Detailed morphometric analysis of Man River Basin in Akola and Buldhana Districts of Maharashtra, India using Cartosat-1 (DEM) Data and GIS techniques

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ABSTRACT

In this study an attempt has been made to understand the morphometric characteristics of the Man river basin with an aim to compute the detailed morpho-tectonic parameters and their bearing on the hydrogeological condition of the region. The drainage map of the area was prepared from the high resolution satellite image and Survey of India (SOI) toposheets which were updated using LISS-III analog data. Updated drainage maps were used for the drainage pattern analysis of the study area. For detailed investigations, SRTM data is being used for preparing digital elevation model (DEM) by utilizing geographical information system (GIS). Different thematic maps i.e. drainage map, stream order map and the digital elevation model (DEM) have been prepared by using Arc GIS software. The detailed study has led to the computation of 85 morphometric parameter of all aspects related to drainage analysis. Based on the results obtained from all morphometric analysis, the study area can be classified as a morpho-tectonic region that is formed due to the erosional development of the area by the streams which have progressed well beyond maturity and that the lithology has had an influence in the drainage development. These studies are very useful for planning rainwater harvesting and watershed management of the region for the future planning and management of water resources for sustainable development of the basin.

Key words: Morphometric Analysis, Digital elevation model (DEM), Drainage map, Stream order map, Geographical information system, Remote sensing.

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). An attempt has been made to find out the scope for artificial recharge by studying various characteristics of watershed (geomorphology, soil, land use and drainage) using RS - GIS dataset. Remote Sensing with its advantages of varying spatial and spectral resolutions and temporal availability of data covering large and inaccessible areas within short time has become a very handy tool in assessing, monitoring and analyzing the groundwater potential. Thematic layers like geology, geomorphology, drainage network, land use/land cover etc. Generated using remote sensing data can be integrated in a Geographical Information System (GIS) framework to find out the further scope for artificial recharge in selected mini watersheds.

The Maharashtra state is located within the peninsular shield area of the country with about 94% of its total geographical area underlain by hard rock formations and the remaining 6% with localized occurrences of sedimentary and alluvial deposits. About 80% area of the state is covered by basaltic lava flows with overlying alluvium confined to the areas in the vicinity of major rivers and the streams. The first and extensive programmed for a systematic exploration of ground water by drilling in Maharashtra was started in 1995. The Purna River is the principal tributary showing perennial nature with seasonal tributary, originating from the southern slope of Gavilgarh hill of Satpura ranges and flows westerly through Akola and Buldhana districts. The Purna basin covers an area of 7500 sq. km. of which 3500 sq. km. area in covered by saline ground water showing critical situation of drinking water. The basin shows complex geological set up which is traversed by east west and north south faults in the northern part. The groundwater salinity in the Purna basin is very crucial as it has attracted the attention of many researchers. Wynne, (1889); Chatterjee (1959) Adyalkar, (1963) and Ayyangar, (1996) have provided possible causes for the salinity which might be due to remnants sea water transmission in the Geological past.

Study Area

The Man river basin is situated in Akola and Buldhana Districts, Maharashtra which is located between 20°54′ 59” N latitude and 76° 41’23’’ E longitude. The study area is covered by Survey of India toposheets55D/7, 55D/9, 55D/11, 55D/13, 55D/14 & 55D/15 on 1:50,000 scale. (Fig.1).

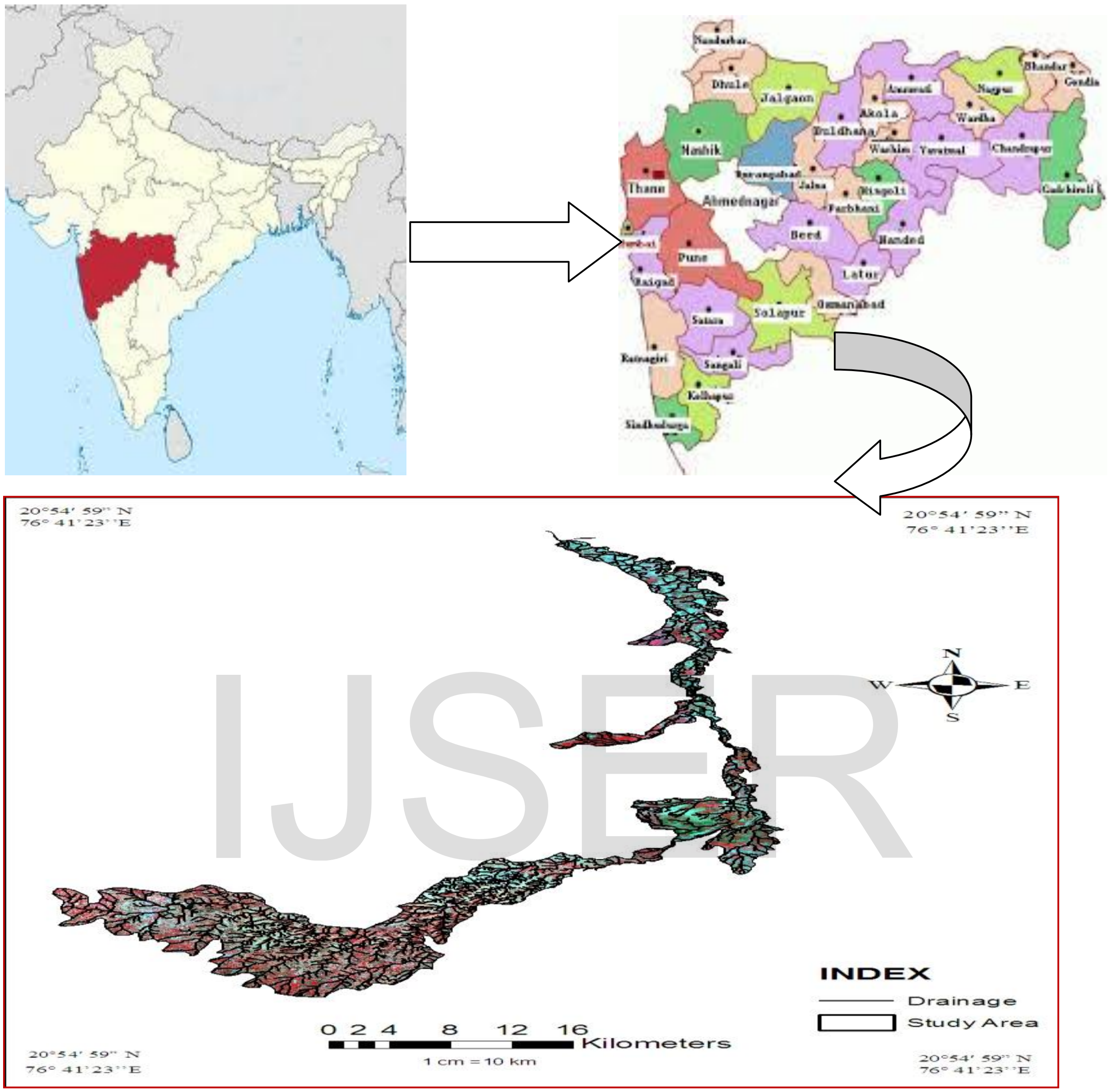

Fig.1 Location Map of the Man River Basin

Methodology

The study area Man river basin which is located in the survey of India toposheet Nos. 55D/7, 55D/9, 55D/11, 55D/13, 55D/14 and 55D/15 is present in the Akola and Buldhana district of Maharashtra and also use the LISS- III satellite image. The database is created using various techniques for the watershed management; the maps are prepared by georefrancing and digitization from SOI toposheet and LISS- III satellite image using Arc GIS 10 digital database. The Survey of India Toposheets of scale 1: 50,000 and LISS- III satellite image are used for delineating the watershed boundary, drainage pattern for the preparation of drainage map. The stream order was assigned by following Strahler's (1964) stream ordering technique. 85 morphometric parameters are presented in Table 1, 2, 3 and 4 using GIS techniques. The drainage basin characteristics help in deciphering and understanding the interrelated relief and slope properties. The DEM model is prepared using the Cartosat-1 (DEM) Data and GIS techniques to understand the detailed nature of Man river basin.

Morphometric Analysis

The measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landform provides the basis of the investigation of maps for a geomorphological survey (Bates & Jackson, 1980). This approach has recently been termed as morphometry. 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 Man river basin was carried out on the Survey of India topographical maps No. 55D/7, 55D/9, 55D/11, 55D/13, 55D/14 and 55D/15 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 of Schumm (1956), Strahler (1956, 1968), Miller (1953), and Horton (1932), and the relief aspects 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, as mentioned in Table 1.

Stream Length (Lu)

The total stream lengths of the Man river basin have various orders, which have computed with the help of SOI topographical sheets and Arc GIS software. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in watershed of increasing order (Strahler, 1964). Author has been computed the stream length based on the low proposed by Horton (1945). (Table 1).

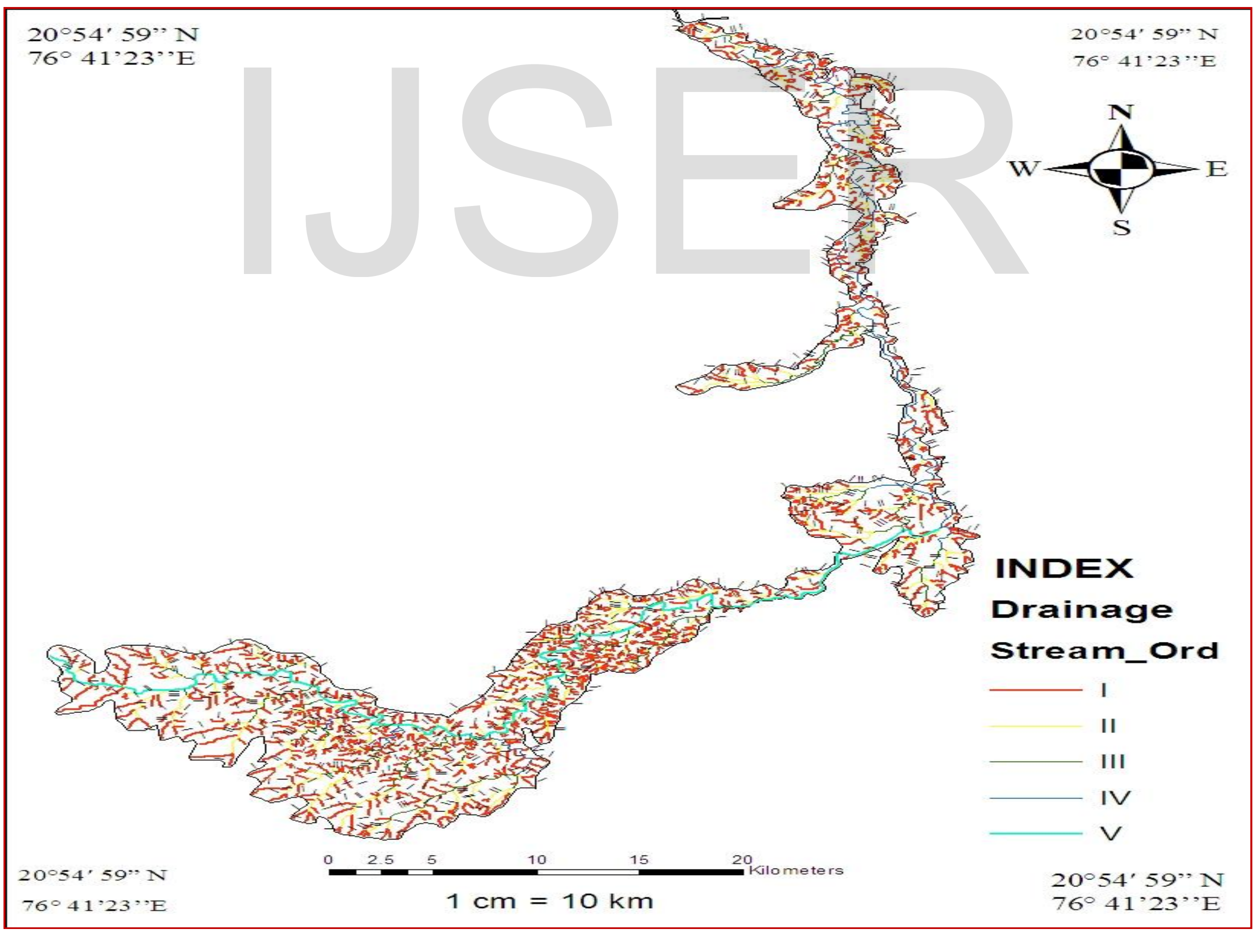

Fig. 2 Stream Order map of Man River Basin

Mean Stream Length (Lum)

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

Table 1: Stream Order, Streams Number, and Bifurcation Ratios of Man River basin

S_u	N_u	R_b	N_{u-r}	R_b*N_{u-r}	R_{bwm}
I	1157	---	---	---	5.76
II	241	4.80	1398	6710.4	
III	47	5.13	294	1508.22	
IV	8	5.88	55	323.4	
V	1	8	9	72	
Total	1454	23.81	1496	8614.02	
Mean		5.95*			

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 of order (So) to mean length of segments of the next lower order (Lu-1), which tends to be constant throughout the successive orders of a basin. His law of stream lengths refers that the mean stream lengths of stream segments of each of the successive orders of a watershed tend to approximate a direct geometric sequence in which the first term (stream length) is the average length of segments of the first order (Table 2). Changes of stream length ratio from one 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' to the number of streams in the next higher order (Nu+1), Table 1. Horton (1945) considered the bifurcation ratio as index of relief and dissertation. Strahler (1957) demonstrated that bifurcation shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. It is observed from the Rb is not same from one order to its next order these irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler 1964). The bifurcation ratio is dimensionless property and generally ranges from 3.0 to 5.0. The lower values of Rb are characteristics of the watersheds, which have suffered less structural disturbances (Strahler

1964) 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 control on the drainage pattern, while the lower values indicative of watershed that are not affect by structural disturbances.

Weighted Mean Bifurcation Ratio (Rbwm)

To arrive at a more representative bifurcation number Strahler (1953) used a 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. Schumm (1956, pp 603) has used this method to determine the mean bifurcation ratio of the value of **5.76** of the drainage of Perth Amboy, N.J. The values of the weighted mean bifurcation ratio this determined are very close to each other.

Table 2: stream length and stream length ratio in Man River basin.

S_u	L_u	L_u/S_u	Lur	L_{ur-r}	$L_{ur}*L_{ur-r}$	L_{uwm}
I	678.43	0.59	---	---	---	6.03
II	200.66	0.83	1.41	879.09	1239.52	
III	108.24	2.30	2.77	308.9	855.65	
IV	31.46	3.93	1.71	139.7	238.89	
V	115.43	115.43	29.37	146.89	4314.16	
Total	1134.36	123.08	35.26	1101.67	6648.22	
Mean			8.82			

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.

Length of Main Channel (Cl)

This is the length along the longest watercourse from the outflow point of designated sun watershed to the upper limit to the watershed boundary. Author has computed the main channel length by using ArcGIS-10 software, which is **129.69** Kms.

Channel Index (Ci) & Valley Index (Vi)

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

Rho Coefficient (ρ)

The Rho coefficient is an important parameter relating drainage density to physiographic development of a watershed which facilitate evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed (Horton 1945). The climatic, geologic, biologic, geomorphologic, and anthropogenic factors determine the changes in this parameter. Rho values of the Man river basin is **1.48**. This is suggesting higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

Basin Geometry

Length of the Basin (Lb)

Several people defined basin length in different ways, such as Schumm (1956) defined the basin 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 are end being the mouth. Gardiner (1975) defined the basin length as the length of the line from a basin mouth to a point on the perimeter equidistant from the basin mouth in either direction around the perimeter. The length of the Man river basin in accordance with the definition of Schumm (1956) that is **115.43**Kms.

Basin Area (A)

The area of the Man river basin is another important parameter like the length of the stream drainage. Schumm (1956) established an interesting relation between the total Man river basin areas and the total stream lengths, which are supported by the contributing areas. The author has computed the basin area by using ArcGIS-10 software, which is **447.80** Sq Kms.

Basin 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 **315.58**Kms.

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

Lemniscate's (k)

Chorely (1957), express the lemniscate's value to determine the slope of the basin. In the formula k = Lb2 / 4 * A. Where, Lb is the basin length (Km) and A is the area of the basin (km2). The lemniscate (k) value for the Man river basin is **29.75**, which shows that the watershed occupies the maximum area in its regions of inception with large number of streams of higher order.

Form Factor (Ff)

According to Horton (1932), form factor may be defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.754 (for a perfectly circular watershed). Smaller the value of form factor, more elongated will be the watershed. The watershed with high form factors have high peak flows of shorter duration, whereas elongated watershed with low form factor ranges from **0.024** indicating them to be elongated in shape and flow for longer duration.

Elongation Ratio (Re)

According to Schumm (1965, p. 612), 'elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5). The elongation ration of Man river basin is **0.21**, which is represented the watershed is less elongated.

Texture Ratio (Rt)

According to Schumm (1965), texture ratio is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. The texture ratio is expressed as the ratio between the first order streams and perimeter of the basin (Rt = Nl / P) and it depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. In the present study, the texture ratio of the Man river basin is **3.7** and categorized as moderate in nature.

Circularity Ratio (Rc)

For the out-line form of watershed (Strahler, 1964, pp 4-51 and Miller, 1953, pp 8) used a dimensionless circularity ratio as a quantitative method. Circularity ratio is defined as the ratio of watershed area to the area of a circle having the same perimeter as the watershed and it is pretentious by the lithological character of the watershed. Miller (1953) has described the basin of the circularity ratios range 0.4 to 0.5, which indicates strongly elongated and highly permeable homogenous geologic materials. The circularity ratio value (**0.06**) of the watershed corroborates the Miller's range, which indicating that the watershed is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition.

Drainage Texture (Dt)

Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines. Drainage texture is on the underlying lithology, infiltration capacity and relief aspect of the terrain. Dt is total number of stream segments of all orders per perimeter of that area (Horton, 1945). (Smith, 1950) has classified drainage texture into five different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). In the present study, the drainage texture of the watershed is **4.60**. It indicates that category is very fine drainage texture.

Compactness Coefficient (Cc)

According to Gravelius (1914), compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. The Cc is independent of size of watershed and dependent only on the slope. The author has computed the compactness coefficient of Man river basin, which is **4.24**.

Fitness Ratio (Rf)

As per Melton (1957), the ratio of main channel length to the length of the watershed perimeter is fitness ratio, which is a measure of topographic fitness. The fitness ratio for Man river basin is **0.41**.

Wandering Ratio (Rw)

According to Smart & Surkan (1967), wandering ratio is defined as the ratio of the main stream length to the valley length. Valley length is the straight-line distance between outlet of the basin and the farthest point on the ridge. In the present study, the wandering ratio of the watershed is **1.12**.

Watershed Eccentricity (τ)

Black (1972) has given the expression for watershed eccentricity, which is: $\tau = [(|Lcm2 - Wcm2|)]0.5 / Wcm$ Where: τ = Watershed eccentricity, a dimensionless factor, Lcm = Straight length from the watershed mouth to the centre of mass of the watershed, and Wcm = Width of the watershed at the centre of mass and perpendicular to Lcm. Author has computed the watershed eccentricity, which is **8.85** .

Centre of Gravity of the Watershed (Gc)

It is the length of the channel measured from the outlet of the watershed to a point on the stream nearest to the center of the watershed. The centre of the Man river basin has been determined using following steps:

1. A cardboard piece was cut in the shape of Man river basin
2. The centre of gravity was located on the watershed shape cardboard piece using point balance standard procedure
3. The cardboard piece marked with centre of gravity was superimposed over the Watershed plan
4. By pressing a sharp edge pin over the centre of gravity of the cardboard piece it was marked on the watershed

The centre of gravity of the watershed has been computed by using ArcGIS-10 software, which is a point showing the latitude **76.74E & 20.50N**.

Sinuosity Index (Si)

Sinuosity deals with the pattern of channel of a drainage basin. Sinuosity has been defined as the ratio of channel length to down valley distance. In general, its value varies from 1 to 4 or more. Rivers having a sinuosity of 1.5 are called sinuous, and above 1.5 are called meandering (Wolman and Miller, 1964, p. 281). It is a significant quantitative index for interpreting the significance of streams in the evolution of landscapes and beneficial for geomorphologists, Hydrologists, and Geologists. For the measurement of sinuosity index Mueller (1968, p. 374-375) has suggested some important computations that deal various types of sinuosity indices. He also defines two main types i.e., topographic and hydraulic sinuosity index concerned with the flow of natural stream courses and with the development of flood plains respectively. Author has computed the hydraulic, topographic, and standard sinuosity index, which are **76.47% 23.53%** and **1.13%** respectively.

Drainage Texture Analysis

Stream Frequency (Fs)

The drainage frequency introduced by Horton (1932, p. 357 and 1945, p. 285) means stream frequency (or channel frequency) Fs as the number of stream segments per unit area. In the present study, the stream frequency of the Man river basin is **3.25**.

Drainage Density (Dd)

Drainage density is the stream length per unit area in region of watershed (Horton, 1945, Strahler, 1952 and 1958; Melton 1958) is another element of drainage analysis. Drainage density is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology and structures and relief history of the region can finally use as an indirect indicator to explain, those variables as well as the morphogenesis of landform. The drainage density has been computed (Fig. 4) by using Spatial Analyst Tool in ArcGIS-10, which is **2.53**Km/Km2 indicating moderate drainage densities. It is suggested that the moderate drainage density indicates the basin is moderate permeable sub-soil and thick vegetative cover (Nag 1998).

Constant of Channel Maintenance (1/D)

Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms. The constant indicates the number of Kms2 of basin surface required to develop and sustain a channel 1 Km long. The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). Channel maintenance constant of the watershed is **0.39**Kms2/Km.

Drainage Intensity (Di)

Faniran (1968) defines the drainage intensity, as the ratio of the stream frequency to the drainage density. This study shows a low drainage intensity of **1.28** for the watershed. This low value of drainage intensity implies that drainage density and stream frequency have little effect (if any) on the extent to which the surface has been lowered by agents of denudation. With these low values of drainage density, stream frequency and drainage intensity, surface runoff is not quickly removed from the watershed, making it highly susceptible to flooding, gully erosion and landslides.

Infiltration Number (If)

The infiltration number of a watershed is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher ran-off.

Drainage Pattern (Dp)

In the watershed, the drainage pattern reflects the influence of slope, lithology and structure. Finally, the study of drainage pattern helps in identifying the stage in the cycle of erosion. Drainage pattern presents some characteristics of drainage basins through drainage pattern and drainage texture. It is possible to deduce the geology of the basin, the strike and dip of depositional rocks, existence of faults and other information about geological structure from drainage patterns. Drainage texture reflects climate, permeability of rocks, vegetation, and relief ratio, etc. Howard (1967) related drainage patterns to geological information. Author has identified the dendritic and radial pattern in the study area. Dendritic pattern is most common pattern is formed in a drainage basin composed of fairly homogeneous rock without control by the underlying geologic structure. The longer the time of formation of a drainage basin is, the more easily the dendritic pattern is formed.

Length of Overland Flow (Lg)

Horton (1945) used this term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. Since this length of overland flow, at an average, is about half the distance between the stream channels, Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density. In this study, the length of overland flow of the Man river basin is **0.20**Kms, which shows low surface runoff of the study area.

Relief Characterizes

Relief Ratio (Rhl)

Difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956). The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin suggested by Schumm who found that sediments loose per unit area is closely correlated with relief ratios. In the study area, the value of relief ratio is **3.25**. It has been observed that areas with low to moderate relief and slope are characterized by moderate value of relief ratios. Low value of relief ratios are mainly due to the resistant basement rocks of the basin and low degree of slope.

Relative Relief (Rhp)

The maximum basin relief was obtained from the highest point on the watershed perimeter to the mouth of the stream. Using the basin relief (174 m), a relief ratio was computed as suggested by Schumm (1956), which is 0.006. Melton's (1957) relative relief was also calculated using the formula: Rhp = (H*100) / P, where P is perimeter in meters. This comes to **118.83** for Man river basin.

Absolute Relief (Ra)

The difference in elevation between a given location and sea level is known as absolute relief.

Channel Gradient (Cg)

The total drops in elevation from the source to the mouth were found out for the Man river basin, and horizontal distances were measured along their channels. The longitudinal profile on logarithmic as well as semi logarithmic paper, and computed the gradient, which are **2.13** m / Kms. It is seen from that the mean channel slope decreases with increasing order number. This testifies to the validity of Horton's Law of Stream Slopes, which states that there is a fairly definite relationship between the slope of the streams and their orders, which can be expressed by an inverse geometric series law.

Ruggedness Number (Rn)

Strahler's (1968) ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. Calculated accordingly, the Man river basin has a ruggedness number of **0.95**. The low ruggedness value of watershed implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density.

Melton Ruggedness Number (MRn)

The MRn is a slope index that provides specialized representation of relief ruggedness within the watershed (Melton 1965). Man river basin has an MRn of **17.72**. According to the classification of Wilfordet al. (2004), this watershed is debris flood watersheds, where bed load component dominates sediment under transport.

Dissection Index (Dis)

Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed (Singh and Dubey 1994). On average, the values of Dis vary between'0' (complete absence of vertical dissection/erosion and hence dominance of flat surface) and'1' (in exceptional cases, vertical cliffs, it may be at vertical escarpment of hill slope or at seashore). Dis value of Man river basin is **0.62**, which indicate the watershed is a moderate dissected.

Gradient Ratio (Rg)

Gradient ratio is an indicator of channel slope, which enables assessment of the runoff volume (Sreedevi, 2004). Man river basin has an Rg of **3.25**, which reflects the mountainous nature of the terrain. Approximately 83% of the main stream flows through the plateau and the relatively low values of Rg confirm the same.

Gradient & Channel Slope (Sgc)

Gradient in the steepness of a slope, expressed as a proportion between its vertical intervals (Vei) reduced to unity, and its horizontal equivalent (Hoe). Gradient was computed as Sgc = Vei / Hoe. The result obtained in the preceding equation was used to compute the tangent of the angle of slope of the basine.

Slope Analysis (Sa)

Slope is the most important and specific feature of the earth's surface form. Maximum slope line is well marked in the direction of a channel reaching downwards on the ground surface. There are many contributions to slope-geomorphology and various methods of representing the slope, but the contributions made by Rich (1916), Wentworth (1930), Raisz and Henry (1937), Smith (1938-39), Robinson (1948), Calef (1950), Calef and Newcomb (1953), Strahler (1956), Miller (1960), Eyles (1965) and Pity (1969), are very important. Slope can evaluated as quantitatively parameter. The mean slope has computed, which is **0.00-90.00**.

Digital elevation model of the study area

The elevation information is represented in computers as elevation data in a digital format. This format is usually called digital elevation models (DEM). Thus a DEM is a computerized representation of the Earths relief. Different formats exists, among the most usual are triangulated irregular networks (TIN), regular grids, contour lines and scattered data points. A DEM is usually described either by a wire frame model or an image matrix in which the value of each pixel is associated with a specific topographic height. Digital elevation models are Digital elevation models are in combination with other spatial data, an important database for topography-related analyses or 3D video animations. Different georeferenced 3D products can be derived and complemented by a coordinate system and presented in a 2D-map projection or as a 3D perspective view DEMs can be used together with other spatial data, image data in geographic information systems (GIS), for instance. A GIS is an information system designed to acquire, store, process and display data referenced by spatial or geographical coordinates. In a sense, a GIS may be thought of as a higher-order map, being both a database system with specific capabilities for spatially referenced data as well as a set of operations for processing and analyzing the data. The DEM provides a basic spatial reference system to the GIS spatial data set. Images or vector information can automatically be draped over and integrated with the DEM for more advanced analysis. In this study , the remote sensing techniques are being utilized to search for promising bearing grounds and to designate locations of wells. High resolution digital elevation models would deliver much needed additional information for the interpretation of the ground water relevant structures and catchment areas (Fig.3).

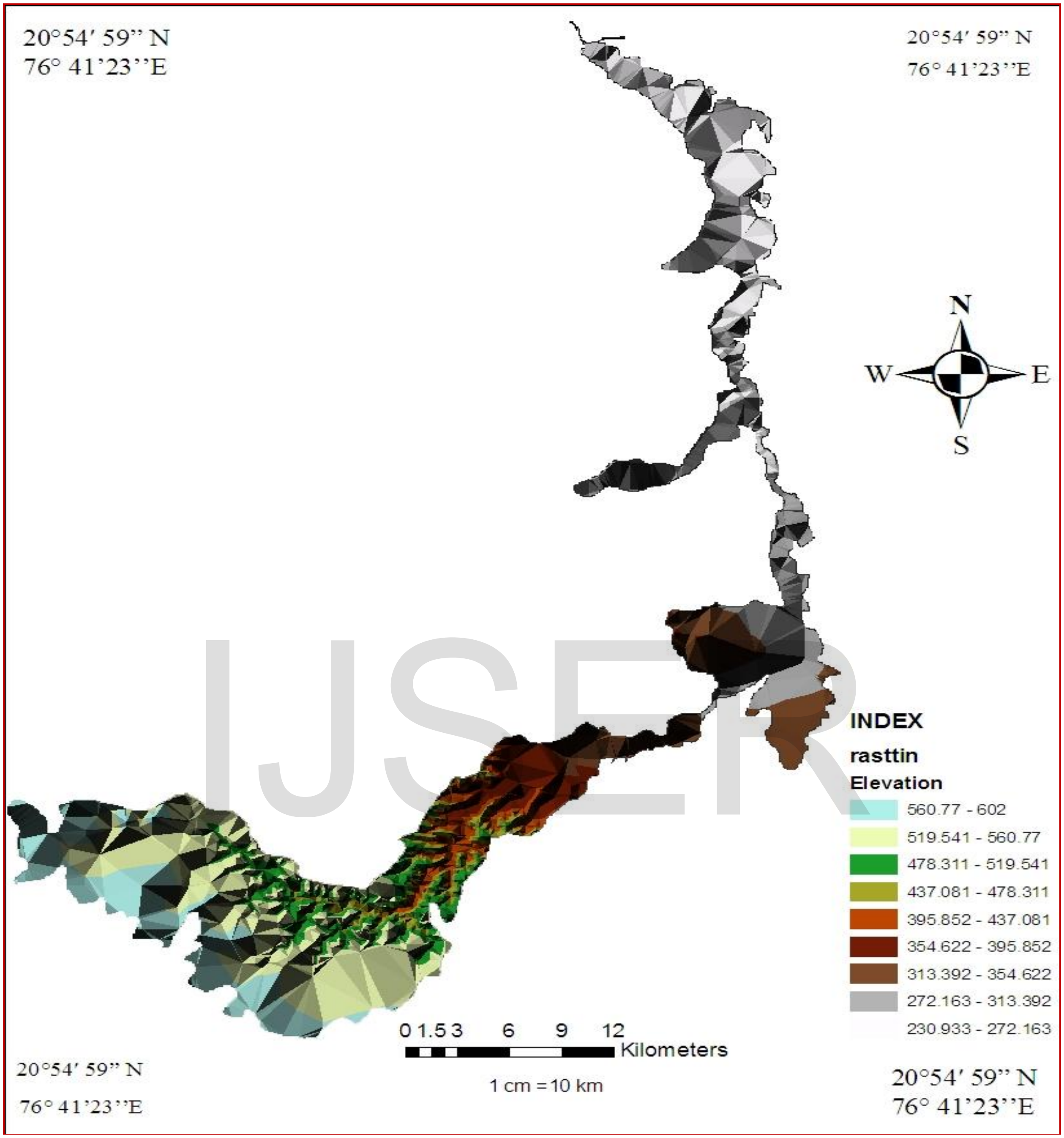

Fig. 3 Elevation/Cartosat-1 (Digital Elevation Model, DEM) map of the study area

Average Slope (S)

According to Wenthworth's (1930), Erodibility of a watershed can be studied and can be compared from its average slope. More the percentage of slopes more are its erosion, if all other things are kept constant. The average slope of the watershed is determined as, S = (Z * (Ctl / H)) / (10 * A). Author has computed the average slope of the Man river basin is **0.75%.**

Table 3: Stream Order, Stream Order wise Mean Area in Man River basin.

Su	Nu	Am	Ar	Arwmn
I	1157	0.59		
II	241	0.83	0.71	
III	47	2.30	2.77	3.56
IV	8	3.93	1.71	
V	1	115.43	29.38	
Total	1454	123.08	34.57	
Mean			8.64	

Su: Stream order, Nu: Number of streams, Am: Stream order wise mean area, Ar: Area ratio, Arm: Mean area ratio*, and Arwm: Weighted mean area

Mean Slope of Overall Basin (Θs)

Mean slope of overall basin was computed after (Chorley, 1979), but slightly modified as $\Theta s = \Sigma Ctl * Cin / A$. Where Θs = Mean slope of overall basin, Ctl = Total length of contour in the watershed, Cin = Contour interval, and A = Area of the watershed. Mean slope of Man river basin is **0.47**.

Clinographic Analysis (Cga)

Similar to the relation between area and altitude, there is an equally meaningful relation between the ground slope and altitude. This is brought out by construction Clinographic curves from hypsometric data. Out of the many methods available for the same (Clarke, 1967), Strahler's (1952) method was found to be best and was adopted, which is $\tan \Theta = Cin / Swc$. Where, Cin: Contour interval, Swc: Average width between two successive contours calculated as Ac / {(L1+L2)/2}, Ac: Total areas between successive contours, L1+L2 are the lengths of two successive contours. Authors have prepared the clinographic curve, and computed the angle, which are **0.99**.

Erosion Surface (Es)

The purpose of a profile is to show with precision, the form of the land (Miller, 1953). They present the variation of altitudes of the surfaces and the magnitude of the summit levels, etc. within the region besides profiles established then as erosion surface. The superimposed, projected and composite profiles are frequently used in the geomorphological interpretation of the terrain as they are useful in depicting the nature of the general relief's and different surfaces having different slopes at various altitudes. The superimposed profiles give a panoramic view of the morphology of the area. The superimposed profiles show not only the surfaces (of some morphological unity, as an erosion surface) by the general uniformity of level of various profiles but also reflect depth of the valleys and amplitude of relief. Author has found the several erosional surfaces in the Man river basin, which are ranging between **590-600m**.

Longitudinal Profiles (Lp)

The study of longitudinal profiles is the best representations of the geometry of valleys forms. The present morphology of the main and tributary stream is the result of different geomorphic processes with varying intensity. These profiles indicate the various stages and characteristics of the valley forms. Fluvial, lithological, and tectonic processes dominate the existing valley forms. The longitudinal profile is an erosional curve, which can interpret the surface history and different stage of valley development from source to mouth.

Concavity Index (Ca)

To calculate the parameters of the form of the longitudinal profile: the concavity index, the gradient, the gradient index, the hypsometric pseudo integral (Snow and Slingerland, 1987; Rhea, 1993). The concavity of the profile was determined as a ratio of the measured areas on the profile graphic, Ca = A1/A2, where A1 is the numerically integrated area between the curve of the profile and a straight line uniting its ends and A2 is the triangular area created by that straight line, the horizontal axis traversing the head of the profile. This parameter permits the quantitative estimation of the folding degree of the longitudinal profile. The concavity index of Man river basin is **0.67.**

Drainage Basin Characteristics

The details of the morphometric analysis and comparison of drainage basin characteristics of Man river basin are present in table 4.

Table 4: Morphometric Analysis of Man River basin- Comparative Characteristics

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)	**1157.00**
3	Stream Number (N_u)	$Nu = N_1+N_2+ \dots N_n$	Horton (1945)	**1454.00**
4	Stream Length (L_u) Kms	$Lu = L_1+L_2 \dots L_n$	Strahler (1964)	**1134.36**
5	Stream Length Ratio (L_{ur})	see Table 2.3	Strahler (1964)	**0.59-115.43**
6	Mean Stream Length Ratio (L_{urm})	see Table 3	Horton (1945)	**8.82**
7	Weighted Mean Stream Length Ratio (L_{uwm})	see Table 3	Horton (1945)	**6.03**
8	Bifurcation Ratio (R_b)	see Table 2	Strahler (1964)	**4.80-23.81**

9	Mean Bifurcation Ratio (R_{bm})	see Table 2	Strahler (1964)	**5.95**
10	Weighted Mean Bifurcation Ratio (R_b)	see Table 2	Strahler (1953)	**5.76**
11	Main Channel Length(C_1) Km.	GIS Software Analysis		**129.69**
12	Valley Length (V_l) Kms	GIS Software Analysis		**115.43**
13	Minimum Aerial Distance (A_{dm}) Kms	GIS Software Analysis		**110.54**
14	Channel Index (C_i)	$C_i = C_l / A_{dm}$ (H & TS)	Miller (1968)	**1.17**
15	Valley Index (V_i)	$Vi = V_l / A_{dm}$ (T_S)	Miller (1968)	**1.04**
16	Rho Coefficient (ρ)	$\rho = L_{ur} / R_b$	Horton (1945)	**1.48**
B	**Basin Geometry**			
17	Length from W's Center to Mouth of W's (L_{cm})Kms	GIS Software Analysis	Black (1972)	**95.78**
18	Width of W's at the Center of Mass(W_{cm}) Kms	GIS Software Analysis	Black (1972)	**10.76**
19	Basin Length (L_b) Kms	GIS Software Analysis	Schumm(1956)	**115.43**
20	Mean Basin Width (W_b)	$W_b = A / L_b$	Horton (1932)	**3.88**
21	Basin Area (A) Sq Kms	GIS Software Analysis	Schumm(1956)	**447.80**
22	Mean Area Ratio (A_{rm})	A_{rm}		**8.64**
23	Weighted Mean Ratio (A_{rwm})	A_{rwm}		**3.56**
24	Basin Perimeter (P)Kms	GIS Software Analysis	Schumm(1956)	**315.58**
25	Relative Perimeter (P_r)	$P_r = A / P$	Schumm(1956)	**1.42**
26	Length Area Relation (L_{ar})	$L_{ar} = 1.4 * A^{.6}$	Hack (1957)	**55.55**
27	Lemniscate's (k)	$k = L_b^2 / A$	Chorley (1957)	**29.75**
28	Form Factor Ratio (F_f)	$F_f = A / L_b^2$	Horton (1932)	**0.024**
29	Shape Factor Ratio (R_s)	$S_f = L_b^2 / A$	Horton (1956)	**42.22**
30	Elongation Ratio (R_e)	$R_e = 2 / L_b * (A / \pi)^{0.5}$	Schumm(1956)	**0.21**
31	Elipticity Index (I_e)	$I_e = \pi * Vl^2 / 4 A$		**23.36**
32	Texture Ratio (R_t)	$R_t = N_1 / P$	Schumm(1965)	**3.7**
33	Circularity Ratio (R_c)	$R_c = 12.57 * (A / P^2)$	Miller (1953)	**0.06**
34	Circularity Ration (R_{cn})	$R_{cn} = A / P$	Strahler (1964)	**1.42**
35	Drainage Texture (D_t)	$D_t = N_u / P$	Horton (1945)	**4.60**
36	Compactness Coefficient (C_c)	$C_c = 0.2841 * P / A^{0.5}$	Gravelius (1914)	**4.24**
37	Fitness Ratio (R_f)	$R_f = C_l / P$	Melton (1957)	**0.41**
38	Wandering Ratio (R_w)	$R_w = C_l / L_b$	Smart & Surkan (1967)	**1.12**
39	Watershed Eccentricity (τ)	$\tau = [(\lvert L_{cm}^2 - W_{cm}^2 \rvert)]^{0.5} / W_{cm}$	Black (1972)	**8.85**
40	Centre of Gravity of the Watershed (G_c)	GIS Software Analysis	Rao (1998)	**76.74E & 20.50N**
41	Hydraulic Sinuosity Index (H_{si}) %	$H_{si} = ((C_i - V_i)/(C_i - 1))*100$	Mueller (1968)	**76.47**
42	Topographic Sinuosity Index (T_{si})	$T_{si} = ((V_i - 1)/(C_i - 1))*100$	Mueller (1968)	**23.53**

43	Standard Sinuosity Index (S_{si})	$S_{si} = C_i / V_i$	Mueller (1968)	**1.13**
44	Longest Dimension Parallel to the Principal Drainage Line (Clp) Kms	GIS Software Analysis	-	**120.21**
C	**Drainage Texture Analysis**			
45	Stream Frequency (F_s)	$F_s = N_u / A$	Horton (1932)	**3.25**
46	Drainage Density (D_d) Km/Km^2	$D_d = L_u / A$	Horton (1932)	**2.53**
47	Constant of Channel Maintenance (Km^2 / Km)	$C = 1 / D_d$	Schumm(1956)	**0.39**
48	Drainage Intensity (Di)	$D_i = F_s / D_d$	Faniran (1968)	**1.28**
49	Infiltration Number (If)	$I_f = F_s * D_d$	Faniran (1968)	**8.22**
50	Drainage Pattern (Dp)	Dp	Horton (1932)	**Den. and Sub Den.**
51	Length of Overland Flow (Lg) Kms	$L_g = A / 2 * L_u$	Horton (1945)	**0.20**
D	**Relief Characters.**			
52	Height of Basin Mouth (z) m	GIS Analysis / DEM	-	**227.00**
53	Maximum Height of the Basin (Z) m	GIS Analysis / DEM	-	**602.00**
54	Total Basin Relief (H) m	$H = Z – z$	Strahler (1952)	**375.00**
55	Relief Ratio (Rhl)	$R_{hl} = H / L_b$	Schumm(1956)	**3.25**
56	Absolute Relief (R_a) m	GIS Software Analysis		**602.00**
57	Relative Relief Ratio (R_{hp})	$R_{hp} = H * 100 / P$	Melton (1957)	**118.83**
58	Dissection Index (D_{is})	$D_{is} = H / R_a$	Singh & Dubey (1994)	**0.62**
59	Channel Gradient (C_g) m / Kms	$C_g = H / \{(\pi/2) * C_{lp}\}$	Broscoe (1959)	**2.13**
60	Gradient Ratio (R_g)	$R_g = (Z - z) / L_b$	Sreedevi(2004)	**3.25**
61	Watershed Slope (S_w)	$S_w = H / L_b$		**3.25**
62	Ruggedness Number (R_n)	$R_n = D_d * (H /1000)$	Patton & Baker (1976)	**0.95**
63	Melton Ruggedness Number (M_{Rn})	$M_{Rn} = H / A^{0.5}$	Melton (1965)	**17.72**
64	Total Contour Length (C_{tl}) Kms	GIS Software Analysis	-	**2097.76**
65	Contour Interval (C_{in}) m	GIS Software Analysis	-	**10**
66	Length of Two Successive Contours (L_1+L_2) Km	GIS Software Analysis	Strahler (1952)	**88.21**
67	Average Slope Width of Contour (S_{wc})	$Swc = A / \{(L_1+L_2) / 2\}$	Strahler (1952)	**10.13**
68	Slope Analysis (S_a)	GIS Analysis / DEM	Rich (1916)	**0.00-90.00**
69	Average Slope (S) %	$S = (Z * (C_{tl}/H)) / (10 * A)$	Wenthworth's (1930)	**0.75**
70	Mean Slope Ratio (Sm)	Sm	Wenthworth's (1930)	**-----------**
71	Weighted Mean Slope Ratio (Swm)	Swm	Wenthworth's (1930)	**-----------**
72	Mean Slope of Overall Basin (Θ_s)	$\Theta_s = (C_{tl} * C_{in}) /A$	Chorley (1979)	**0.47**
73	Relative Height (h/H)	see Table 4 (h/H)	Strahler (1952)	**100 to 0**
74	Relative Area (a/A)	see Table 4 (a/A)	Strahler (1952)	**0 to 100**

75	Hypsometric Integrals (H_i) %	Hypsom Curve h/H & a/A	Strahler (1952)	**------**
76	Erosional Integrals (E_i) %	Hypsom Curve h/H & a/A	Strahler (1952)	**------**
77	Clinographic Analysis(C_{ga})	Tan Q = C_{in} /A_{wc}	Strahler (1952)	**0.99**
78	Erosion Surface (E_s) m	Superimposed Profiles	Miller (1953)	**590-600**
79	Surface Area of Relief (R_{sa}) Sq Kms	Composite Profile	Brown (1952)	**447.80**
80	Composite Profile Area (A_{cp}) Sq Kms	Area between the Composite Curve and Horizontal Line	Pareta (2004)	**447.80**
81	Minimum Elevated Profile Area as Projected Profile (A_{pp}) Sq Kms	Area between the Minimum Elevated Profile as Projected Profile and Horizontal Line	Pareta (2004)	**370.44**
82	Erosion Affected Area (A_{ea}) Sq Kms	$A_{ea} = A_{cp} - A_{pp}$	Pareta (2004)	**77.36**
83	Longitudinal Profile Curve Area (A_1) Sq Kms	Area between the Curve of the Profile and Horizontal Line	Snow & Slingerland(1987)	**220.22**
84	Profile Triangular Area (A_2) Sq Kms	Triangular Area created by that Straight Line, the Horizontal Axis Traversing the Head of the Profile	Snow & Slingerland (1987)	**325.66**
85	Concavity Index (C_a)	$C_a = A_1 / A_2$	Snow &Slingerland(1987)	**0.67**

Summary and Conclusions

The study reveals that remotely sensed data (**Cartosat-1** DEM) and GIS based approach in evaluation of drainage morphometric parameters and their influence on landforms, soils and an eroded land characteristic at river basin level is more appropriate than the conventional methods. GIS based approach facilitates analysis of different morphometric parameters and to explore the relationship between the drainage morphometry and properties of landforms, soils and eroded lands. Different landforms were identified in the watershed based on **Cartosat-1** (DEM) 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 85 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 Man river basin is less elongated. Hence, from the study it can be concluded that **Cartosat-1** (DEM) data, coupled with GIS techniques, prove to be a competent tool in the proper interpretation of the morphometric analysis which will help in understanding the groundwater regime of the river basin for sustainable development..

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