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Morphometric Analysis of WRY-2 sub- watershed using Remote Sensing Data and GIS Technique in Wardha District of Maharashtra, India

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Abstract

*Morphometric analysis of a highland sub-watershed (WRY-2) area was carried out using remote sensing and geographic information system (GIS) techniques. Detailed 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. Updated drainage maps were used for the drainage pattern analysis of the study area, The WRY2 sub watershed shows a sub-trellis drainage pattern with moderate drainage texture. High bifurcation ratio indicates a strong structural control on the drainage pattern.The extracted drainage network was classified according to Strahler's system of classification and it reveals that the terrain exhibits dendritic to sub-dendritic drainage pattern. Hence, from the study, it can be concluded that remote sensing data (SRTM–DEM) coupled with geoprocessing techniques prove to be a competent tool was used in morphometric analysis and evaluation of linear, slope, areal and relief aspects of morphometric parameters. Lithological, structural and geomorphologicalexpression of the sub-watershed controls the flow direction of the entire drainage network.Different thematic maps i.e. drainage map, stream order map, soil map and geomorphological maphave been prepared from satellite LISS-III image by using Arc GIS software. The WRY-2 drainage basin is sprawled over an area of **256.38** km^2. The Main stream Length ratio of the basin is **23.64** indicating that the study area is elongated with and steep slopes. The Morphometric parameters of the stream have been analysed and calculated by applying standard methods and techniques viz. Horton, 1945; Miller,1953, Strahler, 1964. 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 suitable site selection of*

Ground and artificial recharge and watershed management.

Keywords: Drainage map, Digital Elevation Model, soil map, land use land cover map, Geographical information system, Remote sensing.

1. Introduction:-

Watershed is a natural hydrological entity which allow surface run-off to define channel, drain, stream or river at a particular point. It is the basic unit of the water supply which evolves over time. Different workers define water-shed differently. In foreign literature, watershed has been defined as a drainage basin or catchment. The size of a watershed can vary from fraction of hectares to thousands of square kilometers. Watershed is also classified based on the area that a watershed contains. On the basis of area, watersheds can be classified as: micro watershed (0 to 10 ha), small watershed (10 to 40 ha), mini watershed (40 to 200 ha), sub watershed (200 to 400 ha), macro watershed (400 to 1000 ha), river basin (above 1000 ha). One of the major concerns of the present time is the management and protection of the watershed area. Morphometric analysis of watershed requires measurement of linear features, gradient of channel network and contributing ground slopes of drainage basin (Nautiyal, 1994).Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds (Strahler, 1964). GIS techniques are now a day used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information.GIS and remote sensing techniques have opened up wide range of avenues for effective watershed management. The remote sensing data combined with field survey data can provide a unique and hybrid database for optimal planning and management of watershed (Solanke, et al. 2005). Space borne remote sensing technology is a unique tool to provide spatial, multi-spectral and repetitive information for effective planning (Lillesand and Keiffer, 2004).

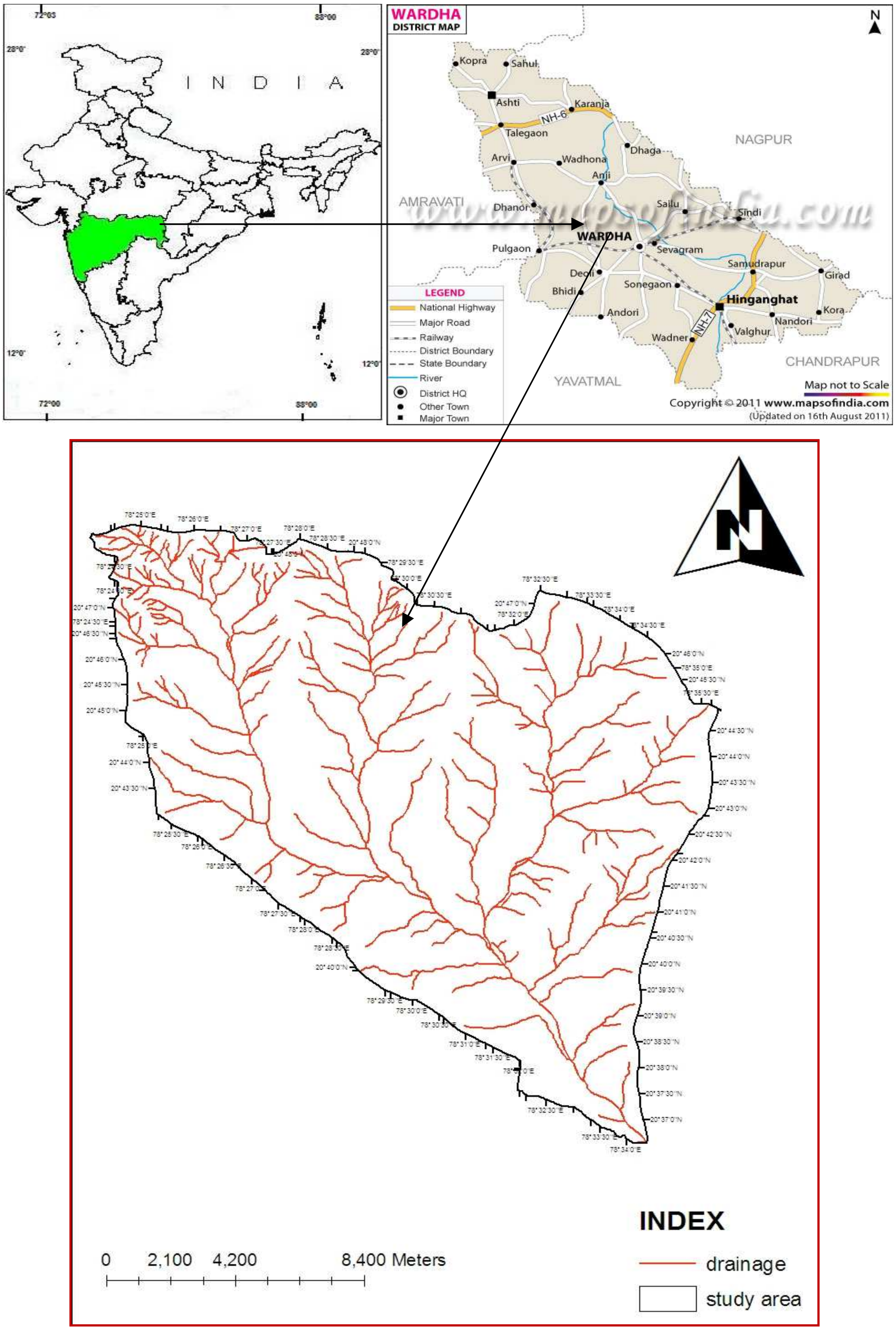

Figure.1. Location Map of WRY-2 Sub-Watershed

2. Study Area and Methodology:-

The study area lies in the Survey of India Topographic Sheets No.55L/13, 55L/14 is bounded by 73°25'00"E 20°37'00"N latitude and longitude is 73°25'30"E 20°44'30"N(Figure 1) and is located at Wardha District. The LISS-III Open Source satellite image was used for linear, aerial for drainage basin analysis and interpretation (Figure 2). The image interpretation characteristics such as tone, texture, shape, size, pattern and association along with sufficient ground truth and local knowledge were used to finalize the maps of the WRY-2watershed area. The maps are prepared by georefrancing and digitization from SOI toposheet using Arc GIS 10. Attributes were assigned to create the digital database. The Survey of India toposheets of scale 1:50,000 are used for delineating the watershed boundary, drainage pattern for the preparation of base map and extracting different thematic layers for the various part of analysis namely drainage, road and water bodies etc.The order was assigned stream by following Strahler,(1964) stream ordering technique. Various morphometric parameters, such as linear aspects of the drainage network: stream order **(N_u)**, stream length **(L_u)**,and bifurcation ratio **(R_b)**, and areal aspects of the drainage basin: drainage density **(D_d)**, as presented in Table (2).

3. Physiography:-

The study area can be broadly divided into low lying plain towards the banks of theWRY-2Sub-watershed in the northeast and horizontal Deccan Trap flows with multiple scarps and abrupt cliffs towards the southern parts. The study area consists of various erosional surfaces in step-like terraces. The horizontal dispositions of the lava flows with a fair degree of uniformity in lithology have considerably simplified the changes brought by the secondary processes like weathering and denudation.

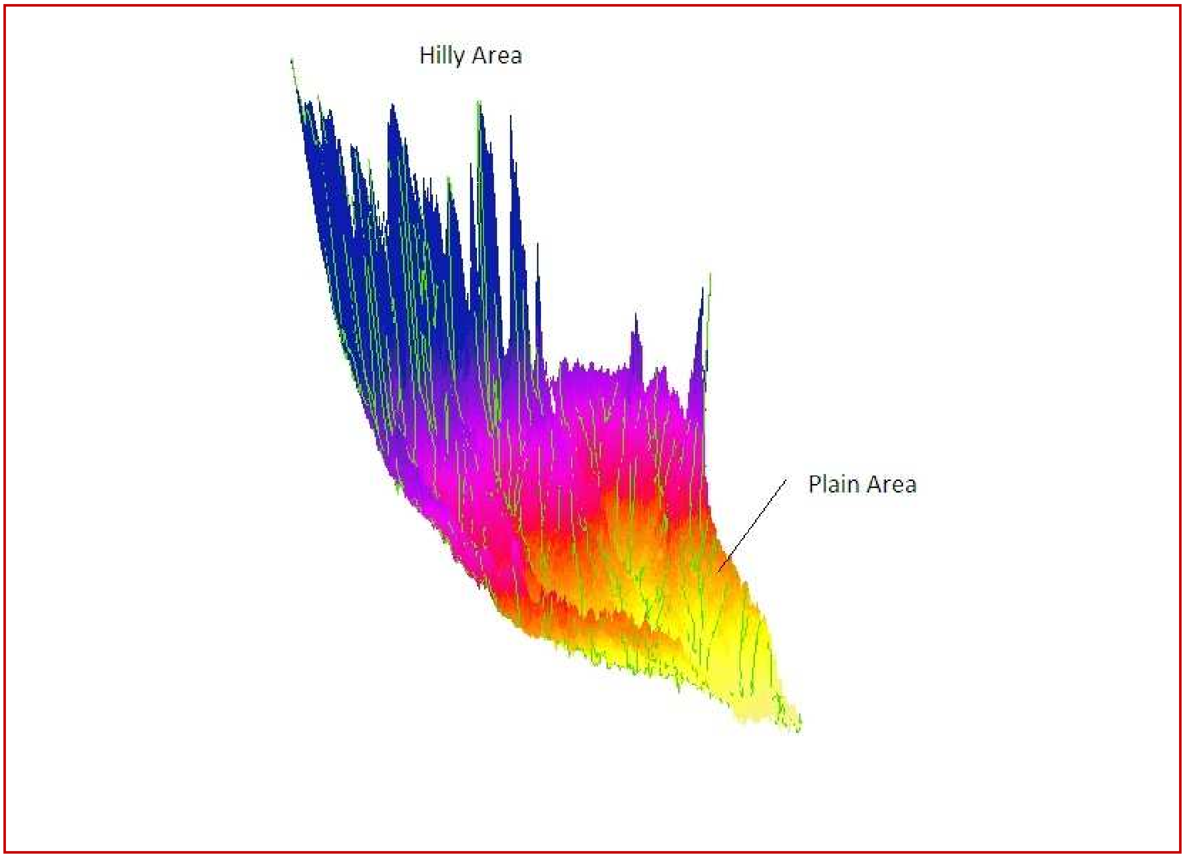

Figure.2. 3D MODEL VIEW OF WRY-2WATERSHED

3. Morphometric Analysis

Morphometry 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. A major emphasis on geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behaviour surface drainage network. The linear aspects were studied using the methods of Horton, (1945), Strahler,(1953); Chorley, (1957) Leopold and Maddock,(1953);Abrahams,(1984). the areal aspects using those of Schumn, (1956); Strahler,(1956 ,1968) ;Miller,(1953), and Horton(1932); and the relief aspects employing the techniques of Horton (1945); Broscoe (1959); Melton(1957); Schumn(1954) Strahler (1952);

and Pareta (2004). The area, altitude, volume, slope, profile and texture 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 WRY-2 basin was carried out on the Survey of India topographical maps No. 55L/13, 55L/14 on the scale 1:50,000 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.

4. Drainage Network:

4.1. 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.

4.2. Stream Number (Nu)

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

4.3. Stream Length (Lu)

The total stream lengths of the WRY-2 sub watershed 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 length

based on the low proposed by Horton (1945), Table 1

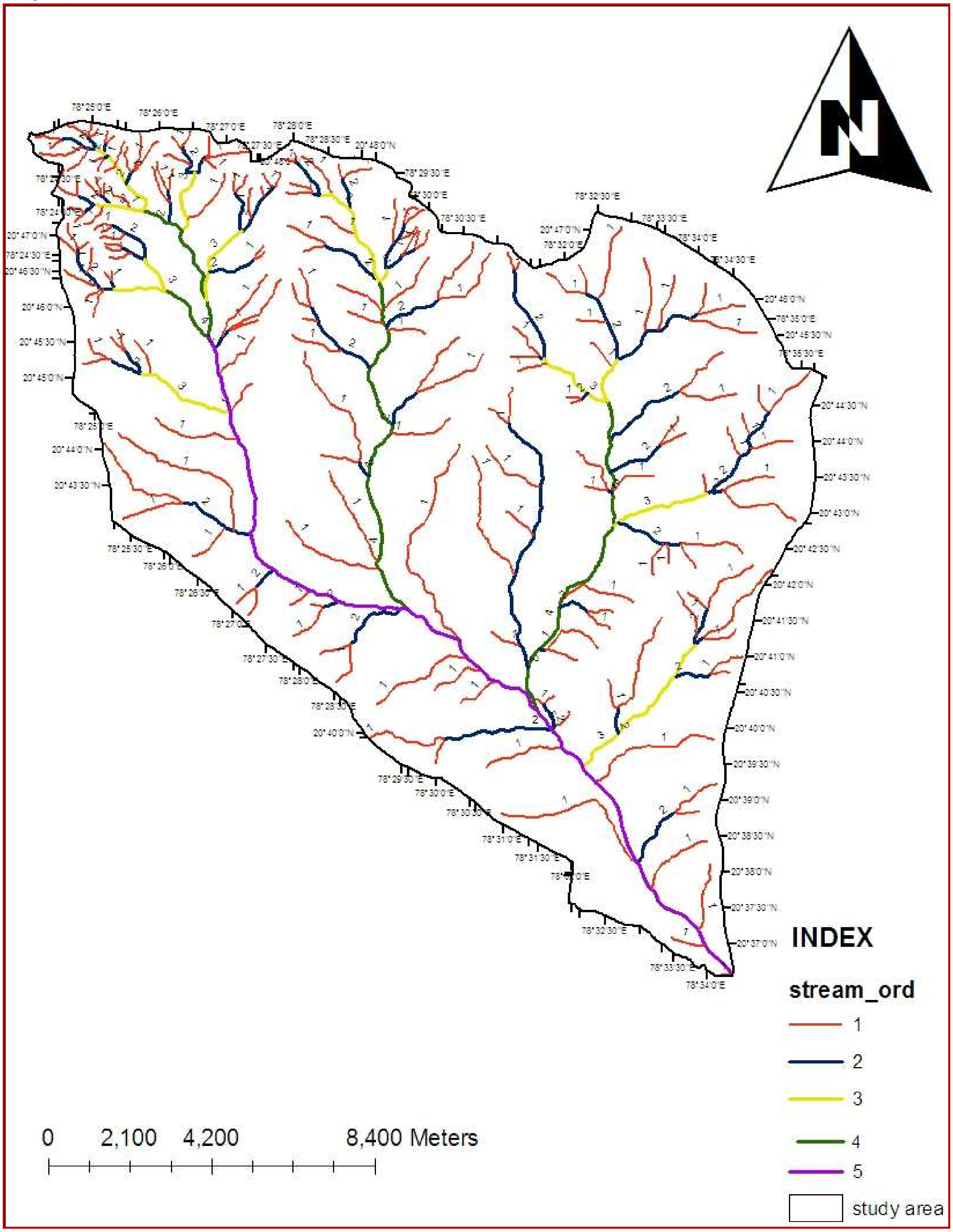

Figure 3.Stream Order Map of WRY-2 Sub-Watershed

4.4. 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, and Bifurcation Ratios of WRY-2 River basin

S_u	N_u	R_b	N_{u-r}	R_b*N_{u-r}	R_{bwm}
I	188	---	---	---	3.55
II	56	3.35	244	817.4	
III	13	4.30	69	296.7	
IV	4	3.25	17	55.25	
V	1	4	5	20	
Total	262	14.9	335	1189.35	
Mean		3.72*			

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

4.5. 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).

4.6. 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 3.35 to 4.0. 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.

4.7 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 **3.72**of 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 in WRY-2River basin.

S_u	L_u	L_u/S_u	Lur	L_{ur-r}	$L_{ur}*L_{ur-r}$	L_{uwm}
I	208.700	1.11				1.68
II	63.987	1.14	1.02	272.68	278.13	
III	26.463	2.03	1.78	90.45	161.00	
IV	24.317	6.07	2.99	50.78	151.83	
V	23.638	23.638	3.89	47.95	186.52	
Total	347.107	33.988	9.68	461.86	777.48	
Mean			2.42			

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.

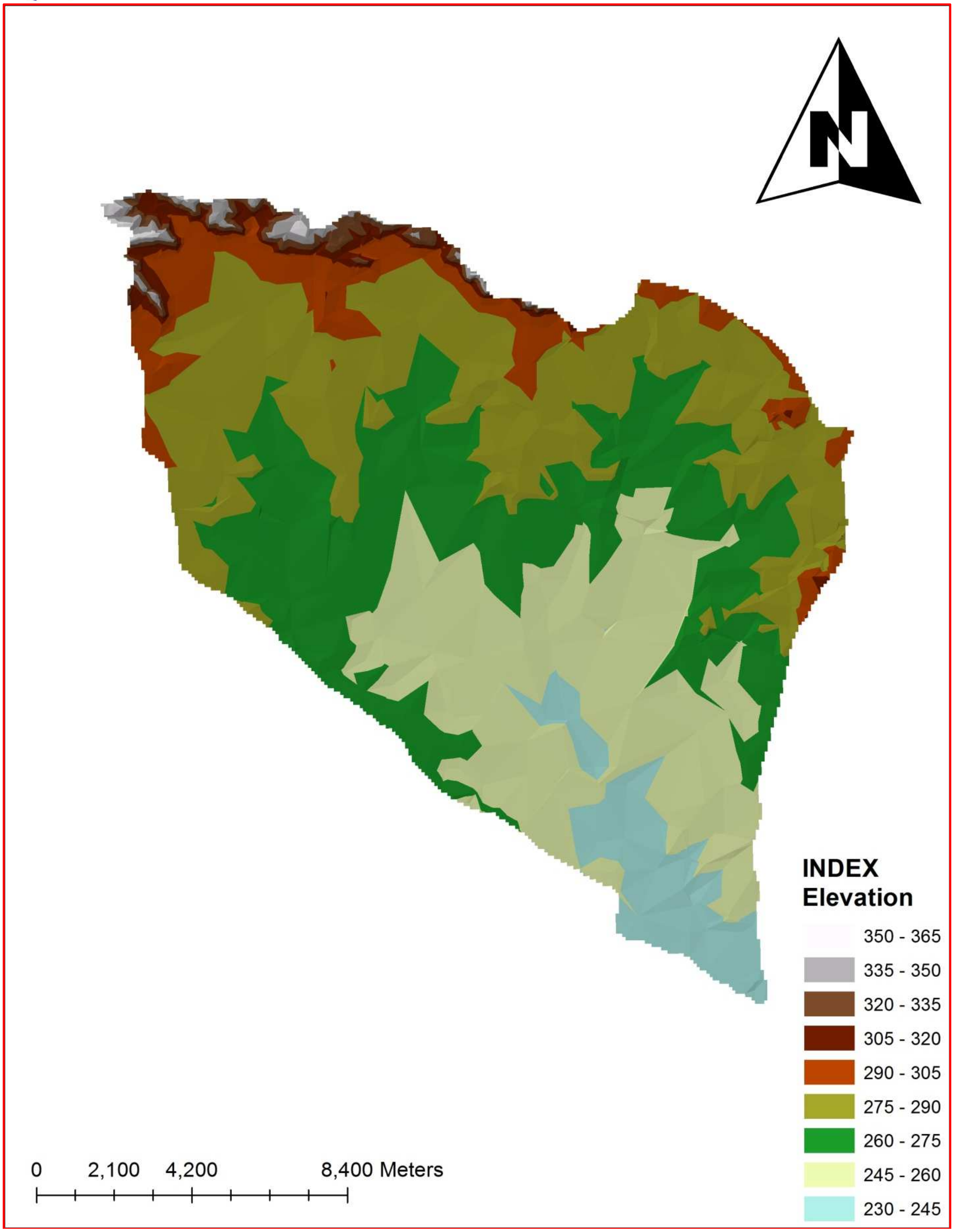

Figure 4. Digital Elevation Model Map

4.8. Length of Main Channel (Cl):-

This is the length along the longest watercourse from the outflow point of designated sun watershedto the upper limit to the watershed boundary. Author has computed the mainchannel length by using ArcGIS-10 software, which is **23.64**Kms.

4.9. Channel Index (Ci) & Valley Index (Vi):-

The river channel has divided into number of segments as suggested by Muller (1968), andFriend and Sinha (1998) for determination of sinuosity parameter. The measurement ofchannel length, valley length, and shortest distance between the source, and mouth of theriver (Adm) i.e. air lengths are used for calculation of Channel index, and valley index.

4.10. Rho Coefficient (ρ):-

The Rho coefficient is an important parameter relating drainage density to physiographicdevelopment of a watershed which facilitate evaluation of storage capacity of drainagenetwork and hence, a determinant of ultimate degree of drainage development in a givenwatershed (Horton 1945). The climatic, geologic, biologic, geomorphologic, andanthropogenic factors determine the changes in this parameter. A Rho value of the WRY-2 sub watershed is**0.64**. This is suggesting higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

5. Basin Geometry

5.1 Length of the Basin (Lb)

Several people defined basin length in different ways, such as Schumm (1956) defined thebasin length as the longest dimension of the basin parallel to the principal drainage line.Gregory and Walling (1973) defined the basin length as the longest in the basin in which areend being the mouth. Gardiner (1975) defined the basin length as the length of the line from abasin mouth to a point on the perimeter equidistant from the basin mouth in either directionaround the perimeter. The length of the WRY-2 sub watershedinaccordance with the definition of Schumm (1956) that is **28.27**Kms.

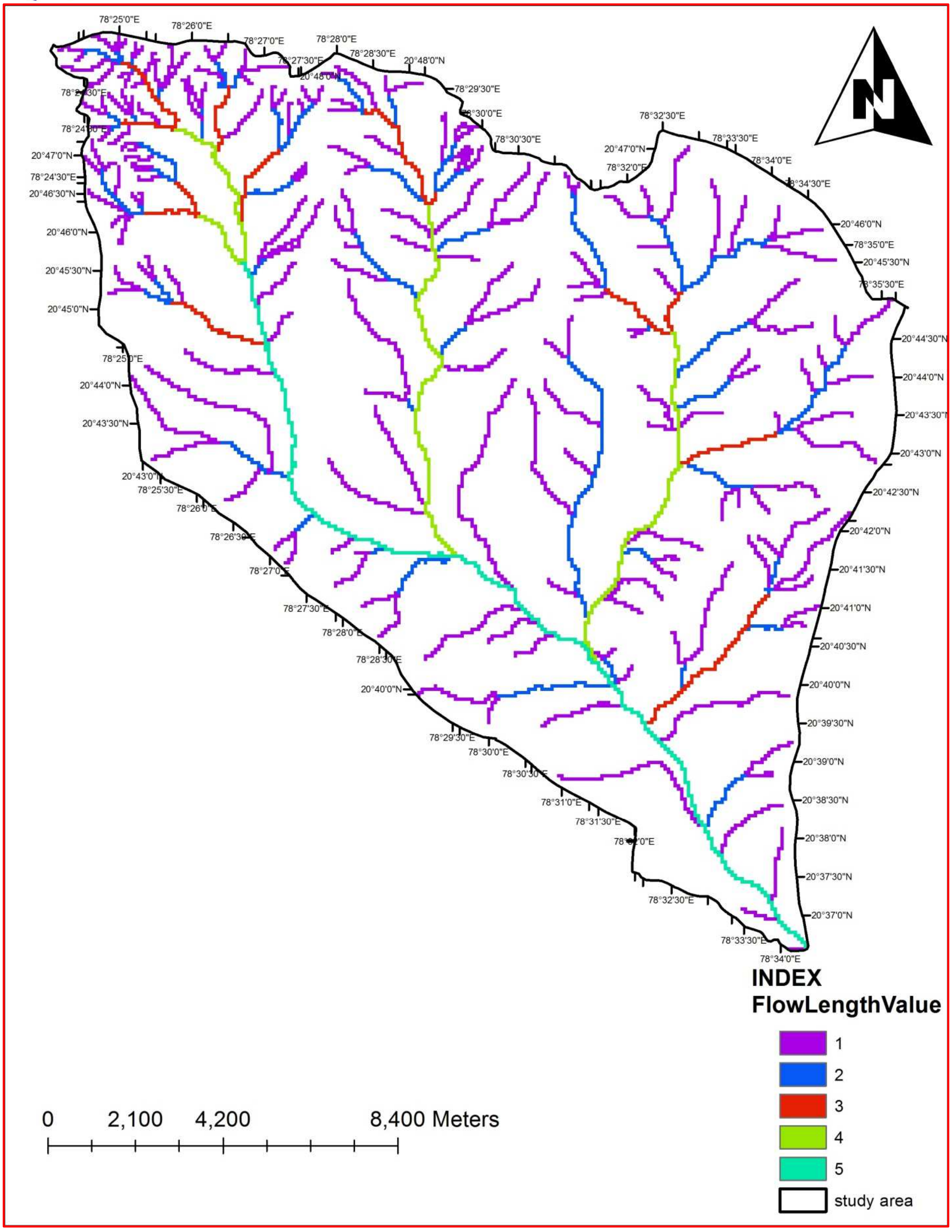

Figure 5. Flow Length Map of WRY2 Sub-Watershed

5.2 Basin Area (A)

The area of the WRY-2 sub watershedis another important parameter like the length of the streamdrainage. Schumm (1956) established an interesting relation between the total WRY-2 sub watershedareas and the total stream lengths, which are supported by the contributing areas. The authorhas computed the basin area by using ArcGIS-10 software, which is 256.38Sq. Kms.

5.3Basin Perimeter (P)

Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measured along the divides between watershed and may be used as an indicator of watershed size and shape. The author has computed the basin perimeter by using ArcGIS-10 software, which is 73.72Kms.

5.4 Length Area Relation (Lar):-

Hack (1957) found that for a large number of basins, the stream length and basin area are related by a simple power function as follows: Lar = 1.4 * A0.6

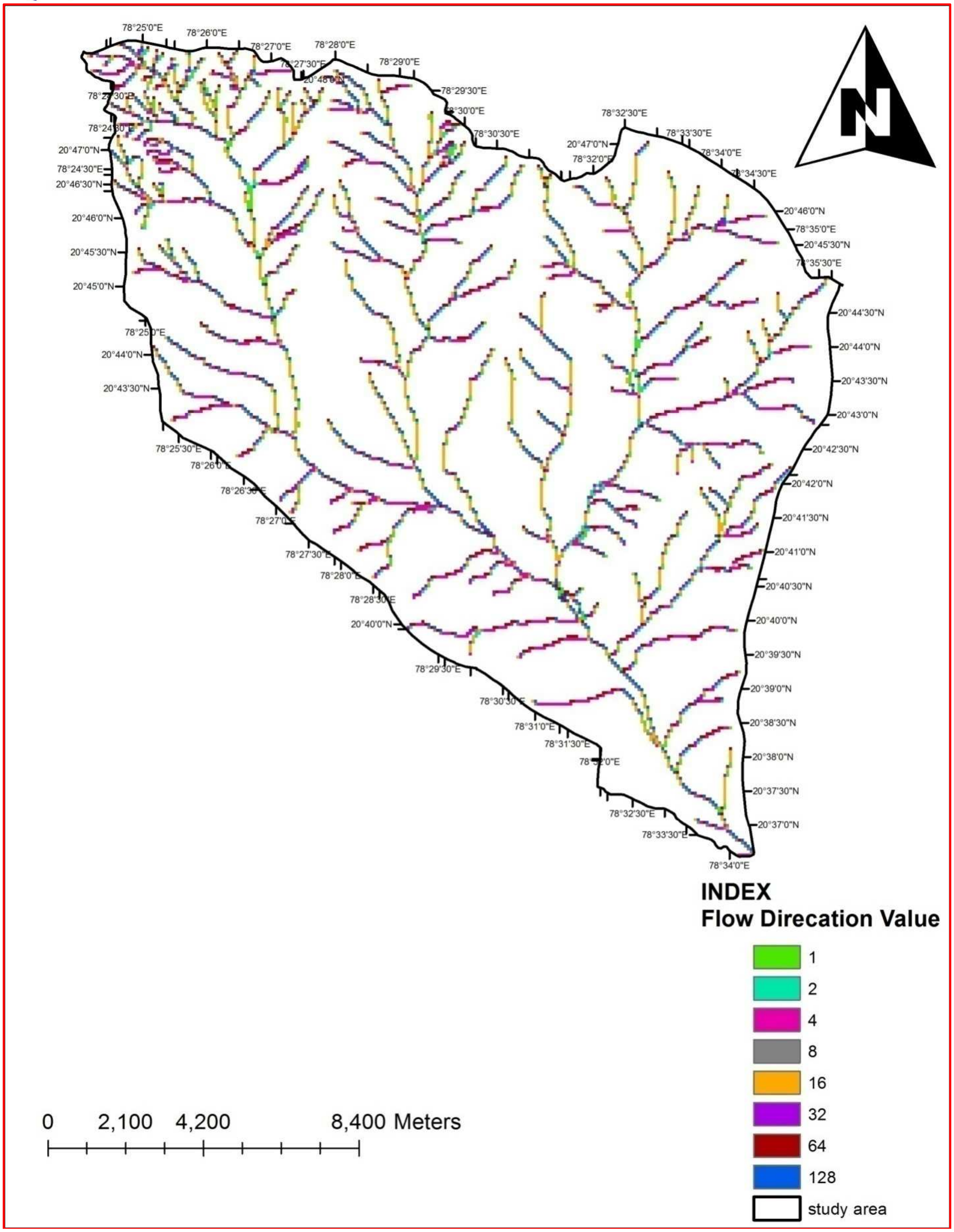

Figure 6. **FLOW DIRECATION MAP OF WRY2 SUB-WATERSHED**

S. N	Morphometric Parameter	Formula	Reference	Results
A	**Drainage Network**			
1	Stream Order (S_u)	Hierarchical Rank	Strahler (1952)	**1 to 5**
2	1st Order Stream (S_{uf})	Suf = N1	Strahler (1952)	**188.00**
3	Stream Number (N_u)	$Nu = N_1+N_2+ \dots N_n$	Horton (1945)	**262.00**
4	Stream Length (L_u) Kms	$Lu = L_1+L_2 \dots L_n$	Strahler (1964)	**347.107**
5	Stream Length Ratio (L_{ur})	see Table 2.3	Strahler (1964)	**9.68**
6	Mean Stream Length Ratio (L_{urm})	see Table 2.3	Horton (1945)	**2.42**
7	Weighted Mean Stream Length Ratio (L_{uwm})	see Table 2.3	Horton (1945)	**1.68**
8	Bifurcation Ratio (R_b)	see Table2.2	Strahler (1964)	**3.35-14.9**
9	Mean Bifurcation Ratio (R_{bm})	see Table 2.2	Strahler (1964)	**3.72**
10	Weighted Mean Bifurcation Ratio (R_b)	see Table 2.2	Strahler (1953)	**3.55**
11	Main Channel Length (C_1) Km.	GIS Software Analysis		**23.64**
12	Valley Length (V_l) Kms	GIS Software Analysis		**31.68**
13	Minimum Aerial Distance (A_{dm}) Kms	GIS Software Analysis		
14	Channel Index (C_i)	$C_i = C_l/ A_{dm}$ (H & TS)	Miller (1968)	
15	Valley Index (V_i)	$Vi = V_l/ A_{dm}$ (T_S)	Miller (1968)	
16	Rho Coefficient (ρ)	$\rho = L_{ur}/ R_b$	Horton (1945)	**0.64**
B	**Basin Geometry**			
17	Length from W's Center to Mouth of W's (L_{cm})Kms	GIS Software Analysis	Black (1972)	
18	Width of W's at the Center of Mass(W_{cm}) Kms	GIS Software Analysis	Black (1972)	**18.86**
19	Basin Length (L_b) Kms	GIS Software Analysis	Schumm(1956)	**28.27**
20	Mean Basin Width (W_b)	$W_b = A / L_b$	Horton (1932)	**9.07**
21	Basin Area (A) SqKms	GIS Software Analysis	Schumm(1956)	**256.38**
22	Mean Area Ratio (A_{rm})			
23	Weighted Mean Ratio (A_{rwm})			
24	Basin Perimeter (P)Kms	GIS Software Analysis	Schumm(1956)	**73.72**
25	Relative Perimeter (P_r)	$P_r = A / P$	Schumm(1956)	**3.50**

6. SOIL:

Soil is important upper layer of the earth surface to support crop and vegetation for the economic development and food requirement of the human. The soil information for the study area was digitized from the soil map. Generally, thirteen (13) types of soil had been identified in the study area. At the lower area of watershed consists of clayey soil.The soil types of study area areclayey soil**,** clay loam, clayey, gravely clay, gravely clay loam, gravely sandy loam, sandy clay, and gravely sandy clay etc. The erosion of the top soil decreases the productivity of land and leads to failure of crops.Since soil spectral reflectance can be rapidly and easily obtained with high repeatability, numerous samples can be studied to establish trends of change in soil hydraulic properties in a watershed. In order to spatially extrapolate the soil physical condition in the watershed, the spectrally defined physical condition indices were calibrated to pixel reflectance extracted from the IRS image of the study area. However, the conditional dependency model was developed to remove potential errors in the calibration model due to correlation between factors. There was significance relationship between soil physical condition indices and reflectance values from band 3, band 5 and band 7 (at 5 % significance level)

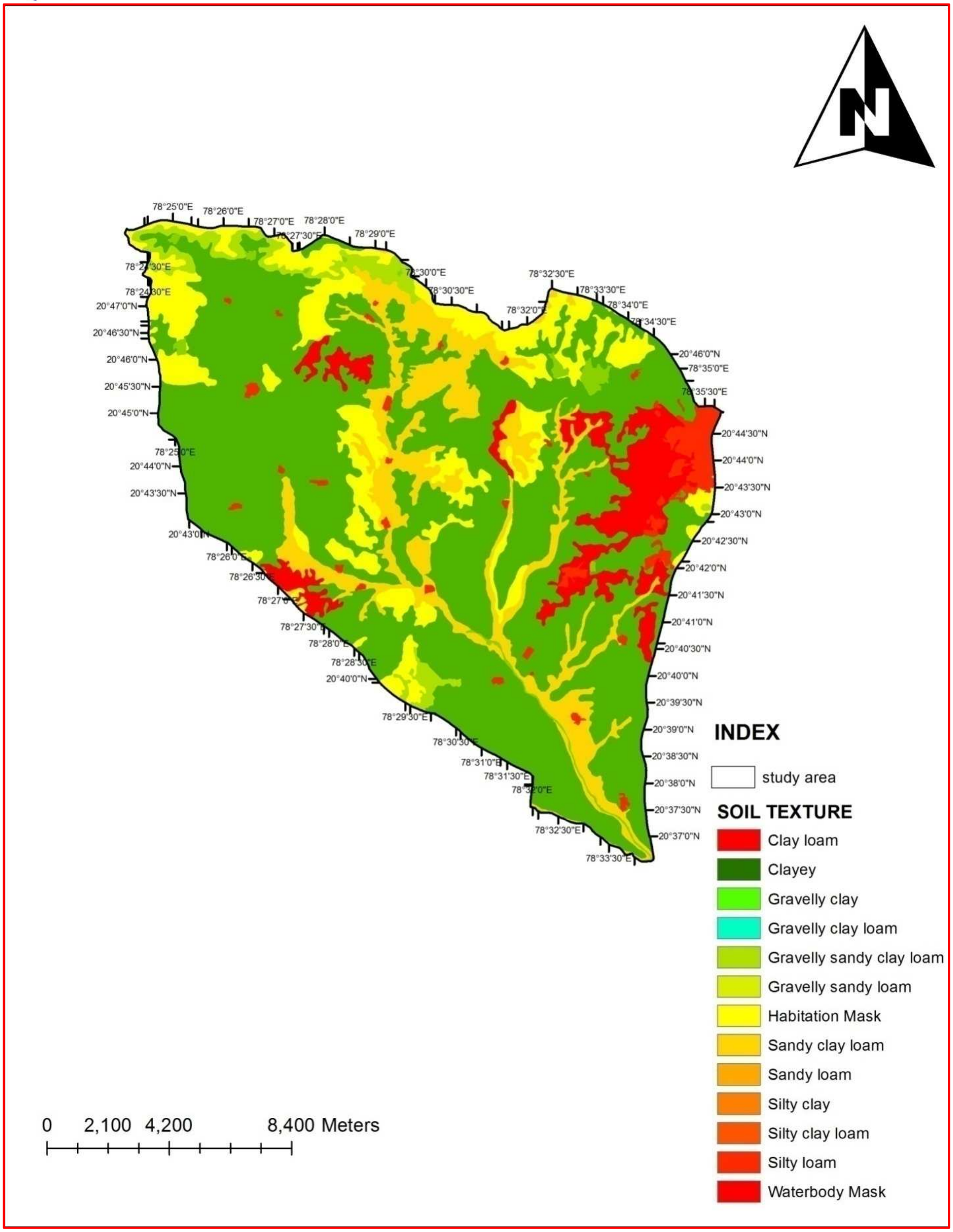

Figure 6. Soil Texture Mapof WRY-2 Sub-Watershed Area

7. Land Use and Land Cover

Land Cover, defined as the assemblage of biotic and a biotic components on the earth's surface is one of the most crucial properties of the earth system. Remote sensing data and GIS techniques provide reliable basic information for land use mapping and play very important role in determining land use pattern by visual interpretation. Land use and land cover is an important component in understanding the interactions of the human activity with the environment and thus it is necessary to be able to simulate changes. Land use refers to man's activities and the varied uses which are carried on over land and land cover refers to natural vegetation, water bodies, rock/soil, artificial cover and others noticed on the land (NRSA, 1989). The land use/ land cover is derived from the LISS-III Open Source satellite image using image classification techniques such as supervised and unsupervised. The most of the land is under agricultural crop land in the present study area and other area is covered by forest, built up, waste land, and Water body. Land use describes how a parcel of land is used such as for agriculture, settlements or industry, whereas land cover refers to the material such as vegetation, rocks or water bodies that are present on the earth surface. The water bodies include river, canal, tank, pond and reservoir etc which is show in the following Fig.7.

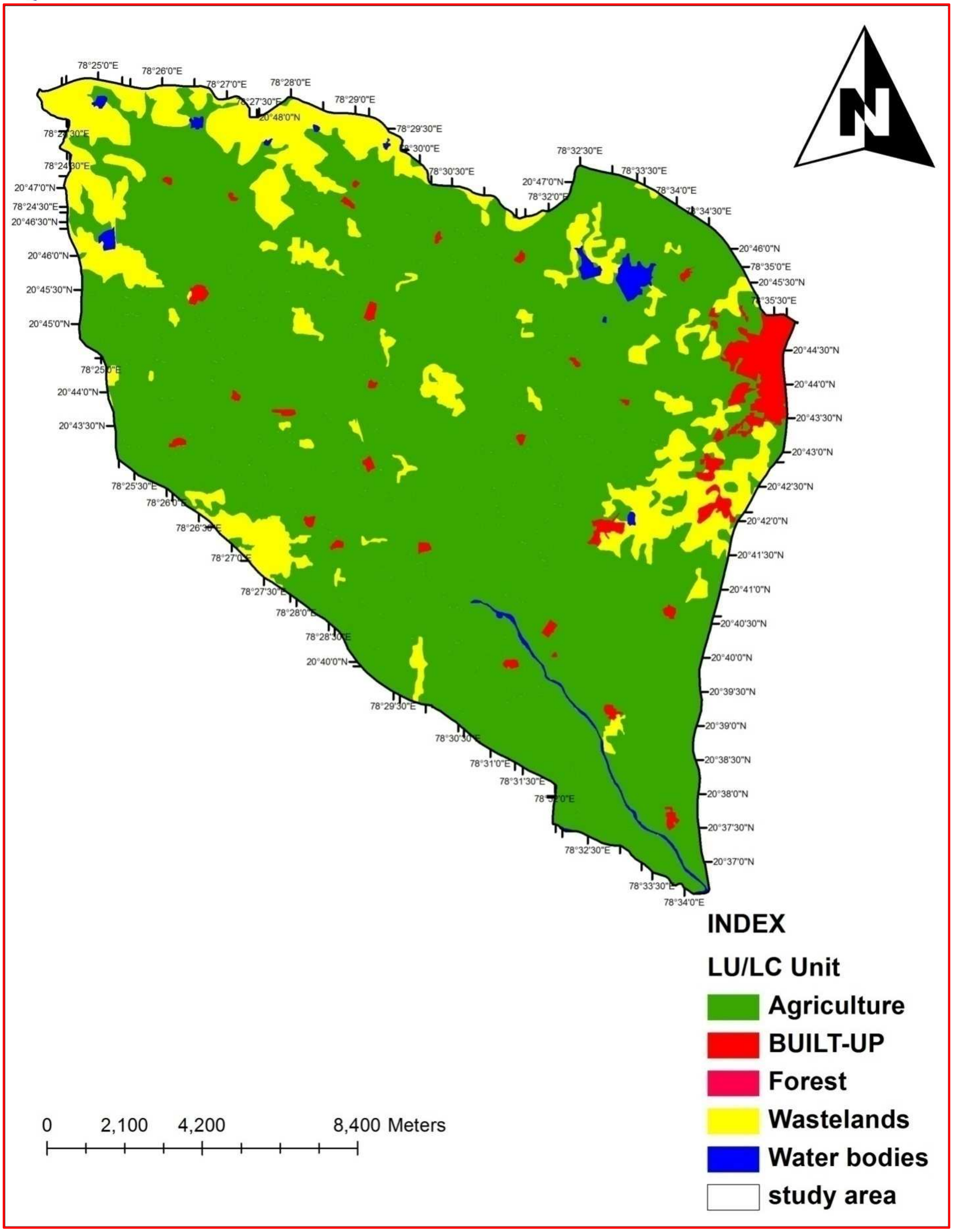

Figure.8. Land Use & Land Cover Map of WRY-2sub-Watershed Area

8. Conclusion:-

The study reveals that remotely sensed data and GIS based approach inevaluation of drainage morphometric parameters and their influence on landforms, soils anderoded land characteristics at river basin level is more appropriate than the conventionalmethods. GIS based approach facilitates analysis of different morphometric parameters and toexplore the relationship between the drainage morphometry and properties of landforms, soilsand eroded lands. Different landforms were identified in the watershed based on remotely sensed data with 30 m spatial resolution, and GIS software. GIS techniques characterized by high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis. GIS techniques characterized by very high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis. The morphometric analyses were carried out through measurement of linear, areal and relief aspects of the watershed with more than 25 morphometric parameters. The morphometric analysis of the drainage network of the watershed show dendritic and radial patterns with moderate drainage texture. The morphometric analysis of the drainage network of the watershed show dendritic and with coarse drainage texture.The variation 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. The value of form factor and circulator ration suggests that WRY-2 sub watershed is less elongated. Hence, from the study it can be concluded with GIS techniques, prove to be a competent tool in morphometric analysis.In this present study, illustration of how we can benefit from remote sensing and GIS technologies in watershed management and planning. Watershed management is the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plant, animal, and human communities within a watershed boundary. The remote sensing data combined with field survey data can provide a unique and hybrid database for optimal planning and management of watershed. Space borne remote sensing technology is a unique tool to provide spatial, multi-spectral and repetitive information for effective planning. The land forms along with slope gradient and relief intensity are other parameters to determine the type of water harvesting and water conservation structures. This study has provided information regarding the soil map, land use land cover map, Morphometric analysis and watershed Managementresponse in WRY-2 Watershed in wardha District Maharashtra, India.The relationship between geological setup and drainage pattern is analyzed. Regional and local trends of geological setup are reflected in the variable orientation of channels of different rank in the catchment.

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