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GIS Based Morphometric Analysis of Bori-Chikli Watershed of Jalgaon District, Maharashtra, India

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Abstract: Water is a very important asset for life on the earth. Because of an increasing demand, groundwater exploration and exploitation needs detailed geo-scientific investigations. GIS and remote sensing are an advent technology useful in drainage morphometric studies. In present investigation, authors studied morphometry of the drainage systems. Geologically, area is composed of alluvium, massive and/or fractured and weathered basaltic flows (simple and compound) and small patches of sand gravel and silt along major streams with E-W, NW-SE and N-S trending dykes. Morphometric analysis explains the geometry of drainage basin, drainage network, texture and relief characteristics. The study area shows dendritic drainage pattern, associated in areas having similar lithology and low relief. Present research paper shows morphometric analysis of drainage basin using high-resolution remote sensing data and GIS tool to evaluate various parameters for watershed development and management plan in Bori-Chikli watershed of the Jalgaon district, Maharashtra state.

Keywords*:* Morphometric analysis, Bori-Chikli watershed, Maharashtra, India.

Introduction

Groundwater is valuable source of drinking water. In hard rock terrain, watershed development and management is an essential task to tackle the scarcity problem. The morphometric analysis gives valuable inputs to decide the watershed development and management policy. Drainage pattern and drainage density varies with topography, underlying geological structure, relative age, differing geology, drainage area etc. and enables comparisons of basins and streams. The emerging trends in the development and application of mapping technology and geodatabase systems for interpretation and manipulation of the quantitative data and surface characterization. Benefits of geospatial technology over the conventional systems are its capacity to generate, handle, store, and utilize spatial data for resource management with faster and rapid rate (Magesh et al., 2011, 2012).

Morphometric analysis is quantitative evaluation of drainage basin providing important information about the regional topography, geological structures, runoff and hydrological properties of underlying rock (Rokade, 2004, Zaidi, 2011 and Umrikar, 2016). Remote sensing and GIS techniques provide more reliable and accurate estimation and it is most applicable for hydrological investigation (Vijith and Satheesh, 2006; Magesh et al., 2012; Wakode et al., 2011). Main objective of present study is to evaluate morphometric properties of the Bori-Chikli watershed using geospatial techniques.

Study Area

Study area is situated in the western region of Jalgaon district in the state of Maharashtra. It lies between longitude 75°19'10" and 74°55'45" E and latitudes 20°40'05" and 21°11'03" N, mapped by Survey of India in toposheet numbers 46 K/16, 46 L/13, 46 L/14, 46 O/4, 46 O/8, 46 P/1, 46 P/2 and 46 P/8 on 1:50,000 scale and cover 1438.57 sq.km area **(**Fig.1). Bori-Chikli watershed is forming a part of Bori River Catchment, Tapti River Basin and Arabian Sea Water Resource Region (AIS & LUS, 1988). As per AIS & LUS (All India Soil and Land Use Survey) codification system the studied area has been coded as 5C3B6 (5-Water Resource Region i.e. Arabian Sea, C-River Basin i.e. Tapti, 3- Catchment i.e. LB Ukai dam to Purna Confluence, B-Sub-Catchment i.e. Burray to Bori and 6-Watershed i.e. Bori- Chikli). Climate of an area is hot and dry during October to June with temperature range 10°C to 46°C. Average rainfall of the area is 736.75 mm mostly received in monsoon season (June to September). Agriculture is main practice for survival of human beings, prominent crops harvesting in the area are Cotton, Jowar, Bajara, Maize and Grains (Rokade, 2013).

Materials and Methods

In present study, spatial and non-spatial data is gathered from source organizations and /or generated from resources like IRS-P6 (L4 MX) satellite data (9th January, 2010 and 6th April, 2010), IRS-1C PAN data (19th May, 2006), District Resource Map mapped by Geological Survey of India, Survey of India's (SOI) toposheet of 1:50000 scale, historic and lithological data, well details from Ground Water Survey and Development Agency (GSDA) Jalgaon and field notes (rock type, geological structures, landforms, stream behavior, land use and land cover pattern, water

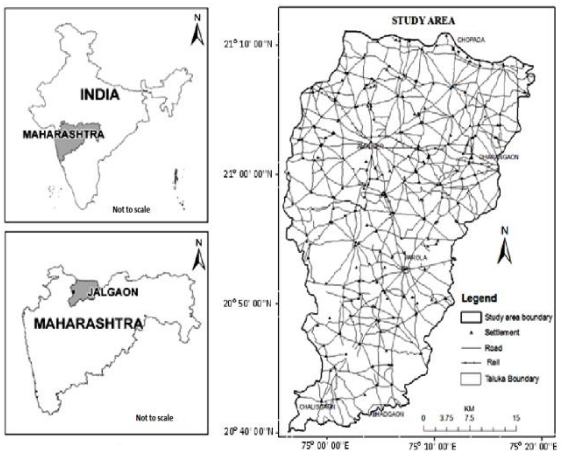

Fig. 1 Location map of Study area

sources etc.). Drainage basin boundary is delineated from Cartosat DEM and SOI toposheet. Image processing and analysis is performed using Erdas Imagine 9.1 software and generation of various thematic layers, GIS integration and GIS analysis is done using ArcGIS 9.3 software. Drainage morphometric parameters like; basin lengths, number of streams, stream length, perimeter and area of the watershed obtained from the drainage layer. Formulae suggested by Horton (1945), Miller (1953), Schumn (1956), Strahler (1964) and Nookaratnam et al. (2005) are used to calculate morphometric parameters of the watershed. Global Mapper (version 13.0) is used to prepare transverse and longitudinal profiles of the watershed.

Results and Discussion

Geological Setup

The area has been mapped on the basis of interpretation of satellite data (IRS-P6 (L4 MX) and IRS-1C PAN data), field work and Geological Survey of India published District Resource Map (1: 2, 50000 scale). Geology of the study area comprises alluvium and basaltic flows of Sahyadri group of Deccan Trap (Upper Cretaceous to Paleogene age) (Fig. 2). Sahyadri group of rocks are represented by alternate Aa and pahoehoe flows (group of compound Pahoehoe flows) having cumulative thickness in the range of 90 to 200 m (GSI, 2009). These basalts are fine to medium grained, massive and highly jointed (Vertical joints and columnar joints). Alternate bands of clay, silt, coarse sand lenses, gravels and pebbles are characteristics of alluvium extending more than 5 m bgl (Rokade, 2013 and GSDA, 2012). Basic dyke intrusions are prominently trending in N-S, NE-SW and NNW-SSE directions **(Fig. 2)**. In hydrogeological perspective, Deccan basalt behaves as good aquifer discharging 0.14 to 29.16 litres per second (lps) through upper weathered and fractured rocks (areas of vertical and columnar joints) of the study area. Static water levels are recorded in the range of 5.20 to 140.00 m bgl (CGWB, 2009).

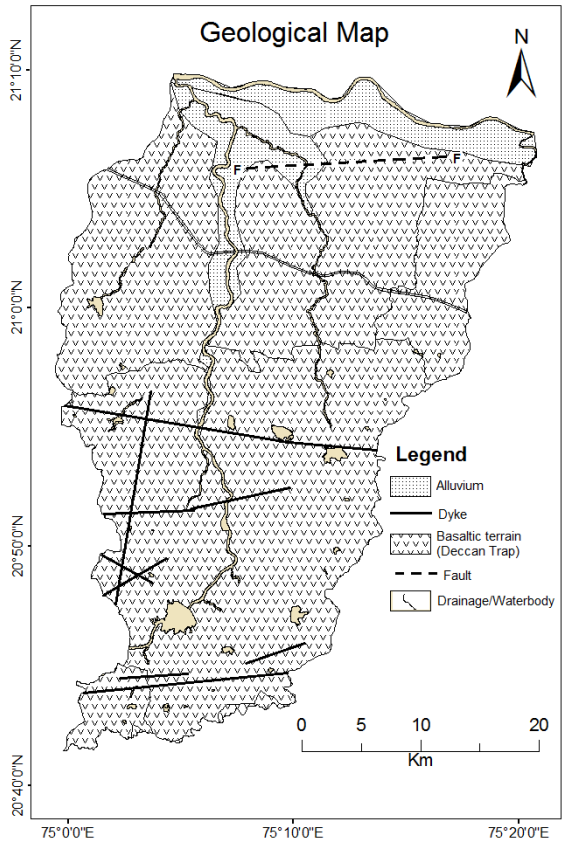

Fig. 2 Geological Map of Study area

Drainage Morphometry

Morphometry include qualitative study of the drainage basin characteristics, basin area, slope, volume, altitude and topographic profile of an area. Fluvial morphometry includes the consideration of linear, areal and relict aspect of the drainage basin (Savindra Singh, 1998). In present study, Drainage basin is delineated from Cartosat DEM and SOI toposheets and database updated using linear stretched and edge enhanced satellite images (IRS-P6 (L4 MX) and IRS-1C PAN data). Drainages are digitally traced and the basin is subdivided into sub-watersheds drained by tributaries. Stream orders and stream numbers are assigned to each streamlet. Quantitative estimation of morphometric parameters is carried out at micro and mini-watershed level using GIS platform. Morphometry of the watershed comprising three aspects - linear, areal and relief and calculated by different established methods.

Bori River is drained by seventh ordered stream. Drainage pattern in study area is mainly observed as dendritic drainage pattern and small patches of annular drainage pattern at few places (Fig. 3). Dendritic drainage pattern is associated with areas having homogeneous lithology and very gentle and/or flat, rolling topographic surface with extremely low relief and annular drainage pattern is shown by small hillocks/mounds present in the area.

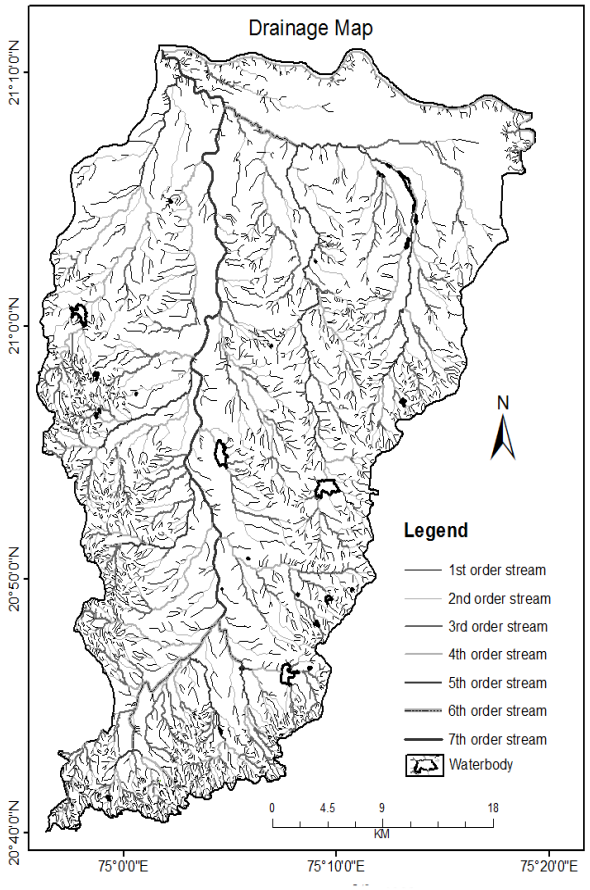

Fig. 3 Drainage map of the area.

Linear Aspects of Drainage Morphometry

Linear aspects like drainage pattern, stream number, stream order, bifurcation ratio, stream length, mean stream length, stream length ratio and length of overland flow (Table 1) estimated by formulas of drainage morphomety**.**

Stream order

In morphometric analysis, a stream ordering is of prime importance, basin size greatly varies by stream order. Stream order (u) is nothing but the hierarchical position of a stream within drainage basin. Strahler's system is a slight modification of Horton's system, has been used for stream ordering. In which, smallest, single streams are considered as first order, the union of two 1st order streams gives 2nd order stream and so on. Bori-Chikli watershed is represented by highest 7th stream order.

Stream number

Stream number (Nu) is the number of the stream segments present in each stream order. In case of Bori-Chikali watershed, 2467 number of stream segments for 1st order, 605 for 2nd order,150 for 3rd order,44 for 4th order, 10 for 5th order,3 for 6th order and 1 for 7th order (Table 1). The study indicates that the 1st order streams developed more in elevated dissected plateau and comparatively less in alluvial zone.

Stream length and mean stream length

Stream length of any order is sum of length of individual stream segments of that order. The length of 1st order stream is 1440.456 km, 2nd order is 641.391 km, 3rd order is 333.993 km, 4th order is 223.960 km, 5th order is 102.392 km, 6th order is of 27.101 km and 7th order is 52.309 and the average length (Lm) of 1st order stream is 0.583 km, 2nd order is 1.060 km, 3rd order is 2.226 km, 4th order is 5.09 km, 5th order is 10.23 km, 6th order is of 9.033 km and 7th order is 52.309 (Table 1).

Stream length ratio

Ratio of mean length of streams of a given order (Lu) to the mean length of streams of subsequent order (Lu+1) is known as length ratio (RL). Length ratio is 1.815 for 1st to 2nd order streams, 2.099 for 2nd to 3rd, 2.292 for 3rd to 4th, 2.011 for 4th to 5th, 0.882 for 5th to 6th and 5.790 for 6th to 7th **(Table 1)**. Length ratio deviation may be due to slope variation indicating development of youth stage in drainage basin (Singh and Singh, 1997, Vittala et al., 2004)

Table 1 Linear drainage morphometric parameters of Bori Chikli watershed.

Stream Order	Number of Streams (Nu)	Total Length of Streams (Lu)	Average Stream Length in km (L_m)	Bifurcation Ratio (R_b)	Stream Length ratio (RL)	Mean Bifurcation Ratio (R_{bm}) - Average of bifurcation ratios of all orders	Basin Length (Lb)
1st	2467	1440.456	0.583	4.077	-	3.708	81.590
2nd	605	641.391	1.060	4.033	1.815		
d	150	333.993	2.226	3.409	2.099		
4th	44	223.960	5.09	4.4	2.292		
5th	10	102.392	10.239	3.33	2.011		
6th	3	27.101	9.033	3	0.882		
7th	1	52.309	52.309	-	5.790		

Bifurcation ratio

Ratio of number of streams in a order and total number of stream segments of next higher order is bifurcation ratio. Bifurcation ratio for 1st to 2nd order is 4.077, 2nd to 3rd order 4.033, 3rd to 4th order 3.409, 4th to 5th order 4.4, 5th to 6th order 3.33 and for 6th to 7th order 3. It is in the range of 3 to 5 for whole studied watershed. The average bifurcation ratio for study area is 3.757 **(**Table 1**)** reflecting moderate sediment yield and less affected by structural disturbances.

Basin length

Longest dimension of the basin along its principal drainage channel is basin length. For studied watershed, basin length is 81.590 km (Table 1).

Areal Aspects of Drainage Morphometry

Two-dimensional properties of basin are calculated by different parameters like; drainage area, drainage density, drainage texture, stream frequency, elongation ratio etc. categorized as areal aspect of drainage morphometry. This information on fluvial morphometry exhibit relationship of stream discharge and watershed area. Calculated values of various areal parameters are given in the Table 2.

Table 2 Areal drainage morphometric parameters of Bori Chikli watershed.

Total number of streams	Total length of streams	Maximum length of stream	Maximum stream order	Drainage Density (D_d)	Stream Frequency (F_u)	Texture Ratio (T)
3280	2821.535	52.309 km	7	1.961	2.28	4.471

Drainage density

Ratio of total number of all channel segments within a basin to the basin area is drainage density. It is significant index measured as inverse of length (Horton, 1932). Low drainage density is indicative of the presence of highly permeable rocks and mounds and/or impermeable areas characterize high drainage density. Drainage density also depends upon the relief; if low basin relief drainage density is also low, similarly high drainage density is due to high basin relief (Strahler, 1964). Drainage density of the study area is calculated as 1.961 (Table 2).

Drainage texture

In hydrological study, drainage texture is of utmost importance obtained by multiplication of drainage density and stream frequency. Calculated value for drainage texture of Bori-Chikli watershed is 4.471, which indicates the very fine drainage texture (Table 2).

Stream Frequency

Stream frequency is total number of stream segments of all order per area of the basin (Horton, 1945). Calculated value for Stream frequency of Bori-Chikli watershed is 2.280 (Table 2).

Drainage / Basin area

Drainage area is an entire basin area drains stream flow to single discharge outlet. So, drainage area helps to calculate available water for artificial recharge in the area. The total basin area of Bori-Chikli is 1438.57 km^2 (Table 3).

Table 3 Areal drainage morphometric parameters depicting shape of Bori Chikli watershed.

Total area of the Basin (A) km^2	Basin Length (Lb)	Basin Perimeter (P) km	Form Factor (R_f)	Circularity Ratio (R_c)	Elongation Ratio (R_e)	Compactness Constant (C_c)
1438.57	81.590	210.546	0.216	0.407	0.524	1.565

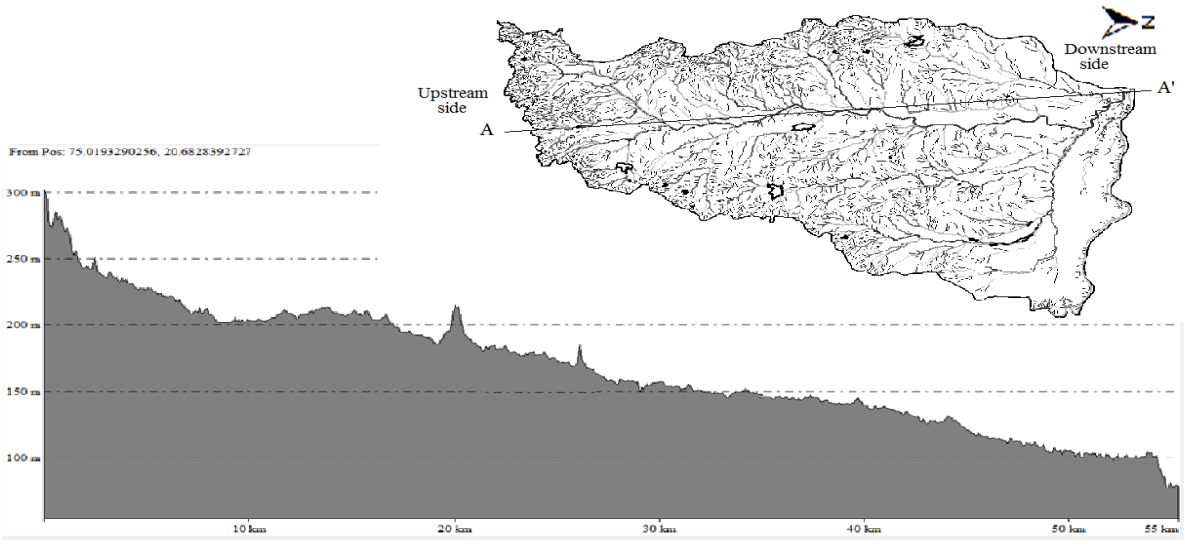

Fig. 4 Longitudinal Profile (alonf A-A') of study area exhibiting altitudinal variation.

Elongation ratio

An elongation ratio (Re) is ratio of diameter of a circle of the same area to the maximum basin length (Schumn, 1956). Elongation ratio with value '0' indicates that basin is highly elongated and '1' indicates circular basin shape (Strahler, 1964). The value for Bori-Chikli watershed is 0.524, indicative of elongated shape (Table 3).

Circulatory ratio

The circulatory ratio is initially defined by Miller (1953), the ratio of the basin area to the area of circle having circumference same to the basin perimeter. Circulatory ratio varies from 0 (in line) to 1 (in circle), in case of study area it is 0.407 demonstrating less circularity or more elongated in the shape of the basin and sudden discharge of the runoff (Table 3).

Form factor

The value of form factor of the Bori-Chikli watershed is 0.216 (Table 3) depicting an elongated shape**.** It is numerical index (Horton, 1932) representing different basin shapes. Form factor is in the range of 0.1-0.8. More elongated basin is having less value.

Relief Aspects of Drainage Morphometry

In relief drainage morphometry three-dimensional properties of the drainage basin is studied. In this investigation, relief parameters like relative relief, relief ratio, basin relief, ruggedness number etc. are studied (Table 4).

Table 4 Relief drainage morphometric parameters of Bori Chikli watershed.

Height of the basin mouth (Z)	Height of the highest point on the basin (z)	Total basin relief (H) meter = Z – z	Relief ratio (Rh) = H/Lb	Relative relief (Rhp) = H/P	Ruggedness number (Rn) = Dd.H/1000	Height of the basin mouth (Z)
292 m	321 m	29 m	3.578	1.386	0.572	1.565

Basin relief

The basin relief is obtained by calculating an elevation difference between highest and lowest point of the watershed. In case of Bori- Chikli watershed, the highest peak is having elevation of 321 m and lowest of 292 m elevation. The basin relief of the study area is 29 m above mean sea level. Relative relief of the basin is calculated by taking the ratio of basin relief to basin perimeter. Relative relief of Bori-Chikli watershed is 1.386.

Relief ratio

Ratio between total basin relief and longest basin dimension parallel to principle drainage line (Schumn, 1956) is called Relief ratio. In case of Bori-Chikli watershed, it is 3.578 indicating poor slope and low relief.

Ruggedness number

Ruggedness number depends upon the slope steepness of an area; it is the product of maximum basin relief and drainage density (Strahler, 1968). Ruggedness number for the Bori-Chikli watershed is 0.572, which is comparatively low value indicating gentle slope and moderate to low dissection.

Longitudinal profile

Longitudinal profile for Bori-Chikli is prepared along A-A' by using Global Mapper (version 13.0) is shown in the Fig. 4. Considering distance verses elevation in the area longitudinal profile drawn. The profile exhibiting moderate slope gradient and low relief in the studied area.

Transverse profiles

The transverse profiles of the study area show cross sections of river channel at various locations **(Fig. 5)**. Three transverse profiles cross profile of Bori river have been prepared along A1-A2, B1-B2, C1-C2 cross sections to understand valley width and its nature. The profile along A1-A2 cross section shows, the upper course of the river having V- shape valley, along section B1-B2, rate of erosion is slowed down and valley shape changes with its widening, cross profile C1-C2 exhibits, the rate of deposition is high; valley is wide with broad floodplain.

Digital Elevation Model and Slope

Surface and subsurface water flows, water infiltration or percolation rate, surface runoff and erosion intensity is mainly influenced by slope. In study area, the maximum elevation is 321 m and the lowest point of elevation is of 29 m. In study area, southern, southern-west region of area is having steep to moderate slope gradient (5-15%) and Northern and eastern region shows gentle to very gentle slope gradient (0-3 %). Most of the watershed area having very gentle slope **(Fig. 6)**. Altitudinal variation in the area is exhibited by Digital Elevation Model (DEM) (Fig. 7).

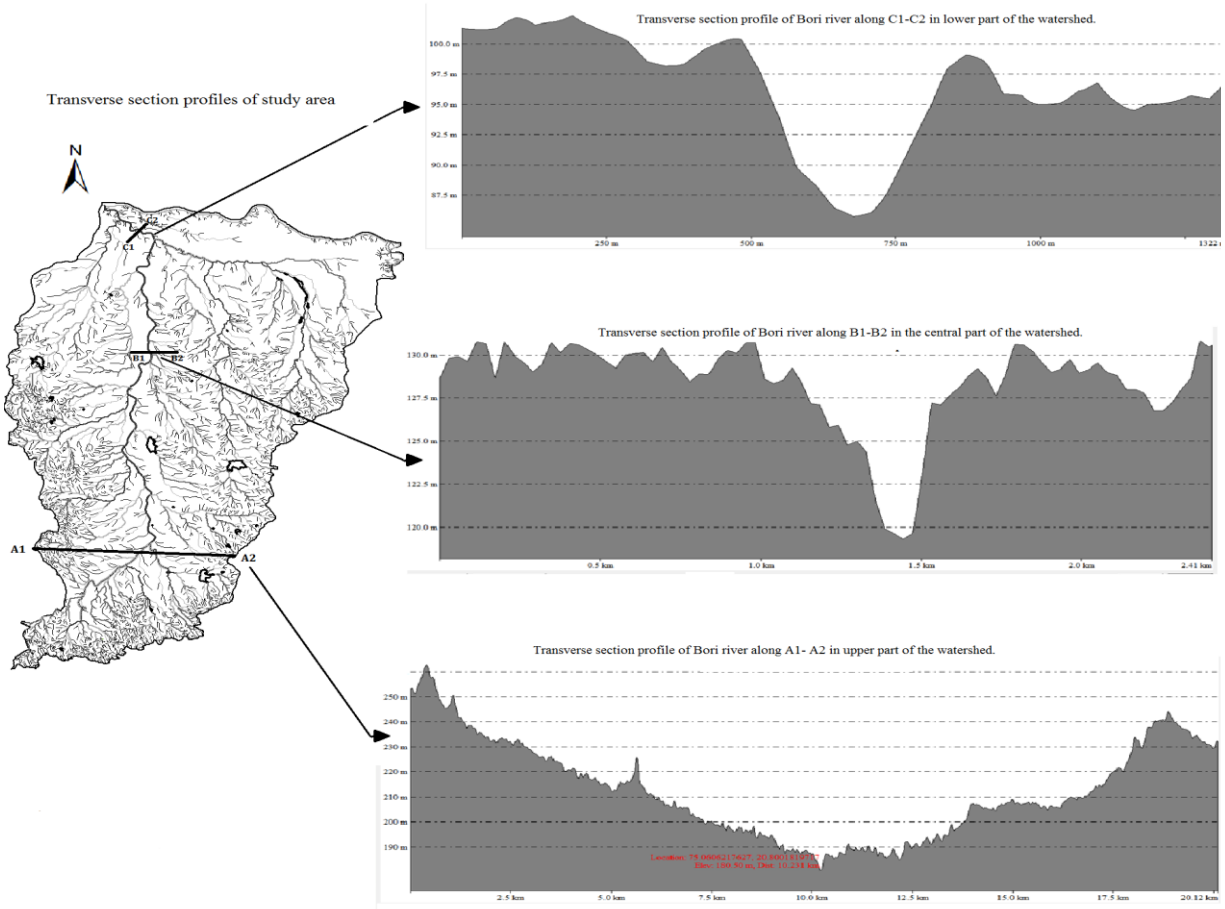

Fig. 5 Transverse sections along A1-A2, B1- B2 and C1- C2 depicting topographical variations.

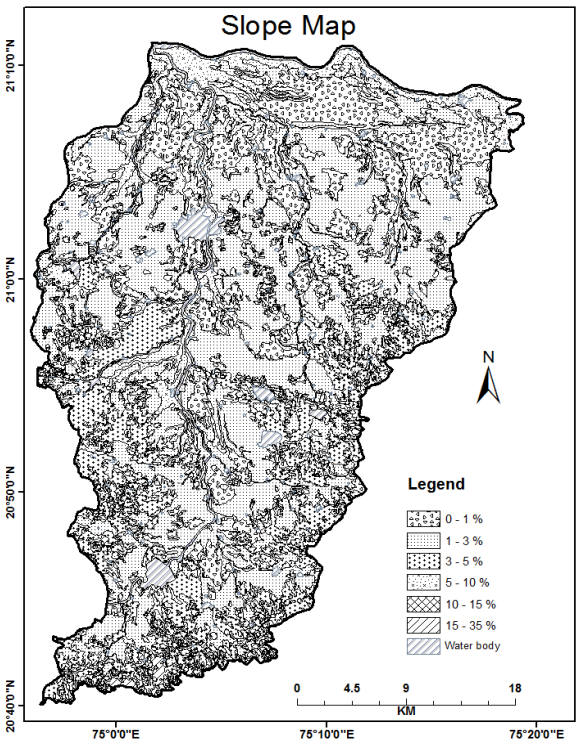

Fig. 6 Map showing different classes of slope in study area.

Conclusion

Hydrological and landform conditions are evaluated by drainage morphometric analysis, so plays a vital role in water resource as well as watershed development and management studies. Geospatial tools like remote sensing and GIS helps in watershed delineation and morphometric evaluations. Drainage morphometry of a river basin reflects the hydrogeologic maturity of the region and alluvium and basaltic flows of the area is behaving accordingly. As per results of morphometric analysis, it is concluded that, Bori-Chikli watershed is having seventh order basin with length of 81.590 km and total area of 1438.57 km^2. Shape of an area is elongated and dendritic, which indicated less structural control and homogeneous lithology. With the increase in basin length, basin slope and elongated shape sediment yield increases. The value of stream frequency indicates more surface runoff.

Low erosion intensity is because of low relief ratio (3.578). Bori-Chikli watershed is elongated watershed with moderate relief and varied geological features exhibited by value of elongation ratio and form factor. The longitudinal profile of the area represents gradient and general nature of landform development. Majority of the area depicting slope less than 10% favoring

surface runoff to stay on the surface for long time. Drainage density in studied area is 1.961 demonstrating low to moderate water discharge through basin. In the upstream portion of the watershed, hard basaltic rock gives high slope percentage (15-35 %) and low-lying area is having alluvium giving poor to null slope percentage. Major slope percentage difference is responsible for high deposition in low-lying area.

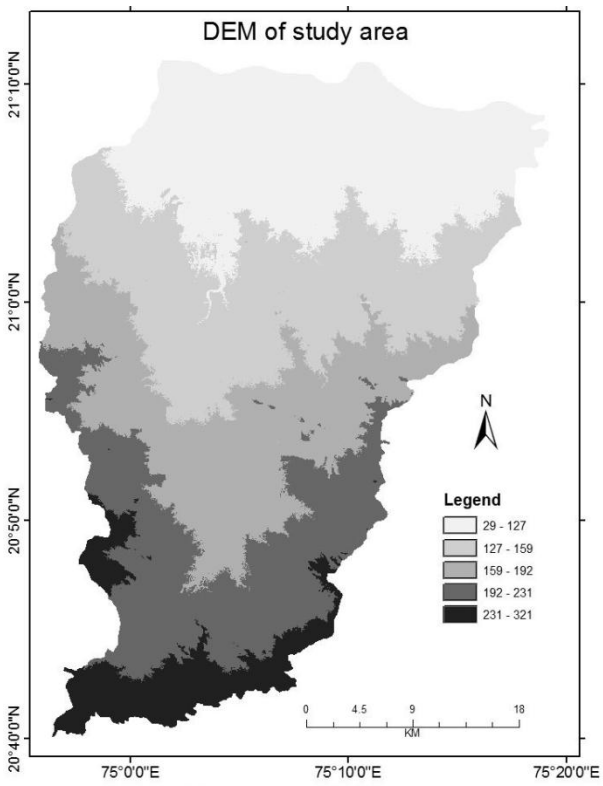

Fig. 7 Digital elecation model of the study area.

The area of Tapti river alluvium is characterized by low drainage density, very gentle slope and none to slight soil erosion. This condition helps it to be an excellent groundwater prospects zone. In the study area, there are several dykes intruded as well as fault and lineaments are present. These structural aspects affect the local region groundwater prospecting. Morphometric analysis of Bori-Chikli watershed provides important information for adopting watershed development strategy in the area. Majority of this region is facing the drought prone condition from several years. Considering results of morphometric analysis, appropriate watershed management treatment with respect to 'ridge to valley' recommended for effective water conservation.

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