

# Morphometric analysis of Usri River basin, Chhotanagpur Plateau, India, using remote sensing and GIS

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**Abstract** A geomorphic unit Usri drainage basin (latitude: 24° 04'00" N to 24° 34'00" N and longitude 86°05'00"E to 86°25'00"E) lies in north-eastern parts of Chhotanagpur Plateau, India, has been selected for morphometric analysis. Digital elevation model (DEM) has been generated by Cartosat stereo pair data at 10-m resolution. The morphometric parameters considered for the analysis includes the linear, areal, and relief aspects of the basin. Morphometric analysis of the river network and the basin revealed that the Usri Basin has sixth-order river network with a dendritic drainage pattern. The dendritic drainage pattern indicates that the basin has homogeneous lithology, gentle regional slope, and lack of structural control. The bifurcation ratio between different successive orders varies but the mean ratio is low that suggests the higher permeability and lesser structural control. The low drainage density, poor stream frequency, and moderately coarse drainage texture values of the basin indicate that the terrain has gentle slope, is made up of loose material, and hence has good permeability of sub-surface material and significant recharge of ground water. The shape parameters indicate that the basin is elongated in shape with low relief, high infiltration capacity, and less water flow for shorter duration in basin. The 50 % of the basin has altitude below 300 m and gently sloping towards the southeast direction. All the morphometric parameters and existing erosional landforms indicated mature to early old stage topography.

**Keywords** Morphometry · Cartosat-1 stereopair · DEM · Usri River · Gondwana

## Introduction

The rapidly emerging spatial information technology (SIT), viz., remote sensing, GIS, and GPS, has effective tools to overcome most of the problems of land and water resource planning and management on the account of usage of conventional methods of data process (Rao et al. 2010). The uses of remote sensing data and GIS techniques in morphometric analysis of drainage basins have emerged as powerful tools in recent years. Morphometry can be defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms (Bates and Jackson 1987). A systematic morphometric analysis helps to understand linear, areal, and relief aspects of the drainage basin. When morphometric analysis is incorporated with GIS technologies, it is termed as digital geomorphometry. Geo-morphometry is the science of the quantification and analysis of the land surface (Pike and Wilson 1971). The morphometric analyses of different basins have been done by various scientists using conventional methods (Horton 1945; Smith 1950; Strahler 1957) and earth observation data and GIS methods (Nongkynrih and Husain 2011; Waikar and Nilawar 2014; Withanage et al. 2014 and others).

The Usri, a tributary of the Barakar River, is an ephemeral river of about 90 km in length in the state of Jharkhand, India. It originates in several small streamlets and headward eroded gullies, in and around the villages of Charghara and Kharagdiha, Jharkhand (Purkait 1983). Purkait (2000 and 2002) studied the morphology, growth pattern, and grain-size distribution of some Usri River point-bars. During the

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winter (October to March) and summer months (April to May) the river dries up almost completely, exposing the channel and point-bars. Usri River basin (latitude 24°04'00"N to 24°34'00"N and longitude 86°05'00"E to 86°25'00"E) located in the north-eastern part of Chhotanagpur Plateau (Fig. 1). The major objective of this study, using advanced remote sensing and GIS technology, is to compute morphometric characteristics of the Usri Basin. Such analysis helps in understanding the hydrological, geological, and topographical characteristics of the Usri drainage basin.

The present study area is a part of Chhotanagpur Gneissic Complex (CGC) of Satpura Mobile Belt (or Central Indian Tectonic Zone). The dominant rock type in the area is granite gneiss of Precambrian age with several small-scale exposures of quartz vein, pegmatite vein, dolerite dikes, meta-dolerite, etc. However, the Usri River is mainly flowing through alluvial sediments (Purkait 1983). The Giridih Gondwana is a small WNW-ESE trending basin occurring in central part of the Usri Basin and comprises Permo-Carboniferous sediments belonging to the Talchir Group, the Karharbari and Barakar members (Sengupta et al. 1988). The basin has a prominent inlier made up of Precambrian rocks occurring in the north-western parts of the basin. The inlier is surrounded by normal faults on all sides. The Talchir sediments overlying on Precambrian gneissic rocks and are overlain by Karharbari sediments. The northern boundary of Talchir group against Precambrian rocks is marked by prominent faulting while

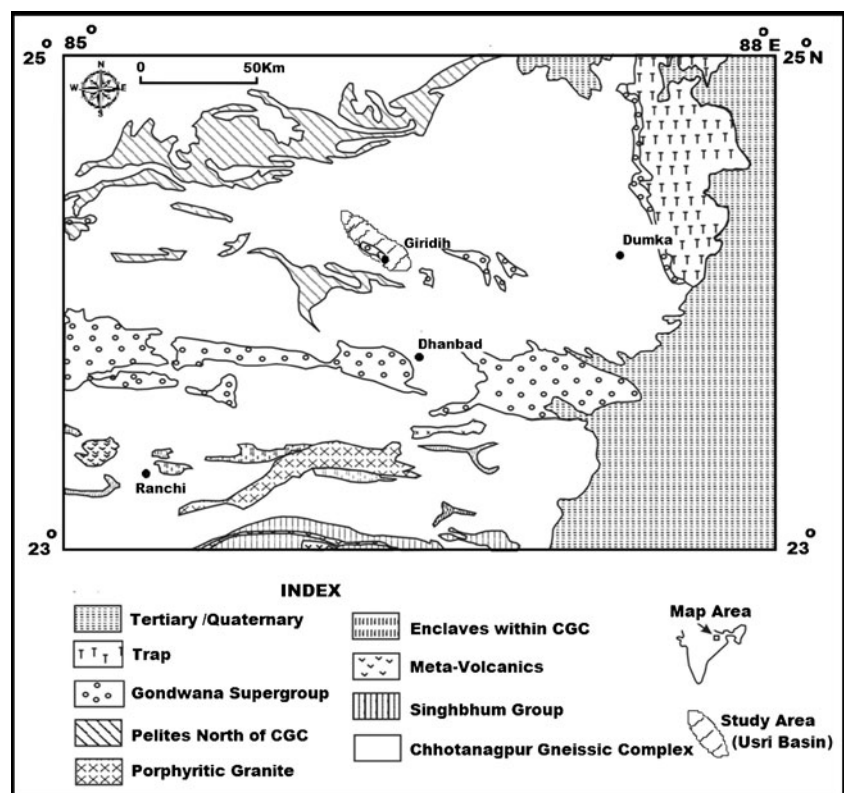
the eastern boundary is an erosional unconformity (Sen 1991). The Talchir group sediments which are mainly exposed in and around the Suknanala comprises basal boulder conglomerate facies succeeded by khaki-green fissile shale facies and an upper sandstone facies (Das and Tripathi 2009). The boulder conglomerate (diamictite) characterized by massive, poorly sorted with clayey and sandy matrix. The conglomerate passes upward in to a bluish-fine grained laminated calcareous siltstone.

The area experiences tropical climate with the major rain-falls during southwest monsoon from June to September. The temperature reaches its high in April and May, low in December and January.

## Methodology

Cartosat-1 is the first operational remote sensing satellite capable of providing orbit stereo images with 2.5-m nadir resolution and 27-km swath. The morphometric variables have been generated through digital elevation model (DEM) using Cartosat-I stereo pair data. DEM is prepared in Leica Photogrammetry Suit inbuilt in ERDAS Imagine 9.3. The LPS which is a composite suite of photogrammetric production tools for triangulation, generating terrain models, producing ortho-mosaics and extracting 3D features, is used for the identification of horizontal and vertical ground control points

**Fig. 1** Generalized geological map of part of Chhotanagpur Plateau showing Usri Basin (redrawn after Mazumdar 1988)



(GCP) and tie points (Bothale et al. 2013). The final product (DEM) is accepted if the root mean square error (RMSE) value is less than 0.5 (Fig. 2). The final DEM is generated in 10-m resolution. The DEM is imported in ARC GIS 10.0 for basin delineation and other morphometric variable measurement and calculation. Thus, both the softwares ARC GIS 10.0 and ERDAS Imagine 9.3 are utilized in present work. The morphometric parameters such as linear, aerial and relief aspects of the Usri River basin were computed. Streams are extracted from DEM data through Arc GIS software. Arc GIS inbuilt hydrology tool in its tool box, fill map, flow direction map, flow accumulation map, con, stream order, and stream to feature is prepared from DEM with the help of hydrology tool. All these are generated in sequence where the previous one becomes base data to generate next map. Stream link is raster data; it is changed in vector form by extracting stream feature.

Geometrically the linear aspect of a drainage basin is concerned with X axis calculations of stream properties. It deals river as a linear feature and count numbers and length of drainages. It is related about arrangement of the drainage network which consists of a major river and its tributaries from source to mouth. The morphometric investigation of

the linear parameters of the basin includes stream order, bifurcation ratio, stream number, stream length, stream length ratio, sinuosity index, and length of overland flow. The streams of the Usri Basin have been ranked according to Strahlers (1964) stream ordering system. Stream length measured from the mouth of a stream to drainage divide with the help of GIS software. This has been computed on the basis of the law proposed by Horton (1945) for all the suborders of the study area. The other linear morphometric parameters are computed using standard methods and formulae (Table 1).

The areal aspect of a drainage basin is concerned with X and Y axes calculations of drainage basin. The areal parameters, basin length, basin perimeter, basin area, form factor, circulatory ratio, elongation ratio, stream frequency, drainage density, drainage texture, and infiltration number, are computed using stand techniques/formulae (Table 1).

The relief morphometry calculates basin in all three dimensions, i.e., it analyzes relief in X, Y, and Z axes. Relief morphometry deals with basin heights, slope, slope aspect, area height ratio, altimetric analysis, relief ratio, dissection index, and hypsometric analysis. The maximum relief is the highest elevation point of the basin and the minimum is of lowest point. The relative relief, an important aspect of terrain analysis, is calculated by the formula suggested by Melton (1957). Table 1 shows the various formulae/techniques adopted for computation of relief aspects of the Usri Basin.

### Results

The results of various morphometric parameters computed are given in Table 2. The Usri River is classified as sixth-order drainage basin (Fig. 3). The bifurcation ratio value of the area varies between 2 and 5.64 with a mean value of the basin of 3.81. The Usri Basin has altogether 715 streams linked with 6 orders of streams. The total number of stream is the maximum in the first order (561 nos.) and gradually decreases with the increase of stream order. The total stream length of the Usri Basin is 971.1 km. The first-order stream shows maximum length (470.82 km) and the minimum length is with the sixth-order stream (40.8 km). The mean stream length of study area is 0.84 for the first order, 2.21 for the second order, 5.61 for the third order, 7.36 for the fourth order, 25.35 for the fifth order, and 40.80 for the sixth order. The cumulative stream length for the basin is 82.2 km. The stream length ratio for the Usri Basin varies between (0.3 and 0.8) streams of different orders. The computed Sinuosity index and length of overland flow values of the Usri River basin is 1.49 and 0.54 km, respectively.

The computed values of basin length, perimeter, and area of Usri River basin are 57.19 km, 231.3 km, and 816.56 km<sup>2</sup>, respectively. Form factor, elongation ratio, and circulatory ratio values of the Usri Basin are calculated as 0.25, 0.32, and

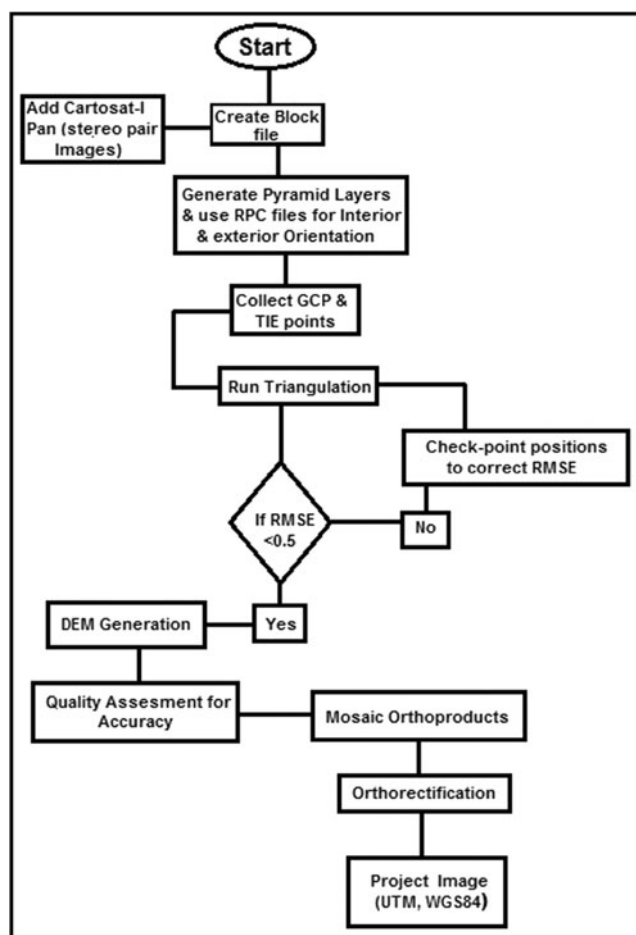


Fig. 2 Flow diagram for DEM generation

**Table 1** Formulae adopted for computation of morphometric parameters

	Morphometric parameters	Formula/definition	References
Linear	Stream order	Hierarchical rank	Strahler (1964)
	Bifurcation ratio	$R_b = N_u / (N_u + 1)$ where $N_u$ = total no. of stream segments of the order $u$ $N_u + 1$ = number of segments of the next higher order	Schumm (1956)
	Mean bifurcation ratio ( $R_{bm}$ )	$R_{bm}$ = average of bifurcation ratios of all orders	Strahler (1964)
	Stream number ( $N_u$ )	$N_u = R_b^{(k-u)}$ where $R_b$ = constant bifurcation ratio; $k$ = highest order of the basin; $u$ = basin order	Horton (1945)
	Stream length ( $L_u$ )	Length of the stream (km)	Horton (1945)
	Mean stream length (Lsm)	$L_{sm} = L_u / N_u$ where $L_u$ = total stream length of order $u$ (km) $N_u$ = total number of stream segments of order $u$	Strahler (1964)
	Stream length ratio ( $R_L$ )	$R_L = L_u / (L_{u-1})$ where $L_u$ = mean stream length of order $u$ $L_{u-1}$ = mean stream length of its next lower order	Horton (1945)
	Sinuosity index ( $C_i$ )	$C_i = C_L / A_L$ where $C_L$ = stream length and $E_L$ = air length	Muller (1968)
	Length of overland flow ( $L_g$ )	$L_g = 1 / (D_d \times 2)$ (km) where $L_g$ = length of overland flow and $D_d$ = drainage density	Horton (1945)
	Areal	Basin length	Channel length from one end to another wind of the basin
Basin perimeter		Total length of outer boundary of drainage basin (km)	Arc measurement tool
Basin area		Area of the basin	Arc measurement tool
Form factor ( $R_f$ )		$R_f = A / L_b^2$ where $A$ = area of the basin (km <sup>2</sup> ) $L_b^2$ = square of basin length	Horton (1932)
Stream frequency ( $F_s$ )		$F_s = N_u / A$ where $N_u$ = total no. of streams of all orders $A$ = area of the basin (km <sup>2</sup> )	Horton (1932)
Drainage density ( $D_d$ )		$D_d = L / A$ where $L$ = total length of stream segments of a basin $A$ = area of the basin	Horton (1932)
Drainage texture ( $D_t$ )		$D_t = N_u / P$ where $N_u$ = total no. of streams of all orders $P$ = perimeter (km)	Horton (1945)
Circularity ratio ( $R_c$ )		$R_c = 4\pi A / P^2$ where $A$ = basin area (km <sup>2</sup> ), $P$ = perimeter of the basin (km)	Miller (1953)
Elongation ratio ( $R_e$ )		$R_e = 2\sqrt{(A/\pi)} / L_b$ where $A$ = area of the basin (km <sup>2</sup> ) and $L_b$ = basin length (km)	Schumm (1956)
Infiltration number ( $I_f$ ):		$I_f = D_d \times F_s$ where $D_d$ = drainage density and $F_s$ = stream frequency	Zavoianca(1985)
Relief	Maximum relief	Highest elevation point of basin	–
	Minimum relief	Lowest elevation point of basin	–
	Mean relief	simple statistics	–
	Relative relief	$R = H / P$ where $H$ = maximum basin relief $P$ = perimeter of the basin	Melton (1957)
	Relief ratio ( $R_h$ )	$R_h = H / L_b$ where $H$ = maximum basin relief $L_b$ = maximum basin length	Schumm (1956)
	Hypsometric integral	(Mean elevation – minimum elevation) / (maximum elevation – minimum elevation)	Pike and Wilson (1971)
	Dissection index ( $D_i$ )	$D_i = R_R / A_R$ where $R_R$ = relative relief and $A_R$ = absolute relief	Dov Nir (1957)
	Gradient ratio ( $R_g$ )	$R_g = (E_s - E_m) / L_b$ where $E_s$ = elevation at source, $E_m$ = elevation at mouth, and $L_b$ = length of main stream	Sreedevi et al. 2005

**Table 2** Linear, areal, and relief aspects of the Usri River basin

Linear Order	Stream length (km)	Mean stream length (km)	Cumulative stream length (km)	Stream length ratio	Stream number	Bifurcation ratio	Sinuosity index	Length of overland flow (km)	
1	470.82	0.84	0.84		561	4.52			
2	273.95	2.21	3.05	0.38	124	5.64			
3	123.43	5.61	8.66	0.40	22	4.40			
4	36.79	7.36	16.02	0.76	5	2.50	1.49	0.54	
5	25.35	25.35	41.37	0.29	2	2.00			
6	40.80	40.80	82.16	0.62	1				
Total	971.10				715	Mean bifurcation ratio 3.81			
Areal	Basin length (km)	Perimeter (km)	Area (km <sup>2</sup> )	Basin area ratio	Drainage density	Stream frequency	Drainage texture	Form factor	Elongation ratio
	57.19	231.3	816.56	0.0010	1.09	2.11	0.52	0.25	0.32
Relief	Maximum relief (m)	Minimum relief (m)	Mean relief (m)	HI	Infiltration number	Relative relief (m)	Dissection index	Dissection index	Gradient ratio
	360	144	275	0.20	2.30	156	0.33	0.33	0.002

0.19, respectively. The drainage density and stream frequency of the basin is 1.09 km/km<sup>2</sup> and 2.11/km<sup>2</sup>, respectively. The computed drainage texture value of the Usri Basin is 0.52. The infiltration number, a parameter of infiltration capacity of the basin, is 2.30.

The maximum and minimum relief of the whole basin is 360 and 144 m, respectively (mean relief 275 m). The relative relief value of the basin is computed as 156 m. The relief ratio of the basin is calculated as 0.01. The dissection index and hypsometric integral (HI) values for the basin are computed as 0.33 and 0.20, respectively.

### Discussion

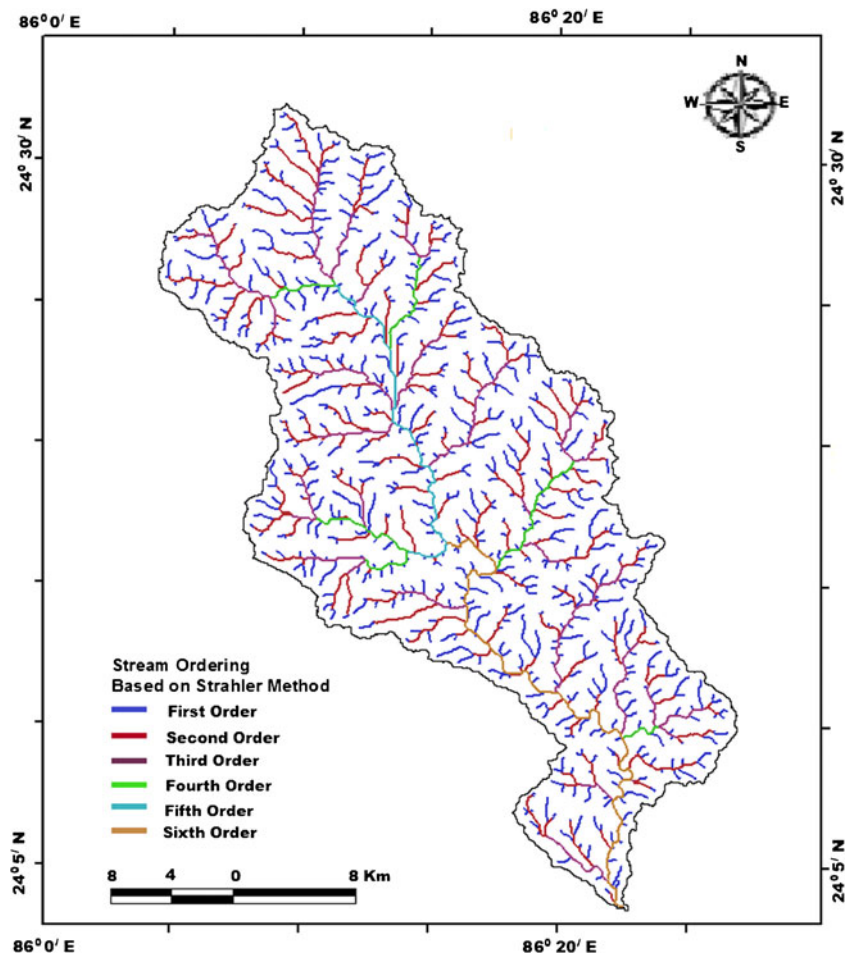
The development of drainage network depends on geology, precipitation apart from exogenic and endogenic forces of the area (Sreedevi et al. 2009). The results obtained on the basis of stream and drainage basin analysis may provide information for terrain analysis. Based on the drainage orders, the Usri Basin has been classified as the sixth-order basin to analyze linear, relief, and aerial morphometric parameters.

### Linear morphometric parameters

Linear aspects of the basin are closely linked with the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system. Stream order is the measure of position of a stream in the hierarchy of tributaries (Leopold et al. 1964). It analyzes the branching pattern of a channel. The unequal distribution of the first-order segment of the basin depends largely on the size and shape of a drainage basin and partly on relief, geologic structure, climate condition, and vegetation cover. Strahler’s (1964) technique adopted in the present work shows that Usri River is of sixth-order drainage basin (Fig. 3). The higher stream order is associated with greater discharge (Hajam et al. 2013). The trunk stream, Usri through which all discharge of water and sediment passes, is a stream segment of highest order. The size of the basin and hierarchy of the basin is controlled by the order. The usefulness of the stream order depends on the premise that on an average, if a large sample is treated, order is directly proportional to size of the contributing watershed, channel dimensions, and stream discharge at the place in the system (Bindu et al. 2012). Ultimately, water volume capacity of the drainage basin is controlled by the river basin order. Due to its not much higher order, the Usri River carries water for the distance of around 90 km.

The term “bifurcation ratio” is defined as the ratio of the number of stream segments of any given order to the number in the next higher order. The bifurcation data ranges between 2 and 5.64 with the mean 3.80 indicating that the basin falls under normal basin category (Bindu et al. 2012). The high

**Fig. 3** Strahler's stream orders of Usri River basin



bifurcation ratio is found in the first, second, and third orders, which indicates that streams up to the third order are surging through highly dissected and steep gradient mountainous terrain, which facilitates high overland flow and less water recharge into the sub-surface. Hence, groundwater potential is low in the zones of the first-, second-, and third-order streams of Usri River basin. Coats (1958) indicated that mean bifurcation ratio mainly lie between 3.0 and 5.0 without differential geological control. Mean bifurcation ratio value found in this basin is common in areas where geological structure do not exercise a dominant influence on drainage pattern (Chow 1964; Sreedevi et al. 2009). Hajam et al. (2013) also indicated that the higher mean bifurcation ratio value suggests less permeable rocks with high slope while lower bifurcation ratio value suggests higher permeable rocks with less structural control.

Stream number is the count of stream channels in a given order (Horton 1945). Usri has altogether 715 streams linked with 6 orders of streams. The total number of streams gradually decreases with the increase of stream order. The data conforms to Horton's (1945) law of stream numbers which states that "The number of stream segments of successively lower order in a given basin tends to form a geometric series

beginning with the single segments of the highest order and increasing according to constant bifurcation ratio". The lower total stream number indicates relatively higher permeability and infiltration. Usri River basin shows a negative correlation between stream orders and stream numbers (co-efficient of correlation 0.99 and percentage of variance 97.6; Fig. 4a), which suggests that the several streams usually decreases in geometric progression as the stream order increases. The variations in lithological characters in the basin are possibly responsible for such inequalities in stream frequencies of each order.

The stream length measured from mouth of a stream to drainage divide. The total length of stream segments is maximum in first-order streams and decreases as the stream order increases except the sixth-order stream whose length is more than the total length of fifth-order stream segments (Table 2). This occurs due to flowing of streams from high altitude, changes in rock type, moderately steep slopes, and probable uplift across the basin (Vittal et al. 2004). It is also observed that the stream segments up to third-order traverse parts of the high to moderate altitudinal zones characterized by steep to moderate slope, whereas fourth-, fifth-, and sixth-order stream segments occur in comparatively in plain lands. Stream length

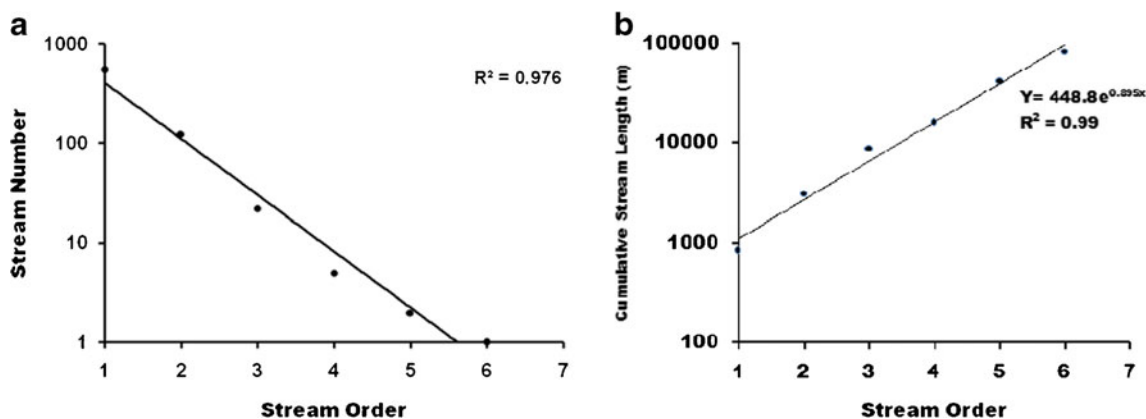


Fig. 4 The relationships between a stream number and stream order, b cumulative stream length and stream order

in pervious terrain is shorter than impervious terrain. The stream of relatively smaller length is characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradient. The source area of Usri consists of badland topography with mesas and buttes of highly erodible pebbly and sandy soils (Purkait 2002). The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler 1964). The mean stream length of study area increases with increase of the order. The cumulative stream length data of the Usri River show positive correlation with the stream order (co-efficient of correlation 0.99 and percentage of variance 98.6; Fig. 4b), which conforms to Horton’s law of stream length which states that “the cumulative stream lengths of stream segments of successive higher orders increase in geometrical progression starting with the mean length of the first order segments with constant ratio”.

The stream length ratio is a parameter which has direct relationship with surface flow, discharge, and erosion stage of the basin. It varies between 0.3 and 0.8 indicating presence of moderately resistant rocks, low slope, and topography in the terrain (Bindu et al. 2012). The stream length ratio (RL) between the streams of different orders of the Usri River basin is variable (Table 2). This variation in stream length ratio from one order to another indicates that the Usri River basin is transient through late youth to early mature stage of development of fluvial geomorphic cycle (Singh and Singh 1997; Singh et al. 2003).

Rivers do not follow straight path due to several topographic, structural, and slope changes. Sinuosity is the measurement of deviation of observed stream path from its actual expected path (Schumm 1956 and 1963). Sinuosity is highly significant in studying the effect of terrain characteristics on the river course. It also gives us information about basin stage and landform development. Sinuosity index of the Usri River basin is 1.49 which indicates that the stream has sinuous course. The index is also very useful for the interpretation of evolution of landscapes and beneficial to geomorphologists and

hydrogeologists. The index value of the study area indicates mature stage of Usri Basin (Singh 1998).

The overland flow refers to that flow of precipitated water, which moves over the land surface leading to stream channels. The length of overland flow considered as a dominant hydrologic and morphometric factor (Horton 1932). It is the mean horizontal length of flow path from the divide to the stream in a first-order basin. The length of overland flow is a measure of stream spacing and degree of dissection and is approximately one half of the reciprocal of the drainage density (Chorley 1969). Overland flow is significantly affected by infiltration of soil that varies in time and space (Schmid 1997). The length of overland flow for Usri Basin is 0.54 km (Table 2), which indicates gentler slopes in the valley and low surface runoff, and hence, the basin is in mature stage (Hajam et al. 2013).

**Areal morphometric parameters**

The areal aspects of a drainage basin reveal regional features like lithology, geological structure, climatic conditions, and denudation history of the basin. These aspects control the spatial arrangement, geometrical shape and form of drainage systems, river discharge, and runoff characteristics (Singh 1998).

Basin length, basin perimeter, and basin area are important areal morphometric variables which are signature of shape, size, and genetic aspect of a drainage basin. Basin area is a good indicator of lithology, rock strata, dip angle, rainfall, and vegetation. The dip angle of bed rocks is inversely proportional to basin area. The huge basin area means that the master stream is longer and the slope of the terrain is low and vice versa. The values of length, perimeter, and area of Usri Basin indicate that slope of the terrain is moderate to low and basin is highly weathered. This also shows that basin is in late mature stage and receives sufficient rainfall.

Form factor, elongation ratio, and circulatory ratio are calculated for basin shape. The basin shape is helpful tool which tells about basin stage. An ideal basin shape is a pear shape.

There are three main categories of basin shape: circular, indented, and elongated. Zero value confirms highly elongated shape and one indicates circular shape of the basin. The form factor value of the basin is low, which indicates elongated shape. Horton (1945) correlated form factor to predict flow intensity of the basin of a defined area. The low value of form factor means flatter peak flow for longer duration with less side flow for shorter duration and main flow for longer duration in the basin (Reddy et al. 2002; Kumar 2013). Flood flows of such elongated basins are easier to manage than of the circular basin. The elongation ratio, another parameter of basin shape, ranges between 0 and 1.0 over a wide climatic conditions and geologic types. Values near to 0 indicate highly elongated and near to unity indicates circular shape. The elongation value of the Usri Basin is also low and conforming to form factor, indicating elongated basin. The low value also indicates that the basin has low relief with moderate to high infiltration capacity and low runoff. The basin is also susceptible to moderate erosion and sediment load (Sreedevi et al. 2009). The basin circulatory ratio is controlled by lithology, slope, relief, basin area, elongation ratio, stream discharge, and ruggedness number. The basin circulatory ratio is correlated with basin area and ruggedness number in inverse proportion. If lithology is same over terrain, there is not much variation in basin shape. The low circulatory ratio value of the Usri Basin again conforming to low form factor and elongation ratio values of the basin indicates elongated basin with moderate to low relief, high infiltration capacity, and sub-dendritic stage.

Drainage density, stream frequency, drainage texture, and infiltration rate are the most important morphometric parameters in terrain analysis much better to say in hydrological studies. The drainage density is an important indicator of the linear scale of landform element in stream eroded topography and defined as the total length of stream of all orders to drainage area. It may be an expression of the closeness of spacing of channels (Horton 1932). The significance of drainage density is recognized as a factor determining the time travel by water (Langbein 1947; Schumm 1956). There is a positive correlation between drainage density and rainfall parameters (Tucker and Bras 1998). Melton (1957), Strahler (1964), and others recognized the effect of geological formations and indicated that in general, high drainage density is favored in the regions of highly dissected drainage basin with relatively rapid hydrological response to rainfall events, while low drainage density is associated with poorly drained basin with slow hydrological response, rainfall resistant or highly permeable sub soil materials, and where relief is low. Drainage density also varies with climatic conditions, vegetation, soil and rock properties, relief, and landscape evolution (Moglen et al. 1998; Ozdemir and Bird 2009). Generally, drainage density increases with decreasing infiltration capacity of the underlying rocks or decreasing transmissivity of the soil (Montgomery

and Dietrich 1992). The drainage density of the Usri drainage basin is very low (Table 2, Fig. 5a). The low drainage density of the basin indicates highly permeable sub-soil materials with dense vegetation and low relief. The above observation is verified with the field visit in the locality, where Tundi-Giridih road is highly vegetated and Tundi, Jharkhand, has a dense forest. The type of rock also affects the drainage density. Generally, lower values of drainage density tend to occur on granite, gneiss, and schist regions (Rao et al. 2010).

The stream frequency or drainage frequency is a measure of total no of streams per unit area (Horton 1945). The stream frequency depends on the lithology of the basin and it reflects the texture of the drainage network. The low value of stream frequency is caused by highly permeable lithology. The stream frequency of Usri Basin is low (Table 2 and Fig. 5b) which indicates that the basin has good vegetation, medium to low relief, high infiltration capacity, and low run-off. The lower values of drainage density and stream frequency of the basin suggest the runoff is slower and flooding is less likely to occur.

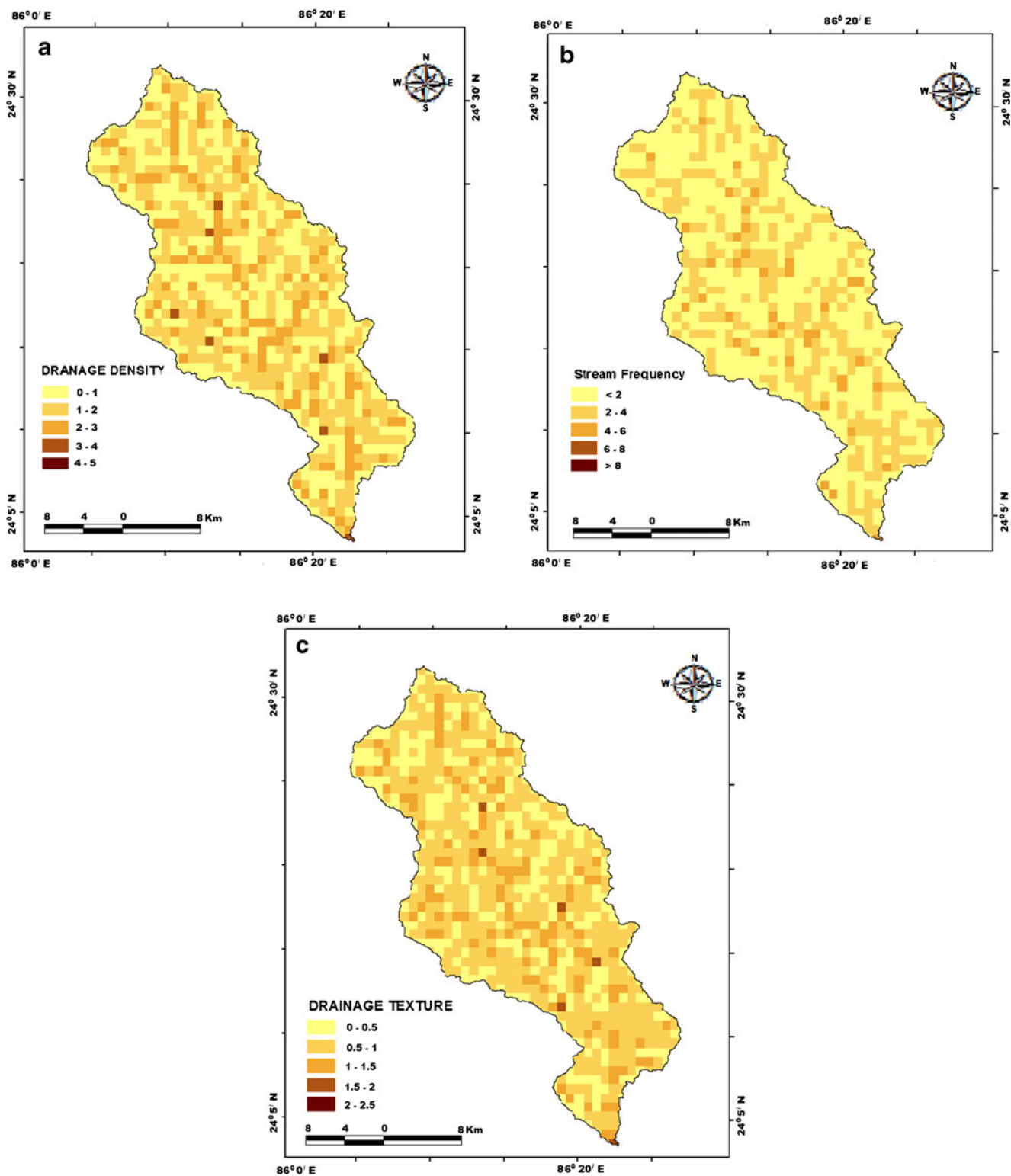
The drainage texture indicates the relative spacing of the drainage lines (Horton 1945). The drainage texture depends on climate, vegetation, rock and soil characters, infiltration capacity, relief, and stage of development (Dornkamp and King 1971; Kale and Gupta 2001). The coarse drainage texture is associated with low drainage density, which is in turn dependent on infiltration capacity of the bed-rock (Ozdemir and Bird 2009). The drainage texture value of the Usri Basin (Table 2 and Fig. 5c) falls under moderately coarse category (Singh 1998). The poor stream frequency, low drainage density, and moderately coarse drainage texture values indicate that the terrain is flat with gentle slope and made up of loose material. The values also indicate that the basin has good permeability of sub-surface material and infiltration capacity, lower runoff, significant recharge of ground water, and old mature topography.

The infiltration number, a parameter of infiltration capacity of the basin, is also very low for the Usri Basin (2.30). The low infiltration number also indicates that the runoff will be very low and infiltration capacity is very high due to presence of highly permeable rocks/soil in the terrain.

### Relief morphometry

The basin relief is an important parameter to understand the denudational characteristics of the basin. It helps to interpret geomorphic processes and landform characteristics. The highest relief of the Usri Basin is 360 m and the lowest is 144 m. The mean relief of the basin is 275 m. The relative relief of the basin is 156 m (Table 2) and the map is shown in Fig. 6a. Most of its area fall between the 0- and 50-m category. The overall low relative relief with few selective areas having moderate relative relief is signature of flat terrain with small



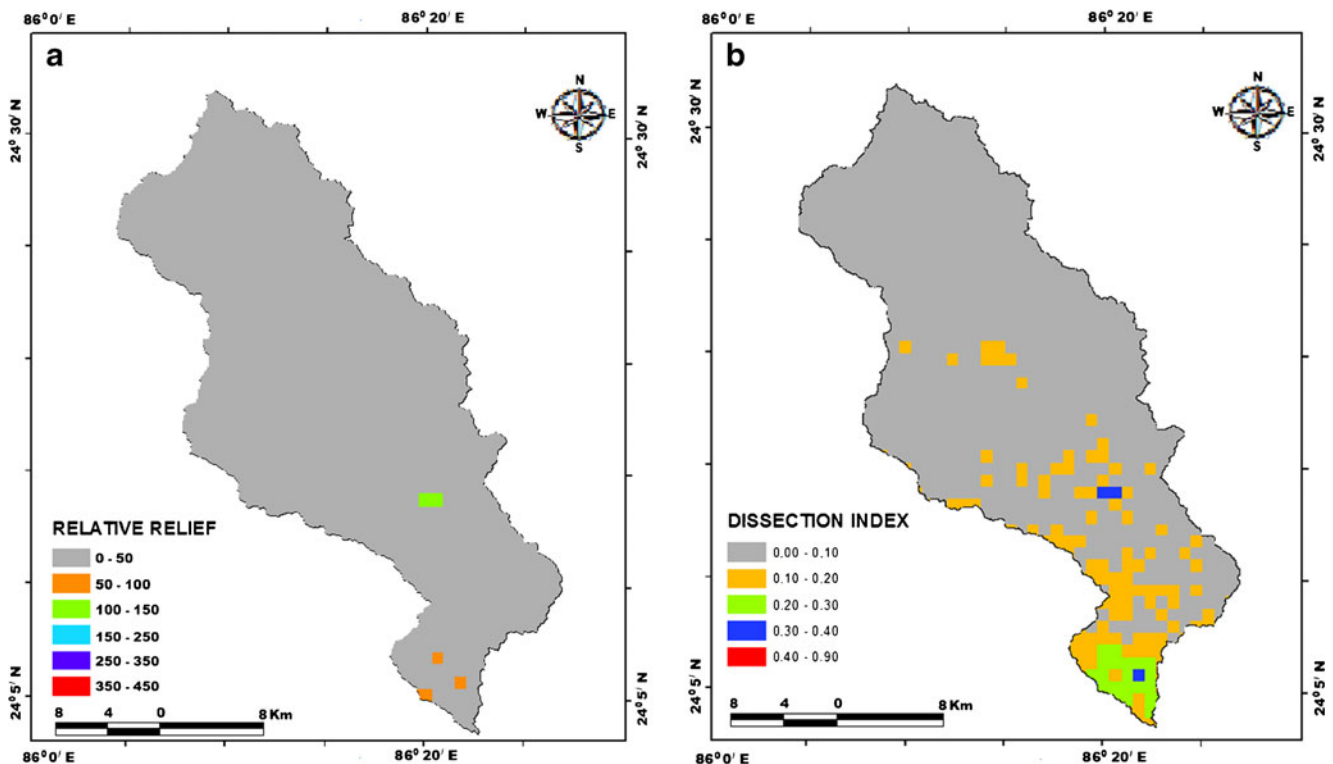


**Fig. 5** Areal aspect maps of Usri Basin: **a** drainage density, **b** stream frequency, and **c** drainage texture

hillocks/inselbergs. The relief ratio indicates the overall steepness of a drainage basin and is an indicator of the intensity of the erosional processes acting on slope of the basin (Schumm 1956). The low value of relief ratio of the Usri Basin indicates

low relief and slope in the terrain. It also indicates existence of pediplains and small inselbergs.

The dissection index is an important morphometric indicator of the nature and it suggests about the magnitude of



**Fig. 6** Relief aspect maps of Usri Basin: **a** relative relief and **b** dissection index

dissection of terrain. It indicates stages of terrain/landscape development in a basin. The dissection index value varies between 0 and 1. The “0” value stands for complete absence of vertical dissection or erosion, hence representing flat surface, whereas “1” value stands for either vertical cliffs/escarpment of hill slope or seashore. The low dissection index value for the Usri Basin (Fig. 6b) indicates that the basin is nearly flat with few inselbergs in some regions.

Pike and Wilson (1971) proved mathematically that the elevation-relief ratio ( $E$ ), which is defined as  $E = (\text{mean elevation} - \text{minimum elevation}) / (\text{maximum elevation} - \text{minimum elevation})$ , is identical to the hypsometric integral but has the advantage that it is much more easy to obtain numerically. The hypsometric integral value of the basin is very low (Table 2). As per Devisian’s cycle of erosion, the low value indicates that the terrain is in mature stage and very close to old stage. The area-height curve indicates actual area between two successive contours. The area-height curve of the Usri Basin (Fig. 7) shows that the 50 % of the basin has altitude ~300 m.

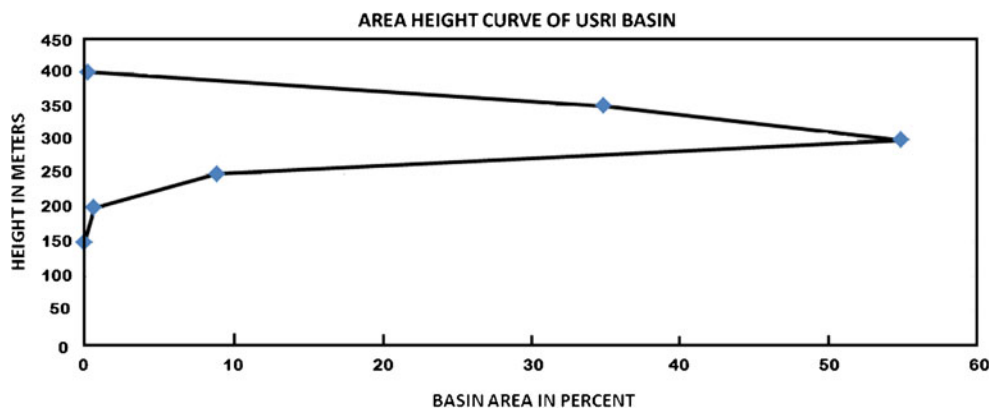
Slope is inclination of terrain from imaginary horizontal plane. It depends upon the nature of terrain—lithology, structure, soil, vegetation, climate, landforms, and morphogenetic processes operating in the underlying rocks (Strahler 1952; Yeh et al. 2009). Figure 8a shows a slope map of the Usri Basin. The map shows that except for few areas, the basin has low slope. The low slope of the basin indicates high infiltration and less runoff (Sreedevi et al. 2009). The low drainage

density of Usri Basin also conforms to above observation. Figure 8b shows an aspect map of the basin. The basin is gently sloping towards south to south-east direction. The slope in any terrain is controlled by climate and morphogenetic processes operating in the underlying rocks (Strahler 1950, 1952; Yeh et al. 2009). The Parasnath Hill has high relief with steep slope which lies at southern periphery of the basin that is why streams are flowing northwest ward at the bottom of the basin.

### River profile, drainage pattern, and landforms

River profile has two aspects: longitudinal profile and transverse profile. Longitudinal profile is a linear representation of drainage from source to mouth which accounts statistical values as well as geomorphic signatures like erosion surfaces. This profile for the Usri River has been drawn with the help of Arc GIS. It gives information about elevation value at different locations of river bed. Longitudinal river profile of the Usri River shows that it is originated at the elevation of 318 m while its base level is at 149 m (Fig. 9). There is one major break of slope near the falls of the Usri River in the long profile. Gradient ratio is an indicator of channel slope which enables assessment of the volume of runoff (Sreedevi et al. 2005). Gradient ratio also tells about valley shape. The gradient ratio value of Usri Basin is very low (Table 2). Usri Basin has dendritic to sub dendritic drainage pattern (Fig. 3) with low gradient ratio, which suggests that the basin has

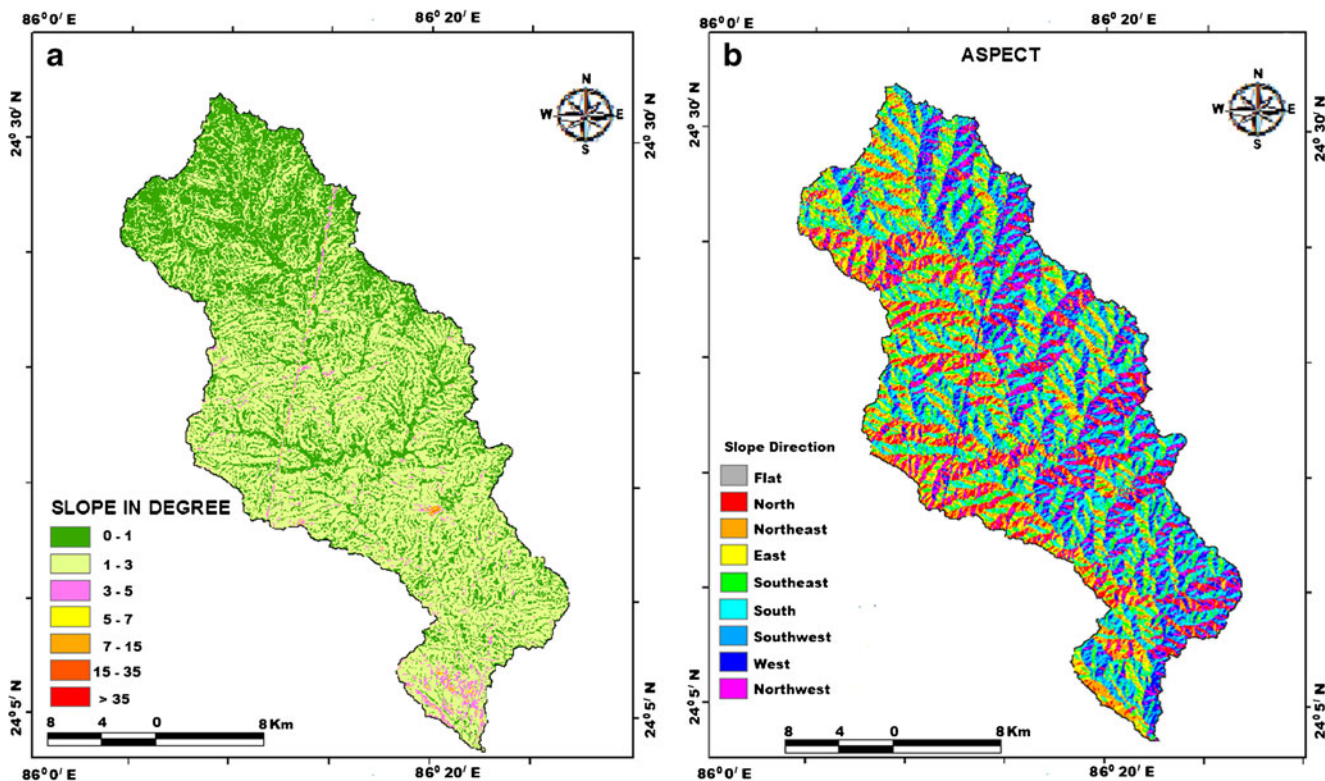
**Fig. 7** Area-height curve of Usri Basin



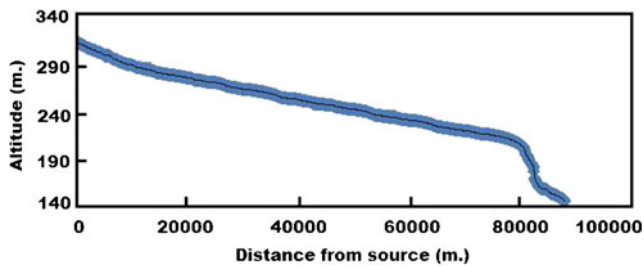
homogeneous lithology, gentle regional slope, and lack of structural control (Waikar and Nilawar 2014). The major landforms which are found during field study in the study region are erosional landforms: inselbergs, pediplain, pediment, denudational hills, meander, and ox-bow lake. Tors and exfoliated domes are also found formed due to weathering of gneissic rocks. The depositional landforms although occupies little area are alluvial plain, channel bar, point-bar, flood plain, natural levee, and valley fill. The dominance of erosional landforms are signature of mature to early old stage topography. The sediments such as sand and mud are deposited by streams generally in their narrow valley.

**Conclusions**

The quantitative analysis of morphometric indices, channel morphology, drainage pattern, and landforms is found to be of immense utility in river basin evaluation. The morphometric parameters evaluated using GIS helped us to understand various terrain parameters such as nature of the bedrock, infiltration capacity, runoff, etc. The morphometric parameters considered for the analysis include the linear, areal, and relief aspects of the Usri Basin, Chhotanagpur Plateau, India, located in the tropical climatic region. Drainage network of the basin exhibits sixth-order basin with dendritic type which



**Fig. 8** Slope (a) and aspect (b) maps of Usri Basin



**Fig. 9** Longitudinal profile of the Usri River

indicates the homogeneity in lithology and lack of structural control. The linear aspects indicated that the Usri River is sinuous and the basin has highly permeable rocks with less geological structural controls. The areal aspects indicate that the basin is elongated and gently sloping. The low drainage density, poor stream frequency, and moderately coarse drainage texture of the basin indicates that the terrain is flat with gentle slope and has good permeability of sub-surface material. The basin is having low relief of the terrain and gently sloping towards southeast direction and has few inselbergs in some regions. All morphological parameters in together indicates that the basin is in mature to early old stage of erosional development. The present study clearly indicated certain relationships (a) among several attributes of the morphometric aspects, (b) helped in assessing the topography, and (c) immensely contributed a basis for water resource development and management.

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