Morphometric analysis of Ural Khurd Nalawatershed in Akola District of Maharashtra, India: Using remote sensing and geographic information system (GIS) techniques

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Abstract

In the present paper, an attempt has been made to study the detail Morphometric characteristics of the Ural Khurd Nala have study. The drainage map of the area was prepared from the high resolution satellite image and Survey of India (SOI) toposheets which was updated using LISS-III analog data. Watershed boundary, flow accumulation, flow direction, flow length, stream ordering have been prepared using spatial analysis Tools and contour, slope-aspect, hill shade have prepared using Surface Analysis Tool in ArcGIS-10.1. Based on all morphometric parameters analysis; that the erosional development of the area by the streams has progressed well beyond maturity and that lithology has had an influence in the drainage development. These studies are very useful for planning rainwater harvesting and watershed management.

Keywords:
Digital elevation model (DEM); Drainage map; Geographical information system

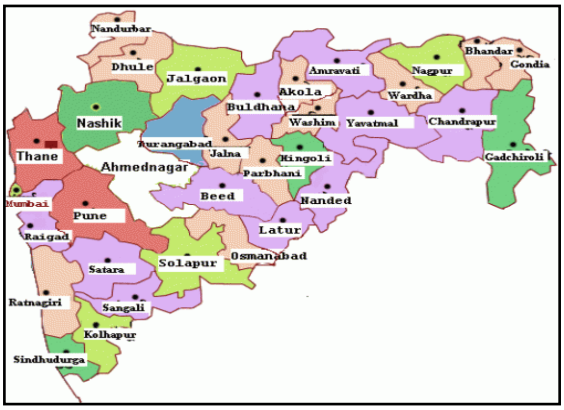
INTRODUCTION:-

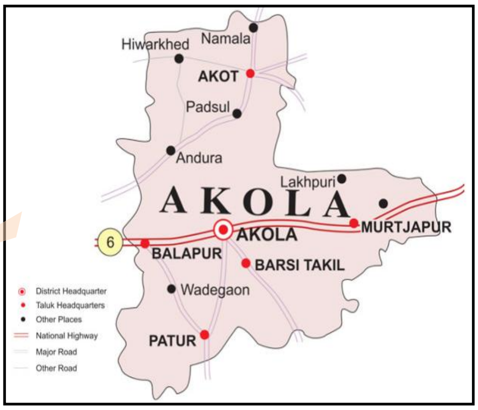
Water is a key driver of economic and social development and one of the fundamental elements in sustaining theintegrity of the natural environment. It is the major renewable resource amongst the various natural resources.Water being an indispensable constituent for all life supporting processes, its assessment, conservation,development and management is of great concern for all those who manage, facilitate and utilize.Water resources of India are quantitatively large but significantly divergent in their occurrence, distribution andutilization. The annual precipitation aggregated as 4000 km3 with utilizable resource of 1122 km3 (28%). Out ofwhich utilizable surface water resources are 690 km3 and ground water resources are 432 km3. According toNational Commission for Integrated Water Resources Development, basins-wise average annual flow in IndianRiver systems is 1953 km3.

Watershed is a natural hydrologic unit, considered as the most appropriate basis for sustainable integratedmanagement of the land and water resources. Judicious management and conservation of soil and water resourceson watershed basis is perquisite for sustaining the productivity. Characterization and prioritization of watershedsare essential steps in the integrated management of land resources. Watershed characterization involvesmeasurement of related parameters, such as geological, hydro geological, geomorphologic, and hydrological,Soil, land cover/land use etc. Remote sensing using aerial and space borne sensors can be effectively used forwatershed characterization and assessing watershed priority, evaluating problems, potentials, managementrequirements and periodic monitoring. Participation of people is essential for the success of the watershed programs. Participatory watershed management is a process which aims to create a self-supporting system essential for sustainability. The concept of participatory watershed management emphasizes a multi-disciplinary and multi-institutional approach (Seshagiri Rao, 2000). For the successful planning and management of watershed, reliable information of spatial and non-spatial data is essential.

Study area and Methodology

The study area Ural KhurdNalais situated in Akola Districts of Maharashtra which is located between 53°29′17 ” to 79°67’60” N latitude and 53°33’92’’ to79°21’25’’ E longitude. The study area is covered by Survey of India (SOI) toposheet 55H/6 and on 1:50,000 scale.The IRS LISS-III satellite image was used for linear, aerial and relief aspects for drainage basin analysis and interpretation. The standard image interpretation characteristics such as tone, texture, shape, size, pattern andassociation along with sufficient ground truth and local knowledge were used to finalize the maps of the microwatershed area. The maps were georeferenced and digitized using the Arc GIS 10.1 and Erdas Imagine 9.1 GIS software’s and attributes were assigned to create the digital database. The order was assigned stream by following Strahler, (1964) stream ordering technique.The drainage basin characteristics help in deciphering and understanding the interrelated relief and slope properties. The previously mentioned DEM model is used to understand the detail nature of Ural KhurdNala area.





Maharashtra State of India **Akola District**

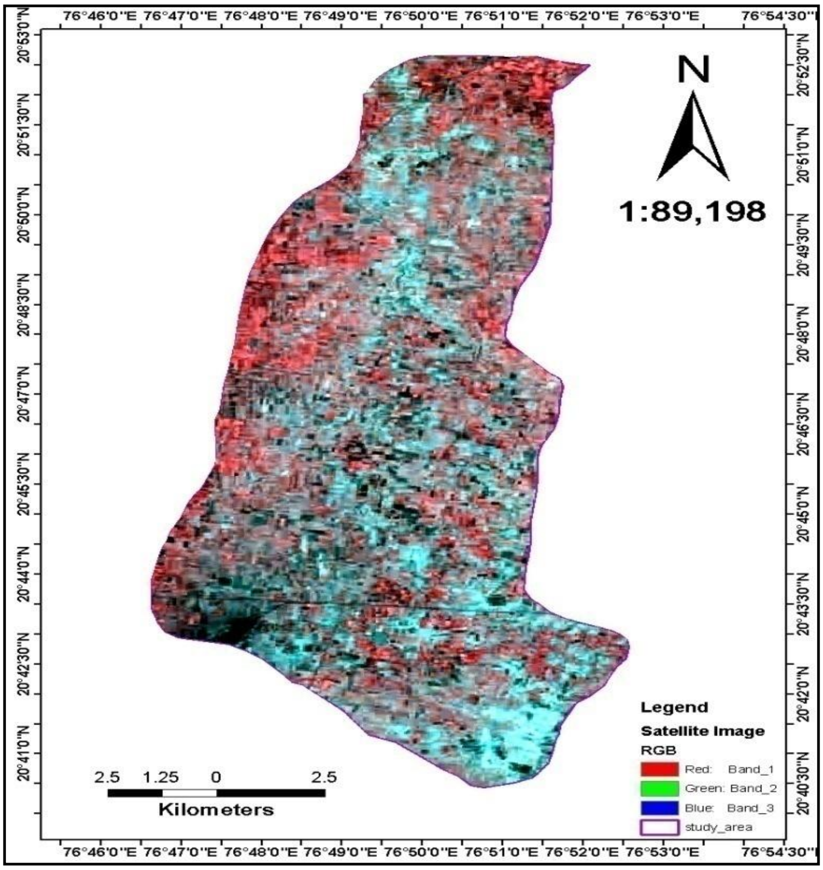


Fig.1. Location Map of Ural Khurd Nala

Aims and objectives:

1. Preparation of Slope Map, Hill shade Map, DEM Map, Aspect Map Topographic Model and Contour Map from SRTM 90m Resolution Data for Water conservation.
2. Preparation of land Use Land Cover Map of watershed management from Land sat TM image 2014 Data.
3. Calculate the morphometric analysis using Arc GIS 9.3version software and SRTM data.

Database:

The data require for watershed management includes drainage, Slope Map, Hill shade Map, Aspect Map, Cut-Fill Map etc.

1. SOI Toposheet (55H/6).
2. Satellite image LISS-III Data.
3. ASTER SRTM DATA 90m Resolutions.

Fig. 2. Flow Chart of Methodology

MORPHOMETRIC ANALYSIS

Morphometry is the measurement and mathematical analysis of configuration of the earth surface and the shape and dimensions of its landforms (Thornbury, 1969). It provides the basis of investigation of maps for a geomorphological survey Bates and Jackson,(1980); Agarwal,(1998); Obi Reddy et.al., (2002). The area altitude volume, slope, Profile and textures of landforms comprise principal parameters of investigation. Dury, (1952); Christian, Jenning and Tuidale, (1957) applied various methods for landform analysis.Which could be classified in different ways and their results presented in the form of graphs, maps or statistical indices. The morphometric analysis of the

Ural KhurdNalawas carried out on the Survey of India topographical maps No. 55H/6 on the scale 1:50,000 and DEM with 30m spatial resolution. The lengths of the streams, areas of the watershed were measured by using ArcGIS-10 software, and stream ordering has been generated using Strahler (1953) system, and Arc Hydro tool in ArcGIS-10 software. The linear aspects were studied using the methods of Horton (1945), Strahler (1953), Chorley (1957), the areal aspects using those ofSchumm (1956), Strahler (1956, 1968), Miller (1953), and Horton (1932), and the reliefaspects employing the techniques of Horton (1945), Broscoe (1959), Melton (1957), Schumm(1954), Strahler (1952), and Pareta (2004). The average slope analysis of the watershed area was done using the Wentworth (1930) method. The Drainage density and frequency distribution analysis of the watershed area were done using the spatial analyst tool in ArcGIS-10 software.

Drainage Network:

Stream Order (Su):

Stream ordering is the first step of quantitative analysis of the watershed. The stream ordering systems has first advocated by Horton (1945), but Strahler (1952) has proposed this ordering system with some modifications. Author has been carried out the stream ordering based on the method proposed by Strahler, Table 1. It has observed that the maximum frequency is in the case of first order streams. It has also noticed that there is a decrease in stream frequency as the stream order increases.

Stream Number (Nu)

The total of order wise stream segments is known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number, Table 1.

Stream Length (Lu)

The total stream lengths of the Ural KhurdNala have various orders, which havecomputed with the help of SOI topographical sheets and ArcGIS software. Horton's law ofstream lengths supports the theory that geometrical similarity is preserved generally inwatershed of increasing order (Strahler, 1964). Author has been computed the stream lengthbased on the low proposed by Horton (1945), Table 1

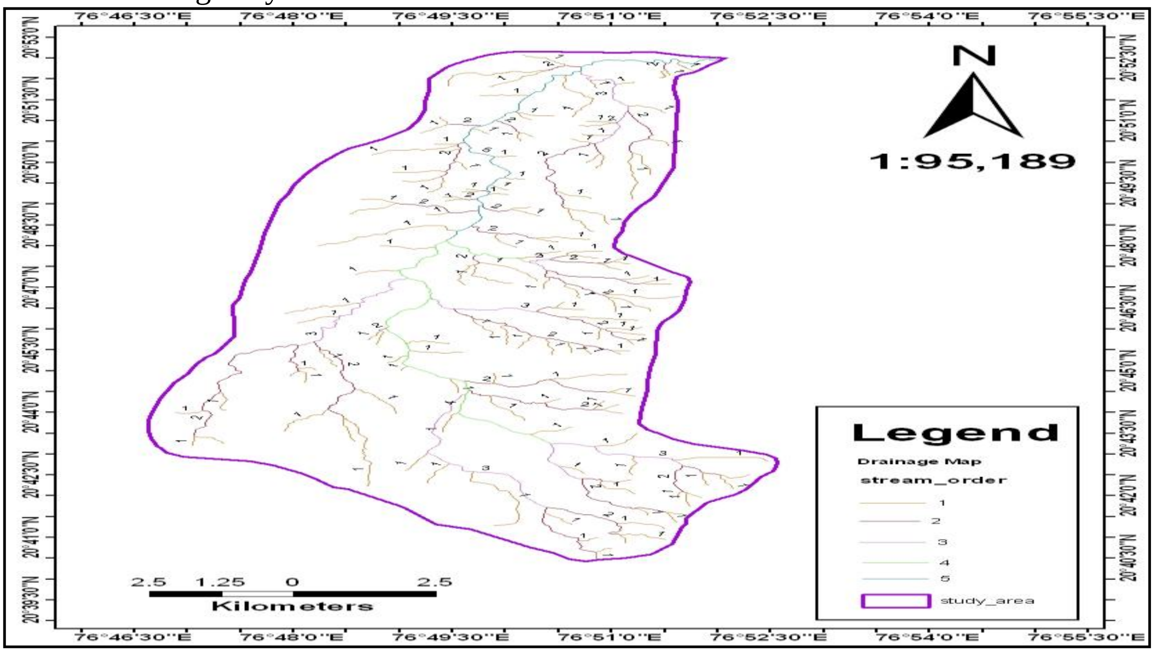


Fig.3. Drainage Stream Order Map of Ural KhurdNala

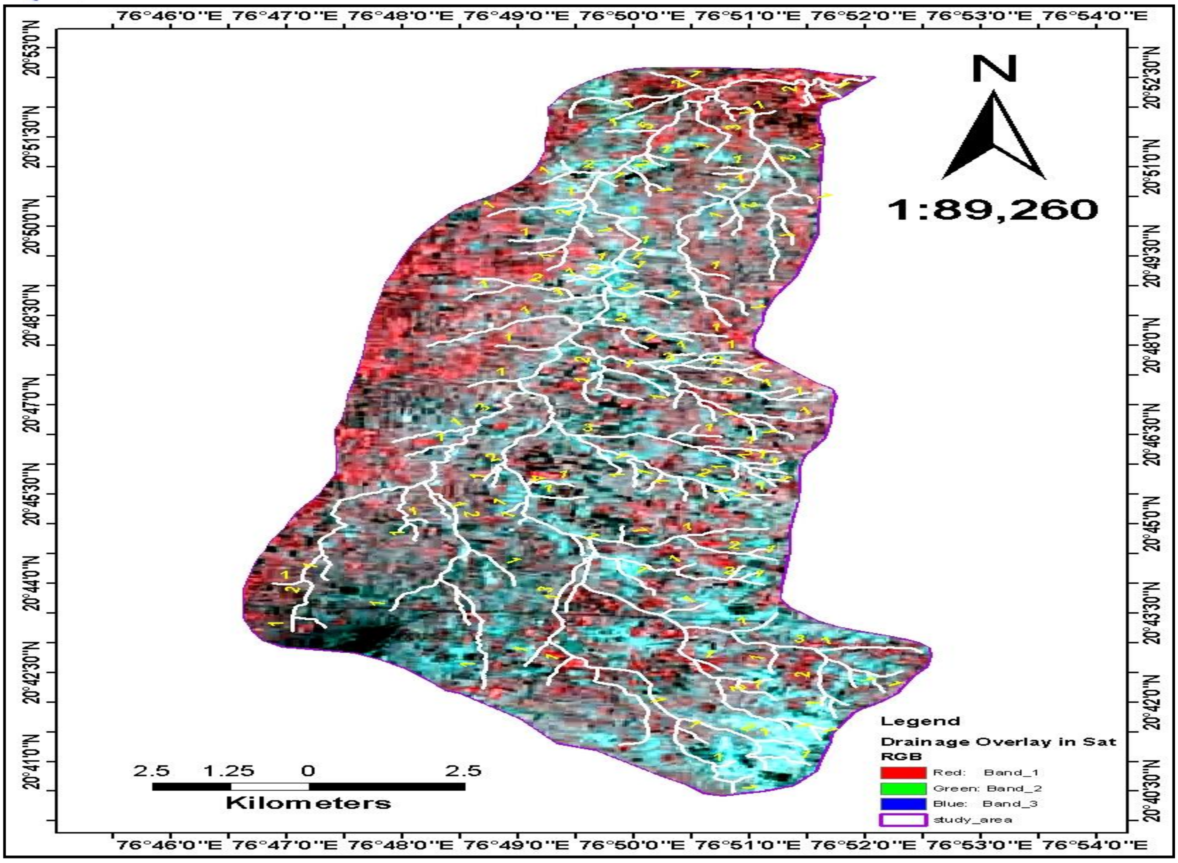


Fig.3.Update Drainage from Satellite image of Ural KhurdNala

Mean Stream Length (Lum):-

Mean Stream length is a dimensional property revealing the characteristic size of componentsof a drainage network and its contributing watershed surfaces (Strahler, 1964). It is obtained by dividing the total length of stream of an order by total number of segments in the order.

Table-1: Stream Order, Streams Number, & Bifurcation Ratios of Ural KhurdNala.

Su	Nu	Rb	Nu-r	Rb* Nu-r	*Rbwm*
I	147				3.48
II	43	3.42	190	649.8	
III	11	3.91	54	211.14	
IV	6	1.83	17	31.11	
V	1	6	7	42	
TOTAL	208	15.16	268	934.05	
MEAN	41.6	3.79*			

S_u: Stream order, N_u: Number of streams, R_b: Bifurcation ratios, R_{bm}: Mean bifurcation ratio*, N_{u-r}: Number of stream used in the ratio, R_{bwm}: Weighted mean bifurcation ratios.

Stream Length Ratio (Lurm)

Horton (1945, p.291) states that the length ratio is the ratio of the mean (Lu) of segments oforder (So) to mean length of segments of the next lower order (Lu-1), which tends to beconstant throughout the successive orders of a basin. His law of stream lengths refers that themean stream lengths of stream segments of each of the successive orders of a watershed tendto approximate a direct geometric sequence in which the first term (stream length) is theaverage length of segments of the first order (Table 2). Changes of stream length ratio fromone order to another order indicating their late youth stage of geomorphic development(Singh and Singh, 1997).

Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of the stream segments of given order 'Nu' tothe number of streams in the next higher order (Nu+1), Table 1. Horton (1945) considered thebifurcation ratio as index of relief and dissertation. Strahler (1957) demonstrated thatbifurcation shows a small range of variation for different regions or for different environmentexcept where the powerful geological control dominates. It is observed from the Rb is notsame from one order to its next order these irregularities are dependent upon the geologicaland lithological development of the drainage basin (Strahler 1964). The bifurcation ratio isdimensionless property and generally ranges from 3.0 to 5.0. The lower values of Rb arecharacteristics of the watersheds, which have suffered less structural disturbances (Strahler1964) and the drainage pattern has not been distorted because of the structural disturbances(Nag 1998). In the present study, the higher values of Rb indicates strong structural controlon the drainage pattern, while the lower values indicative of watershed that are not affect bystructural disturbances.

Weighted Mean Bifurcation Ratio (Rbwm)

To arrive at a more representative bifurcation number Strahler (1953) used a weighted meanbifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair oforders by the total numbers of streams involved in the ratio and taking the mean of the sum ofthese values. Schumm (1956, pp 603) has used this method to determine the mean bifurcationratio of the value of 3.48of the drainage of Perth Amboy, N.J. The values of the weightedmean bifurcation ratio this determined are very close to each other.

Table-2:-Stream Length and Stream Length Ratio of Ural KhurdNala.

Su	Lu	Lu/Su	Lur	Lur-r	Lur*Lur-r	Luwm
I	108.02	0.73				1.94
II	51.45	1.20	1.64	159.47	261.53	
III	22.13	2.01	1.68	73.58	123.61	
IV	13.41	2.24	1.11	35.54	39.45	
V	12.66	12.66	5.65	26.07	147.30	
Total	207.67	18.84	10.08	294.66	571.89	
Mean	41.53		2.52			

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.

TIN MODEL:-

A Triangulated Irregular Network (TIN) is terrain model that uses a sheet of continuous, connected triangular facets based on Delaunay triangulation of irregularly spaced nodes which approximates the land surface with a series of non-overlapping triangles. A TIN model of the study region has been generated by using the DEM data. It is a vector topological network of triangular facets generated by joining the irregular points with straight-line segments. These are irregularly spaced triangles that represent a surface as contiguous non-overlapping triangular elements.A TIN model can be used to calculate flow direction of watershed areas, as well as a variety of other applications. It represents the surface as a set of contiguous, non-overlapping network of triangles by storing the topological relationships of the triangles. The triangles vary in size according to need based on the roughness of the terrain. The TIN creates triangles from a set of points called mass points, which always become nodes.

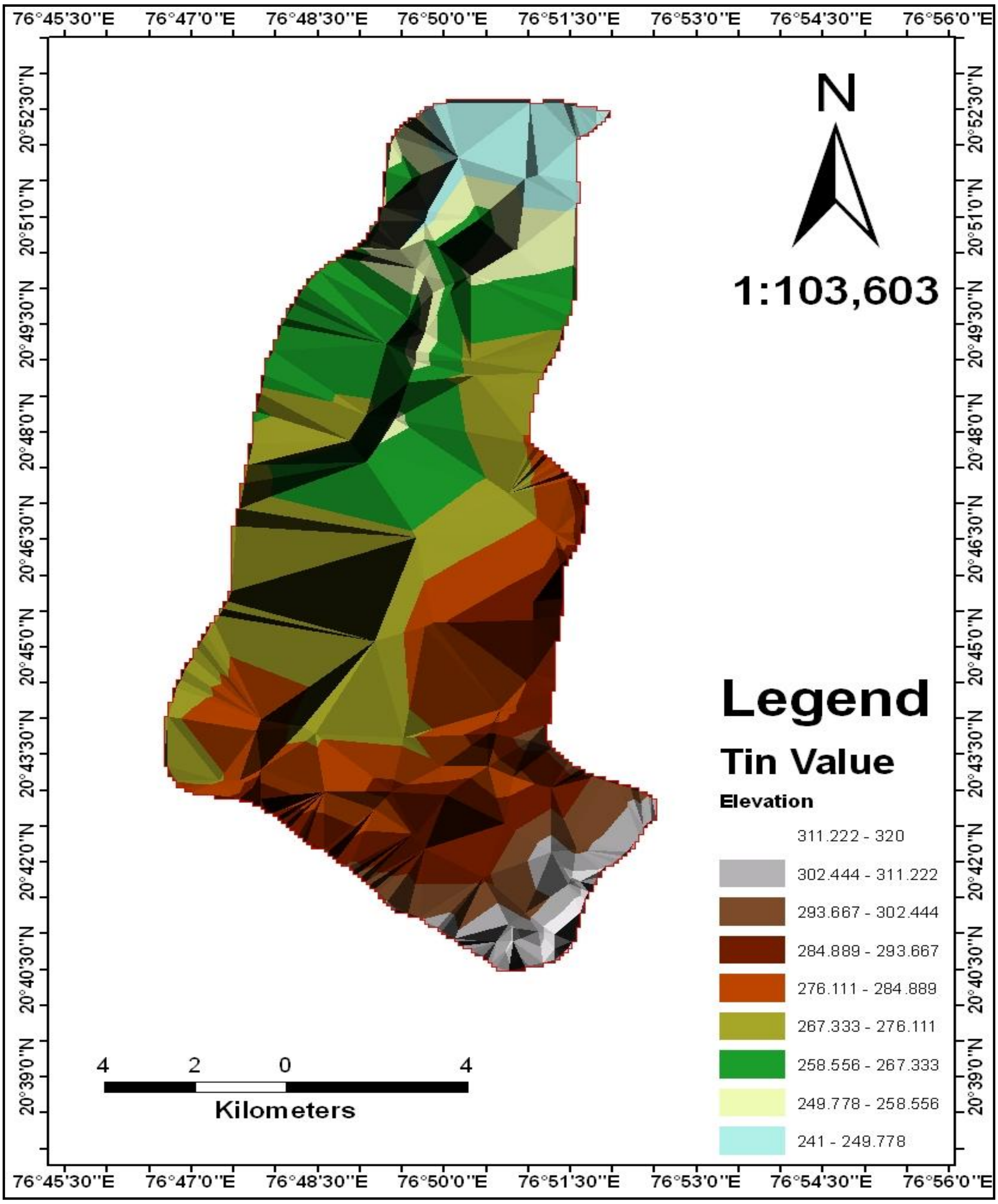


Fig.4. TIN Mode Map of Ural KhurdNala

HILL SHADE:

By using 3D analyst extension of ArcGIS 10.00 software, a shaded relief map of the study region has been prepared. It works as a model and simulates how the terrain looks with the interaction between sunlight and surface features. A mountain slope directly facing towards sunlight will be very bright and a slope opposite to the light will be dark. The analysis reveals that the south western part of the study region is hilly and undulating as compare to north eastern part.

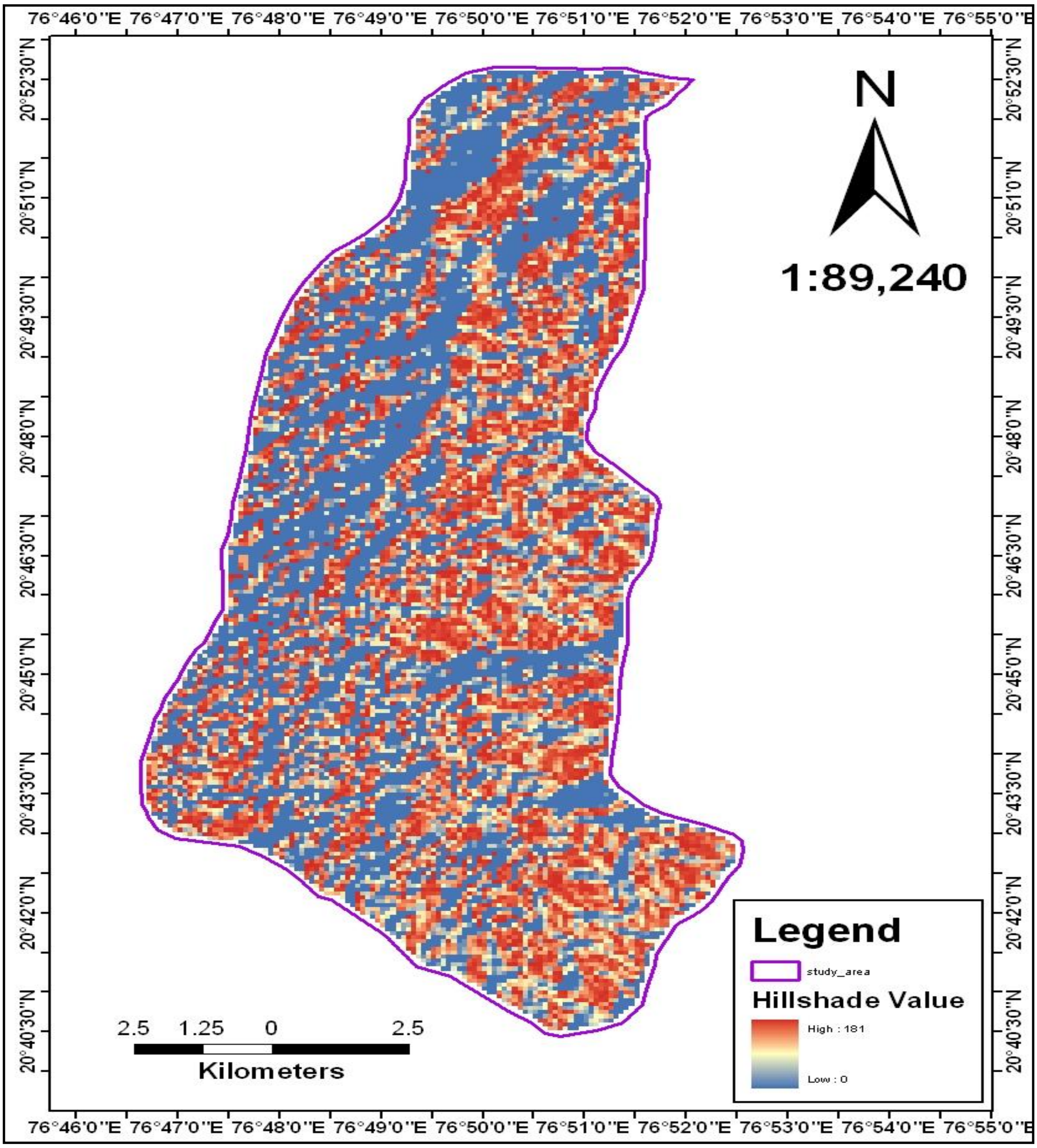


Fig.5. Hill shade Map of Ural KhurdNala

SLOPE AND ASPECT:-

Slope and aspect are the basic elements for analyzing and visualizing landform characteristics. They are important in studies of watershed units, landscape units, and morphometric measures (Moore et al., 1991). When used with other variables slope and aspect can assist in runoff calculation, forest inventory estimates, soil erosion, wild life habitat suitability and site analysis (Wilson and Gallant, 2000). An aspect-slope map simultaneously shows the aspect (direction) and degree (steepness) of slope for a terrain. Aspect categories are symbolized using hues (e .g. red, orange, yellow, etc.) and degree of slope classes are mapped with saturation (or brilliance of color) so that the steeper slopes are brighter. Aspect is the directional measure of slope.

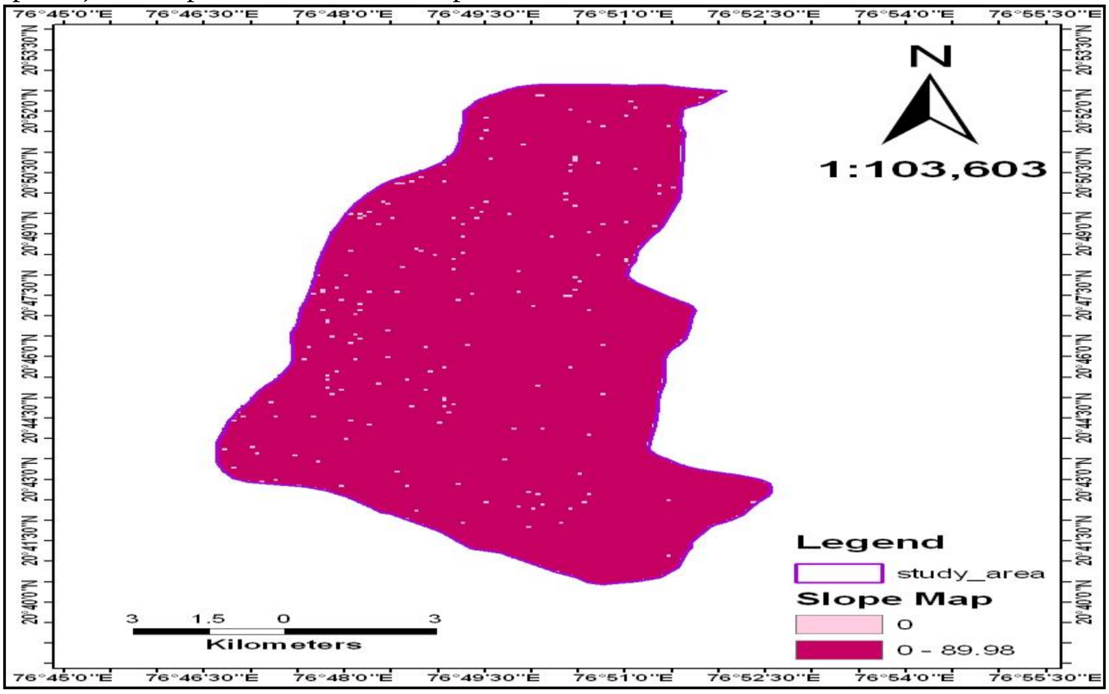


Fig.6. Slope Map of Ural of KhurdNala

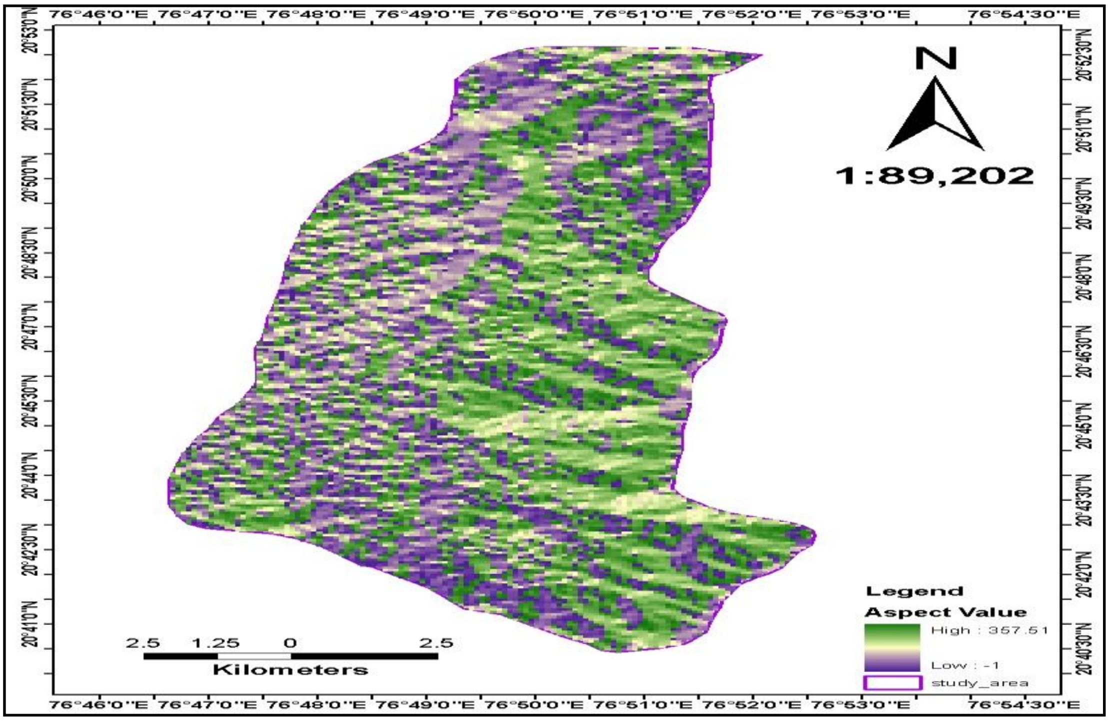


Fig. 6. Aspect Map of Ural KhurdNala

Conclusion

The relationship between geological setup and drainage pattern is analyzed using a triangulated irregular network (TIN). Regional and local trends of geological setup are reflected in the variable orientation of channels of different rank in the catchment.The study reveals that remotely sensed data (ASTER-DEM) and GIS based approach in evaluation of drainage morphometric parameters and their influence on landforms, soils and eroded land characteristics at KuralNala basin level is more appropriate than the conventional methods. GIS based approach facilitates analysis of different morphometric parameters. GIS techniques characterized by very high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis. Thevariation in stream length ratio due to change in slope and topography. The bifurcation ratio in the watershed indicates normal watershed category and the presence of moderate drainage density suggesting that it has moderate permeable sub-soil, and coarse drainage texture. The value of stream frequency indicate that the watershed show positive correlation with increasing stream population with respect to increasing drainage density. Hence, from the study it can be concluded that (DEM) data, coupled with GIS techniques, prove to be a competent tool in morphometric analysis.These processes include impact of climate, geologic and topographic conditions on the distribution of soils, vegetation and occurrence of water. For better development and management of the watershed areas, it is necessary to have timely and reliable information on geomorphologic as well as environmental status.

References

1. Alexander, P.O (1979), "Age and Duration of Deccan Volcanism: K. Ar. Evidence Deccan Volcanism Geological Society of India, Memoir No. 3, Bangalore, pp 244-257.

2. Broscoe, A.J (1959), "Quantitative Analysis of Longitudinal Stream Profiles of Small
Watersheds", Project N. 389-042, Tech. Bep. 18,Geology Department, Columbian University, ONR, Geography Branch, New York.

3. Calef, W. C (1950), "Form and Process, Cambridge University Press", London, pp 473.

4. Chorley, R.J (1972), "Spatial Analysis in Geomorphology", Mathuen and Co. Ltd., London.

5. Chorley, R.L (1967), "Models in Geomorphology", in R.J. Chorley and P. Haggett (eds.), Models in Geography, London, pp 59-96.

6. Dury, G.H (1952), "Methods of Cartographical Analysis in Geomorphological Research", Silver Jubilee Volume, Indian Geographical Society, Madras, pp 136-139.

7. Faniran, A (1968), "The Index of Drainage Intensity - A Provisional New DrainageFactor", Australian Journal of Science, 31, pp 328-330.

8. Gold, D. P (1980), "Structural Geology", Chapter 14 in Remote Sensing in Geology,edit by Siegal, B. S. and Gillespie, A. R., John Wiley, New York, pp 410-483.

9. Gregory, K.J. & Walling, D.E (1968), "The Variation of Drainage Density within aCatchment", International Association of Scientific Hydrology - Bulletin, 13, pp 61-68.

10. Horton, R.E (1932), "Drainage Basin Characteristics", Transactions, American Geophysical Union, 13, pp 350-61.

11. Schumm SA (1956) Evolution of drainage systems and slopes in bedlands at Perth Amboy, New Jersey. Bull GeolSoc Am 67:597–646.

12. Schumm SA (1963) Sinuosity of alluvial rivers in the Great Plains. Bull GeolSoc Am 74:1089–1100.

13. Sharma HS (1981) Perspectives in geomorphology. NaurangRai, Cocept publishing company. New Delhi-110015, pp 109–140.

14. Smith KG (1950) Standards for grading texture of erosional topography. Am J Sci 248:655–668.

15. Smith KG (1958) Erosional processes and landforms in badlandsnational monument, South Dakota. GeolSoc Am Bull 69:975–1008

16. Strahler, A.N (1952), “Hypsometric Analysis of Erosional Topography”, Bulletin ofthe Geological Society of America, 63,pp 1117-42.

17. Strahler AN (1957) Quantitative analysis of watershed geomorphology. Trans Am Geophys Union 38:913–920.

18. Strahler AN (1964) Quantitative geomorphology of drainage basins and channel networks. In: Chow ByVenTe (ed) Handbook of applied hydrology. McGraw Hill Book Company, New York.

19.Verstappen H (1983) The applied geomorphology. InternationalInstitute for Aerial Survey and Earth Science (ITC), Enschede.

20. .Woldenberg, N.J (1967), “Geography & Properties of Surface”, Handward Paper inTheoretical Geography, 1 pp 95-189.

21. Young, A (1972), "Slope", Oliver & Boyd, Edinburgh, pp 5.

22. Zwnnitz, E.R (1932) "Drainage Pattern and their Significance", Journal of Geology,XL(6), pp 498-521