Morphometric Analysis of a Lower Wardha River sub basin of Maharashtra, India Using ASTER DEM Data and GIS

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Abstract:

The study area is part of lower Wardha river of Wardha River basin, lies between 20^0 16' 00'' N to 20^0 35' 00''N latitude and 78^0 14' 00'' E to 78^0 38' 00'' E longitude with an area about 781.84 km^2 and entire study area has been further divided into sub-watersheds,. It is covered in the Survey of India (SOI) toposheet numbers 55 L/2, L/3, L/6. L/7, L/11 & L/12 on 1:50,000 scale in Yeotmal and Wardha District Maharashtra area, India and forming a part of the hardrock terrain. The drainage network shows dendritic to sub-dendritic pattern and is non-perennial in nature. Poor soil cover, sparse vegetation, erratic rainfall and lack of soil moisture characterize the area for most part of the year. Recurring drought coupled with increase in groundwater exploitation results in decline the groundwater level. For detailed study we used Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data for preparing Digital Elevation Model (DEM) and slope maps, Geographical information system (GIS) was used in evaluation of linear, areal and relief aspects of morphometric parameters. After then topology building of the drainage layer in GIS software, from these parameters various drainage characteristics are calculated such as bifurcation ratio, drainage density, stream frequency circulatory ratio, and elongation ratios for basin evolution studies. The understanding of streams in a drainage system constitutes the drainage pattern, which in turn replicates mainly structural/lithologic controls of the underlying rocks. The development of stream segments in the basin area is more or less affected by rainfall. The morphometric parameters are computed using Arc Map 10.2 version GIS software. It is concluded that remote sensing and GIS have been proved to be efficient tools in drainage delineation and updation. Relief ratio indicates that the discharge capability of these watersheds is very high and the groundwater potential is meager. These studies are extremely useful for planning rainwater harvesting and watershed management.

Keywords: Morphometric analysis, ASTER data, GIS and Wardha River sub basin

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Introduction

Remotely sensed high spatial resolution data together with topographical data based analysis procedures, have come out as highly effective tool to understand and manage the natural resources. It provides the near real time and accurate information related to distinct geological formation, landforms and helps in identification of drainage channels, which are altered by natural forces and human activities. GIS is an effective tool to analyze spatial and non-spatial data on drainage, geology, landforms parameters to understand their interrelationship. Basin morphometry is a means of numerically analyzing or mathematically quantifying various aspects of drainage channel and its characteristics that can be measured for comparison which includes, the number, length, drainage density and bifurcation of rivers as well as shape, area, relief and slope of the basin.

Drainage characteristics of basin and sub-basin have been studied using conventional methods (Horton, 1945; Miller, 1953; Strahler, 1964). Morphometric analysis using remote sensing and GIS techniques have been well demonstrated by some of the researchers (Nautiyal, 1994; Srivastava et al., 1995; Srivastava, 1997; Nag, 1998; Agarwal 1998; Biswas et al., 1999; Shreedevi et al., 2001, 2004, Vittala et al., 2004). As a common conclusion they indicated that remote sensing and geographical information system as powerful tools for studying basin morphometry and continuous monitoring. In the present paper an attempt has been made to (i) delineate different physical characteristics of the drainage basins and understand the relationship among them, (ii) understand the role of lithology and geologic structures in development of drainage pattern. The importance of water has been recognized and more emphasis is being given on its economic use and better management. The basin morphometric characteristics of the various basins have been studied by many studied by scientists using conventional methods (Krishnamurthy and Srinivas, 1995, Srivastava and Mitra, 1995; Agarwal, 1998; Biswas et al., 1999, Narendra and Nageswara Rao, 2006).

Study area

The study area comprises of Deccan trap basaltic hard rock and recently deposited alluvium connected by an intervening tract. The lower Wardha watersheds are elongated watershed in shape occupies in Yeotmal district of Maharashtra, India (Fig. 1). The study area is bounded within 78°12’ 00’’E and 78° 40’ 00’’ E longitudes and 20° 16’ 00’’N to 20° 36’ 00’’N latitudes. The given study area is major part of the lower Wardha river sub which flows up the hilly terrain of Yeotmal district of Maharashtra, India from northwest to south east direction.

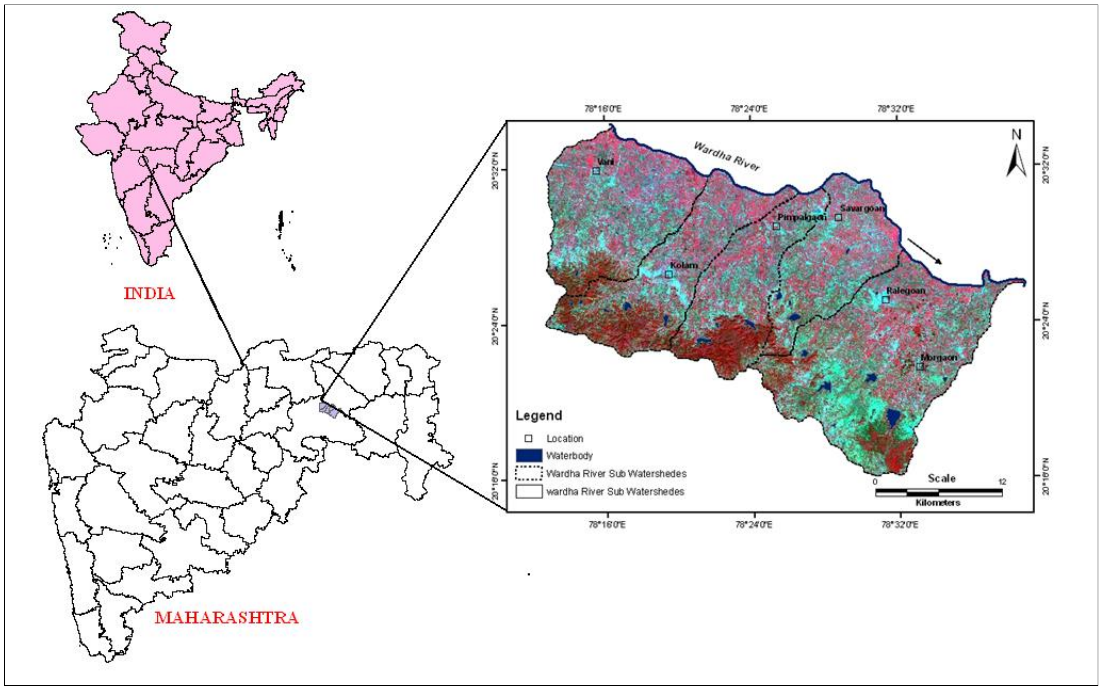

Fig.1: Location map of the study area

Methodology and Data used

In the present study fallowing database is being used for the analysis;

(1) Drainage data obtained from Survey of India Topographical map

(2) Geological map of the study area

(3) Satellite imagery IRS P6 L3 false color composite (Fig.2)

(4) ASTER-GDEM 30m (USGS/NASA ASTER DEM data), available from http://www.gdem.ASTER.ersdac.or.jp (Fig.3).

For the preparation of base map, SOI top sheets on 1:50,000 scales were used. The digital data and georectified from Indian remote sensing satellite (LISS) III with 23.5 m spatial resolution with four spectral bands was used to meet the requirement of area under study. False colour composite (FCC) on 1:50,000 scale, having band combination of 3:2:1 (NIR: red: green) (Fig. 2). The SOI topsheets and digital satellite data were geometrically rectified and georeferenced and merged using ARC GIS 10.2 software. The morphometric analysis of the Lower Wardha watershed has been analyzed using Indian remote sensing satellite imagery which were collected and registered to survey of India topographical sheets at 1:50,000 scale.

The study area has been subdivided into five subwatersheds based on the arrangement of the stream namely Kotha watershed, Chakravati watersheds, Pimpalgaon watersheds, Savargaon watersheds and Ralegaon watersheds (Fig.). A quantitative, morphometric analysis of a drainage basin is considered to be the most satisfactory method because it enables (i) to understand the relationship among different aspects of the drainage pattern of the basin, (ii) to make a comparative evaluation of different drainage basins developed in various geologic and climatic regimes and (iii) to define certain useful variables of drainage basins in numerical terms. The morphometric parameters computed include stream order (u), Bifurcation ratio (Rb), stream length (Lu), stream frequency, basin shape, form factor (Rf), circulatory ratio (Rc), and drainage density (D), constant of channel maintenance.

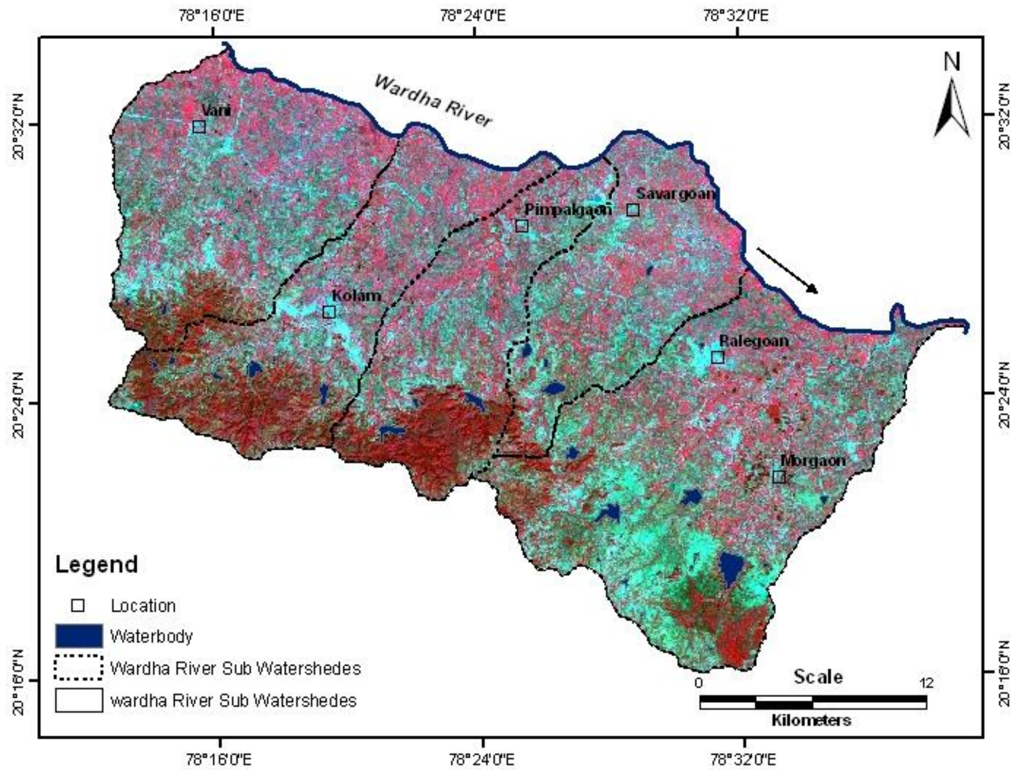

Fig. 2: IRS LISS III false color composite data (23.5mt) of the study area

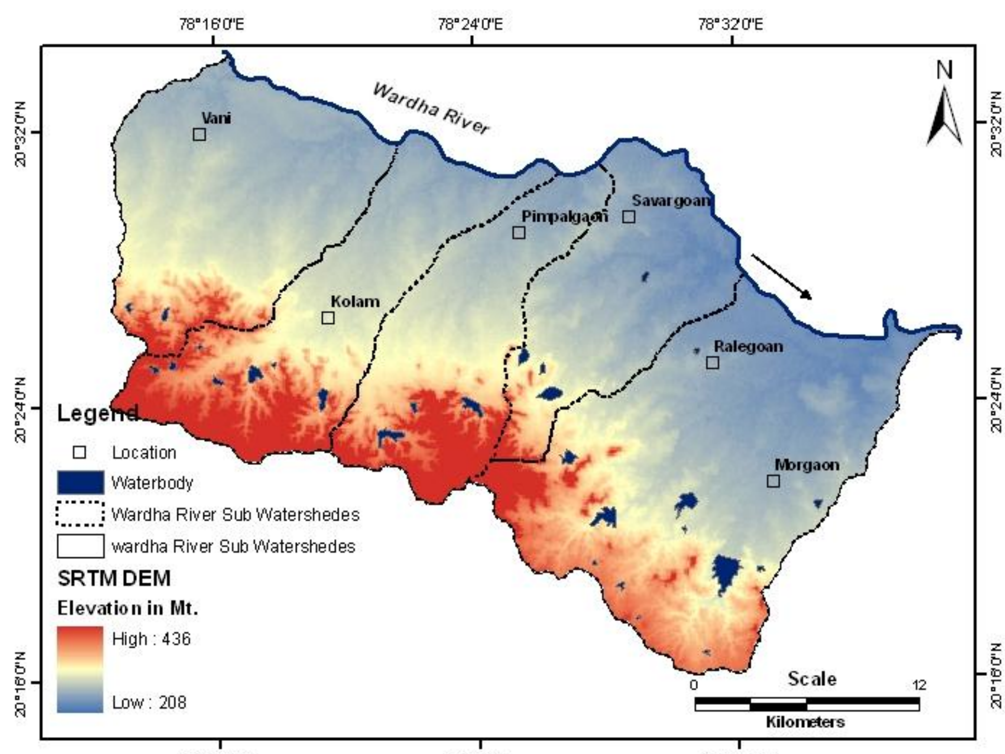

Fig.3: ASTER DEM data of 30 mt of the study area

Morphometry

According to Clarke (1966), morphometry is the measurement and mathematical analysis of the configuration of the earth surface, shape and dimensions of its landforms. The morphometric analysis is carried out through measurement of linear, areal and relief aspects of the basin and slope contribution (Nag and Chakraborty, 2003). The measurement of various morphometric parameters namely- stream order, stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb),mean bifurcation ratio(Rbm), relief ratio (Rh) drainage density (D), stream frequency (Fs) drainage fexture (Rt), from factor (Rf), circulatory ratio (Rc), elongation ratio (Re) length of overland flow (Lg) has been carried out and the data are presented in Table 1 .

Table 1: Formulae adopted for computation of Morphometric parameters

Sr. No.	Morphometric parameters	Formula	Reference
1	Stream Order	Heirachial rank	Strahler (1964)
2	Stream Length(Lu)	Length of the Stream	Horton (1945)
3	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'	Schumn(1956)
4	Stream Length ratio (RL)	RL=Lu/Lu-1 Where,RL=Stream Length ratio; Lu=Total stream length of the order 'u'; Lu-1=The total stream length of its next order	Horton (1945)
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	Schumn(1956)
6	Mean Bifurcation ratio	Rbm=Average of Bifurcation ratios of all orders	Strahler(1957)
7	Relief ratio(Rf)	Rh=H/Lb Where,Rh= Releif ratio, H= Total Relief (Relative Relief) of the basin (km), Lb=Basic length	Schumn(1956)
8	Drainage Density (D)	D= Lu/A, Where, D= Drainage Density Lu=Toatl stream length of all orders, A= Area of the basin(km^2)	Horton (1945)
9	Stream Frequency(Fs)	Fs= Nu/A Where, Fs= Stream Frequency, Nu=Toatl no.of streams of all orders, A= Area of the basin(km^2)	Horton (1932)
10	Drainage Texture(Rt)	Rt=Nu/P Where, Rt=Drainage Texture, Nu=Total no.of streams of all orders, P=Perimeter(Km)	Horton (1945)
11	Form Factor(Rf)	$Rf= A/Lb^2$ Where, Rf=Form Factor, A=Area of the basin(km^2), Lb^2= Square of Basin length	Horton (1932)
12	Circulatory Ratio (Rc)	$Rc=4*Pi*A/P^2$ Where ,Rc=Circulatory ratio, Pi=Pi value i.e., 3.14A= Area of the basin(km^2), P^2=Square of the	Miller(1953)

		perimeter (km)	
13	Elongation ratio (Re)	Re=2√(A/π)/Lb Where.Re=Elongation ratio, A=Area of the basin(km^2), Pi='Pi' value i.e., 3.14 Lb= Basin length	Schumn(1956)
14	Length of overland flow (Lg)	Lg=1/D*2, where,Lg=Length of overland flow, D= Drainage Density	Horton (1945)

Results and Conclusion

Quantitative analysis of drainage basin and channel networks, developed from qualitative and deductive studies subsequent to the valuable contribution of Horton (1945), Strahler (1957), Morisawa (1959), Melton (1957), Leopold and Miller (1956). The analysis of basins as either single unit or group of units comprises a distinct morphological region and it has particular relevance to geomorphology (Doornkamp and Cuchlaine 1971).

Linear aspects, Stream order (Nu), stream length (Lu), stream length ratio, mean stream length, and bifurcation ratio (Rb) are linear aspects that were determined and results have been given in Table 2, 3 & 4. Stream order (Nu). The first step in morphometric analysis of a drainage basin is the designation of stream orders. The designation of stream orders is based on a hierarchic ranking of stream. Measurements and statistical analysis of stream's lengths and overland flow length are among the most commonly used attributes. There are a number of methods of indicating stream orders for a stream network (Horton, 1945; Strahler, 1964). According to Strahler (1964), the smallest tributaries having one end free are designated as order 1. Where two first-order tributaries join, the resultant tributary of order 2 is formed; where two of order 2 join, a segment of order 3 is formed; and so forth. The order wise stream numbers, area and stream length of the seven watersheds are presented in table 1. The order wise total number of stream segment is known as the stream number. Horton (1945) laws of stream numbers states that the number of stream of each order forms an inverse relation with stream order (Fig.4). The linear pattern also indicates homogeneous lithology subjected to weathering. Out of five, watersheds 1(Kotha) & 4(Savar) have total 4 (1 to 4) stream orders each whereas watershed 2 (Chakravati) & watershed 3 (Pim) has five stream orders each (1 to 5) & the watershed 5 (Ralegaon) has total 6 stream orders (1 to 6).

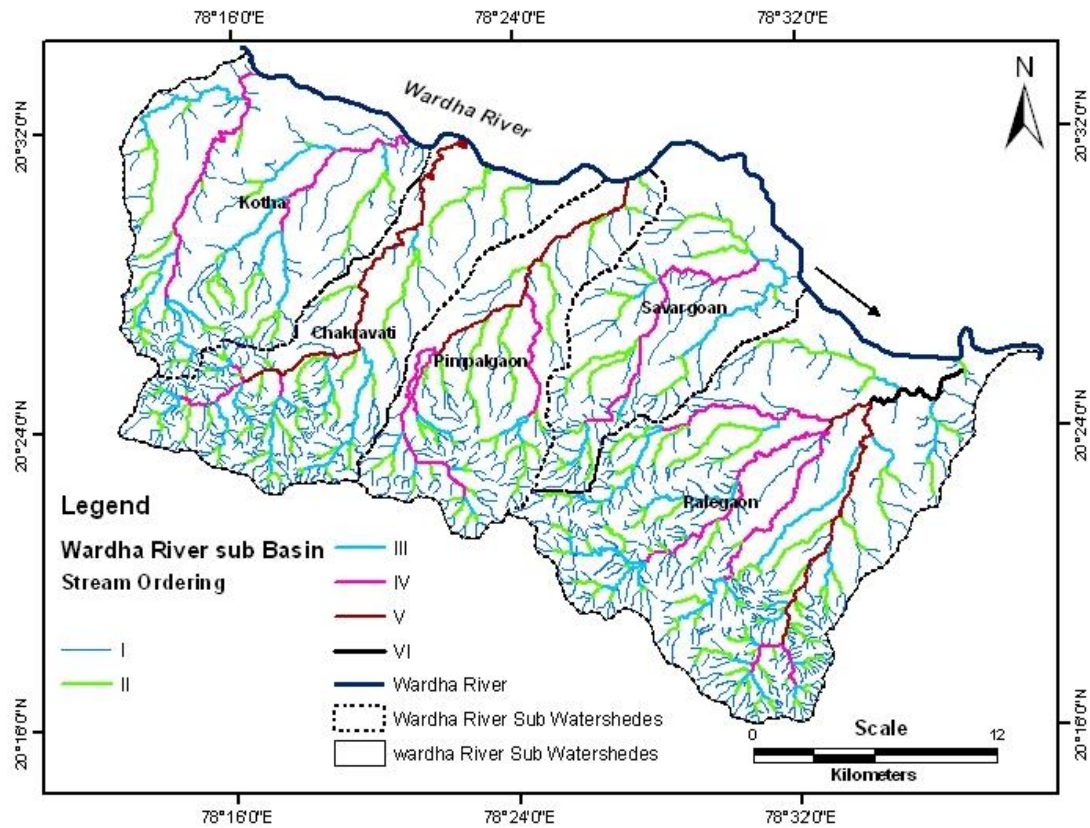

Fig.4: Drainage map of the study area

Stream length (Lu)

The length of river network has been measured using GIS techniques. Stream length is measured separately for each stream order & those has been computed based on the law proposed by Horton (1945) for all the watersheds of the study area. Usually the total length of stream segment is maximum for the first order streams & decreases as the stream order increase. In the present case, watershed 2 (Chakravi) & watershed 3 (Pim) show variation from general observation (Table 2). This may be due to flowing of streams from high altitude, change in rock type & moderately steep slopes and probable uplift across the basin (Singh & Singh, 1997; Vittala et al., 2004 and chopra et al., 2005). The total sum of stream lengths of watershed V is larger than watershed I to IV clearly indicating more infilteration in the watershed I to IV.

Mean Stram Length

Mean stream length (Lsm) is a characteristic properly related to the drainage network components and its associated basin surfaces (Strahler, 1964). This has been calculated by dividing the total stream length of order (u) by the number of streams of segments in the order. The mean stream length is presented in table 3. It is seen that, Lsm values exhibit variation from 0.67 to 24.15. Here, generally the mean stream length show increase in the number (Table 3).

Bifurcation ratio (Rb)

The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in the next higher order (Schumn, 1956). The bifurcation ratio, for a given density of drainage lines, is very much controlled by basin shape and shows a very little variation (ranging between 3 and 5) in homogeneous bedrock from one area to another (Chorley, 1984). The bifurcation ratio will not be precisely the same from one order to the next because of the possibility of variations in basin geometry and the lithology, but tends to be a constant throughout the series. Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern (Strahler, 1964, Gokhale, 2005). The lower bifurcation ratio values are characteristics of the watershed, which has suffered less structural disturbances and the drainage pattern has not been distorted by the structural disturbances. The bifurcation ratio is also indicative of shape of the basin also. An elongated basin is likely to have a high Rb, whereas a circular basin is likely to have low Rb. Abnormally high values of bifurcation ratio in the study area can be because of steeply dipping rock strata. The average bifurcation ratios calculated for five watersheds are given in (Table 4).

Relief aspect

Relief is the elevation difference between the heights and lowest point on the valley floor of the region. The relief measurements like relief ratio, basin length and total relief have been carried out and the data given in table 5.

Relief ratio

The maximum relief to horizontal distance along the longest dimension of the basin parallel to the principle drainage line is termed as relief ratio (Schumn, 1956). Relief ratio has direct relation between the relief and channel gradient. The relief ratio normally increases with decreasing drainage area and size of the watersheds of a given drainage basin (Gottaschalk, 1964). In the study area, the values of relief ratio are ranging from 7.02 to 10.17 (Table 5). It is observed that the Rh values increase with decreasing drainage area and size of a given drainage basin as proposed by Gottaschalk (1964).

Aerial aspects

Aerial aspects include different morphometric parameters, like drainage density, texture ratio, stream frequency, form factor, circulatory ratio, elongation ratio and length of the overland flow. The values of these parameters are presented in table 2 and interpreted below.

Drainage density (Dd)

It is measured as a sum of the channel lengths per unit area and obtained by dividing the total stream length by total area of the basin. Drainage density is controlled by the type of formations in the basin areas with impervious formations will have higher drainage density than those with pervious formations (Gokhale, 2005). In an area with high precipitation, the run-off results in more surface drainage channels. So the amount of precipitation along with vegetation & rainfall absorption capacity of soils influences the rate of surface run-off affecting the drainage texture of an area. In general low drainage density is favored in regions of high resistant or highly permeable sub soil materials, under dense vegetation cover and where relief is low. High drainage density is favored in regions of weak or impermeable surface materials, sparse vegetation, and mountainous relief. The drainage density is governed by the factors like rock type, run off intensity, soil type, infiltration capacity and percentage of rocky area. The drainage density in watersheds of the study area shows variation from 0.84 to 4.30 per km^2 suggesting low to moderate drainage density (Table 5). This suggests that, it has considerably high permeable sub-soil and coarse drainage texture.

Stream frequency /Channel frequency

The total number of stream segments of all orders per unit area is known as stream frequency (Horton, 1932). The Fs values of the sub-basins of the study area are presented in Table 5. It is noted that the values of Fs vary from 0.67 to 4.38 (Table 5). It is also seen that the drainage density values of the sub-basins exhibits +ve correlation with the stream frequency suggesting that there is an increase in stream population with respect to increasing drainage density.

Drainage texture

It is the total number of stream sequence of all orders per perimeter of that area (Horton 1945). It is one of the important concepts of Geomorphology which means that the relative spacing of drainage lines are numerous over impermeable areas than permeable areas. According to Horton (1945), infiltration capacity as the single important factor which influences drainage texture & considered drainage texture which includes drainage density & stream frequency. The values of drainage texture ratio of study area vary from 1.99 to 9.41 (Table 5). According to Smith (1950) there are five different classes of drainage texture based on drainage density. The drainage density less than 2 indicates very coarse, between 2 & 4 is related to coarse, between 4 & 6 is moderate, between 6 7 8 is fine whereas above 8 is referred as very fine drainage texture. Watershed I, III & IV show very coarse to coarse drainage texture indicating softer & more permeable rock formation. In watershed II value of drainage texture is 5.39 indicating moderate drainage texture. Whereas, watershed V shows drainage texture value 9.41 which indicates the hard rock lithology in the area.

Form factor

Form factor may be defined as the ratio of the area of the basin and square of basin length (Horton, 1932). The value of form factor would always be greater than 0.78 for a perfectly circular basin. Smaller the value of form factor, more elongated will be the basin. Rf values of the study area are presented in Table 5. It is noted that the Rf values vary from 0.15 to 0.98 (Table 5). The values in all the watersheds indicate that they are elongated to sub-circular in shape.

Circulatory ratio

The circulatory ratio is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. It is the ratio of the area of the basins to the area of circle having the same circumference as the perimeter of the basin. In the study area, the Re values are ranging from 0.36 to 0.70 (Table 5). All watersheds are found to be elongated to sub circular in shape.

Elongation ratio

Elongation ratio is the ratio between the diameter of the circle of the same area as the drainage basin arid the maximum length of the basin. The elongation ratio values of the watersheds vary from 0.43 to 1.11 (Table 5). The elongation ratio values generally exhibit variation from 0.6 to 1.0 over a wide variety of climatic and geologic types. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6–0.8 are usually associated with high relief. In case of watersheds II & V the elongation ratios are considerably below 0.6 indicating very high relief, whereas in watersheds II & IV, values show high relief. The watershed I show elongation value 1.11 which indicates low relief & gentle slope compared to other four watersheds.

Length of overland flow

The length of overland flow (Lg) approximately equals to half of reciprocal of drainage density (Horton, 1945). It is the length of water over the ground before it gets concentrated into definite stream channels. This factor basically relates inversely to the average slope of the channel and is quite synonymous with the length of the sheet flow to the large degree. The Lg values of the study area show variation from 0.11 to 0.58 (Table 5). The values of Lg are low in all watersheds indicating overall high relief in area.

Slope

Slope analysis is an important parameter in geomorphic studies. The slope elements, in turn are controlled by the climatomorphogenic processes in the area having the rock of varying resistance. An understanding of slope distribution is essential as a slope map provides data for planning, settlement, mechanization of agriculture, deforestation, planning of engineering structures, morphoconservation practices etc. (Sreedevi et al. 2005). In the study area slope map was prepared based on ASTER DEM data of 30 mt. were converted into slope using Arcview method (ESRI, 2000). Slope grid is identified as "the maximum rate of change in value from each cell to its neighbors, using methodology described in Burrough (1986).The calculated slope in degree are Level to gentle (0 to 1.5), Gentle (2^0-5^0), Moderate (5^0-10^0) and Moderately steep (10^0-16^0).The lower Wardha river watershed area slope varies from 0° to 16° with a mean slope of 2.56° and Slope Standard Deviation 3.83°. A high degree of slope is noticed in the north western and northwestern parts of the basin (Fig.3). The elevation in the study area ranges from 208 to 436 mt. which extracted from the ASTER DEM data (Fig.5).

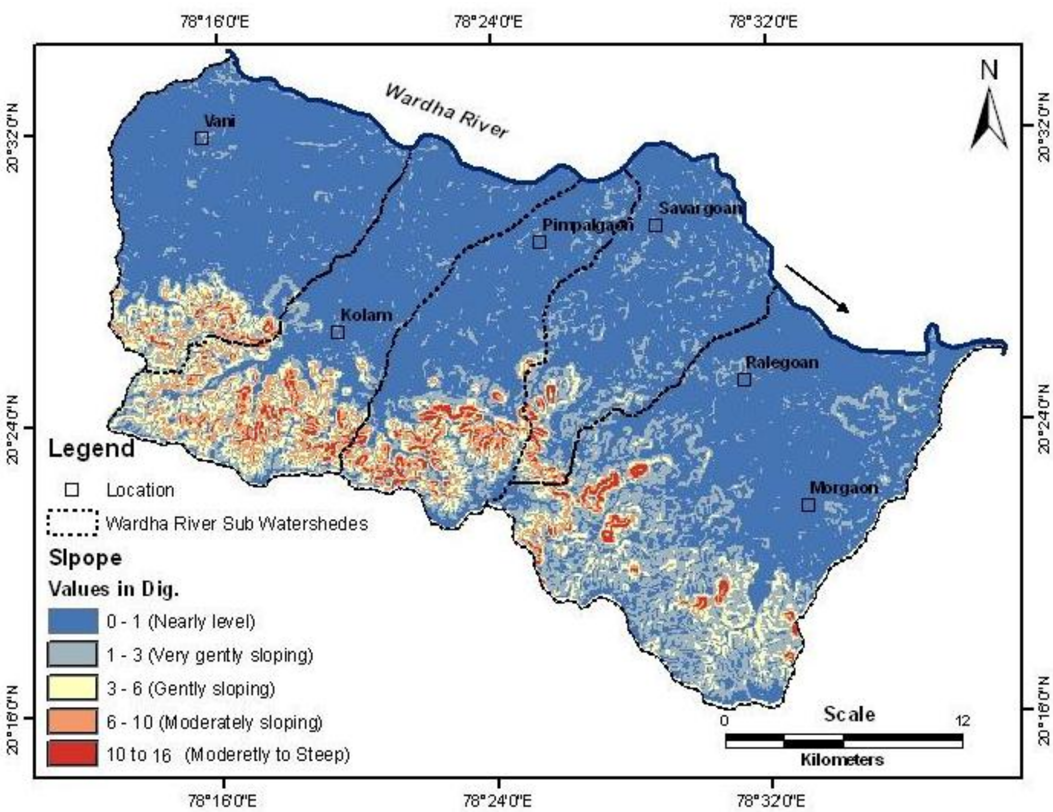

Fig.5: Slope map of the study area

Conclusion

The quantitative analysis of morphometric parameters is of immense utility in river basin evaluation, watershed analysis for soil and water conservation and natural resource management at micro level. The morphometric parameters evaluated using GIS helped to understand various terrain parameters such as nature of bedrock, infiltration capacity, runoff, etc. The study reveals that drainage network of the basin is mainly dendritic type indicative of homogeneity in texture and lack of structural control. The drainage basin is being frequently selected as an ideal geomorphological unit. Watershed as a basic unit of morphometric analysis has put on importance because of its topographic and hydrological unity. Drainage density and stream frequency are the most useful criterion for the morphometric classification of drainage basins which certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. The drainage density in watersheds of the study area shows variation from 0.84 to 4.30 per km^2 suggesting low to moderate drainage density ultimately depicting considerably permeable sub-soil throughout the study area (Table 5). It is noted that the Rf values in all the watersheds indicate that all the watersheds are more or less elongated to sub-circular in shape. The values of Lg are low in all watersheds indicating overall considerably high relief in area. Relief ratio indicates that the discharge capability of these watersheds is very high. ASTER data provides the opportunity for extracting elevation information from nadir and aft images. The simultaneous along-track stereo data eliminates radiometric variations caused by multi-date stereo data acquisition while improving image-matching performance and it is useful for geomorphological mapping especially at medium scales.

Table 2: Calculation of different morphometric parameters of study area

Sl no.	Sub basin name	Stream Order	Basin area	Stream No.(Nu)						Stream Length in Km (Lu)					
				I	II	III	IV	V	VI	I	II	III	IV	V	VI
1	I	IV	258.76	135	29	9	2	-	-	114.77	42.76	39.02	25.73	-	-
2	II	V	157.89	211	58	11	4	1	-	141.55	58.54	28.68	6.40	24.15	-
3	III	V	135.97	111	34	10	4	1	-	97.47	46.68	9.85	22.30	15.09	-
4	IV	IV	116.27	82	19	6	1	-	-	82.97	31.52	16.63	16.51	-	-
5	V	VI	112.94	354	102	29	6	3	1	263.21	97.13	58.05	42.01	18.81	7.02

Table 3: Calculation of different morphometric parameters of study area

Sl no.	**Sub basin name**	**Mean Stream Length in Km**						**Stream length ratio (RL)**				
		I	II	III	IV	V	VI	I	II	III	IV	V
1	I	0.85	1.47	4.33	12.86	-	-	0.37	0.91	0.65	-	-
2	II	0.67	1	2.60	1.6	24.15	-	0.41	0.48	0.22	3.77	-
3	III	0.87	1.37	0.98	5.57	15.09	-	0.47	0.21	2.26	0.67	-
4	IV	1.01	1.65	2.77	16.51	-	-	0.37	0.52	0.99	-	-
5	V	0.74	0.95	2.00	7.00	6.27	7.02	0.36	0.59	0.72	0.44	0.37

Table 4: Calculation of different morphometric parameters of study area

Sub basin name	**Bifurcation ratio (Rb)**					**Mean Bifurcation ratio (Rbm)**
	I	II	III	IV	V	
I	4.65	3.22	4.5	-	-	4.12
II	3.63	5.27	2.75	4	-	3.91
III	3.26	3.4	2.5	4	-	3.29
IV	4.31	3.1	6	-	-	4.47
V	3.47	3.51	4.83	2	3	3.3

Table 5: Calculation of different morphometric parameters of study area

Sl no.	**Sub basin name**	**Perimeter**	**Basin length**	**Total relief**	**Relief ratio**	**Elongation ratio**	**Length of Overland**
1	I	81.69	16.21	165	10.17	1.11	0.58

2	II	52.85	26.92	189	7.02	0.52	0.30
3	III	68.35	21.17	187	8.83	0.62	0.35
4	IV	54.01	19.47	188	9.65	0.62	0.39
5	V	52.55	27.28	203	7.44	0.43	0.11
Sl no.	Sub basin name	**Drainage density**	**Stream frequency**	**Texture ratio**	**Form factor**	**Circulatory ratio**	**Drainage Texture**
1	I	0.85	0.67	1.65	0.98	0.48	2.14
2	II	1.64	1.80	0.38	0.21	0.70	5.39
3	III	1.40	1.17	1.62	0.30	0.36	2.34
4	IV	1.26	0.92	1.51	0.30	0.50	1.99
5	V	4.30	4.38	6.73	0.15	0.51	9.41

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