INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES
Volume 5, No 1, 2014

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Research article ISSN 0976 – 4380

Drainage characteristics of Manchi basin, Karauli district, Eastern Rajasthan using remote sensing and GIS techniques

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ABSTRACT

An attempt has been made to study drainage morphometry of Manchi basin, which covers an area of 235.67 km².Drainage Map prepared from Survey of India (SOI) toposheet and later updated from IRS-1C (LISS III) imagery to examine drainage characteristics. ASTER data is used for preparing Digital Elevation Model (DEM) and Slope map. Geographic Information System (GIS) is used in evaluation of linear, areal and relief aspects of morphometric parameters. Moderate drainage density 2.72 km/km² indicate that the area is underlain by permeable sub surface material and has coarse to moderate drainage texture. The mean bifurcation ratio of entire basin is 5.2 which indicate that the drainage pattern is little influenced by geological structures. Analysis of shape parameters- form factor, elongation ratio, circularity ratio, suggests that the basin is in an elongated shape. Relief ratio indicates that the discharge capability of the basin is very high and the groundwater potential is meager. This study will be very useful for watershed management strategies and for planning rainwater harvesting structures within the sub-basin areas to conserve the natural resources.

Keywords: Basin, Morphometric analysis, ASTER data, GIS, Remote Sensing.

1. Introduction

Drainage basins are the fundamental units to understand geometric characteristics of fluvial landscape, such as topology of stream networks, and quantitative description of drainage texture, pattern, shape and relief characteristics (Obi Reddy et al., 2004; Subba Rao, 2009). Morphometric analysis is an important technique to evaluate and understand the behaviour of hydrological system. It provides quantitative specification of basin geometry to understand initial slope or inconsistencies in rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler, 1964; Esper Angillieri, 2008).

Drainage analysis based on morphometric parameters is very important for watershed planning since it gives an idea about the basin characteristics in terms of slope, topography, soil condition, runoff characteristics, surface water potential etc (Javed et al., 2011). The morphometric characteristics of various basins have been studied by many scientists using conventional (Horton, 1945; Smith, 1950; Strahler, 1957) and remote sensing and GIS methods (Krishnamurthy and Srinivas, 1995; Srivastava and Mitra, 1995; Agarwal, 1998; Biswas et al., 1999; Narendra and Nageswara Rao, 2006). In the present study, an attempt has been made to quantitatively analyze the drainage and morphometric characteristics of Manchi basin.

2. Area of study

Manchi basin is located in Karauli district, eastern Rajasthan and covers an area of 235.67 km². The drainage basin extends from latitudes 26º25' to 26º45'N and longitudes 77º00' to 77º15' E (Figure. 1). The maximum and minimum elevation encountered in the study area is 367m and 231m above mean sea level. The slope ranges from 0º to 28º, indicating a fairly large variation within the basin.

It experiences semi-arid climate with low and erratic rainfall. Climate data of (1977-2012) period has revealed that the average annual rainfall has shown a decline rainfall of 200mm which has adversely affected both surface as well as ground water resources. Increasing trends have been observed for average maximum and minimum temperature. Average maximum and minimum temperature has increased by 1.2°C and 0.4°C respectively.

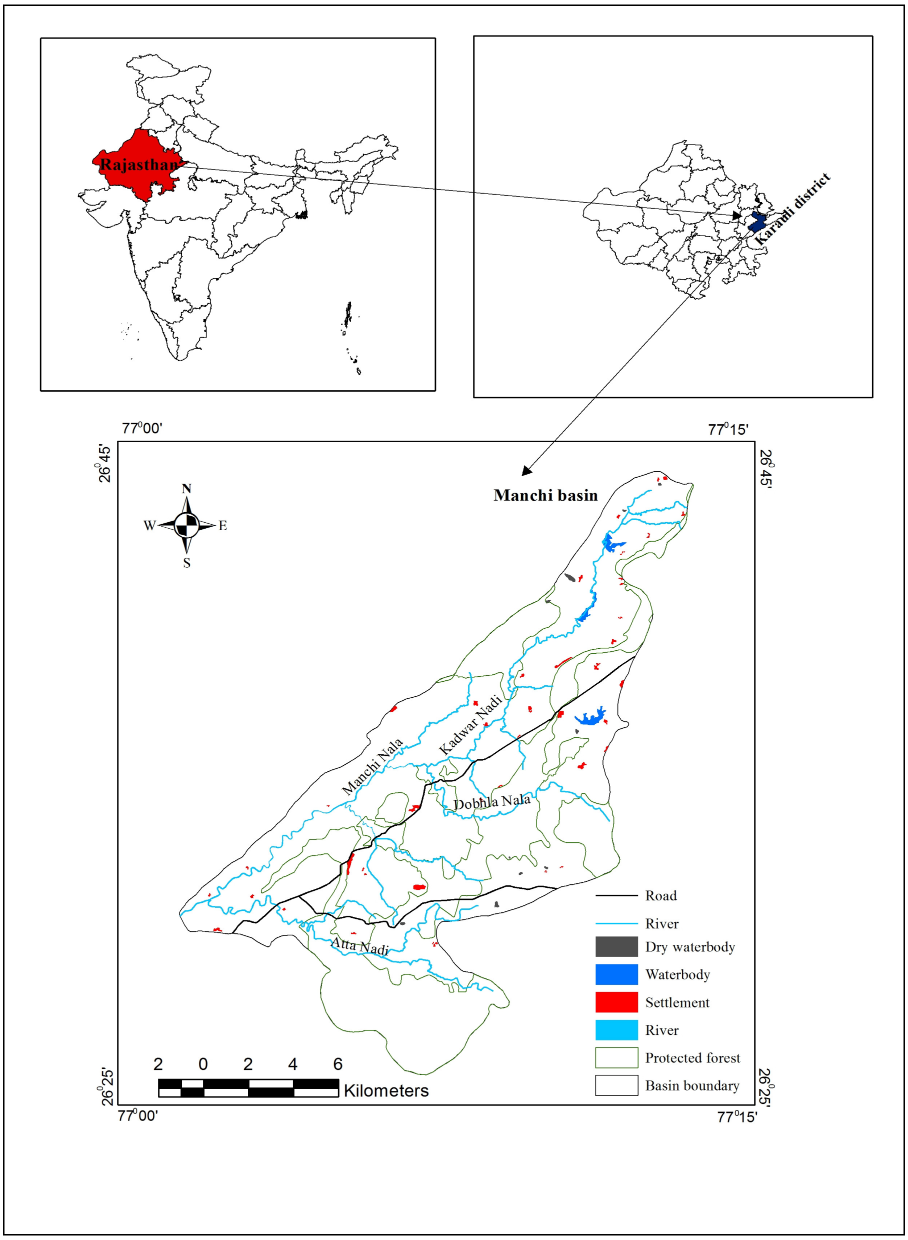
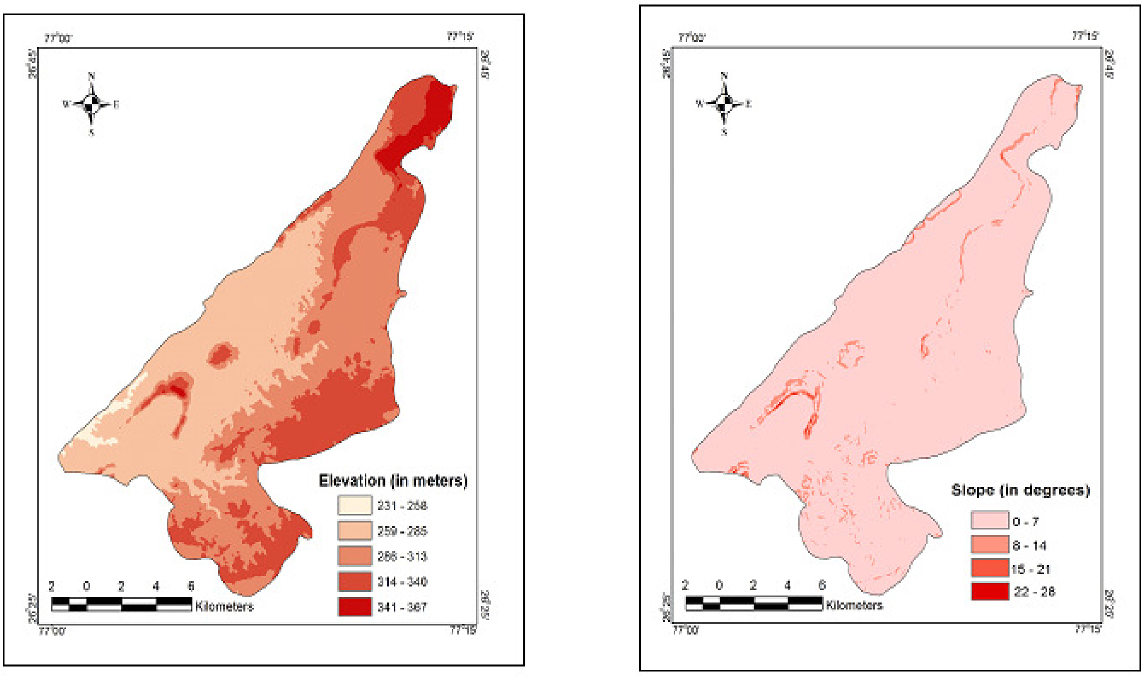


Figure 1: Location map of the study area

3. Methods and methodology

Survey of India toposheets (SOI) 54F/2 and 54F/3 on 1:50,000 scale and Standard Geocoded FCC of Indian Remote Sensing Satellite IRS-IC LISS III of 13th May, 1998 using a spatial resolution of 23.5m have been used for preparation of drainage map. Advanced Space borne Thermal Emission Radiometer (ASTER) was downloaded from the website http://www.gdem.aster.erdac.or.jp/search.jsp and was subsequently utilized for the preparation of DEM and Slope map of the area (Figure. 2). Besides, secondary information/data were collected and utilized wherever required, including published research papers from various journals, technical reports, special volumes and memoirs of Geological Society of India, and information from other government and non-government sources were consulted. Limited ground truth verification was also carried out in key areas to ascertain the veracity of satellite data, and as an input to the final analysis.

The SOI toposheets and digital satellite data were geometrically rectified and georeferenced to world space coordinate system using digital image processing software (ERDAS 11).Drainage network of the basin was traced on transparency from the Survey of India toposheet (54F/2 & 54F/3), latter updated from the imagery (IRS-IC LISS III), and was digitized using Arc GIS software. Geological map showing lithounits was derived from GSI District Resource map, and later digitized in GIS environment. Polygon topology was built for each litho unit, after assigning unique ids for every polygon feature using Arc map10. The coverage was edited and cleaned before further analysis. Advanced Space borne Thermal Emission Radiometer (ASTER) at 30m resolution was downloaded from the website (http://www.gdem.aster.erdac.or.jp/search.jsp) and was subsequently utilized for preparation of Digital Elevation Model. A colour coded DEM was generated using SAGA software. Thus, taking the DEM as input Slope map was created in Arc GIS software.



(a) (b)

Figure 2: (a) Digital Elevation Model (DEM) and (b) Slope map of the study area

4. Results and discussions

4.1 Geology

The rock types expose in the study area belong to the Vindhyan Supergroups of Archaean to Lower Proterozoic and Middle to Upper Proterozoic age. Sirbu shale, limestone and Upper Bhandar Maihar sandstone belong to Bhandar Group represented by soft, laminated, fissile rock and thin to thickly bed spotted rock. The geological map of the Manchi basin was prepared using District Resource Map from Geological Survey of India (GSI), which shows four litho units i.e. Alluvium, Shale, Sandstone and Limestone (Figure. 3).

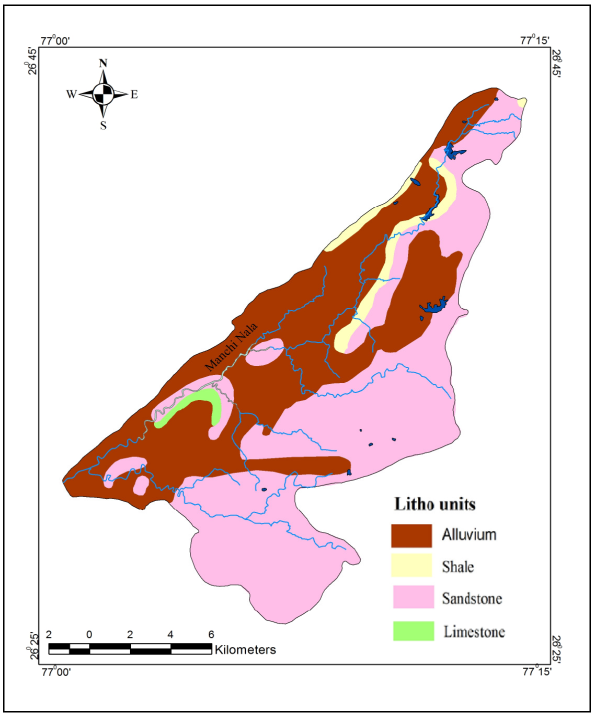


Figure 3: Geological map of the study area

4.2 Morphometric Analysis

Morphometry is the measurement and mathematical analysis of the configuration of the Earth's surface, shape and dimensions of its landforms (Clarke, 1966). This analysis can be achieved through measurement of linear, areal and relief aspects of basin and slope contributions (Nag and Chakraborty, 2003). Calculated morphometric parameters– linear, areal and relief are discussed below.

4.2.1 Linear parameters

4.2.1.1 Stream order (u)

The designation of stream orders is the first step in drainage basin analysis and is based on a hierarchic ranking of streams. Stream order or classification of streams is a useful indicator of stream size, discharge and drainage area (Strahler, 1957). It can be used for comparison of geometry for drainage networks on different linear scales. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964).In sub basins (SB I to SB V) number of total streams varies from 80 (SB III) to 332 (SB V). Sub basin I, II, III and IV were identified under 4th order and V Sub basin under 5th order (Table. 1). The lower number of streams of sub basin indicates maturity of topography, whereas higher number of streams (1st and 2nd orders) indicates, the area is prone to erosion (K.Avinash et al., 2011). The sub basin covers an average area of ~47 km² and an average length (L) of ~13km. According to Horton (1932), the geometric relation between the logarithm of average number of streams (Nu) and stream orders (u) show an inverse linear relationship (Figure. 4).

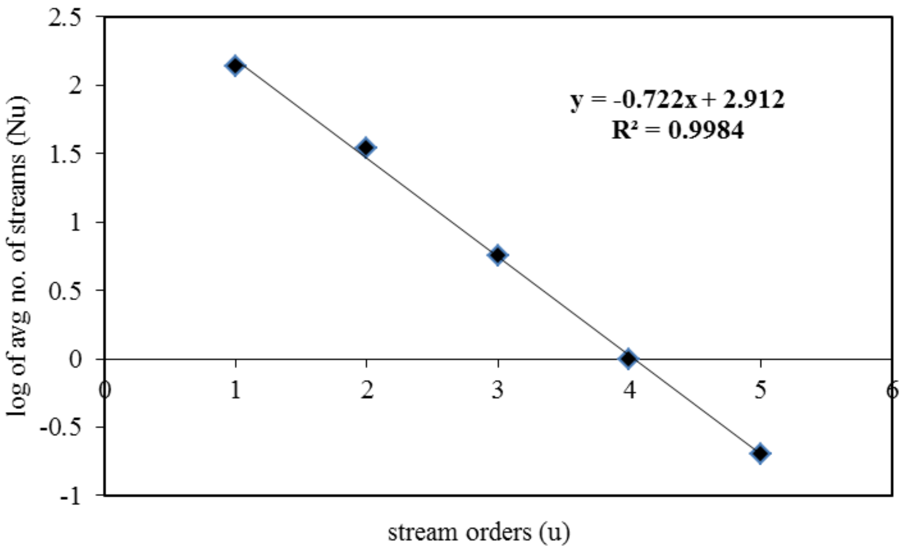


Figure 4: Relation between stream orders (u) and number of streams (Nu) in different basins of the study area.

4.2.1.2 Bifurcation ratio (Rb)

The term bifurcation ratio (Rb) may be 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) (Table. 1). Strahler (1964) stated that wherever the Rb ranges from 3-5 is not influenced by geological structures. These irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). In the present study Rb within the sub basins varies from 3.90 (SB III) to 7.36 (SB V).The lower values of Rb 4.42 (SB II) and 3.90 (SB III) are characteristics of less structural disturbances (Strahler, 1964) and the drainage patterns has not been distorted (Nag, 1998).It even indicates that the drainage basin is underlined by uniform materials and the streams are usually branched systematically (Vijay Pakhmode et al., 2003). Whereas, Rb 5.69 (SB I), 5.74 (SB 1V) and 7.36 (SB V) indicates structurally controlled pattern as the values are greater than 5.

4.2.1.3 Stream length (Lu)

It is a dimensional property, Horton's law (1945) of stream length states that mean stream length segments of each of the successive orders of a basin tend to approximate a direct geometric series with streams length increasing towards higher order of streams. Generally, if the rock formations are permeable, a small number of relatively longer streams are formed, whereas if the rock formations are less permeable, a large number of smaller streams are developed (Vijay Pakhmode et al., 2003).

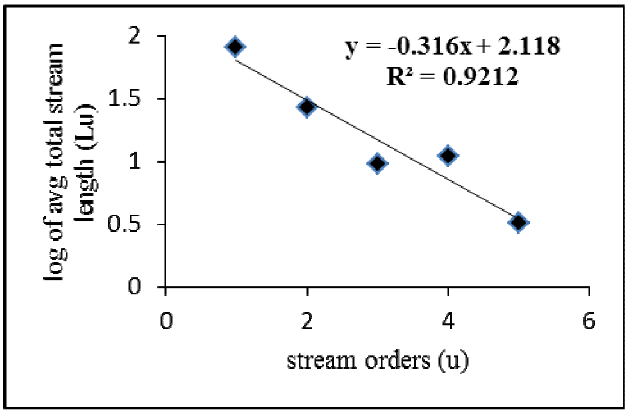
Table 1: Computational results of linear Morphometric parameters such as number of streams and bifurcation ratio of sub-basins of the Manchi basin

Sub- Basins	No. of streams of different stream order						Bifurcation Ratio(Rb)				
	1	2	3	4	5	Σ Nu	1/2	2/3	3/4	4/5	mean Rb
I	165	36	8	1	-	210	4.58	4.5	8	-	5.69
II	79	16	3	1	-	99	4.93	5.33	3	-	4.42
III	59	16	4	1	-	80	3.69	4	4	-	3.90
IV	129	40	10	1	-	180	3.23	4	10	-	5.74
V	263	64	3	1	1	332	4.11	21.33	3	1	7.36
Average[a]	139	34.4	5.6	1	0.2	180.2	4.11	7.83	5.6	0.2	4.44
Manchi Basin	695	172	28	5	1	901	4.04	6.14	5.6	5	5.20

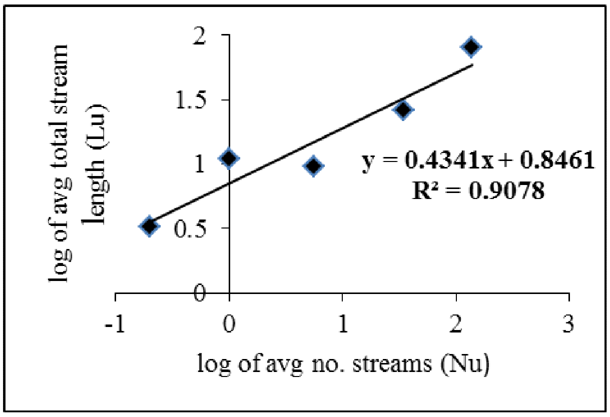
The total stream length (∑Lu) is minimum (50.13 km) in the SB-III and maximum (233.41 km) in the SB-V (Table. 2). Further, it is also noted that the Lu is maximum (average of 129.63km) in the case of first-order streams of all the sub-basins, as geometrical similarity is preserved in the basins of increasing order (Strahler, 1964). However, the average values of Lu computed for the first- and second-order streams are 0.56 (0.48-0.62) km and 0.80 (0.68–0.93) km, respectively, and that of third- and fourth-order streams are 2.16 (0.34–4.41) km and 10.85 (2.9–20.43) km, and fifth order 3.25(16.24) respectively (Table. 2).The distribution of number of streams and their lengths in different orders are favored by these differences. The geometrical relationship is shown graphically in the form of a straight line when the log of average total stream lengths vs. stream orders is plotted (Figure. 5*a, b*). This relation shows positive linear relationship (R=0.9212), which clearly indicates that the number of streams increases as stream lengths increase (Figure. 5a).

Table 2: Sub-basin wise computational results of stream lengths of Manchi basin

SB	Total stream length(Lu)						Average Lu (km) in different orders u (Lu/u)				
	1	2	3	4	5	Σ Lu	1	2	3	4	5
I	97.88	29.89	17.11	15.93	-	160.81	0.59	0.83	2.14	15.93	-
II	48.66	12.59	9.57	2.9	-	73.72	0.62	0.79	3.19	2.90	-
III	28.33	14.97	1.35	5.48	-	50.13	0.48	0.93	0.34	5.48	-
IV	71.41	31.20	7.03	20.43	-	130.07	0.55	0.78	0.70	20.43	-
V	150.62	43.79	13.24	9.52	16.24	233.41	0.57	0.68	4.41	9.52	16.24
Avg	79.38	26.49	9.66	10.85	3.25	129.63	0.56	0.80	2.16	10.85	3.25



5(a)



5(b)

Figure 5: Graphs showing the geometric relationship (a) between stream orders (u) and stream lengths (Lu), and (b) between number of streams (Nu) and stream lengths (Lu) of whole Manchi basin.

4.2.2 Areal parameters

4.2.2.1 Form factor (Rf)

According to Horton (1932), form factor (Rf) may be defined, as the ratio of basin area to square of the basin length. The value of form factor would always be greater than 0.78 for a perfectly circular basin (Rajeev chopra et al., 2005). Smaller the value of form factor, more elongated will be the basin. In the present study Rf varies from 0.11 (SB-III) to 0.40 (SB-V), indicating that the whole basin is in an elongated form (Table. 3).

4.2.2.2 Elongation ratio (Re)

Elongation ratio is the ratio between the diameter of the circle of the same area as the drainage basin (A) and the maximum length (L) of the basin (Schumm, 1956). Higher value of Re indicates active denudational processes with high infiltration capacity and low run-off

in the basin. Whereas, lower Re values indicate higher elevation of the basin susceptible to high headward erosion along tectonic lineaments (Obi Reddy et al., 2004, Manu and Anirudhan, 2008). These values can be grouped into the three categories, namely circular (>0.9), oval (0.9-0.8) and less elongated (<0.7). Hence, the Re values 0.37 (SB III) to 0.50

(SB IV) indicate that the Manchi basin is associated with low relief and moderate slopes. The sub basin having low Re values are susptible to high erosion and sedimentation load and elongated basin (Table. 3).

4.2.2.3 Circularity ratio (Rc)

Circularity ratio (Rc) is the ratio of the area of the basin (A) to the area of the circle having the same circumference as the perimeter (P) of the basin (Miller, 1953; Strahler, 1964). The Rc is more influenced by stream length (lu), stream frequency (Fs) and gradient of streams of various orders rather than the slope conditions and drainage pattern of a basin (Strahler, 1964). Values > 0.5 suggest that the basin is more or less circular in shape and the quantity of discharge is comparatively less in sub-basins with lower Rc values. The present study shows that the values of Rc ranging from 0.25 (SB-III, SB-IV, SB-V) to 0.38 (SB-I, SB-II) (Table. 3) also indicate that the basin is not circular in shape.

4.2.2.4 Drainage density (D)

Drainage density is the total length of streams of all orders divided by the area of drainage basin (Horton 1932, 1945). It provides a numerical measurement of landscape dissection and run-off potential (Obi Reddy et al., 2004). According to Horton (1945), low D i.e. 2.41 (SB-IV), is an indication of the prevalence of highly resistant/ permeable strata under dense vegetation and low relief, whereas, high D 2.99 (SB-V) prevails in the weak/impermeable rocks under sparse vegetation and mountainous relief. The drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture (Table. 3).

4.2.2.5 Drainage texture (Dt)

Drainage texture (Dt) is the total number of stream segments of all orders per perimeter of that area. It is a measure of closeness of the channel spacing, depending on climate, rainfall, vegetation, soil and rock type, infiltration rate, relief and the stage of development (Horton, 1945; Smith, 1950; Schumm, 1956). Smith (1950) has classified drainage density into five different textures. Vegetation covers play an important role in determining the drainage density and texture (Kale and Gupta, 2001). In the present study, the drainage texture (Table. 3) is coarse in SB II (3.46), SB III (2.64) and SB IV (3.84). Whereas, it falls under moderate texture category in SB I (4.57) and SB V (4.67).

4.2.2.6 Stream frequency (Fs)

Stream frequency (Fs) is the ratio between the number of streams (Nu) of all orders within a basin and the basin area (A) (Horton, 1932). The high value of Fs indicates greater surface run-off and a steep ground surface (Horton, 1932; 1945). The computed Fs values of Manchi basin range from 3.33 (SB-IV) to 4.25 (SB-V), with an average value of 3.83 per km² (Table. 3) .High Fs values (>2/km²) of 3.63, 3.76, 4.17 and 3.33, 4.25 per km² are observed in the SB-I, SB-II, SB-III and SB-IV, and SB-V respectively. This indicates that these sub-basins

have steep slopes with less permeable rocks, which facilitate greater runoff, less infiltration, sparse vegetation and high relief conditions.

Table 3: Sub basin wise areal morphometric parameters of the Manchi basin

Parameters	Sub-basins					
	I	II	III	IV	V	Average
Length(km)	14.14	9.23	13.14	16.47	13.90	13.38
Area(km^2)	57.84	26.36	19.2	54.05	78.18	47.13
Perimeter(km)	45.93	28.62	30.30	46.83	71.10	44.56
Drainage density (D)	2.78	2.80	2.61	2.41	2.99	2.72
Drainage texture (Dt)	4.57	3.46	2.64	3.84	4.67	3.84
Stream frequency (Fs)	3.63	3.76	4.17	3.33	4.25	3.83
Form factor (Rf)	0.29	0.31	0.11	0.20	0.40	0.26
Circularity ratio (Rc)	0.38	0.38	0.25	0.25	0.25	0.30
Elongation ratio (Re)	0.60	0.61	0.37	0.50	0.70	0.56
Basin shape (Bs)	3.46	3.23	8.99	5.02	2.47	4.63
Compactness co-efficient (Cc)	0.45	0.61	0.89	0.49	0.51	0.59
Constant of channel maintenance (C)	0.36	0.36	0.38	0.41	0.33	0.37
Length of overland flow (Lo)	0.18	0.18	0.19	0.21	0.17	0.19

4.2.2.7 Length of Overland flow (Lo)

It is the length of water over the ground before it gets concentrated into definite stream channels (Horton, 1945).It is approximately equals to half of the reciprocal of drainage density (Horton, 1945). For a comparison of the sub-basins in respect of the nature of flow path, the Lo is classified as: (1) low (<.20 km²/km), (2) medium (0.20–0.30 km²/ km) and (3) high (>0.30 km²/km) in the study area. The high Lo values indicate the occurrence of long flow-paths, and thus, gentle ground slopes, which reflect areas of less run-offs and more infiltration. Whereas, the low Lo values in the SB I, SB-II (0.18 km²/km), SB-III (0.19) and SB-V (0.17) reveal short flow paths, with steep ground slopes, reflecting the areas as associated with more run-off and less infiltration (Table. 3).

4.2.2.8 Consant of channel maintenance (C)

Schumm (1956) has used the inverse of drainage density (D) as a property termed as Constant of channel maintenance. Generally, the higher the C values of a basin, the higher the permeability of the rocks of that basin and vice-versa (Vijay Pakhmode et al., 2003, Subba Rao, 2009). The SB-I, SB-II (0.36), SB-III (0.38), SB-IV (0.41) and SB-V (0.33) have low ‘C’ value (<0.5), indicating that they are under the influence of less structural disturbance, low permeability, steep to very steep slopes and high surface run-off, while a high value indicates structural disturbances and less run-off conditions.

4.2.2.9 Compactness Coefficient (Cc)

Compactness Coefficient (Cc) is used to express the relationship of a hydrologic basin to that of a circular basin having the same area as the hydrologic basin. A circular basin is the most susceptible from a drainage point of view because it will yield shortest time of concentration before peak flow occurs in the basin (Nooka Ratnam et al., 2005). The values of Cc in the study area vary from 0.45 (SB I) to 0.89 (SB III) showing wide variations across sub basins (Table. 3).

4.2.2.10 Basin Shape (Bs)

Basin shape (Bs) is the ratio of square of basin length (Lb) to the area of the basin (A). The values of Bs range from 2.47 (SB-V) to 8.99 (SB III), which indicate that the sub basin have sharp peaked flood discharge (Table. 3).

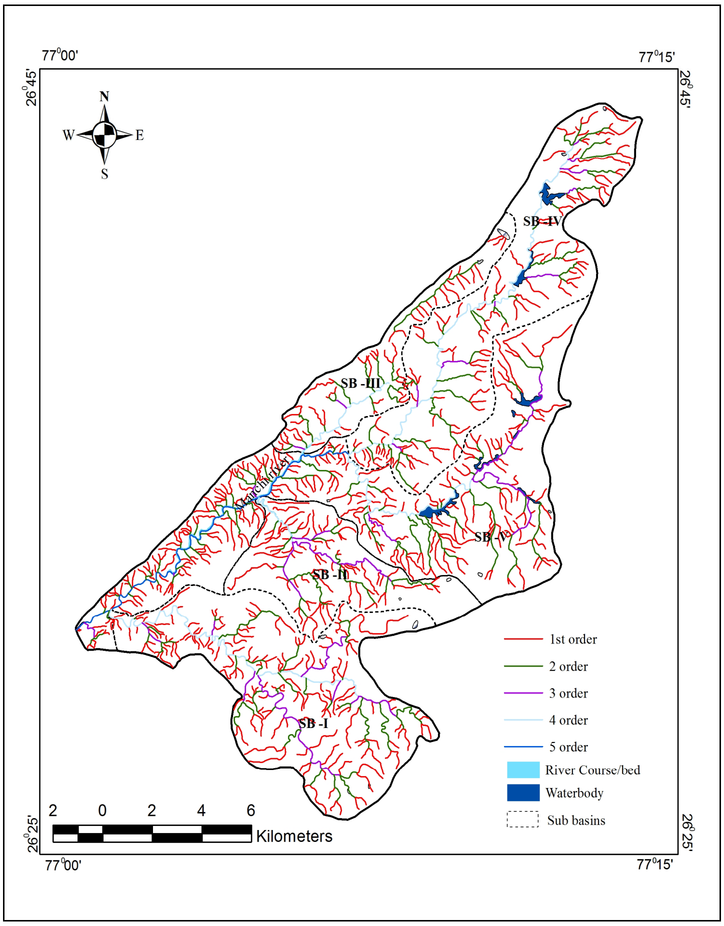


Figure 6: Drainage map of the study area

4.2.3 Relief aspects

4.2.3.1 Basin relief (R)

Basin relief is the difference in elevation between the highest and the lowest point of the basin: The R controls the stream gradient and therefore influences floods patterns and the amount of sediment that can be transported (Hadley and Schumm, 1961). It is an important factor in understanding the denudational characteristics of the basin. The maximum height of the Manchi basin is found to be ~367 m and the lowest is ~231 m. Hence, the relief of the basin is 136 m (Table. 4).

4.2.3.2 Relief ratio (Rh)

The relief ratio (Rh) of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as Rh (Schumm, 1956). The Rh normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin (Gottschalk, 1964). The Rh of the Manchi basin is 0.004, whereas Rh value of sub-basins varies from 0.004 (SB-III) to 0.01 (SB-II) (Table. 4).

4.2.3.3 Ruggedness number (Rn)

Ruggedness number (Rn) is a result of basin relief (R) and drainage density (D) that indicates the structural complexity of the terrain (Schumm, 1956). An increased peak discharge is the result of the network's improved efficiency due to an increase in relief and drainage density (Patton, 1998). The Manchi basin with Rn value of 0.38 (Table. 4) indicates moderate basin relief (136 m).

Table 4: Relief aspect of Manchi basin

Sub basin/Basin	Elevation in 'm'		Basin relief (R)	Basin relief (R)	Longest Axis 'L' (km)	Relief ratio (Rh)	Ruggedness Number (Rn)
	Max 'H'	Min 'h'	(H-h) (m)	(H-h) (km)			R*Dd (km)
I	339	256	83	0.083	14.14	0.006	0.23
II	356	263	93	0.093	9.57	0.01	0.26
III	325	266	59	0.059	13.12	0.004	0.15
IV	367	266	101	0.101	16.57	0.006	0.24
V	355	231	124	0.124	24.39	0.005	0.37
Manchi	367	231	136	0.136	29.86	0.005	0.38

4.2.3.4 Gradient Ratio (Gr)

Gradient ratio is an indication of channel slope from which the runoff volume could be evaluated. The basin has a gradient ratio of 0.004, while those of the 4 sub-basins as shown in (Table. 5), ranging from 0.004 (SB-III, SB-V) to 0.008 (SB-II).

4.2.3.5 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, morpho conservation practices etc. (Sreedevi et al., 2005). In the study area slope map was prepared based on ASTER data were converted into slope and aspect grids using Arc view method (ESRI, 2000). Aspect grid is identified as "the down-slope direction of the maximum rate of change in value from each to its neighbours" (Gorokhovich, 2006). In the Manchi basin area, slope varies from 0º to 28º, it was categorized into four classes as Gentle (0º-7º), Moderate (8º-14º), Steep (15º–21º), Very steep (22º-28º). Slope plays a very significant role in determining infiltration vs. runoff relation. Infiltration is inversely related to slope i.e. gentler is the slope, higher is infiltration and less is runoff and vice-versa.

Table 5: Gradient aspect of Manchi basin

Sub basin/Basin	Elevation (m) at		Fall in height (m)	Fall in height (km)	Length of main stream L (km)	Gradient ratio Gr (a-b/L)
	Source 'a'	Mouth 'b'				
I	330	260	70	0.070	14.14	0.005
II	350	270	80	0.080	9.57	0.008
III	320	270	50	0.050	13.12	0.004
IV	360	270	90	0.090	16.57	0.005
V	340	240	100	0.100	24.39	0.004
Manchi	360	250	110	0.110	29.14	0.004

5. Conclusion

Based on the drainage orders the Manchi Basin has been classified as fifth order basin. Delineation of drainage network was achieved by using traditional methods such as field observations, topographic maps and with the advanced methods of using remote sensing and DEM. High Fs values (>2/km²) in the SB I, SB-II, SB-III and SB-IV indicate the occurrence of steep ground slopes, with less permeable rocks, which facilitate greater run-off, less infiltration, sparse vegetation and high relief conditions. The Drainage density value suggests that the nature of the surface strata of the river basin is permeable, which is a characteristic feature of a coarse-drainage density. High Rb of whole Manchi basin indicate structural control on drainage Whereas, the low Lo values in the SB I, SB-II and SB-IV reveal short flow paths, with steep ground slopes, reflecting the areas as associated with more run-off and less infiltration. GIS techniques characterized by very high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis.

Acknowledgements

The financial assistance received from University Grants Commission (UGC), New Delhi is gratefully acknowledged in the form of Maulana Azad National Fellowship for Minority Students. Authors are thankful to the Chairman, Department of Geology, Aligarh Muslim University, and Aligarh for providing infrastructure facilities of the Remote Sensing Lab, which made the study possible. Thanks are due to National Remote Sensing Centre, Hyderabad, for providing satellite data.

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