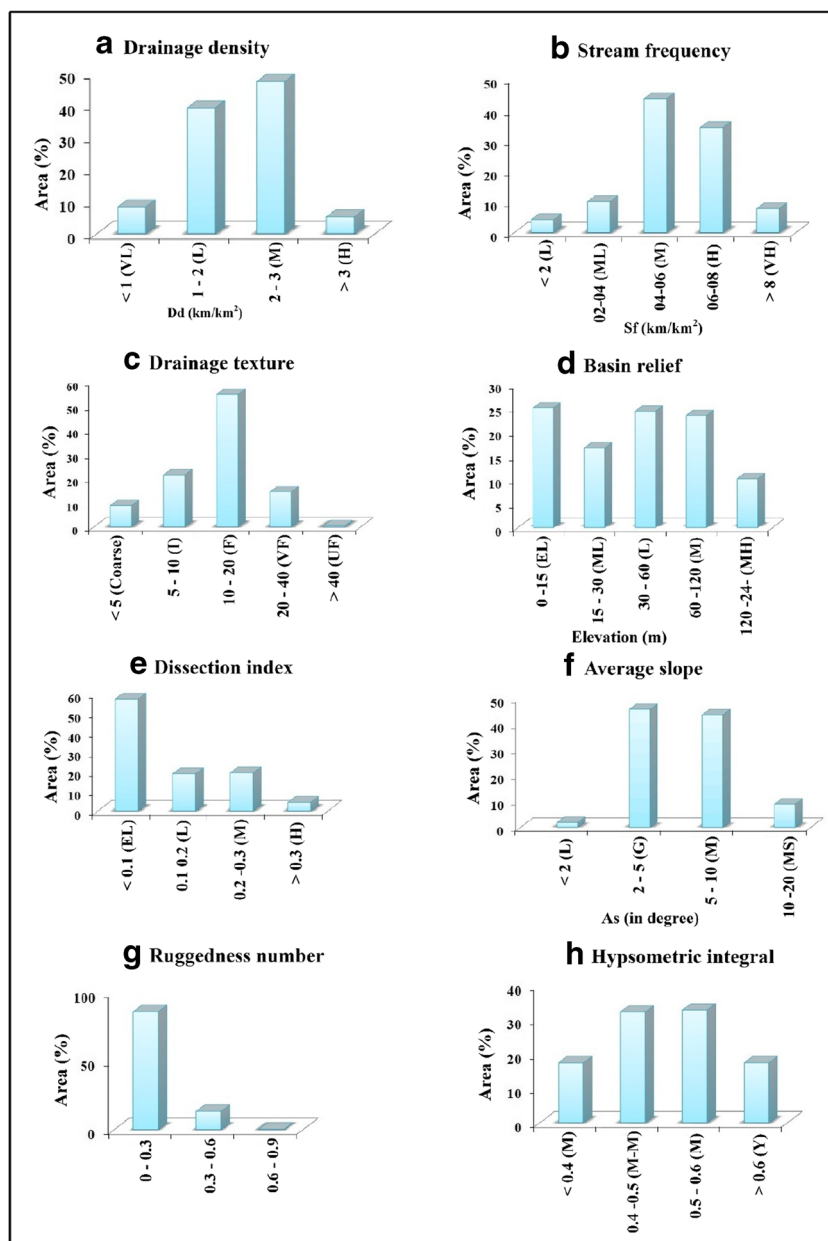


## Correlation matrix

The parameters of morphometry, how much influence and how much influenced by other parameters, and the correlation matrix give quantitative amount of interrelationship between each parameters. The correlation matrix has been generated with the help of attribute table (basin data matrix) of fishnet point of 1-km$^2$ grid, and the calculation was conducted using SPSS 20.0 software. The basic data matrix of the study region is composed of nine morphometric variables (calculated in 1-km$^2$ grid), namely, drainage density ($D_d$), stream frequency ($S_f$), drainage texture ($D_t$), basin relief ($R$), dissection index ($D_i$), average slope ($A_s$), ruggedness number ($R_n$), hypsometric integral (HI),

and length of overland flow ($L_o$), each of them having 217 grid data (Choudhary 2002).

## Result and discussion

### Drainage pattern

The drainage patterns of river basin are controlled by geological characteristics, climatic environment, and denudational history (Yadav et al. 2014). In the present study, area dendritic pattern is the most dominant type (Fig. 3).
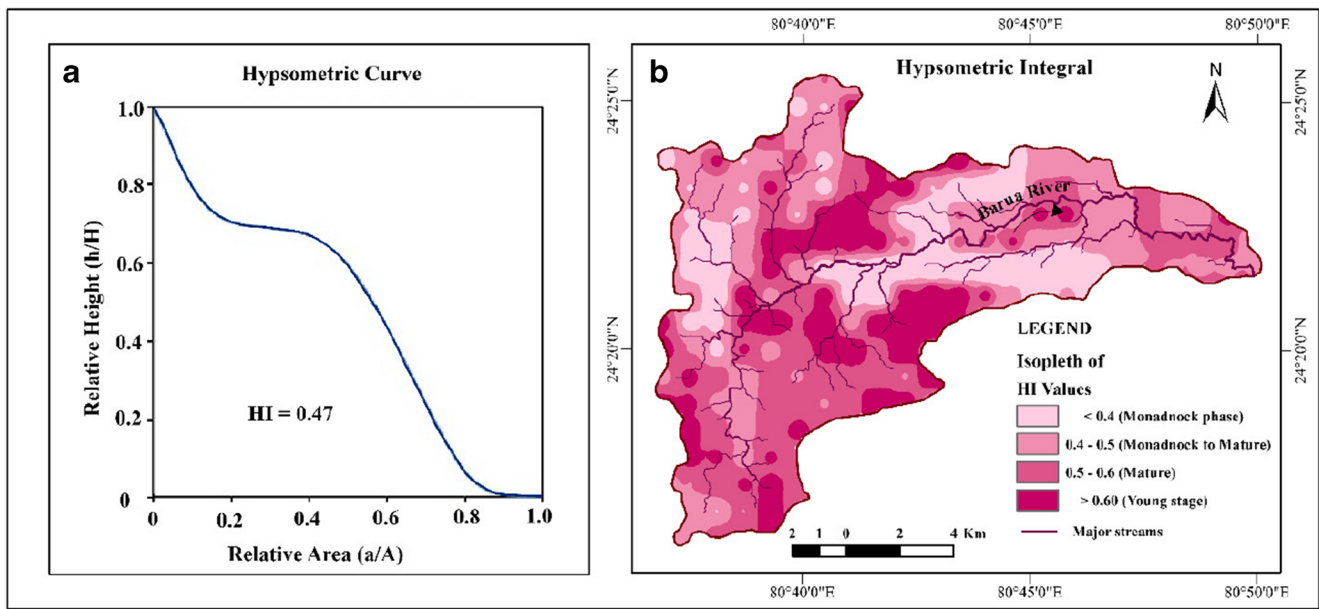
**Fig. 7** **a** The sigmoidal shape of the hypsometric curve with HI value. **b** The spatial distribution of HI values in the study region (here H is the difference of maximum elevation and minimum elevation, the total area

(A) is total surface area of the basin, and area (a) refers the surface area within the basin above a selected altitude (h)

## Bifurcation ratio ($R_b$) and stream length ratio ($R_l$)

The average bifurcation ratio ($R_{mb}$) of the Barua watershed is 5.16 (Table 1); this high value indicates moderate hilly region, moderate ground slope, high run-off, and moderate permeability of bed rocks and geological control in the basin. In this Barua watershed, fifth-order stream has the highest stream length ratio (9.20); the highest value indicates the area drained by the fifth-order stream is permeable enough; gradients are gentler than the area drained by lower order streams (Table 1).

## Drainage density ($D_d$)

Figure 6(a) shows that around 8% of the total area is concentrated in very low drainage density whereas around 40% of the area has low drainage density of 1–2 km/km$^2$. The moderate (2–3 km/km$^2$) drainage density category covers nearly 48% of the area whereas high (> 3) category comprises only around

5% of the total area. A general view of the Barua basin shows more than 50% of the area under moderate and high categories (2–3 and > 3 km/km$^2$) that is visible almost over the entire hilly terrain of the study region. A dense network of streams results in steep slopes and highly dissected and uneven terrain of the Bhander highlands which have forced the streams to be divided into numerous channels as they descend the highly ravenous slopes of these highlands resulting in high drainage density per unit area.

The low-to-very low values of drainage density (1–2 and < 1 km/km$^2$) are associated with subdued relief and very little dissection which prevents bifurcation and branching of streams and their tributaries. In the present study, the drainage density of whole basin is 2.87 per km (Table 2), which indicates moderate permeability of surface strata, moderate hilly region, and enough vegetation cover. Figure 4 b shows spatial distribution of drainage density in the study region.

**Table 1**   Bifurcation ratio and stream length ratio of Barua watershed

| Steam order ($\mu$) | Number of stream ($N_\mu$) | Total length of stream (km) | Bifurcation ratio ($R_b$) = $N_\mu/N_{(\mu+1)}$ | $\overline{L}_\mu = \sum L_\mu/N_\mu$ | Stream length ratio $R_l = \overline{L}_\mu/\overline{L}_{(\mu-1)}$ |
|---|---|---|---|---|---|
| 1 | 527 | 275.09 | 3.82 | 0.52 | - |
| 2 | 138 | 104.53 | 3.83 | 0.757 | 1.45 |
| 3 | 36 | 53.82 | 4 | 1.495 | 1.97 |
| 4 | 9 | 31.00 | 9 | 3.44 | 2.30 |
| 5 | 1 | 31.70 | | 31.70 | 9.20 |
| Total | 711 | 496.14 | Average = 5.16 | | |

## Stream frequency ($F_s$)

More than 77% of the area of the study region falls within the moderate to high (4–8 streams/km$^2$), nearly 15% of the area cover by moderate-to-low categories (< 4 streams/km$^2$) and about 8% areas have more than 8 streams in the 1 km$^2$ (Fig. 6b). The average value of stream frequency of the whole Barua watershed is 4.10 per km$^2$ (Table 2) which indicates moderate permeability of surface strata. The escarpment zones show high stream frequency, where first-order streams are very high perhaps due to steep slope and geological control (sandstone and shales) (Fig. 4c).

## Drainage texture ($D_t$)

In the region, nearly 10% of the area come under the coarse (< 5) drainage texture; around 75% of the area lies within the categories intermediate-to-fine texture whereas about 15% of the area covered by fine-to-ultrafine categories of $D_t$ (Fig. 6c). The average value of drainage texture of the whole Barua watershed is 11.78 (Table 2), relating with fine texture. The spatial distribution of the $D_t$ is well-represented in the drainage texture map of the study region (Fig. 4d).

The analysis of drainage variables (such as $D_d$, $F_s$, and $D_t$) helps to delineate deficit and surplus zones of groundwater that play very a effective role in drought and flood management in the study region. The isopleth maps of drainage variables show that water management projects (as check dams, irrigation networks etc.) can first be applied in western, north-western, and south-western parts of the study region then to the other region. Whereas, in the eastern part (around Unchahra block) of the watershed, the drainage variables indicate high permeability and better groundwater-potential zones; these areas are characterised by thick alluvial valley plains.

## The shape aspect of the watershed

The value of form factor ($F_f$) of the Barua watershed is 0.32 (Table 2) which indicates elongated shape of the watershed. The value of elongation ratio of the Barua watershed is 0.64 (Table 2) which indicates elongated with moderate relief and moderate slope of terrain. The value of $R_C$ parameter of the Barua watershed is 0.31 (Table 3), indicating basin is not in circular shape and shows low run-off, and indicating enough time for infiltration. The shape factor ($B_s$) of a basin helps to analyse shape irregularity of the drainage basin. The shape factor of the Barua watershed is 3.12 (Table 2).

## Constant of channel maintenance (C) and length of overland flow ($L_o$)

The $C$ value of the whole Barua watershed is 0.34, which means an average 0.34 km$^2$ of surface area is required to maintain 1-km length of stream channel. The $L_o$ value of the Barua watershed is 0.17 (Table 2).

## Relief aspect

The highest point of the Barua watershed is 558.16 m, and the lowest point is 251.72 m; hence, the basin relief ($R$) is 306.44 m which indicates moderate slope, low surface flow, and better infiltration in the basin. The relief ratio ($R_r$) of the Barua watershed is 0.007; the gradient ratio of the Barua watershed is 6.02 m/km. Its mean 6.02 m height decreases along the valley at per kilometre.

### Basin relief

The low basin relief (< 60 m) includes extremely low (< 15 m), low (15–30 m), and moderately low (30–60 m) having around 65% of the area of the basin (Fig. 6d). The eastern and

**Table 2**  Morphometric parameters of Barua watershed

| Morphometric parameters | Results | Morphometric parameters | Results |
|---|---|---|---|
| Area ($A$) km$^2$ | 169.67 | Shape factor ($B_S$) | 3.12 |
| Perimeter ($P$) km | 81.96 | Constant of channel maintenance ($C$) | 0.34 |
| Number of stream ($N_\mu$) | 711 | Length of overland flow ($L_o$) | 0.17 |
| Stream order ($\mu$) | 5 | Basin relief ($R$) (m) | 306.44 |
| Mean bifurcation ratio ($R_{bm}$) | 5.16 | Relief ratio ($R_r$) | 0.007 |
| Drainage density ($D_d$) km/km$^2$ | 2.87 | Gradient ratio ($G_r$) (m) | 6.02 |
| Mean stream length ($\overline{L}_\mu$) km | 0.69 | Ruggedness number ($R_n$) | 0.88 |
| Stream frequency ($F_s$) | 4.10 | Maximum elevation (m) | 558.16 |
| Drainage texture ($T$) | 11.78 | Minimum elevation (m) | 521.72 |
| Form Factor ($F_f$) | 0.32 | Mean elevation (m) | 395.79 |
| Elongation ratio ($R_e$) | 0.64 | Elevation (m) at source of river (a) | 521 |

**Table 3** The correlation matrix of nine morphometric (geomorphic) parameters of Barua basin

| | $D_d$ | $S_f$ | $D_t$ | $R$ | $D_i$ | $A_s$ | $R_n$ | HI | $L_o$ |
|---|---|---|---|---|---|---|---|---|---|
| $D_d$ | *1* | | | | | | | | |
| $S_f$ | *0.83* | *1* | | | | | | | |
| $D_t$ | *0.90* | *0.91* | *1* | | | | | | |
| $R$ | 0.09 | 0.10 | 0.08 | *1* | | | | | |
| $D_i$ | 0.14 | 0.13 | 0.13 | *0.99* | *1* | | | | |
| $A_s$ | 0.15 | 0.13 | 0.10 | 0.62 | 0.63 | *1* | | | |
| $R_n$ | 0.03 | 0.04 | 0.01 | 0.65 | 0.67 | *0.77* | *1* | | |
| HI | − 0.19 | − 0.13 | − 0.19 | − 0.03 | − 0.08 | 0.13 | − 0.04 | *1* | |
| $L_o$ | − 0.15 | − 0.16 | − 0.11 | − 0.14 | − 0.15 | − 0.17 | − 0.16 | 0.02 | *1* |

$D_d$ = drainage density, $S_f$ = drainage frequency, $D_t$ = drainage texture, $R$ = basin relief, $D_i$ = dissection index, $A_s$ = average slope, $R_n$ = ruggedness number, $HI$ = hypsometric integral, $L_o$ = length of overland flow. The italic values show the significant strong positive correlation

small pockets of the southern portion of the study region comprise areas of extremely low (< 15 m) basin relief; this region belong to alluvial tract of the Barua and its tributaries (Fig. 5a). The flat top of the plateau region have also low-to-moderately low basin relief. The bar diagram (Fig. 6d) of the basin relief reveals that moderately-to-moderately high basin relief covers nearly 34% of the area of the basin. It is continuously extended along the escarpment of the Bhander Plateau.

### Dissection index

The low-to-extremely low (< 0.2) categories of the dissection index cover more than 75% of the area of the entire basin (Fig. 6e); the spatial coverage of these categories of the dissection index is confined in the eastern (alluvial plain) and almost flat uplands of south-western and north-western parts of the study region (Fig. 5b). In this region, angles of average slope are very gentle (< 5°). Moderate (0.2–0.3)-to-high (> 0.3) categories cover about 25% of the area of the basin; the spatial coverage of these categories is found along and surrounding the steep slope of escarpment (Fig. 5b).

### Average slope

The spatial coverage as shown in Fig. 5c shows only about 2% of the total area of the study region lying within the category of level slope (< 2°). The gentle slope (2–5°) category shows covering nearly 46% of the total area of the study region (Fig. 6f). Maximum area of this slope group is mostly confined in three sections of the study region. The first one is Barua alluvial plain. Another two sections are associated with southern and northern parts, almost flat upland of the region. Moderate slope (5–10°) region has the second highest spatial coverage

(about 44% of the area) of the Barua watershed (Fig. 6f). This slope category is distributed surrounding the region of the escarpment. Moderately steep slope (10–20°) covers only about 9% of the total area; moderate steep slope is found along steep escarpment of the Bhander Plateau (Fig. 6f).

### Ruggedness number ($R_n$)

The Barua watershed with a moderately high $R_n$ value of 0.88 (Table 2) indicates moderate basin relief. The isopleth map of the values of ruggedness number shows spatial distribution of the characteristics of ruggedness in the study region (Fig. 5d). The bar diagram of the ruggedness number represents spatial coverage in percent (Fig. 6g).

### The hypsometric curve and hypsometric integral

The shape of hypsometric curve of Barua watershed (Fig. 7a) is sigmoid, indicating mature equilibrium stage of development; the value of hypsometric integral (0.47) also shows association with mature stage of the watershed (Fig. 7b). Figure 6 h shows only about 18% of the area indicating young stage (> 0.60) of the watershed; nearly 33% of the area reflect mature (equilibrium) stage (0.5–0.6). The spatial coverage of mature-to-Monadnock phase is around 32% of the total area. More than 17% of the area of the entire basin is showing association with the Monadnock phase (< 0.4) of geomorphic development. The isopleth map of HI values shows uplands (the Bhander Plateau and Parsamania hills) of the region reflecting high values (> 0.60) of hypsometric integral; the areas started from the foothill (scarpment) of the Bhander Plateau indicating the Monadnock phase of the basin with the value below 0.40 (Fig. 7b).

### Correlation matrix

The values of correlation coefficient among the nine significant morphometric parameters are shown in the Table 3. The correlation matrix of the Barua watershed reveals that the parameters, drainage density ($D_d$), stream frequency ($S_f$), and drainage texture ($D_t$), have strong positive correlations (correlation coefficients more than 0.83) between each other; the basin relief ($R$) and dissection index ($D_i$) also have very strong positive correlation (with correlation coefficients 0.99). Some more moderately positive correlated parameters (correlation coefficient more than 0.6) are the basin relief ($R$); average slope ($A_s$) and ruggedness number ($R_n$); and dissection index ($D_i$) with average slope ($A_s$) and $R_n$. The hypsometric integral (HI) and the length of overland flow ($L_o$) are weakly correlated with other parameters; they are reflecting like independent variables (Table 3).

# Conclusion

The quantitative study using geospatial techniques is an effective tool in the analysis of spatial regionalisation to determine spatial variation and correlation of morphometric characteristics of a watershed. These morphometric parameters facilitate to estimate interrelationship between lithological characteristics and hydrological activities. The isopleth maps of spatial variability of morphometric parameters allow the comparisons among drainage aspects and altimetric aspects, while bar diagram reveals percentage amount of spatial coverage of morphometric attributes. The region having high drainage density, stream frequency, and drainage texture is associated with moderately hilly region, moderate permeability of rock strata, high run-off, and lesser possibility of groundwater infiltration. These regions are indicating towards higher possibility of erosional activities and need plantation and more vegetation cover. The low basin relief (< 60 m) covers about 65% of the area of the total study region; the remaining one-third of the area has moderately-to-moderately high basin relief. In the region, more than 85% of the area have gentle-to-moderate average slope (2–10°) which is due to the flat top of the Bhander upland; steep slope was found only along the escarpment of the Bhander Plateau. The hypsometric curve and the value (0.47) of hypsometric integral indicate the mature (equilibrium) stage of geomorphic development of the watershed. After calculating the morphometric parameters and extensive field survey, we have estimated that the Barua basin has elongated shape, moderate-to-steep slope, and moderate infiltration capacity. The morphometric study of the region proposed that western, north-western, and south-western parts of the study region need preference to implicate hydrological planning projects (as check dams, irrigation networks etc.) and prevention measures of soil erosion first then other region. The correlation matrix enables to determine correlation between and among the morphometric parameters of the study region. The correlation matrix clearly shows that in the study region where stream frequency is high, drainage density and drainage texture are also high. This study helps in planning of groundwater management and prevention of soil erosion in the basin and such type of other drainage basin.

## Compliance with ethical standards

**Conflict of interest**   The authors declare that they have no confilct of interest.

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