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RESEARCH ARTICLE

MORPHOLOGICAL CHARACTER OF A MICRO WATERSHED OF KATLA RIVER IN UDAIPUR DISTRICT, RAJASTHAN

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ABSTRACT

Drainage characteristic of a micro watershed of Katla river has been studied by using topographic map of 1:50,000 scale and satellite data under GIS environment. The drainage network and morphometric parameters of the micro watershed were delineated and computed by using Arc GIS 10.2. Various morphometric parameters including linear, areal and relief parameter has been computed by standard method and formulae. The streams of Katla river basin shows trellis drainage pattern and in somewhere sub-parallel drainage pattern with maximum stream order of 5. The total stream length of 312 streams of Katla river basin is 181.808 Km and stream length ratio is 2.155. The bifurcation ratio of the study area is 3.95 which indicate that the watershed has more affected of structural disturbance. High drainage density of 3.436 with fine texture indicates that the area is composed of impermeable subsurface material. To identify the shape of the basin, the form factor 0.308 and circularity ratio 0.46 shows that the basin is sub circular to elongated in shape. The main course of Katla river is sinuous in nature and migrated towards north-east direction.

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INTRODUCTION

Most of the cases for understanding the hydrological study, we consider watershed as a basic unit. Morphometric study in the field of hydrology were first initiated by Hortan (1945) to identify and measurement of shape. Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds (Strahler 1964). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke 1966). This analysis can be achieved through measurement of linear, aerial and relief aspects of the basin and slope contribution (Nag and Chakraborty 2003; Putty 2007). Morphometric analysis provides quantitative description of basin geometry to--5 understand initial slop or inconsistencies in rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler 1964; Esper and Angillieri 2008;). Morphometric analysis involves the evaluation of stream parameters through the measurements of different stream properties (Kumar *et al.*, 2000; Ali *et al.*, 2003; Ali *et al.*, 2005; Pirasteh *et al.*, 2007). Identification of drainage networks within basins or sub basins can be achieved using traditional methods such as field observations and topographic maps or alternatively with advanced methods using remote sensing and GIS (Macka 2001; Sreedevi *et al.*, 2009). It is very difficult to work out drainage network by using traditional methods. The study of drainage characteristic have been carried out in different part of the globe by using conventional method (Krishnamurthy *et al.*, 1996). In recent years GIS is very powerful tools for morphometric analysis in India as well as world. The morphometric study of Katla river basin has also been done by using Remote Sensing and GIS techniques.

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Study area

The micro watershed of western part of the Katla river, where the river is initiated, has been carried out for detail study. The study area of 52.91 Km^2 is located between the villages of Kundal ka gura, Jhalon ka gura, Ghodach, Khatpal ka gura, Borvaliya, Kailashpuri, Kunda of Udaipur district of Rajasthan. The geographical location of this basin lies between longitude $73^0 38.125'E$ to $73^0 45'E$ and latitude $24^0 44'N$ to $24^0 48.75'N$ falling Survey of India toposheet no. 45H/9 and 45H/10 on 1:50,000 scale. The study area falls semi-arid region under tropical climatic condition.

MATERIALS AND METHODS

In the present study the area, streams were digitized using SOI topographic map 45H/9 and 45H/10 on 1:50,000 scale and updation through DEM and google earth image.

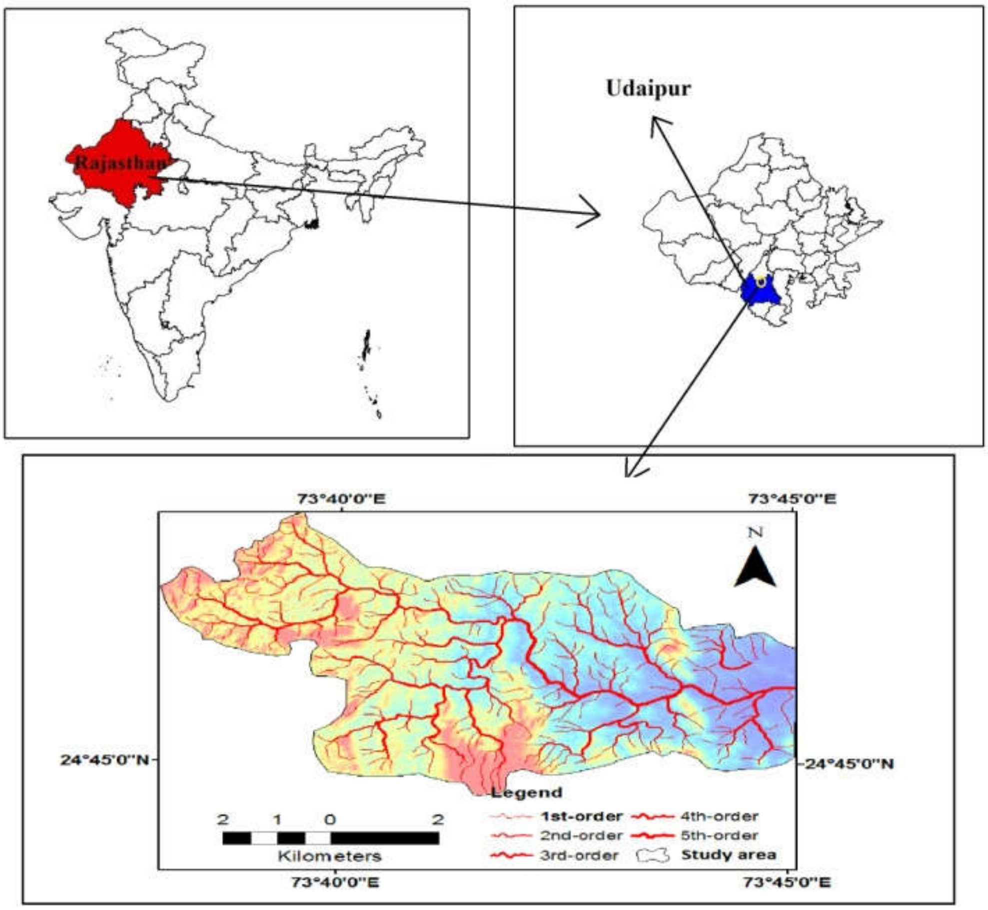

Fig. 1. Location map

The dividing lines for the runoff or the ridgelines were identified by SRTM DEM of 1 arc resolution. The ArcMap 10 software has been used to digitize the drainage network. Three aspects of morphometric parameter were calculated using standard formulae. Elevation (Fig 3b), Slope (Fig 3c) and Aspect map (3d) has prepared using SRTM data to understand about the behaviour of the study area. River sinuosity and Transverse Topographic Symmetry Factor has been analysed to study the behaviour of the area.

RESULT AND DISCUSSION

Morphometric parameters are classified as 1. Linear aspect 2. Areal aspect 3. Relief aspect.

Linear aspect

Linear aspect include Stream order (U), Stream number (Nu), Stream length (Lu), Mean stream length (Lsm), Stream length ratio (Rl) and Bifurcation ratio (Rb) which are discussed below.

Stream order (U)

Differentiate the stream order in the basin is the first step to analyse. Stream order expresses the hierarchical relationship between stream segments. The channel segments has been ranked according to Strahler's (1964) stream ordering system that is 1^{st} order stream has no tributaries, 2^{nd} order streams have tributaries only of 1^{st} order streams and by joining two 2^{nd} order, 3^{rd} order stream is formed and so on. In this study area the highest order is five (Fig 1).

Stream number (Nu)

Horton (1945) "laws of stream numbers" states that the number of stream segments of each order forms an inverse geometric sequence against plotted order. The total number of streams are 312. Out of which 229 are 1^{st} order, 58 are 2^{nd} order, 19 are 3^{rd} order, 5 are 4^{th} order and 1 is 5^{th} order. Most of the places the streams have been formed trellis pattern. The calculated number of streams with order shows that the number of streams decreases with increasing order Fig.2a). With small deviation from straight line most of the drainage network shows linear relationship (Fig. 2b).

Stream length (Lu)

Horton (1945) states that the average length of streams of each order in a drainage basin tends closely to approximate a direct geometric ratio. Generally the total length of stream segments decreases with increasing stream order (Fig. 2c, Fig. 2d). The total length of all stream segments is 181.81 Km. The length of 1^{st} order is 107.59 Km, 2^{nd} order is 34.64 Km, 3^{rd} order is 17.77 Km, 4^{th} order is 14 Km and 5^{th} order is 7.81 Km.

Mean Stream Length (Lsm)

The Mean Stream Length varies from 0.47 to 7.81 respectively 1^{st} order to 5^{th} order as shown in table 2. The mean stream length of a particular order is greater than that of next lower order and less than that next higher order (Fig. 2e). The mean length of a channel is a dimensional property and reveals the characteristic size of drainage network components and its contributing basin surface (Strahler 1964). Table 2 shows total Lsm value of the micro watershed is 12.612.

Table 1. Formulae for Calculating Morphometric parameters

Morphometric Parameters	Formula	Reference
Linear Parameters		
Stream Order (u)	Hierarchical rank	Strahler (1964)
Stream Length (Lu)	Length of the stream	Horton (1945)
Mean Stream Length (Lsm)	Lsm=Lu/Nu Where, Lsm =Mean stream length Lu= Total stream length of order ‘u’ Nu= Total no. of stream segments of order ‘u’	Strahler (1964)
Stream Length Ratio (RL)	RL =Lu/Lu-1 where RL=Stream length ratio Lu=Total stream length of order ‘u’ Lu-1=The total stream length of its next lower order	Horton (1945)
Bifurcation Ratio (Rb)	Rb=Nu/Nu+1 where Rb=Bifurcation ratio Nu=Total no. of stream segments of order ‘u’ Nu+1=Number of segments of the next higher order	Schumm (1956)
Mean Bifurcation Ratio (Rbm)	Rbm=Average of bifurcation ratios of all orders	Strahler (1957)
Areal Parameters		
Drainage Density (Dd)	Dd=Lu/A Lu=Total stream length of all orders (Km) A=Area of the Basin (Km^2)	Horton (1945)
Drainage Texture(Dt)	T=Nu/P Nu=Total no. of streams of all orders P=Perimeter(Km)	Horton (1945)
Stream Frequency (Fs)	Fs =∑Nu/A where Fs =Stream frequency ∑Nu =Total no. of streams of all orders A=Area of the Basin (km^2)	Horton (1932, 1945)
Form Factor (Ff)	Ff =$A/L^2$where Ff=Form factor A=Area of the basin (km^2) L=Basin length (km)	Horton (1932, 1945)
Elongation Ratio (Re)	Re =$2\sqrt{(A/\pi)} \div L$ where Re=Elongation ratio A=Area of the basin (km^2) π = 3.14 L=Basin length (km)	Schumm (1956)
Circularity Ratio (Rc)	Rc =$4\pi A/P^2$ where Rc =Circularity ratio π=3.14 A=Area of the basin (km^2) P=Perimeter (km)	Miller (1953), Strahler (1964)
Constant of channel maintenance (C)	C=1/Dd where C=Constant of channel maintenance Dd=Drainage density	Schumm (1956)
Length of overland flow (Lg)	Lg =1/2Dd where Lg =Length of overland flow Dd=Drainage density	Horton (1945)
Relief Parameters		
Basin relief (R)	R =H-h where R=Basin relief H=Maximum elevation in meter H=Minimum elevation in meter	Hadley and Schumm (1961)
Relief ratio (Rr)	Rr=R/L Where Rr =Relief ratio R=Basin relief L=Basin length in kilometre	Schumm (1956)
Ruggedness number (Rn)	Rn =R*Dd where Rn =Ruggedness number R=Basin relief Dd =Drainage density	Schumm (1956)

Stream Length Ratio (Rl)

The stream length ratio can be defined as the ratio of the total stream length of a given order to the total stream length of next lower order and having important relationship with surface flow and discharge. First three values of stream length ratio increases with increasing order but at higher order the value decreases (Table-3, Fig. 2f). The changes of stream length ratio from one order to another indicating their late youth stage of geomorphic development (Sing and Sing 1997). The variation may be due to changes in slope and topography (Sreedevi *et al.*,2005). Mean stream length ratio of the micro watershed is 2.155.

Table 2. Linear aspects of the drainage network of the study area

Stream Order (u)	Number Of Stream (Nu)	Stream Length (Lu)	Mean Stream Length (Lsm)
1	229	107.59	0.47
2	58	34.64	0.597
3	19	17.77	0.935
4	5	14	2.8
5	1	7.81	7.81
Total	312	181.81	12.612

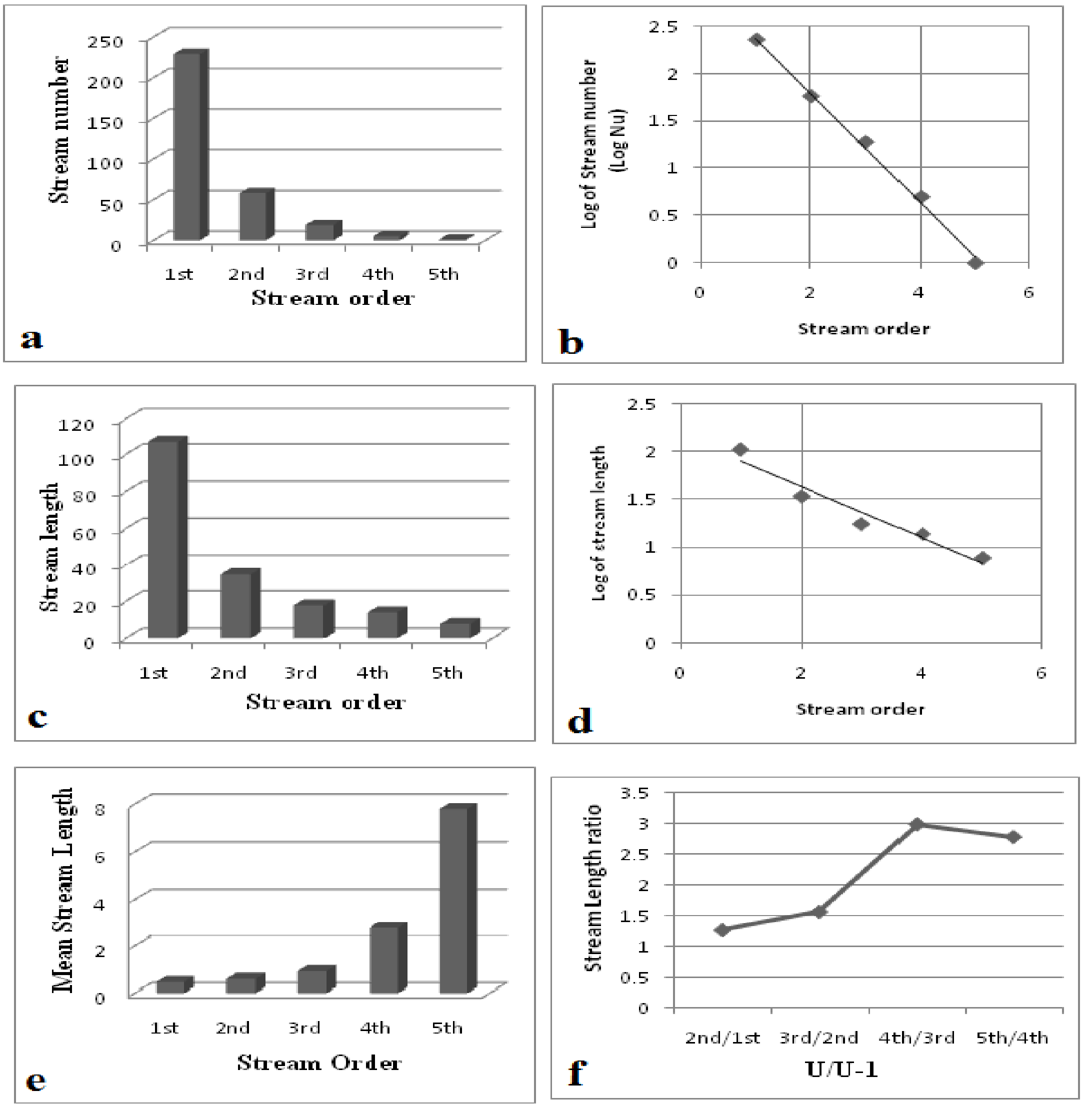

Fig. 2. Linear aspect (a) Stream number vs. Stream order (b) Log of Stream number vs. stream order (c) Stream length vs. Stream order (d) Log of Stream length vs. Stream order (e) Mean Stream length vs. Stream order (f) Stream length ratio vs. U/U-1

Stream Length Ratio (Rl)

The stream length ratio can be defined as the ratio of the total stream length of a given order to the total stream length of next lower order and having important relationship with surface flow and discharge. First three values of stream length ratio increases with increasing order but at higher order the value decreases (Table-3, Fig. 2f). The changes of stream length ratio from one order to another indicating their late youth stage of geomorphic development (Sing and Sing 1997). The variation may be due to changes in slope and topography (Sreedevi *et al.*, 2005). Mean stream length ratio of the micro watershed is 2.155.

Table 3. Stream length ratio of the study area

Stream Length Ratio (Rl)	
2nd order/ 1st order	1.27
3rd order/ 2nd order	1.566
4th order/ 3rd order	2.994
5th order/ 4th order	2.788
Mean Stream length ratio (Rlm) = 2.155	

Bifurcation Ratio (Rb)

The bifurcation ratio (Rb) is the ratio between stream numbers of a particular order and next higher order (Schumm 1956). Horton (1945) considered bifurcation ratio (Rb) as an index of relief and dissections. It is a dimensionless parameter. According to Strahler (1957), bifurcation ratio shows only a small variation from region to region or different environments except where powerful geological control dominates. If bifurcation ratio vary from one order to its next order, then these irregularities are attributed to geological and lithological development of a drainage basin (Strahler 1964). Generally, bifurcation ratios range between 2.0 to 5.0 for sub basins in which the geologic structure does not exercise a dominant influence on the drainage pattern and indicates that the basin is falling under normal basin category (Strahler 1964). Here the bifurcation ratio ranges from 3.05 to 5 indicates that this value falls under normal basin category (Table 4). The mean bifurcation ratio is 3.95 which indicates the area has suffered highly structural disturbance (Nag and Chakroborty 2003).

Table 4. Bifurcation ratio of the study area

Bifurcation Ratio (Rb)	
1st order/ 2nd order	3.95
2nd order/ 3rd order	3.05
3rd order/ 4th order	3.8
4th order/ 5th order	5
Mean Bifurcation Ratio (Rbm) = 3.95	

Areal Aspect

Areal aspects include Drainage Density (Dd), Stream Frequency (Fs), Drainage Texture (T), Form Factor (Ff), Elongation Ratio (Re), Circularity Ratio (Rc), Constant of channel maintenance (C), Length of overland flow (Lg) which are discuss below.

Table 5. Aerial aspects of the study area

Area (A) in Km2	52.91
Perimeter (P) in Km	37.927
Length of Basin (L) in Km	13.10
Width of Basin (W) in Km	6.217
Drainage Density (Dd)	3.436
Drainage Texture (T)	8.226
Stream Frequency (Fs)	5.897
Form Factor (Ff)	0.308
Elongation Ratio (Re)	2.267
Circularity Ratio (Rc)	0.462
Constant of channel maintenance (C)	0.291
Length of overland flow (Lg)	0.146

Drainage Density (Dd)

Drainage density is defined as the total length of all streams in a basin divided by the area of the basin (Strahler 1958). It describes the spacing of channel. Low value of drainage density Dd indicated that the region is having permeable subsoil material under vegetative cover and it also indicates the watershed has low relief (Strahler 1964), where as high Dd is favored in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief (Nag 1998). Low drainage density leads to coarse drainage texture whereas high drainage density leads to fine drainage texture. Drainage density of the micro watershed is 3.436, suggests that streams network are closely spaced in the watershed (fig 3e). This high drainage density with fine texture indicates that the area is composed of impermeable subsurface material with mountainous relief and also basin falls late youth stage towards maturity.

Drainage Texture (T)

Drainage texture is defined as the total number of stream segments of all orders divided by the perimeter of the watershed (Horton 1945). It describes relative spacing of drainage lines, which are more prominent in impermeable material compared to the permeable ones (Ali and Khan, 2013). Drainage texture (T) depends upon a number of natural factors such as climate, rainfall, vegetation, lithology, soil type, infiltration capacity, relief and stage of development (Smith 1954). Soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture (Iqbal *et al.*, 2012). Sparse vegetation of arid climate causes finer textures than those developed on similar rocks in a humid climate. Smith (1954) classified drainage density into five different classes of drainage texture, i.e. less than 2, indicates very coarse, between 2 and 4 is coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. The study area has a value of 8.23 which falls very fine drainage texture.

Stream Frequency (Fs)

Stream frequency is the total number of stream segments of all order per unit basin area (Horton 1932, 1945). Flooding is commonly occurring in a basin with high drainage and stream frequency (Howard 1967). A higher Fs reflects greater surface runoff and a steeper ground surface. lower Fs values indicate permeable sub-surface material and low relief (Reddy *at al.*;2004). The Fs value of the study area is 5.897, which indicate impermeable sub-surface material and moderate to high relief.

Form Factor (Ff)

Form factor is measured dividing the basin area by the square of basin length (Horton 1932). For a perfectly circular basin the form factor would always be near about 0.7854. The basins with high form factors have high peak flows of shorter duration. The study area has form factor value of 0.308 which indicate elongated shape with medium peak of flow.

Circularity Ratio (Rc)

Circularity ratio is the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin, which is dimensionless and expresses the degree of circularity of the basin (Miller 1953). In the study area Rc value is 0.462 indicates the micro watershed is sub circular in nature.

Elongation ratio (Re)

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (schumm 1956). Values near to 1.0 are the characteristics of the region of very low relief, while values in the range of 0.6 - 0.8 usually occur in the areas of high relief and steep ground slope (Strahler 1964). The Re value is 0.627 indicates the micro watershed is high relief and steep ground slope.

Constant of Channel Maintenance (C)

It is a inverse of drainage density (Schumm 1956). It depends on the lithology, permeability and infiltration capacity of surface material, climatic condition and vegetation (Schumm 1956). In the study area the value of C is 0.291, means 0.291 Km^2 of area is required to sustain 1 km of the channel.

Length of overland flow (Lg)

It is the length of water over the ground before it gets concentrated into definite stream channels, (Horton 1945). It is like sheet flow of water over the ground. It approximately equals to half of reciprocal of drainage density (Horton 1945). The calculated Lg value 0.146 indicates of high relief of the study area.

Relief aspect

Relief aspect inlude Basin relief (R), Relief ratio (Rr) and Ruggedness number (Rn) which are discuss below.

Table 6. Relief aspect of the study area

Basin relief (R)	306
Relief ratio (Rr)	0.023
Ruggedness number (Rn)	1.05

Basin Relief (R)

Basin relief is the difference in elevation between the highest and the lowest point of the basin. The maximum elevation of the study area is 866 meter and minimum elevation is 560 meter so the basin relief of the micro watershed is 306 meter (Fig 3). This high value of R indicates gravity of water flow, low infiltration and high runoff conditions of the study area.

Relief ratio (Rr)

The relief ratio is the ratio between the basin relief and the length of the basin (Schumm, 1956). It is also an indicator of intensity of erosion processes and sediment delivery rate of the basin (Strahler 1964). The relief ratio of the study area is 0.023 which is the characteristic features of less resistant rocks of the area (Dahiphale *et al.*, 2014)

Ruggedness number (Rn)

It is the product of maximum basin relief and drainage density. It is a dimensionless number. It can describe the slope steepness and length of the basin. In the study area the value of Rn is 1.05, which indicates that the area is rugged with high relief and high stream density (Fig. 3a).

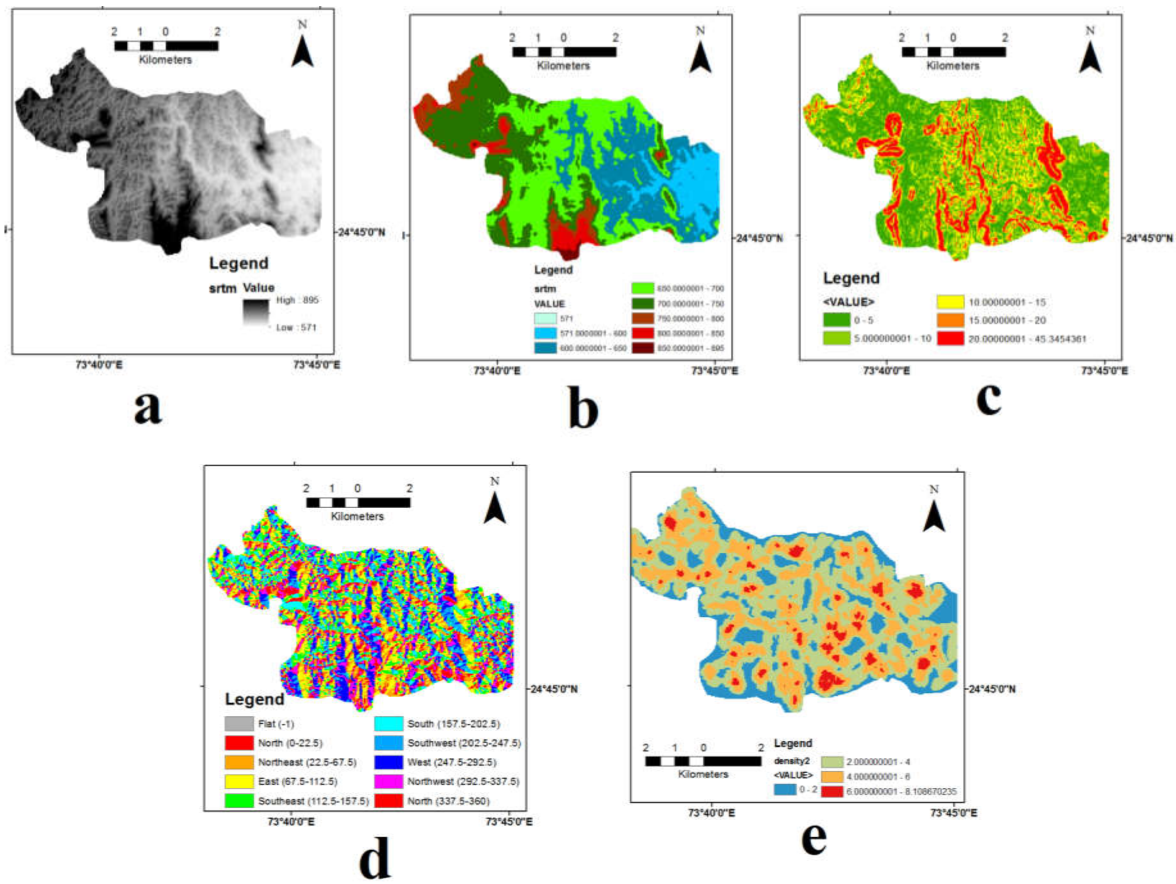

Fig. 3. (a) DEM, (b) Elevation map, (c) Slope map, (d) Aspect map, (e) Drainage density map

Table 7. River sinuosity

Segment	Lmax (Km)	Lr (Km)	P (Sinuosity)	Channel deflection (Maximum) from straight line (Km)
1	5.94	4.97	1.19	0.43
2	6.92	4.39	1.57	0.58
3	4.18	3.37	1.24	0.77
4	3.45	2.95	1.16	0.38

Table 8. Transverse Topographic Symmetry Factor

Da (KM)	Dd (KM)	Da/Dd	Da (KM)	Dd (KM)	Da/Dd
0.76	1.67	0.455	0.25	2.33	0.107
1.02	1.66	0.614	0.36	1.70	0.211
1.22	2.24	0.544	0.22	1.85	0.118
1.74	3.06	0.568	0.42	1.60	0.262

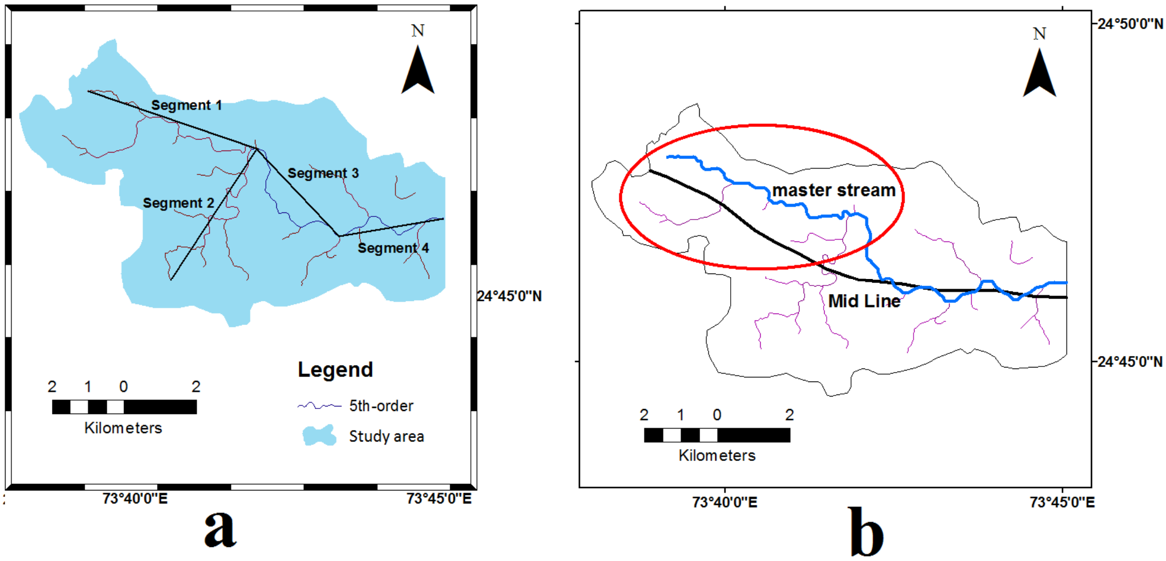

Fig. 4. (a) River sinuosity map, (b) Transverse Topographic Symmetry Factor map

River Sinuosity

Although Sinuosity of river channel put its imprint on geomorphic history it also depends on the geological control like active tectonics (Burnett and Schumm 1983; Wyzga 2006). channel sinuosity is controlled by channel gradient, sediment load, resistance to lateral erosion of a river and stage of valley development and the structural characteristics of the area through which it flows (Prasad 1982). Mathematically it can be computed through following formula: SI=CL/SL, where, SI is sinuosity index, CL is the actual length of the channel and SL is the straight line length or the air length between the same point. According to Morisawa (1985) classification except segment 2 all are shows sinuous channel where segment 2 shows meandering in nature (Fig 4a).

Transverse Topographic symmetry factor (TTSF)

TTSF is important tool to identifying the active tectonic nature in the area of poorly exposed active structure of quaternary rock (Cox *et al*, 2001). TTSF can be evaluate by the following formula T=Da/Dd, where Da is the distance from the stream channel to the middle of its drainage basin and Dd is the distance from the basin margin to the middle of the basin. If there is no tectonic activity occurs, then the main river will flow evenly from both sides as a perfect symmetric basin and the value of TTSF will be zero. TTSF value of master stream in the area indicated by red circle is more than 4.5 and fall in class 1 (Mosavi and Arian, 2015) indicate the stream has migrated towards north-east direction (Fig 4b).

Conclusion

Morphometric analysis of Katla river basin has been done by the use of Remote sensing and GIS software. Three aspects of morphometric analysis tell us about the character of the micro watershed. The morphometric analysis reveals that the study area of high drainage density is highly structurally controlled and the area has developed late youth stage of geomorphic development. Drainage density, drainage texture and stream frequency shows that the area falls in impermeable sub surface material. The sub circular to elongated shaped micro watershed has high relief with undulating topography so that surface water can move with high velocity in monsoon season. TTSF map shows that in the red circled area the stream flows along northern margin of the watershed is due to north-east tilting of the watershed. High meandering nature of segment 2 in the river sinuosity map is also the reason of tilting.

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