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Geomorphology and Morphometry of the Uttar Mand River Basin, Satara District, Maharashtra, India

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Abstract:
In the present investigation various morphometric parameters of the Uttar Mand river basin are outlined. The Survey of India Toposheet numbers 47 G/15, 47 K/3 on the scale of 1: 50,000 were used for the present study. Stream ordering method as suggested by the Strahler has been employed. According to morphometric analysis of the Uttar Mand river basin, it is a fifth-order basin that is transitioning from an early mature to an older stage of the fluvial geomorphic cycle. The drainage pattern of the basin is dendritic in nature. A particular order's mean channel segment length is more than the next lower order but less than the next higher order. The relationship between stream order and mean stream length provides a group of points that lie roughly along a curve line, indicating that the area is not subject to severe structural influence.

Keywords: *Uttar Mand River Basin, Morphometric Parameters, Geomorphology, watershed management, Satara District*

INTRODUCTION

Morphometric characteristics of drainage basins provide evidence to describe the topographical, geological and hydrological behavior of a basin. Morphometric characteristics influence basin processes (Singh et al., 2014); describe geomorphology and hydrogeology feat ures (Soni, 2016) and provide valuable information on water resources potential assessment and management. Quantitative morphometric analysis requires measurement of linear aspects of drainage network (e.g., stream order, stream length, stream number and bifurcation ratio), areal aspects of the drainage basin (e.g., length of overland flow, drainage density and basin shape) and relief aspects (e.g., basin relief, relief ratio, ruggedness number, gradient ratio, basin slope and relative relief) of the channel network and contributing ground slope. Such morphometric parameters can be readily determined from DEM using GIS than in conventional methods. GIS is ideal for morphometric analysis because of its strength in visualizing, processing and quantifying topographic attributes. This research tried to fill these research gaps by quantifying valuable drainage morphometric parameters and characterize the hydro-geomorphology of the basin using the computed parameters. Therefore, the aim of the study was: i) to quantify morphometric parameters of the Uttar Mand river Basin from SRTM derived DEM data using ArcGIS software and ii) to characterize the hydrology, geology, and topography of the basin from the computed morphometric parameters (linear, areal and relief aspects). This valuable information could help guide with soil and water resource planning and management in a river basin. The study area have the latitudes of 17°26'36.56"N and 17°23'49.40"N, as well as the longitudes of 73°57'11.86"E and 74° 5'11.00"E. The area forms part of Survey of India toposheets no. 47 K/3 and 47 G/15 of the scale 1:50000. Major and minor streams run through the area. Streams that run from west to east and north to south are mostly found in the western part of the area. The Uttar Mand River is flowing from NW to SE. The settlement in the area is confined to the North and South side of the Uttar Mand river Basin.

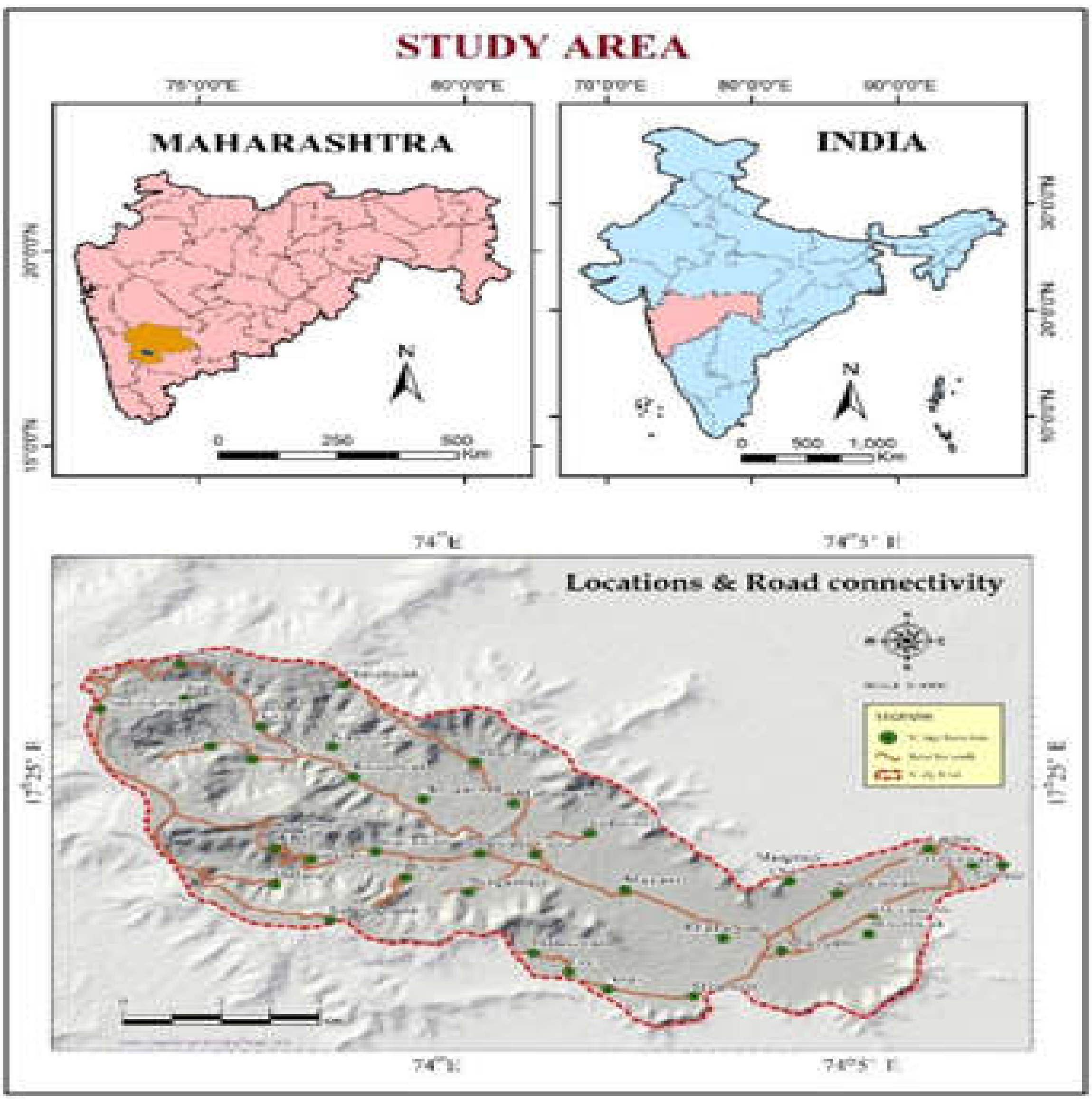

Figure 1: Location of Study Area

METHODOLOGY

The Survey of India Toposheet numbers 47 G/15, 47 K/3 on the scale of 1: 50,000 were used for the present study. Stream ordering method as suggested by the Strahler has been employed. For stream ordering method suggested by Strahler (1957) has been used. The toposheets were purchased from Survey of India. The topographical maps were geo-referenced in ArcGIS software. The SRTM (Shuttle Radar Topography Mission) 30m data were used; boundary layer is used as GSDA boundary layer of Panjhara river. The DEM data of study area were freely available and it was downloaded from (usgs.gov). Thereafter, the pre-processed DEM were used for extraction of morphometric parameters. It is economical and time saving method which used in present study. Geological and geomorphological maps are referred as District Resource map which is also digitized. Rock exposure and geomorphological landforms were observed during the field work and its is shown in this papers with its descriptions.

RESULT AND DISCUSSION

Geology of study area

The study area belongs to Deccan Volcanic Province. Lava flows of various thickness are observed along the steep slopes of hilly region in the western part of study area. Lava flows of Mahabaleshwar formation are most commonly Aa type flows (CGWB, 2018).

Deccan Basalt

Flows have a rough surface composed of broken lava blocks called clinkers. Thickness of this formation in about 300 m. Spheroidal weathering is common feature to about a meter in diameter. In Chafal-Sadadadholi Ghat section seven red boles are marked. Flow top breccia in the red boles is mostly vesicular in nature and filled by white and yellow colour secondary mineralization. At Chafal Sadawagapur road section red boles are marked. Polygonal columnar structure is observed in red boles of few outcrops (Figure 2). In red bole this type of feature is developed due to loss of fluid after deposition.

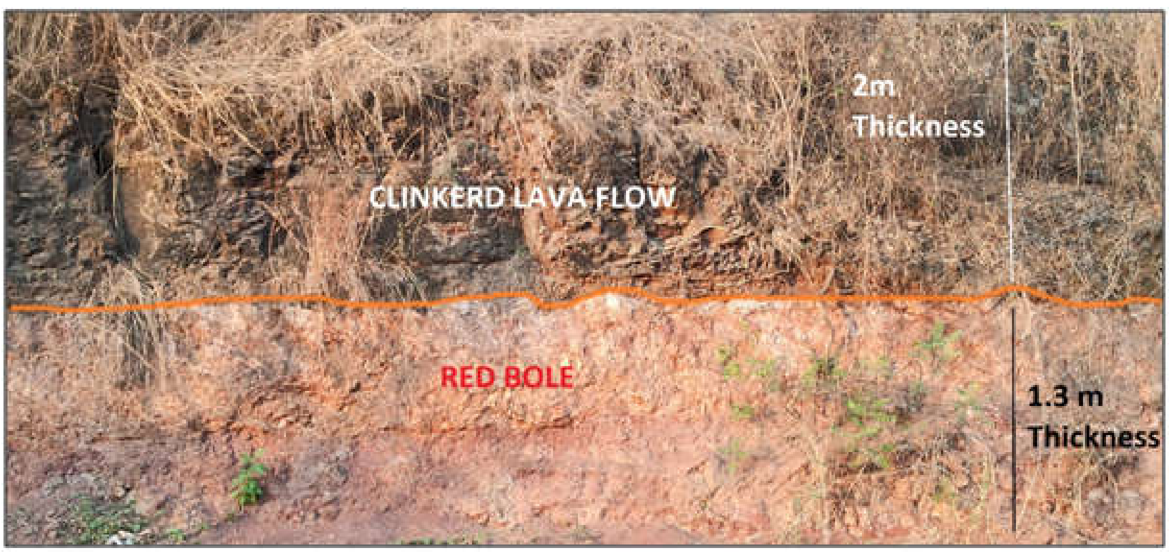

Figure 2: Contact between Red bole and Lava Flow (Chafal- Sadadadholi ghat section)

Laterites

Mottled appearance exhibiting a vesicular and tubular structure with a dark brown limonitic coating observed prominently at reverse waterfall outcrop. These laterite capping are found covering almost the entire plateaus present in the Sadawaghapur area. The laterite deposits are considered to be sub-recent (Cenozoic) in geological age. A freshly cut surface of the laterite bed is usually soft but becomes very hard, on exposure to atmosphere. Most of the laterite beds in the study area are categorised as ferruginous laterite or a very low-grade aluminous laterite. The laterite ultimately yields a red to reddish-brown ferruginous soil (Figure 3).

Figure 3: Weathered Laterite at Sadawaghapur reverse waterfall.

Lithomarge clay:

Weathered basalt gradually changes into lithomarge clay. The lithomarge clay is observed between basalt and hard Duricrust Laterite. The particle size is less than 1/64 mm for lithomarge clay present in the study area.

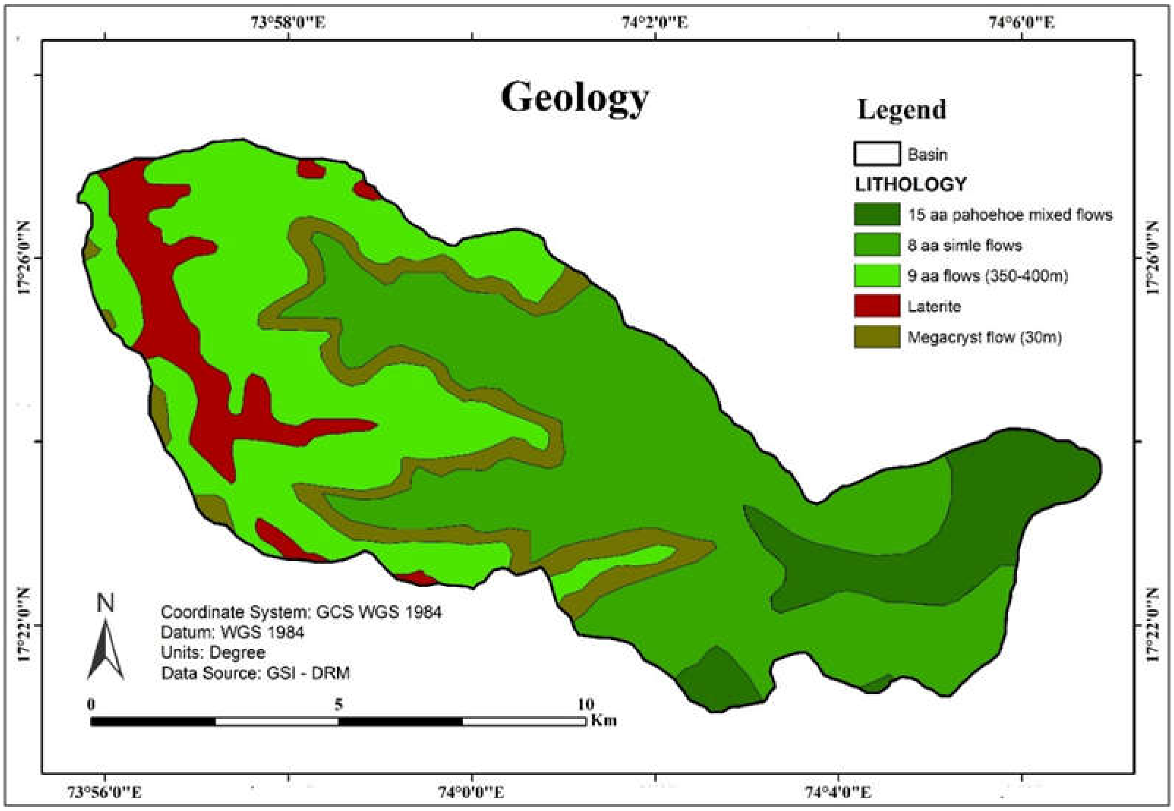

Figure 4: Geology of the Study area

Table 1: Startigraphy of the study area (after Deshpande, 1998)

Age	Formation	Thickness in meters	Lithology
Cainozoic (1 to 60 million years)	Laterites	Found at different elevation with varying thickness	Ferruginous, hard, and massive, exhibiting a vesicular and tubular structure with a dark brown limonitic coating.
Upper Cretaceous to Eocene (30-60 million years)	Mahabaleshwar	350	Deccan Trap basalt with inter-trappeans. : Aa aa flows, phyric
	Purandargad	300	Deccan Trap basalt with inter-trappeans. : Simple flows, aphyric to plagioclase microphyric

Geomorphology

Geomorphological study includes looking at landscapes to work out how the earth surface processes, such as air, water and ice, can mould the landscape. Landforms are produced by erosion or deposition, as rock and sediment is worn away by these earth-surface processes and transported and deposited to different localities. The different climatic environments produce different suites of landforms. The landforms of deserts, such as sand dunes and ergs, are a world apart from the glacial and perigla features found in polar and sub-polar regi Geomorphologists map the distribution of th landforms so as to understand better t occurrence (Figure 5). Advancements in ren sensing from satellites and GIS mapping benefited geomorphologists greatly over past few decades, allowing them to underst global distributions. The drainage pattern in study area is predominantly dendritic, as car seen in the NW part of the area. While at central part of the area trellis drainage pattern has been observed. Study of the topographic sheet, followed by subsequent field checks reveals that the area in the Western part is rugged topography. The maximum elevation Observed in the study area is 1105 m above MSL and minimum is 574 m above MSL. Total area of basin is 110 km^2 and Perimeter is 55.7 km.

LAND FORMS

A variety of landforms have been developed and identified in the study area due to the erosional and depositional processes of fluvial origin.

Feature due to fluvial processes:

Erosional features:

- Mesa: Fluvial erosional process guided by laterite has given rise to the geomorphic features of mesa. Flat top table land that is mesa has been observed at Sadawaghapur village at an altitude of 1105 m. Plateaus in basaltic flows are capped by laterites. Area under laterite capping is 4.24 km^2 which is 7.70 percentage of total study area.
- River valleys and stream basins: The River originates at the Sahyadri ranges at west and flow towards east and meets to Krishna River. V shaped valley are observed in western part of study area.
- Hills and escarpment: Hills and hillocks either continuous or discontinuous are observed in study area. This represented more or less promontories of the Sahyadri ranges exposed due west of the area: continuous hills have been recorded in the central part of the area, having flat top.

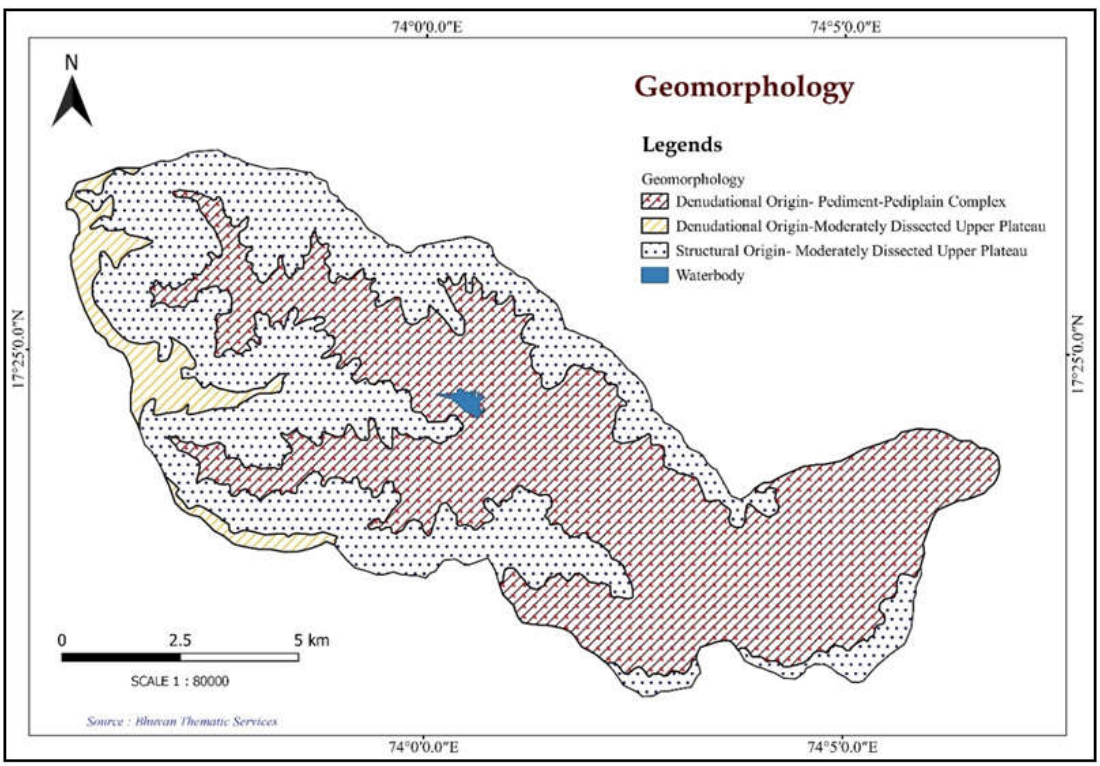

Figure 5: Geomorphology of study area

Depositional landforms

Meander: A meandering pattern is observed towards east of Chafal village. This is one of a series of regular turns in the channel of a river (Fig. 6). It is a tendency of a river to move back and forth along its channel, in an S shaped pattern over time. As the river takes a meander across flood plain or a channel it may leave behind a trace of the previous path of the channel. Its length is 1.58 km.

Figure 6: Meandering path of Uttar Mand River at Chafal

Drainage Morphometry

Stream ordering

'Stream order is defined as a measure of the portion of a stream in the hierarchical tributaries. Stream orders were calculated using Strahlers method (Strahler, 1964) and its length computed with the help of QGIS. The Uttar mand river is 5th order stream covering an area of 109.85 km^2. Stream order of drainage basin is the successive assimilation of the streams within a drainage basin. The ordering of the basin has been carried out by the method suggested by Strahler (1957). The Uttar Mand river basin is 5^{th} Orders (Table 2).

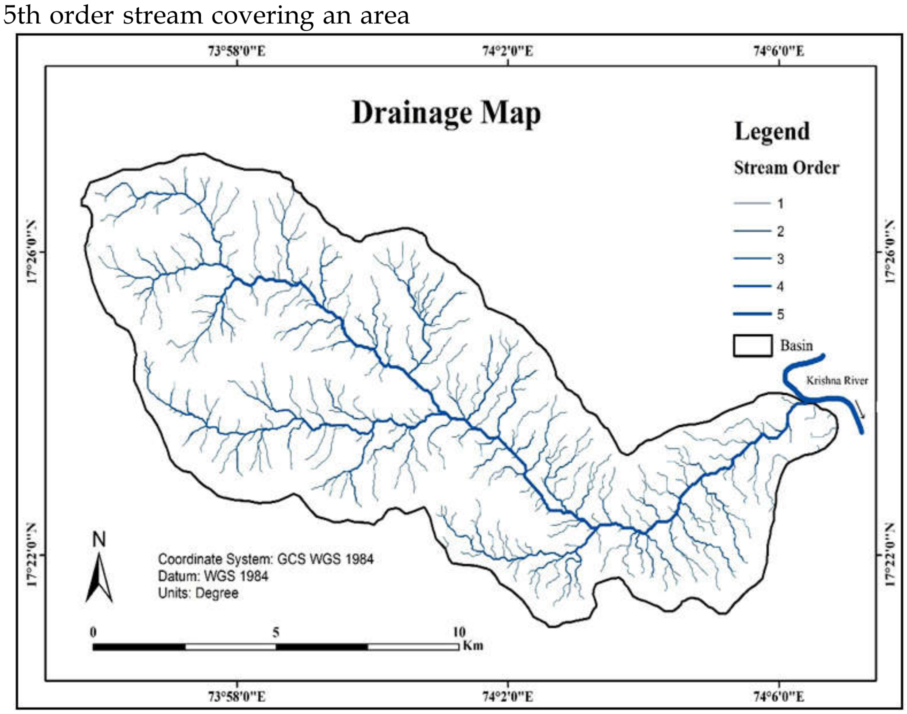

Figure 7: Drainage of the Study area

Bifurcation Ratio (Rb)

Bifurcation ratio is associated with the ordering sequence and appearance of the drainage network. It is measured by the ratio between given order (Nu) to the next higher order (Nu+1) to find out the bifurcation pattern of the stream related with geomorphology of the basin. 'Mean bifurcation ratios vary from about 2.00 for flat or rolling basins to 3.00 - 4.00 < for mountainous, hilly dissected basins' (R.E. Horton, 1945). It is the ratio of number and streams and any given order to the number streams in the next lower order (Horton, 1945).

$$Rb = \frac{Nu}{Nu + 1}$$

In the Uttar Mand river basin bifurcation ratio ranges from 3.97 to 5. The mean bifurcation ratio for Uttar Mand river basin is 4.29. This means that on average there are 4.29 times as many channel segments to any given order as of the next higher order. The average bifurcation ratio and the basin reveals that there appears to be no strong geological control in the development and the drainage, homogeneous nature of Lithology and drainage network in study area as well developed stage.

Stream Length (Lu)

Study of the streams length with respect to the stream order is of significant importance. Stream length for the basin and the given order is inversely proportional to the stream order. Stream length of the basin indicates surface runoff characteristics. Streams are relatively smaller lengths and characteristics and area with greater slopes. Stream length of Uttar Mand river basin is measured with the help of rotometer. The total stream length in Uttar Mand river basin is 267.57km (Table 2). The mean length of channel Lu and order U is the ratio of the total length to the number of streams of a given order. Mean length of channel segments of a given order is greater than that of the next lower order but less than that of the next higher order.

Table 2: Morphometric parameters of Uttar Mand River

Sr. No.	Parameters	Symbol	Formula	Ref.	Values obtained				
1.	Stream order	Su	Hierarchical rank	Strahler (1964)	I	II	III	IV	V
2.	Stream number	Nu	Hierarchical rank		334	84	20	4	1
3.	Stream length	Lu	Length of the stream	Horton (1945)	154.85	56.83	32.03	9.15	14.71
4.	Stream length ratio	Rl	Rl=Lu/Lu-1 Where, RL = Stream Length Ratio Lu = The total stream length of the order 'u' Lu – 1 = The total stream length of its next lower order		II/I	III/II	IV/III	V/IV	VI/V
					0.36	0.56	0.28	1.60	_
5.	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		I/II	II/III	III/IV	IV/V	V/VI
					3.97	4.2	5	4	_
6.	Mean bifurcation ratio	Rbm	Rbm=Average of bifurcation ratios of all orders	Strahler (1964)	4.29				
7.	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'	Horton (1945)	0.603 Km				
8.	Basin	P	P= perimeter of drainage		55.72 Km				

	perimeter		basin		
9.	Basin length	Lb	Lb=1.312*$A^{0.568}$		25.38 Km
10.	Basin area	A	Area from which water drains to common stream	Strahler (1964)	109.83 Km^2
11.	Drainage density	Dd	Dd=Lu/A Where, D = Drainage Density Lu = Total stream length of all orders A = Area of the Basin (km^2)	Horton (1945)	2.44 Km/Km^2
Sr. No.	**Parameters**	**Symbol**	**Formula**		**Values obtained**
12.	length of overland flow		$Length\ of\ overland\ flow = \frac{1}{2} \times \frac{1}{Dd}$		0.204 Km
13.	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)		4.03
14.	Drainage texture	Dt	Dt=Nu/P Where, Dt = Drainage Texture Nu = Total no. of streams of all orders P = Perimeter (km) Horton	Smith (1950)	7.85 Km
15.	Form factor ratio	Rf	Rf=A/Lb^2 Where, Rf = Form Factor A = Area of the Basin (km^2) Lb^2 = Square of Basin length	Horton (1945)	0.17
16.	Circulatory ratio	Rc	Rc = 4 * Pi * A / P^2 Where, Rc = Circularity Ratio Pi = 'Pi' value i.e., 3.14 A = Area of the Basin (km^2) P^2 = Square of the Perimeter (Km)	Strahler (1964)	0.44
17.	Elongation ratio	Re	Re = 2 v (A / Pi) / Lb Where, Re = Elongation Ratio A = Area of the Basin (km^2) Pi = 'Pi' value i.e., 3.14 Lb = Basin length	Schumm (1956)	0.46

AREAL ASPECT

Mean Basin area

The area of the different orders has been calculated with the help of planimeter and the data is refined with QGIS software. Basin area is one of the most important factors like stream length. The mean area of the basin for each order has been computed. Considering pairs of stream orders the area ratio were obtained, between the mean area of the basin of one order and that of the next lower order. From area ratio mean area ratio has been calculated. The values are presented in table 5. By plotting contributing area of the basin of each order against the total length of stream in that particular order, (Schum 1956) has come out with linear relationship between these two. The same plot has also been made by calculating area and total length of stream within a Uttar Mand Basin data is given in table 3, this complies with the observations made by (Schum 1956).

Table 3: Area Ratio

Stream order	Mean area	Area ratio	Total area in sq. km.	Product of 3×4
1	**2**	**3**	**4**	**5**
I	0.09	3.22	39.97	128.70
II	0.29	4.13	29.43	121.54
III	1.20	1.82	26.59	48.39
IV	2.19	6.67	8.77	58.49
V	14.61		14.61	
Total			119.37	357.12

Mean area ratio = 3.50
Weighted mean = 357.12 / 119.37
= 2.99

BASIN CONFIGURATION:

This quantitative measurement is made by computing three dimensionless ratios for determining the shape of a drainage basin which are described in following ways.
1. Form factor- It is the ratio of basin area to the square of basin length. The form factor for the Uttar Mand basin comes to 0.17.
2. Circulatory ratio- The ratio of area of the basin to the area of circle having the same circumference as the perimeter of the basin is called as circulatory ratio (Miller 1953). This is also called circularity or compactness ratio and for Uttar Mand basin it comes to 0.444.
3. Elongation ratio:- It is the ratio between diameter of circle of the same area as that of the drainage basin and the maximum length of the basin, for Uttar Mand basin elongation ratio comes to 0.46.

From the above three factors it can be stated that the average area of the streams of different order in a drainage basin increases geometrically with lower order basin area and show a linear relationship this is true also for Uttar Mand basin . Mean area ratio is 3.50. On the basis of values obtained for the Uttar Mand basin it can be inferred that in the Uttar Mand basin conditions are favorable for recharge of groundwater, as the ratio tends to higher value.

The Uttar Mand river basin is moderately compact and more elongated, the areal setup shows that the basin has low circulatory and higher elongation ratio. The shape of basin is significant as it affects stream discharge characteristic, Strahler (1957). The results of shape aspects show that surface water in Uttar Mand basin has to flow for longer distance in eastern direction, there by implying that there is more scope for infiltration as the water stays in the basin for longer time.

Drainage Density (Dd)

Drainage density is defined as a ratio of total length of all streams to the total area of the basin (Horton, 1932).

$$Dd = \frac{Lu}{A}$$

Drainage density of the any basin reveals the terrain configuration that is properties of rock of the area. In the study area southern half part of basin shows high drainage density which indicates region having non-resistant or impermeable subsurface material and mountainous relief, whereas northern half part of basin shows low drainage density which indicates region having highly resistant rock or highly permeable subsoil material and area with low relief (Geena, 2011). The overall drainage density (Dd) of the Uttar Mand river basin is 2.44 km/sq.km (Table 2).

Stream Frequency (Fs)

The stream frequency of the basin is the ratio of total number of stream segments of all orders to the basin area. (Horton, 1945)

$$Fs = \frac{Nu}{A}$$

It is a good indicator of drainage pattern. Stream frequency has been calculated by the number of streams divided by the total area of basin in sq. km. The stream frequency value of the Uttar Mand river basin is 4.03. High drainage density and high stream frequency in Uttar Mand river basin indicate larger runoff from the basin (Table 2).

Drainage Texture (Dt)

Strahler (1964) and others have explained the term drainage texture ratio to express the composition of a drainage network, using drainage density and steam frequency.

$$Dt = \frac{Fs}{Dd}$$

Uttar Mand has low texture ratio 7.85. Low Drainage texture ratio suggests higher infiltration (Ragarajan 2006). Hence Uttar Mand basin may have higher infiltration rate.

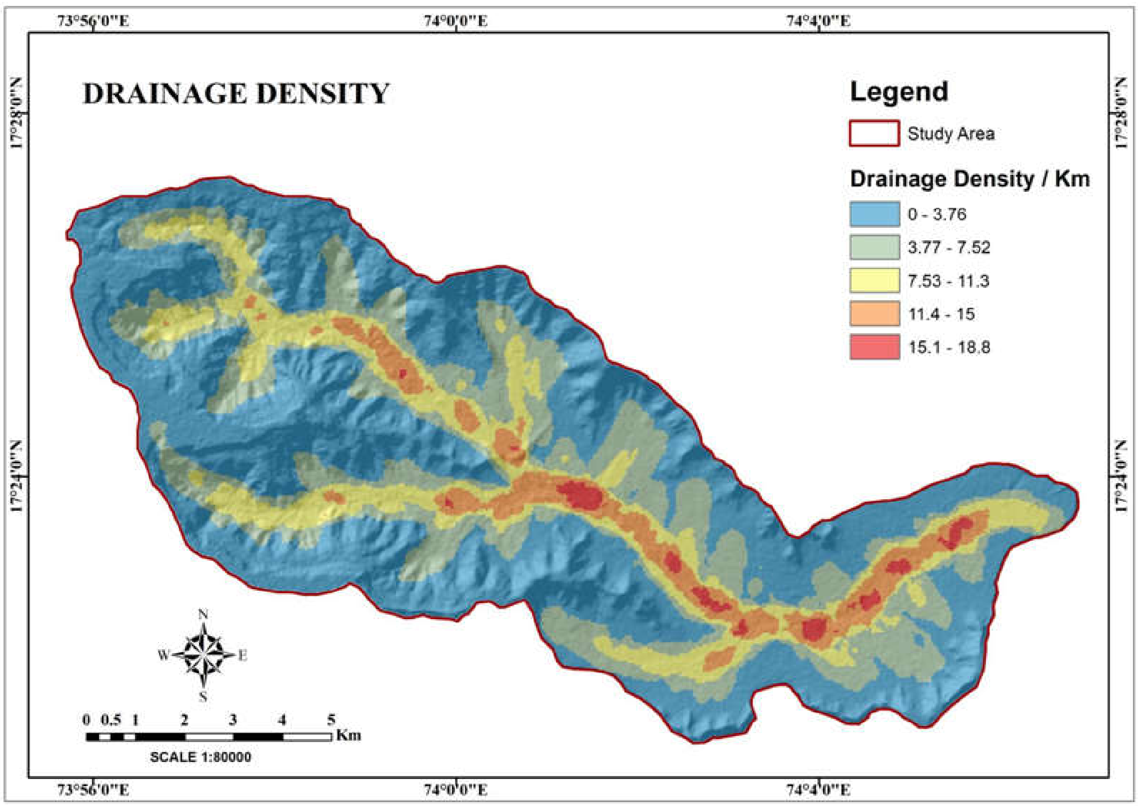

Figure 8: Drainage Density of the Study area

Length of overland flow:-

Length of overland flow refers to the distance travelled by rain water on the ground surface, before it gets localized into definite channel. It is roughly equal to half of the reciprocal of the drainage density.

$$Length\ of\ overland\ flow = \frac{1}{2} \times \frac{1}{Dd}$$

The length of overland flow for Uttar Mand basin is 0.204 kilometre.

RELIEF ASPECTS

The study area Uttar Mand watershed is characterized by altitudinal differences of 1105 m above sea level and 574 m above sea level maximum and minimum elevations respectively.

Channel gradient

The total difference of altitude that is height above mean sea level, from the source to the mouth is defined as Channel gradients. The total difference in altitude has been divided by horizontal distance measured along the channel.

$$Channel\ gradient\ = \frac{H}{Length\ of\ river}$$

The channel gradient computed for Uttar mand basin is 20.92 m/km.

Relief measures

The difference in elevation between source point to the mouth point of a basin, for Uttar Mand this difference is 531m and maximum measured length 25.38 km. The ratio between maximum relief differences (H) to the maximum length is the relief measure, for Uttar Mand it comes to 20.92.

Ruggedness number (Rn)

Ruggedness number (Rn) is the product of basin relief (H) and drainage density (Dd). The Rn of the entire Uttar Mand River Basin is 1.29, indicating a Moderate basin relief. Such values are characteristic of Moderate elevation region (Schumn1956).

Constant of Channel Maintenance (1/Dd)

The constant indicates the number of Km^2 of basin surface required to develop and sustain a channel of 1 Km length. Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms. The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). Channel maintenance constant of the sub watershed varies between 0.409 Km^2/Km.

Sub watersheds of Uttar Mand river basin.

Uttar Mand River is further sub divided into four sub watersheds. These sub watersheds are named as SW1, SW2, SW3 and SW4 respectively.

1. Stream order- The Uttar Mand river is fifth order basin covering an area of 109.83 Km^2. The sub-watershed SW1, SW2, SW3 and SW4 have 4^{th} order streams cover an area of 32.86, 28.66, 27.98 and 20.34 Km2, respectively.
2. Stream length- The stream length (Lu) has been computed based on the law proposed by Stralher (1964) for all the four sub-watersheds (table 4). Normally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. This change indicate flowing of streams from high altitude, lithological variation and moderately steep slopes.
3. Mean stream length (Lsm)- The mean stream length of a channel is a dimensional property and reveals the characteristic size of drainage network components and its contributing basin surfaces (Strahler, 1964). By dividing the total stream length of every order by the total number of stream segments in all order, the mean stream length (Lsm) was computed. Table 4 indicates that Lsm in the sub-watersheds ranges from 0.55 to 0.59 km. This deviation is due to variation in slope and topography.
4. Stream length ratio (Rl)- Horton's law (1945) of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with stream length increasing towards higher order of streams. The RL across streams of different orders in the research area demonstrates that each sub-watershed has a different RL. (Table 4). This variation is due to changes in slope and topography. Sub-watershed numbered SW3, SW4, SW2 and SW1 show an increasing trend resprctively in the length ratio from lower order to higher order indicating their mature geomorphic stage.
5. Bifurcation ratio (Rb)- The term bifurcation ratio (Rb) is defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher order (Schumn, 1956). Further, Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation for different regions/environment except where the

powerful geological control dominates. If the bifurcation ratio is not same from one order to its next order, then these irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). In the study area mean bifurcation ratio (Rbm) varies from 4.15 to 4.64, lower value in SW4 suggest less structural disturbance, whereas higher value in SW1 indicates that it has structurally controlled drainage pattern.

6. Drainage density (Dd) - Horton (1932), proposed the term drainage density (Dd), which is a key measure of the linear scale of fluvial topographic landform features. It is defined as the total length of streams of all orders per drainage area. Drainage density in all the sub-watersheds of Uttar Mand watershed varies from 2.16 to 2.39 Km/Km^2. The highest value of drainage density is recorded in SW 3 and SW4, whereas lowest drainage density is found in SW 2.
7. Stream frequency (Fs) - Stream frequency is expressed as the total number of stream segments of all orders per unit area. Reddy et al. (2004) stated that low values of stream frequency (Fs) indicate presence of a permeable subsurface material and low relief. Stream frequency values of the sub-watersheds vary from 3.77 (SW4) to 4.32 (SW3), suggests sub-watersheds having lower Fs values represents low relief and permeable sub surface material like vesicular and fractured basalts. Whereas, Higher Fs values indicate resistant/low conducting subsurface material such as huge basalt, scarce vegetation, and high topography in sub-watersheds.
8. Form Factor (Rf) - Horton's (1932), form factor may be defined, as the ratio of basin area to basin length squared. Larger peak flows for shorter durations occur in basins with high form factors, whereas lower peak flows for extended time frames occur in elongated watersheds with low form factors. In the Uttar Mand watershed, Rf values have been found varying from 0.162(SW 3) to 0.304 (SW1), which is very nearer to zero and thus represents highly elongated in shape. A flatter peak flow of longer duration is expected in these elongated basins with low form factor. Flood flows in elongated basin are easier to manage that of the circular basin.
9. Circulatory ratio (Rc) - Circulatory ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length, frequency and gradient of streams, geological structures, land use /land cover, climate and slope of the basin. The sub-watershed SW1, SW2, SW3 and SW4 gave of 0.59, 0.379, 0.279, 0.302 value respectively. SW1 with greater than 0.5 values suggests that they are more or less circular in shape and are characterised by the high to moderate relief and the drainage system were structurally controlled.
10. Elongation ratio (Re) - Schumm (1956) defined elongation ratio (Re) as the ratio of the diameter of a circle in the same area as the drainage basin to the basin's greatest length. Values of Re generally vary from 0.45 to 0.62 over a wide variety of climatic and geological conditions.

Table 4: Morphometric parameters of individual sub watershed

Sr. No.	Parameters		Values obtained			
	Sub Watershed		**SW 1**	**SW 2**	**SW 3**	**SW 4**
1	Stream number	1	99	82	92	61
		2	24	21	23	16
		3	5	4	5	6
		4	1	1	1	1
2	Stream length	1	45.99	38.33	43.39	27.14
		2	14.61	13.12	15.46	13.64
		3	9.11	8.7	8.16	6.06
		4	6.46	1.77	0.08	0.84
3	Stream length ratio	II/I	0.317	0.342	0.356	0.502
		III/II	0.623	0.663	0.527	0.444

		IV/III	0.709	0.203	0.009	0.138
4	Bifurcation ratio	I/II	4.12	3.9	4	3.81
		II/III	4.8	5.25	4.6	2.66
		III/IV	5	4	5	6
5	Area (Km2)		32.86	28.66	27.98	20.34
6	Perimeter (Km)		26.24	30.8	35.44	29.06
7	Mean stream length		0.59	0.57	0.55	0.56
8	Mean bifurcation ratio		4.64	4.383	4.533	4.156
9	Basin Length (Km)		10.38	13	13.11	10.05
10	Drainage density Dd Km/Km2)		2.318	2.160	2.397	2.344
11	Stream frequency Fs		3.925	3.77	4.32	4.13
12	Form Factor (Rf)		0.304	0.169	0.162	0.201
13	Circulatory ratio (Rc)		0.59	0.379	0.279	0.302
14	Elongation ration\ (Rc)		0.623	0.464	0.455	0.506

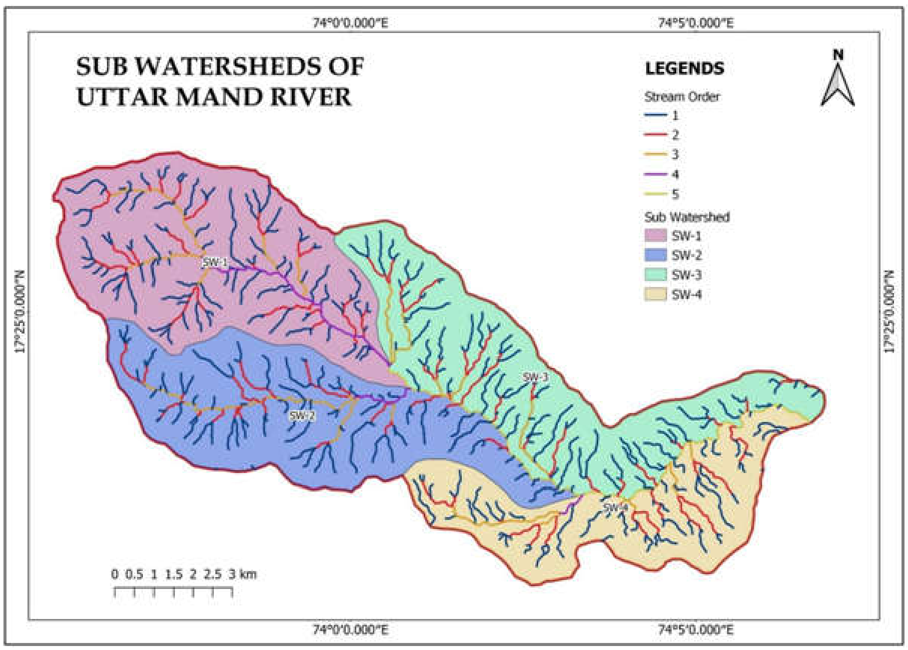

Figure 9: Sub watersheds of Uttar mand River

Slope analysis

The areas showing nearly level land (0-1% slope) occur in the highland terrain located in Sadavaghapur, Sadadhadoli, Bodkewadi and also in low land areas of Khalkarwadi, Charegaon, Bhavanwadi & Shivde. Very gently sloping (1-3 % slope) area occurs in Majgaon, Jadhavwadi, Chaphal, Polachiwadi, Shankarwadi Sitalwadi. Bodkewadi, Jangalwadi, Singanwadi, Dervan, Vaghjaiwadi, Gamewadi, Kadawadi, Kharadewadi, Nanegaon Khurd include the area which are gently Moderately sloping land (3-8 % Slope). Areas of Vanaswadi, Singanwadi, Babarwadi, Dadoli, Kochrewadi, Sadaninai, Dhayati, Padloshi, Tawarewadi & Bhatwadi show Strongly sloping to Steep Sloping area i.e. 8-30% Slope. Parts of Chavanwadi, Virwadi, Weir, Sadawaghapur, Muslewadi, Naralwadi, Sadakalid, Sadaninai, Kocharewadi, Bhairewadi villages show very steep slope (>30% Slope).

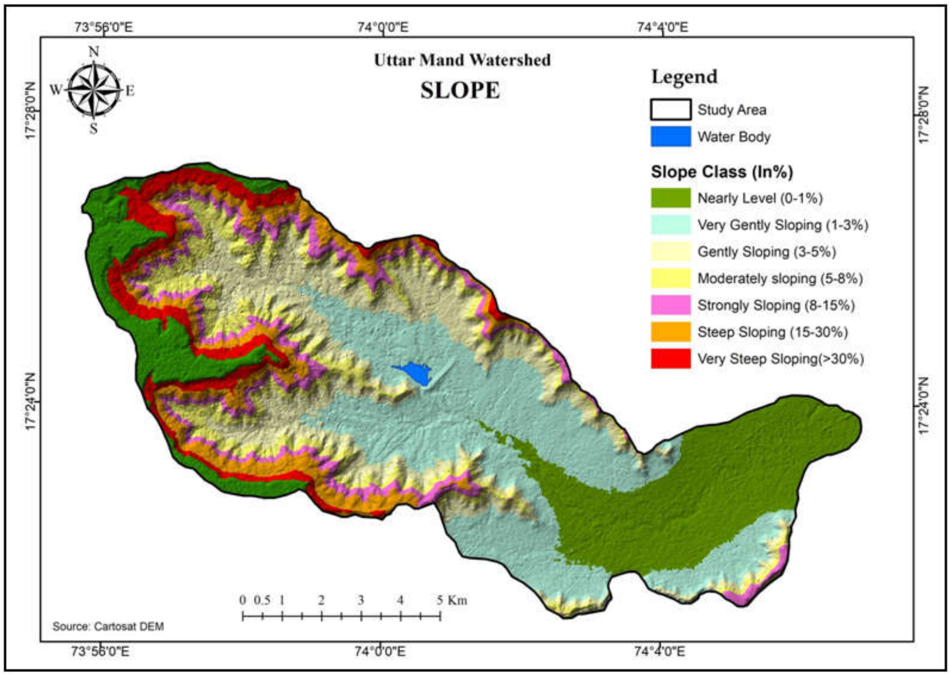

Figure 10: Slope of study area.

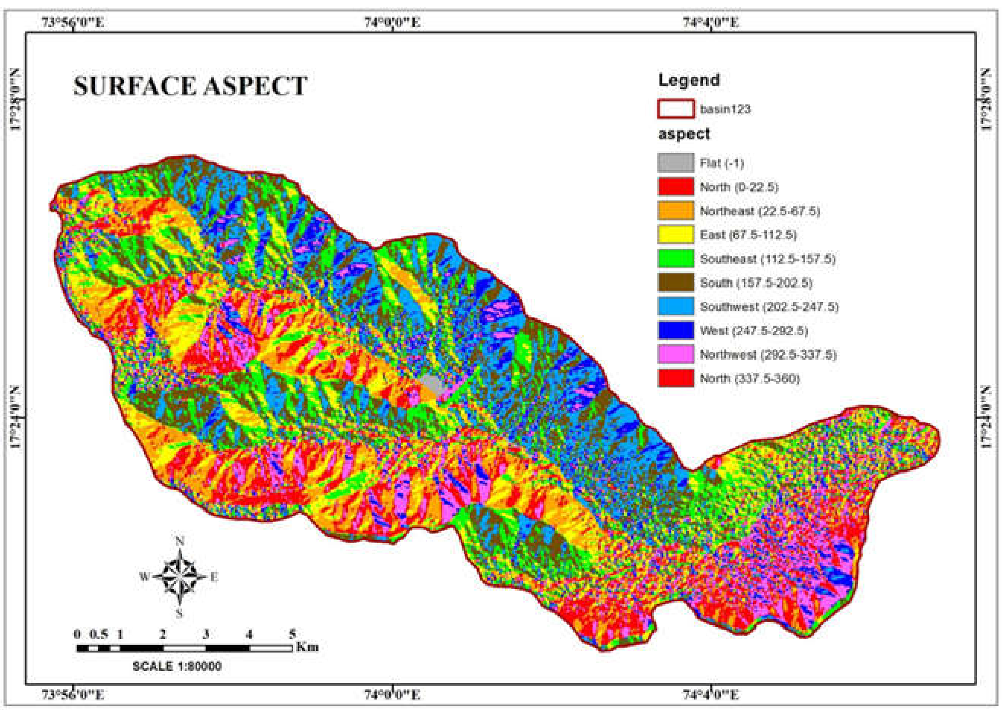

Figure 11: Aspect map of study area

Lineaments

The lineaments are linear structural features and are considered as surface signatures of the faults present in the area. The most significant numbers of lineaments orient towards NW-SE. The other prominent direction in which the lineaments are aligned is NNE-SSW. Some of the lineaments identified in the region aligned in the E-W direction. The lineaments in the study area are derived NRSC Bhuvan Geo Portal. All the lineaments observed in area are drainage parallel type.

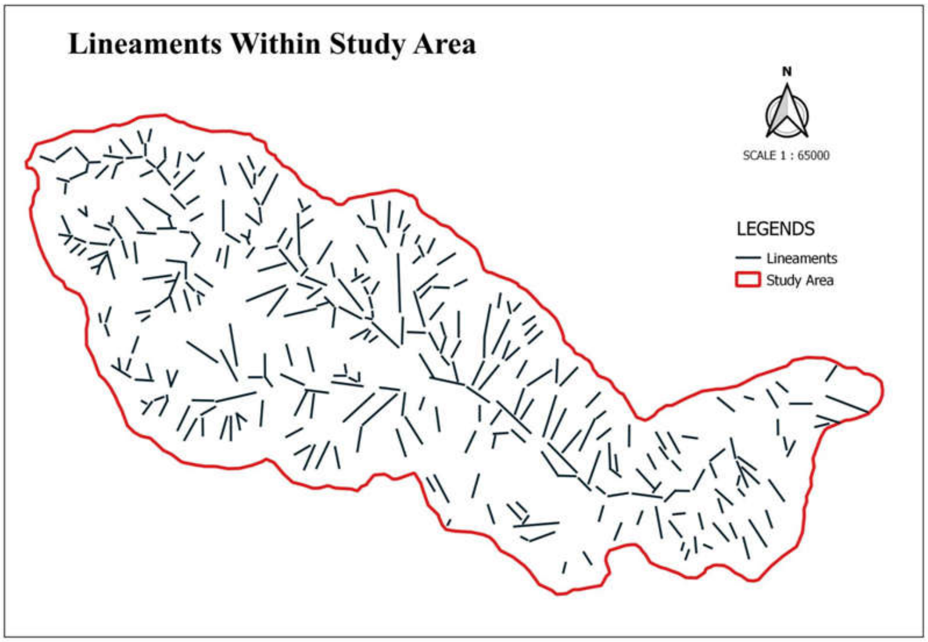

Figure 12: Lineaments within study area

Table 5: Lineament Analysis

Azimuth	*Lineament number*	*Lineament number %*	*Lineament Length*	*Lineament Length %*
0_10	22	8.17	8.6	6.55
10_20	14	5.2	6.9	5.25
20_30	18	6.69	7.7	5.86
30_40	12	4.46	6.7	5.1
40_50	14	5.2	6.1	4.64
50_60	12	4.46	4.6	3.5
60_70	12	4.46	5.5	4.19
70_80	8	2.97	4	3.04
80_90	10	3.71	5.4	4.11
90_100	4	1.48	1.5	1.14
100_110	5	1.85	2.4	1.82

110_120	21	7.80	9.2	7.01
120_130	10	3.71	5.7	4.34
130_140	22	8.17	11.9	9.07
140_150	27	10.03	12.9	9.83
150_160	19	7.06	9.6	7.31
160_170	20	7.43	9.6	7.31
170_180	19	7.06	12.9	9.83

Hypsometric analysis

Hypsometric analysis describes the elevation distribution across an area of land surface. It is an important tool to assess and compare the geomorphic evolution of various landforms irrespective of the factor that may be responsible for it. The major factors governing the evolution of landscape are tectonics and/or climate and the variation in lithology. The hydrological process depends on many basin properties, the relief ratio and catchment volume plays important roles in determining runoff. The relief ratio indicates over all change in gradient of a basin and controls lateral water redistribution, while the catchment volume which is defines as the amount of mass above a datum provides a measure of storage capacity and determines locations of ground water seepage.

The relief ratio and catchment volume can be concisely captured through the hypsometric curve. The hypsometry curve is typically represented as distribution of the relative height (h/H) with relative area (a/A) (Strahler 1952).

$$Relative\ Area = \frac{Total\ area - Area\ below\ Specific\ contour}{Total\ Area}$$

$$Relative\ Height = \frac{Relative\ Relief - (Value\ of\ contour - Lowest\ elevation\ in\ basin)}{Relative\ Relief}$$

Strahler (1952) interpreted the shapes of the hypsometric curves by analyzing numerous drainage basins and classified the basins as youth (convex upward curves) mature (S shaped hypsometric curves which is concave upwards at high elevations and convex downwards at low elevations) and peneplain or distorted (concave upwards curves). These hypsometric curve shapes described the stages of landscape evolution which also provides an indication of erosion status of watershed. Convex shaped hypsometric curves indicate that the watershed is stabilized and the concave hypsometric curve more proneness of watershed to the erosion processes (Hurtrez and Lucazeau 1999). The link between horizontal cross-sectional drainage basin area and elevation is known as hypsometric analysis. Langbein (1947) was the first to use hypsometric analysis to express the overall slope and drainage basin shapes. For hypsometric analysis, two ratios are computed, one a/A where "a" is the area enclosed between given contour within the basin and "A" is the total area of the basin. And second ratio h/H, where "h" is the height of the contour above the base contour and "H" is the total difference of elevation in the basin.

The hypsometric integral (HI) is geo-morphological parameter classified under the geological stages of watershed development. It assumes importance in estimation of erosion status of watershed and subsequent prioritization for taking up soil and water conservation activities. A hypsometric integral is usually calculated by plotting the cumulative height and the cumulative area under that height for individual watersheds and then taking the area under that curve to get the hypsometric integral.

Table 6: Hypsometric data

S. No.	Contour Elevation	Area Below Respective Contour	a	a/A	h	h/H
1	574	0.00	106.63	1	0	1
2	600	34.54	72.09	0.68	26.00	0.95
3	700	63.79	42.84	0.40	126.00	0.76
4	800	79.12	27.51	0.26	226.00	0.57
5	900	91.85	14.78	0.14	326.00	0.39
6	1000	102.11	4.52	0.04	426.00	0.20
7	1105	106.63	0.00	0.00	531.00	0.00

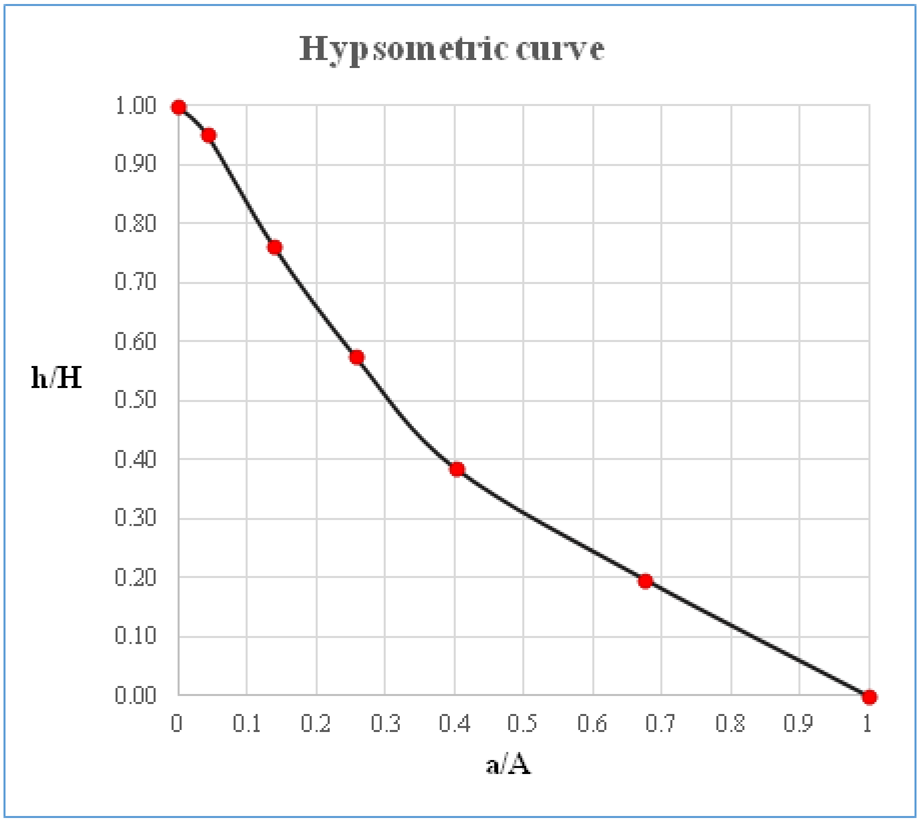

Figure 13: Hypsometric Curve of the Uttar Mand river basin

CONCLUSION

According to morphometric analysis of the Uttar Mand river basin, it is a fifth-order basin that is transitioning from an early mature to an older stage of the fluvial geomorphic cycle. The drainage pattern of the basin is dendritic in nature. A particular order's mean channel segment length is more than the next lower order but less than the next higher order. The relationship between stream order and mean stream length provides a group of points that lie roughly along a curve line, indicating that the area is not subject to severe structural influence. The average bifurcation ratio of the basin demonstrates that there appears to be no strong geological constraint over drainage development, uniform lithology, and a well-developed drainage network in the research area. The elongation ratio, circulatory ratio and form factor reveals that the Uttar Mand river basin is highly elongated and flood flows are easier to manage than that of circulatory basins. The study also reveals that the texture of Uttar Mand river basin is very fine and basin is highly elongated. The drainage basin size analysis reveals that the flooding is lesser. The difference in elevation between source point to the mouth point of a basin, for Uttar Mand this difference is 531m and maximum measured length 25.38 km. The ratio between maximum relief differences (H) to the maximum length is the relief measure, for Uttar Mand it comes to 20.92. Ruggedness number (Rn) is the product of basin relief (H) and drainage density (Dd). The Rn of the entire Uttar Mand River Basin is 1.29, indicating a Moderate basin relief. Such values are characteristic of Moderate elevation region (Schumn1956). The length of overland flow for Uttar Mand basin is 0.204 kilometre. The study area Uttar Mand watershed is characterized by altitudinal differences of 1105 m above sea level and 574 m above sea level maximum and minimum elevations respectively. Hypsometric integral is 0.37. It indicates an old stream as 37 percent of basin landmass is to be old stage of dissection.

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