Morphometric analysis in Koldari watershed of Buldhana district (MS), India using geoinformatics techniques

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Abstract: This current study, an attempt is made to study the morphometric characteristics of Koldari watershed of Buldhana district, Maharashtra, India by using geo-informatics techniques and Carto satellite DEM data at 30m spatial resolution. Morphometric analysis is carried out for watershed boundary, flow accumulation, stream number, stream ordering and stream length. The watershed boundary was delineated from digital elevation model data. The total length of all stream segments under stream order I to IV in the watershed is 61.56 km2. The area of Koldari watershed is 22.28 km2. This study is very useful for planning of rain water harvesting structures and watershed management.

Keywords: Morphometric analysis, DEM, Remote sensing, GIS

1. Introduction

In India, the population is continuously increasing land and water resources are decreasing. Watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point (Anon., 1990). Soil and water conservation are key issues in watershed management in India. In developing countries, watershed projects focus on three objectives. Namely, (i) to conserve and strengthen the natural resource base; (ii) to make natural resource based activities like agriculture more productive and (iii) to support rural livelihood to alleviate poverty.

Watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. Watersheds have been classified into different categories based on area viz., micro watershed (5 to 10 km2), mini watershed (10 to 30 km2), sub watershed (30 to 50 km2) (Anon. 1995). Watersheds can be delineated by several methods. One used extensively is manually delineation based on the contour information depicted on topographic maps. Even with the advent of GIS technology, this method is still prevalent. With the availability of digital topographic maps, digital techniques are possible. The watershed features should be derived and made available for its use in watershed planning and management, estimating upland erosion and evaluating the impacts of human activities on the quality and quantity of the streams. Geographical Information System (GIS), with its ability to gather spatial data from different sources into an integrated environment, has emerged as an important tool for delineation of watersheds. GIS provides a consistent method for watershed delineation using contours derived from digital elevation models (DEM's). GIS has unique features to relate to the point, liner and areal features in terms of the topology as well as connectivity (Murali Krishna, 2006).

Morphometry is the measurement and analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998). The morphometric analysis involves measurement of linear aspects of the watershed and slope contribution. The morphometric characteristics of a watershed are helpful in synthesizing hydrological behavior (Pandey et. al., 2004). The watershed morphometric characteristics have been studied by many scientists using conventional (Horton, 1945; Smith, 1950; Strahler, 1957; Dhinwa, 1982) and remote sensing and GIS methods (Biswas et al., 1999; Khadri and Moharir, 2013; Narendra and Rao, 2006; Rudraiah et al., 2008). In the present study, stream number, order, length, Rho coefficient and bifurcation ratio are derived and tabulated on the basis of linear properties of drainage channels using GIS based on drainage lines as represented over the topographical maps (scale 1:50,000).

2. Study area and data used

Koldari watershed is situated in Buldhana district, Maharashtra and located between 20°15′ 59” N and 76° 42’30’’ E, 77° 39’00’’E and 20°21′00” N longitude and covers an area of 22.28 km2 (Fig. 1). The study area is covered in Survey of India toposheet (55D/11) on 1:50,000 scale. Survey of India toposheet (55D/11) on 1:50,000 scale and CartoSAT-1 DEM (30m) have been used in this study to extract watershed boundary, drainage network and analysis of morphometric parameters.

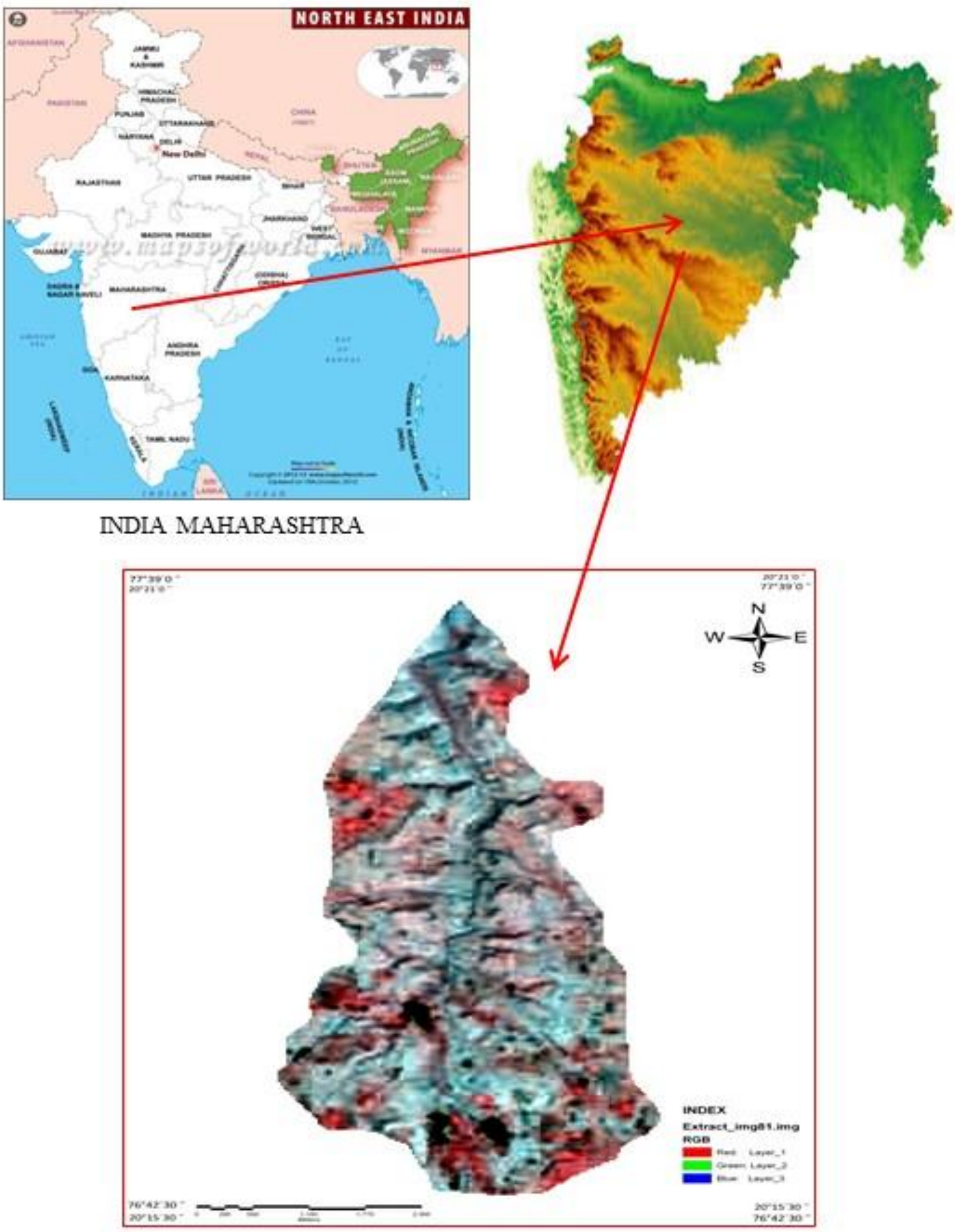

Figure 1: Location map of study area

3. Methodology

There are two major components of the methodology namely, extraction of drainage network from DEM data and morphometric analysis.

3.1 Extraction of drainage network from DEM data

The extraction of the drainage network of the study area is carried out using Cartosat data (March 15, 2015) based DEM with a 30m*30m grid cell size. which was downloaded from Bhuvan site (www.nrsc.gov.in). Hydrology tool under Spatial Analyst Tools in ArcGIS-10.1 software are used to extract drainage channels, and other parameters. The automated method for delineating streams followed a series of steps i.e. DEM, watershed and stream order (fig. 2).

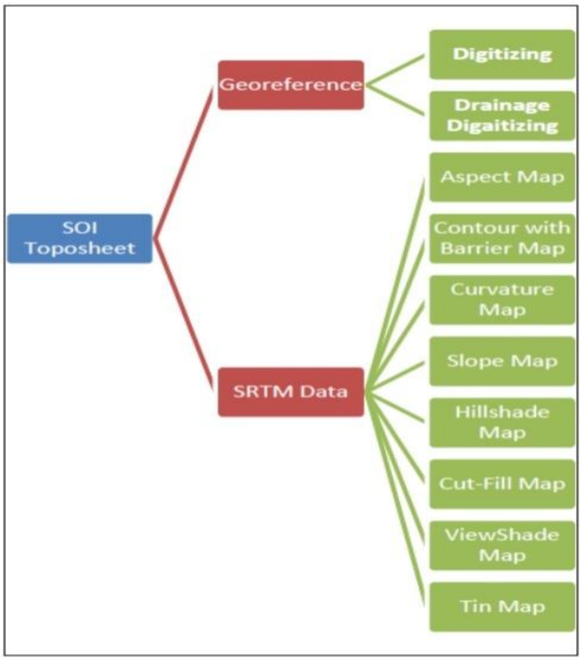

Figure 2: Flowchart of the methodology

3.2 Morphometric analysis

The present study integrated the use of remote sensing and GIS techniques in morphometric analysis. Morphometric indicators such as Stream Order (Su), Stream Number (Nu), Bifurcation Ratio (Rb), Weighted Mean Bifurcation Ratio (Rbwm), Stream Length (Lu), Ratio of stream length and stream order, Stream Length Ratio (Lur), Stream Length used in the ratio (Lur-r), Weighted Mean Stream Length ratio (Luwm) are calculated from the Cartosat DEM derived drainage network (fig. 3)

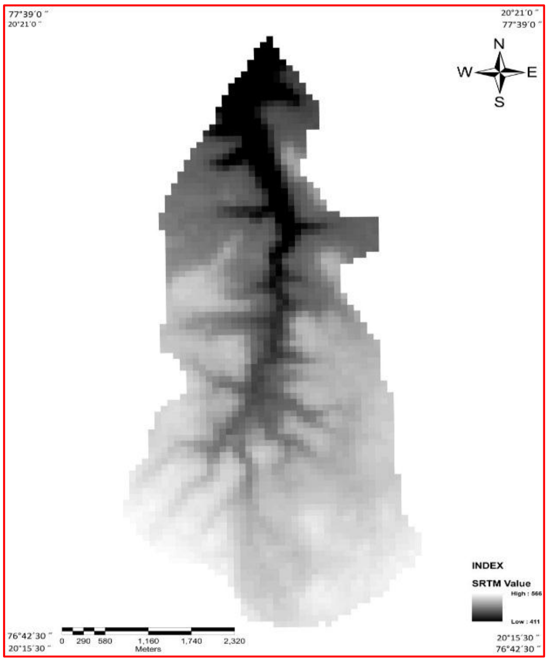

Figure 3: Digital Elevation Model (DEM) map of Koldari watershed

4. Results and discussion

4.1 Stream Order (Su)

Stream ordering is the first step of quantitative analysis. In this research, stream order of Koldari watershed is carried out by using Arc GIS10.1 software. It is observed that first order stream has maximum frequency followed by second order, third order and fourth order respectively as shown in (Table 2). It is also noticed that there is a decrease in stream frequency as the stream order increases (Fig. 4).

4.2 Stream Number (Nu)

When two channel of different order join then the higher order is maintained. Stream number is derived by using Arc GIS10.1. Total 106 streams are identified of which 73 are of first order, 28 of second order, 4 of third order and 1 of fourth order as is shown in table 2 and 1. Higher order of stream indicates lesser permeability and infiltration in the watershed (Strahler, 1964). In this watershed area, dendritic type of drainage patterns is observed which indicates homogeneity in texture and lack of structural control.

4.3 Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of the stream segments of given order ‘Nu’ to the number of streams in the next higher order (Nu+1),

Rb =Nu/Nu+1

where, Nu =Total no. of stream segments of order ‘u’; Nu + 1= Number of stream segments of the next higher order.

The bifurcation ratio is a dimensionless property. It was found that range of bifurcation ratio vary from 2.6 to 7.0 (table 2). The higher values of Rb indicates strong structural control on the drainage pattern, while the lower values indicative of watershed that are not affect by structural disturbances. The lower values of Rb are characteristics of the watersheds, which have suffered less structural disturbances and the drainage pattern has not been distorted because of the structural disturbances. The highest Rb (7.0) is found between 4th order in Kolderi watershed which indicates corresponding highest overland flow and discharge due to hilly metamorphic formation associated with high slope configuration. Also the higher values of Rb indicate strong structural control in the drainage pattern whereas the lower value indicates that the Kolderi watershed is less affected by structural disturbances. The lowest Rb is found between 2nd orders in Kolderi watershed which indicates corresponding lower overland flow and discharge moderate slope configuration. The bifurcation ratio of different stream number and mean bifurcation ratio are shown (Table 1 and 2).

4.4 Weighted Mean Bifurcation Ratio (Rbwm)

Weighted mean bifurcation ratio in the M/s. Weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values. It has been observed that the mean bifurcation ratio is 4.53 of the Kolderi watershed Maharashtra. The values of the weighted mean bifurcation ratio have been found to be very close to the mean value of bifurcation ratio in Kolderi watershed (Table 2).

4.5 Stream Length (Lu)

The total length of the 1st order streams is highest, that is, respectively. Generally, the higher the order, the longer the length of stream is noticed in the nature. Longer length of stream is advantageous over the shorter length, in that the former collects water from wider area and greater option for construction of a bund along the length. Lower stream lengths are likely to have lower runoff. Longer lengths of streams are generally indicative of flatter gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as stream order increase (Table 1).

4.6 Ratio of stream length and stream order

Stream length and stream order ratio for different stream order has been calculated for Kolderi watershed. Highest value for Lu/Su has been found in the 1st stream order whereas lowest Lu/Su has been found in the 4th stream order (Table 1 and 3).

4.7 Stream Length Ratio (Lur)

Stream Length Ratio is defined as the ratio of the mean (Lu) of segments of order (So) to mean length of segments of the next lower order (Lu-1).

RL = Lsm/Lsm-1

Lsm =Mean stream length of a given order and

Lsm-1 = Mean stream length of next lower order.

After calculating the stream length ratio it has been absorbed that stream length ration has been changed from one order to another (Table 1). Change of stream length ratio from one order to another order indicating there late youth stage of geomorphic development (Singh and Singh, 1997). The variation in stream length ratio might be due to change in slope and topography.

4.8 Stream Length used in the ratio (Lur-r)

Stream Length used in the ratio (Lur-r) is defined as the Sum of first order Stream Length and second order Stream Length. Lur-r value is calculated for all stream length which is shown in table 1.

4.9 Weighted Mean Stream Length ratio (Luwm)

Weighted Mean Stream Length ratio obtained by summation of Stream Length Ratio multiplied by Stream Length used in the ratio divided by Stream Length used in the ratio shown in table 1 and 3.

Luwm = Lur*Lur-r/Lur-r

Figure 4: Stream order map of study area

Table 1: Morphometric Parameters of Kolderi watershed

Sr. No.	Morphometric Parameter	Formula	Reference	Results
A	**Drainage Network**			
1	Stream Order (S_u)	Hierarchical Rank	Strahler (1952a)	1 to 4
2	1st Order Stream (S_{uf})	Suf = N1	Strahler (1952b)	73.00
3	Stream Number (N_u)	$Nu = N_1+N_2+ \ldots N_n$	Horton (1945)	106.00
4	Stream Length (L_u) mts	$Lu = L_1+L_2 \ldots L_n$	Strahler (1964)	616.44
5	Stream Length Ratio (L_{ur})	see Table 3	Strahler (1964)	8.45
6	Mean Stream Length Ratio (L_{urm})	see Table 3	Horton (1945)	2.81
7	Weighted Mean Stream Length Ratio (L_{uwm})	see Table 3	Horton (1945)	2.059
8	Bifurcation Ratio (R_b)	see Table2	Strahler (1964)	4.53-13.6
9	Mean Bifurcation Ratio (R_{bm})	see Table 2	Strahler (1964)	4.53
10	Weighted Mean Bifurcation Ratio (R_b)	see Table 2	Strahler (1953)	3.67
11	Main Channel Length (C_1) Km.	GIS Software Analysis		11.192
12	Valley Length (Vl) km	GIS Software Analysis		9.31
13	Basin Length (L_b) km	GIS Software Analysis	Schumm(1956)	9.31
14	Basin Perimeter (P)km	GIS Software Analysis	Schumm(1956)	23.05
15	Basin Area (A) km^2			22.28

Table 2: Stream order, stream number and bifurcation ratio's in Kolderi watershed

S_u	N_u	R_b	N_{u-r}	R_b*N_{u-r}	R_{bwm}
I	73	---	---	---	
II	28	2.60	101	262.6	
III	4	7	32	224	3.67
IV	1	4	5	20	
Total	106	13.6	138	506.6	
Mean		4.53			

Su: Stream order, Nu: Number of streams, Rb: Bifurcation ratios, Rbm: Mean bifurcation ratio*,
Nu-r: Number of stream used in the ratio, Rbwm: Weighted mean bifurcation ratios.

Table 3: Stream length and stream length ratios in Kolderi watershed

S_u	L_u	L_u/S_u	Lur	L_{ur-r}	L_{ur}*L_{ur-r}	L_{uwm}
I	401.24	5.49	---	---	---	
II	95.85	3.42	0.23	497.09	114.33	
III	86.98	21.74	0.90	182.83	164.54	
IV	32.37	32.37	0.37	119.35	44.15	0.40
Total	616.44	63.02	1.5	799.2	323.02	
Mean	154.11		0.5			

S_u: Stream order, L_u: Stream length, L_{ur}: Stream length ratio, L_{urm}: Mean stream length ratio*, L_{ur-r}: Stream length used in the ratio, L_{uwm}: Weighted mean stream length ratio.

4.10 Discussion

This analysis has revealed that the total number and length of stream segments is higher in first order streams and decreases as the stream order increases. The bifurcation ratio (R_b) between different successive orders varies revealing the geostructural control. From this study it can be concluded that the higher values of R_b in Kolderi watershed shows strong structural control, while the lower values indicate that watershed are not affected by structural disturbances. The lower values of R_b are characteristics of the watersheds, which have suffered less structural disturbances and the drainage pattern has not been distorted because of the structural disturbances.

Thus, it can be perceived that morphometric analysis provides a better understanding for the status of land form and their processes, stream management and evolution of groundwater potential zone mapping for watershed development planning and their management in water-deficient areas. The created data may be used for various future soil and water conservation projects Kolderi watershed management like groundwater surveys by locating the zones of higher secondary porosity through drainage density data. Such studies are very useful for planning of rain water harvesting structures and watershed management.

5. Conclusion

Morphometric parameters of watershed were calculated from Cartosat DEM and their influence on landforms was studied through GIS based analysis. This study reveals that morphometric analysis based on GIS technique is a very useful and adequate tool for conducting geo-hydrological studies.

References:

Anonymous (1995). Integrated mission for sustainable development. Technical Guidelines, NRSC, Hydearabad.

Agarwal, C.S. (1998). Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P. Journal of Indian Society of Remote Sensing, 26, 169-175.

Biswas, S., S. Sudhakar and V.R. Desai (1999). Prioritization of sub-watersheds based on morphometric analysis of drainage basin, district Midnapore West Bengal. Journal Indian Society Remote sensing 27(3): 155-166.

Dhinwa, P.S., (1982). Geomorphology and human settlements in the Berach basin, Rajasthan. Unpublished Ph.D. Thesis.

Horton, R.E. (1945). Erosional development of streams and their drainage basins. Bulletin of the Geological Society of America, 56, 275-370.

Khadri, S.F.R. and Kanak Moharir (2013). Detailed morphometric analysis of Man river basin in Akola and Buldhana districts of Maharashtra, India using Cartosat-1 (DEM) data and GIS techniques. International Journal of Scientific & Engineering Research, Volume 4, Issue 11, 832-854.

Murali Krishna, I.V. (2006). Spatial information technology for water resources management. Proc. of National workshop on Watershed management and impact of Environmental changes on Water resources (WMEC) JNTUCEH, JNT.

Narendra, K. and K.N. Rao (2006). Morphometry of the Mehadrigedda watershed, Visakhapatnam district, Andhra Pradesh using GIS and Resourcesat data. J. Indian Soc. Remote Sensing, 34(2), 101-110.

Pandey, A., V.M. Chowdhary and B.C. Mal (2004). Morphological analysis and watershed management using GIS. J. of Hydrology, 27(3), 71-84.

Rudraiah, M., S. Govindaiah and S.S. Vittala (2008). Morphometry using remote sensing and GIS techniques in the sub-basins of kagna river basin. Journal of the Indian Society of Remote Sensing, December 2008, Volume 36, Issue 4, 351–360

Singh, S. and M.C. Singh (1997). Morphometric analysis of Kanhar river basin, National Geographical Journal of lndia, 43(1), 31-43.

Smith, G.H. (1950). The morphometry of Ohio: The average slope of the land (abstract). Annals of the Association of American Geographers, 29, 94.

Strahler, A.N. (1952a). Dynamic basis of geomorphology. Bulletin of the Geological Society of America, 63, 923-938.

Strahler, A.N. (1952b). Hypsometric analysis of erosional topography. Bulletin of the Geological Society of America, 63, 1117-42.

Strahler, A.N. (1957). Quantitative analysis of watershed geomorphology. Transactions-American Geophysical Union, 38, 913-920.

Strahler, A.N. (1964). Quantitative geomorphology of drainage basin and channel network. Handbook of Applied Hydrology, 39-76.