INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES
Volume 2, No 1, 2011

Research article ISSN 0976 – 4380

Quantitative Morphometric Analysis of a Watershed of Yamuna Basin, India using ASTER (DEM) Data and GIS

Kuldeep Pareta[1], Upasana Pareta[2]
1- NRM & RS/GIS Division, Spatial Decisions, B-30 Kailash Colony, New Delhi - 48
2- Department of Mathematics, PG College, District Sagar (Madhya Pradesh)
kuldeep.p@spatialdecisions.in

ABSTRACT

In the present paper, an attempt has been made to study the detail morphometric characteristics of Karawan watershed in Dhasan basin, which itself is part of the mega Yamuna basin in Sagar district, Madhya Pradesh. For detailed study, we used ASTER data for preparing digital elevation model (DEM), and geographical information system (GIS) was used in evaluation of linear, areal and relief aspects of morphometric parameters. Watershed boundary, flow accumulation, flow direction, flow length, stream ordering have been prepared using ArcHydro Tool; and contour, slope-aspect, hillshade have been prepared using Surface Tool in ArcGIS-10 software, and ASTER (DEM). Different thematic maps i.e. drainage density, slope, relief, superimposed profile, and longitudinal profiles have been prepared by using ArcGIS software. Authors have computed more than 85 morphometric parameter of all aspects. Based on all morphometric parameters analysis; that the erosional development of the area by the streams has progressed well beyond maturity and that lithology has had an influence in the drainage development. These studies are very useful for planning rainwater harvesting and watershed management.

Keywords: Morphometric Analysis, Geomorphology, ASTER (DEM), Karawan Watershed, and GIS

1. Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy et al., 2002). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1945; Leopold & Maddock, 1953; Abrahams, 1984). The source of the watershed drainage lines have been discussed since they were made predominantly by surface fluvial runoff has very important climatic, geologic and biologic effects e.g. Sharp and Malin, 1975; Pieri, 1976, 1980; Carr and Clow, 1981; Carr, 1999; Baker, 1982, 1990; Higgins, 1982; Mars Channel Working Group, 1983; Laity and Malin, 1985; Gulick and Baker, 1989; Haberle, 1998; Malin and Carr, 1999; Grant, 2000; Malin and Edgett, 2000; Goldspiel and Squyres, 2000; Williams and Phillips, 2001; Cabrol and Grin, 2001; Gulick, 2001; Craddock and Howard, 2002; Carr and Head, 2003; Hynek and Phillips, 2003; Craddock et al., 2003; Stepinski and Collier, 2004; Pareta, 2004; Howard et al., 2005. The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed (Singh, 1992). 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.

2. Study Area

The watershed area of Karawan river is 289.41 Sq Kms (Figure 1) & located between 23.74 to 23.97 N latitude and 78.59 to 78.77 E longitudes. The Karawan river originates from the southwest part of the Sagar town located at about 621 meter near the Gond village (23.74 N latitude & 78.66 E longitudes). Karawan river is 32.52 Kms long, however there is no main tributaries of the Karawan river, there are some small tributaries pouring into the river, notable amongst there are Rajauwa Nala, Garhpahara Nala on the right bank and no any major tributaries on the left bank. The Karawan River flows towards to northeast and meets the river Dhasan near Mehar village in Sagar district; Dhasan River is an important right bank tributary of the Yamuna river. The study area falls in Survey of India (1:50,000) toposheets No. 55I/9, and 55I/13.

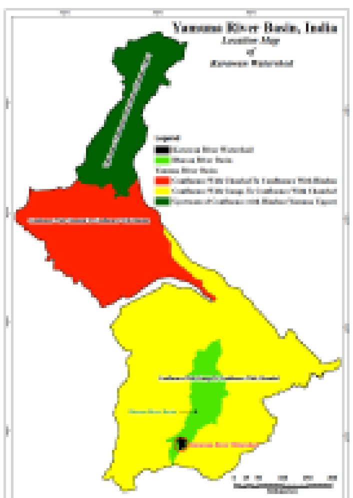

Figure 1: Location Map of Karawan Watershed

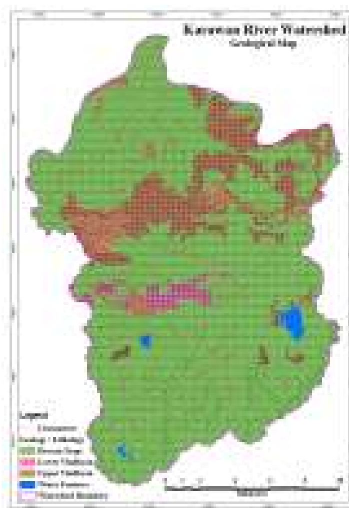

Figure 2: Geological Map

3. Data Used and Methodology

Topographical Map: Survey of India (1:50,000) 55I/09, & 55I/13; ASTER (DEM) with 30m spatial resolution

Remote Sensing Data: IRS-P6 (ResourceSAT-1) LISS-IV Mx satellite imagery with 5.8m spatial resolution

Geological Map: Sagar District Geological Map has been collected from GSI and updated through IRS-P6 LISS-IV Mx satellite remote sensing data with limited field check

Morphometric Analysis: Quantitative analysis has been done based on SOI toposheets/ASTER (DEM) & different morphometric parameters have been generated in GIS environment

Land Use/Land Cover Map: Digitally land use and land cover map has been prepared by using knowledge classification method in ERDAS IMAGINE 2010 and IRS-P6 (ResourceSAT-1) LISS-IV Mx satellite imagery and it was verified through limited field check

4. Results and Discussion

4.1 Geology

In order to understand the geomorphology of the study area, a general lithological map has been prepared with the help of IRS-P6 (ResourceSAT-1) LISS-IV Mx satellite imagery and shown in Figure 2. Through the general geology of the area has been mapped by the GSI in the usually way, various their similar have contributed to diverse geological aspects of the study area. Notable among these are Alexander (1979), Babu (1967), Blanford (1869), Barrooah (1962), Choubey (1967), Dixit (1970), Dubey (1952), Durge (1970), Gandhe (1970), Krishan (1982), Medlicott (1859, 1860), Mishra (1970), Pascoe (1975), Rajrajan (1978), Subramanyan (1972, 81), Wadia (1981), West (1964-81), and Pareta (2004) etc. They recorded the principal rock formations namely upper vindhyan supergroup, deccan traps & intertrappean beds, and alluvium & laterite.

Near by the Sagar town, comprises of hills of horizontal Vindhyan and Deccan Trap, the former commonly standing up above the level of the latter. The topography of the Vindhyan in the Sagar area is one that is characteristic of horizontal sedimentary rocks, where the highest bed is massive sandstone; the hills are generally flat topped. Southeast of the watershed, two Vindhyan hills have occurred, and between that, Berkheri village is situated. Here, for some distance around the hills, the Deccan trap has been completely removed, and the original Vindhyan topography can be seen to consist of the steep scarp slopes surrounding the two hills, with a platform between and around the hills. This platform is not neutrally horizontal, sloping gently away flow the sharps, & unlike the horizontal Deccan trap platforms, be appropriately termed a pediment. A further difference between the topography of the two formations in the study area has seen in the shapes of the contours on the scarp slopes. In the case of the Vindhyan scarps, the contours are fairly smooth, with few indentations but on the Deccan Trap scarps the contours are indented by many little streams which unite lower down to provide a dendrite pattern of drainage.

4.2 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 Karawan watershed was carried out on the Survey of India topographical maps No. 55I/09, and 55I/13 on the scale 1:50,000 and ASTER-DEM with 30 m 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 ArcHydro 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.

4.2.1 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 (Figure 3). It has observed that the maximum frequency is in the case of first order streams. It has also noticed that there is a decrease in stream frequency as the stream order increases.

Stream Number (Nu)

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

Stream Length (Lu)

The total stream lengths of the Karawan watershed have various orders, which have computed with the help of SOI topographical sheets and ArcGIS 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 2.

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). It is obtained by dividing the total length of stream of an order by total number of segments in the order, Table 2.

Table 1: Stream Order, Streams Number, and Bifurcation Ratios in Karawan Watershed

Su	Nu	Rb	Nu-r	Rb*Nu-r	Rbwm
I	938				3.91
II	244	3.84	1,182	4,543.92	
III	62	3.94	306	1204.26	
IV	13	4.77	75	357.69	
V	3	4.33	16	69.33	
VI	1	3.00	4	12.00	
Total	1261	19.88	1583	6187.20	
Mean		3.98*			

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

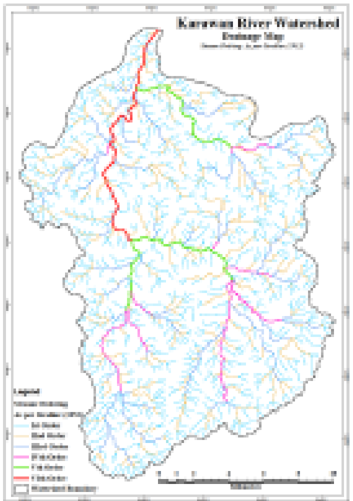

Figure 3: Drainage Map of Karawan Watershed

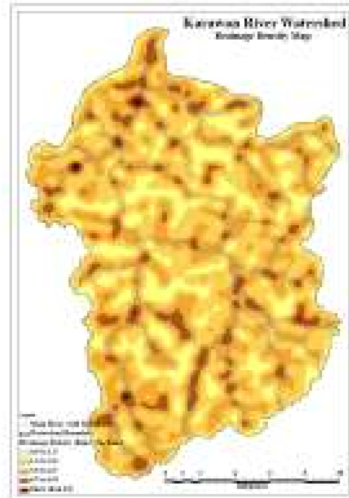

Figure 4: Drainage Density

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 4.87 of the drainage of Perth Amboy, N.J. The values of the weighted mean bifurcation ratio this determined are very close to each other (Karawan watershed 3.91), Table 1.

Table 2: Stream Length, and Stream Length Ratio in Karawan Watershed

Su	Lu	Lu/Su	Lur	Lur-r	Lur*Lur-r	Luwm
I	455.6	0.49				1.78
II	186.0	0.76	1.57	641.64	1,007.00	
III	99.20	1.60	2.10	285.21	598.58	
IV	32.20	2.48	1.55	131.39	203.40	
V	21.04	7.01	2.83	53.23	150.72	
VI	15.65	15.65	2.23	36.69	81.88	
Total	809.7	27.99	10.28	1148.1	2,041.58	
Mean			2.06*			

Su: Stream order, Lu: Stream length, Lur: Stream length ratio, Lurm: Mean stream length ratio, Lur-r: Stream length used in the ratio, Luwm: 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 32.52 Kms, Table 5.

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 (Table 5).

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 Karawan watershed is 0.52, Table 5. This is suggesting higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

4.2.2 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 author has determined length of the Karawan watershed in accordance with the definition of Schumm (1956) that is 26.07 Kms, Table 5.

Basin Area (A)

The area of the watershed is another important parameter like the length of the stream drainage. Schumm (1956) established an interesting relation between the total watershed 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 289.41 Sq Kms (Table 5).

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 90.68 Kms (Table 5).

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 watershed is 2.34 (Table 5), 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 0.42 indicating them to be elongated in shape and flow for longer duration, Table 5.

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 Karawan watershed is 0.73, which is represented the watershed is less elongated, Table 5.

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 watershed is 9.11 and categorized as moderate in nature, Table 5.

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 (0.44) 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, Table 5.

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 12.06 (Table 5). 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 Karawan watershed, which is 1.51, Table 5.

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 Karawan watershed is 0.35, Table 5.

Wandering Ratio (Rw)

According to Smart & Surkan (1967), wandering ratio is defined as the ratio of the mainstream 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 1.24, Table 5.

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 0.81 (Table 5).

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 Karawan watershed has been determined using following steps:

1. A cardboard piece was cut in the shape of Karawan watershed
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

Authors have also computed the centre of gravity of the watershed by using ArcGIS-10 software, which is a point showing the latitude 23.8 N, and longitudes 78.6 E (Table 5).

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 88.59%, 11.41%, and 1.24 respectively, Table 5.

4.2.3 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 Karawan watershed is 4.35, Table 5.

Drainage Density (Dd)

Drainage density is the stream length per unit area in region of watershed (Horton, 1945, p.243 and 1932, p. 357; 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. Author has calculated the drainage density (Figure 4) by using Spatial Analyst Tool in ArcGIS-10, which are 2.79 Km/Km^2 indicating moderate drainage densities (Table 5). 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 Kms^2 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 0.35 Kms^2/Km (Table 5).

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 1.55 for the watershed, Table 5. 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, see Table 5.

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 Karawan watershed is 0.17 Kms, (Table 5), which shows low surface runoff of the study area.

4.2.4 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 0.006 (Table 5). 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 metres. This comes to 0.19 for Karawan watershed.

Absolute Relief (Ra)

The difference in elevation between a given location and sea level.

Channel Gradient (Cg)

The total drops in elevation from the source to the mouth were found out for the Karawan watershed, and horizontal distances were measured along their channels. Author has drawn the longitudinal profile on antihmetic paper as well as semilogarithmic paper, and computed the gradient, which are 1.83 m / Kms. It is seen from Table 4 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. The mean slope ratio derived from the regression coefficient of the plot is 2.51 for the Karawan watershed. These compare well with their calculation weighted mean slope ratio is 2.64.

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

Karawan watershed has a ruggedness number of 0.48, Table 5. 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). Karawan watershed has an MRn of 10.22 (Table 5). 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 Karawan watershed is 0.28 (Table 5), 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). Watershed has an Rg of 0.006 (Table 5), 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 watershed.

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. Slope map (Figure 6) has created by using Surface Analysis Tool in ArcGIS-10 & mean slope has computed, which is 20 1’ to 70 2’ (Table 5).

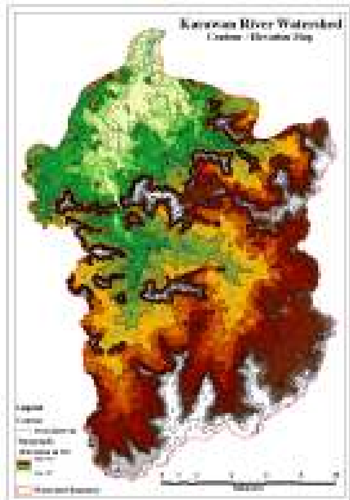

Figure 5: Elevation / ASTER (DEM) Map

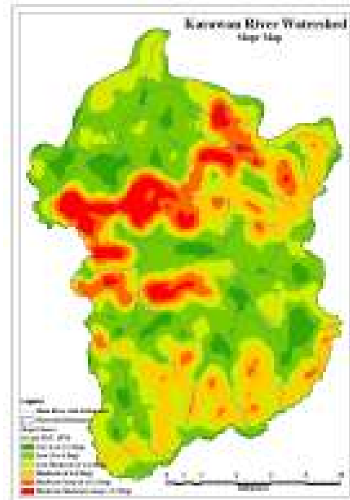

Figure 6: Slope Map

Average Slope of the Watershed (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 Karawan watershed, which is 1.96%, Table 5.

Table 3: Stream Order, Stream Order wise Mean Area in Karawan Watershed

Su	Nu	Am	Ar	Arwm
I	938	0.13		4.24
II	244	0.52	4.08	
III	62	2.13	4.12	
IV	13	9.51	4.47	
V	3	57.97	6.10	
VI	1	219.1	3.78	
Total	1261	289.4		
Mean			4.51*	

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 ratio*

Mean Slope of Overall Basin (ϴs)

Mean slope of overall basin was computed after (Chorley, 1979), but slightly modified as ϴs = ∑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 Karawan watershed is 0.54, Table 5.

Hypsometric Analysis (Hs)

Langbein at el (1947) appear to have been the first to use such a line of study to collect hydrologic data. However, again Strahler (1952) popularized it in his excellent paper. According to Strahler (1952) topography produced by stream channel erosion and associated processes of weathering mass-movement, and sheet runoff is extremely complex, both in the geometry of the forms themselves and in the inter-relations of the process which produce the forms. The form of hypsometric curve and the value of the integral are important elements in topographic form. It show marked variations in regions differing in stage of development and geologic structure, because in the stage of youth hypsometric integral is large but it decreases as the landscape is denuded towards a stage of maturity and old age (Strahler, 1952, p. 118).

The author used the percentage hypsometric curve method, and calculated the hypsometric integral (Hi), erosion integrals (Ei), which provided the accurate knowledge of the stage of the erosion cycle. The hypsometric integral (King, 1966, pp 319-321) of Karawan watershed is 36.91% and the erosion integral of the watershed is 63.09% (Table 5), which indicates the mature stage of the watershed.

Table 4: Hypsometric Data of Hypsometric Integrals

S. No.	Altitude Range (m)	Height (m) h	Area (Kms^2) a	h / H^1	a / A^2
1	621	221	0.20	1.000	0.001
2	600-621	200	7.84	0.905	0.027
3	550-621	150	44.24	0.679	0.153
4	500-621	100	93.78	0.452	0.324
5	450-621	50	221.17	0.226	0.764
6	400-621	0	289.41	0.000	1.000

1^1 = 221 m, and A^2 = 289.41 Sq Kms

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 (Table 4). 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 Θ = 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 2.980. (Table 5).

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. They outline higher plateau surface over 621 m and lower surfaces of about 447 m. 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 erosion surface in the Karawan watershed, which are ranging between 490 m to 500 m, Table 5.

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, lithologic, 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.

Comparison of Drainage Basin Characteristics

The details of the morphometric analysis and comparison of drainage basin characteristics of Karawan watershed are present in Table 5.

Table 5: Morphometric Analysis of Karawan Watershed - Comparative Characteristics

S. No.	Morphometric Parameter	Formula	Reference	Result
A	**Drainage Network**			
1	Stream Order (Su)	Hierarchical Rank	Strahler (1952)	1 to 6
2	1st Order Stream (Suf)	Suf = N1	Strahler (1952)	938.00
3	Stream Number (Nu)	Nu = N1+N2+ …Nn	Horton (1945)	1261.00
4	Stream Length (Lu) Kms	Lu = L1+L2 …… Ln	Strahler (1964)	809.72
5	Stream Length Ratio (Lur)	see Table 2	Strahler (1964)	1.5-10.2
6	Mean Stream Length Ratio (Lurm)	see Table 2	Horton (1945)	2.06
7	Weighted Mean Stream Length Ratio (Luwm)	see Table 2	Horton (1945)	1.78
8	Bifurcation Ratio (Rb)	see Table 1	Strahler (1964)	3.0-4.7
9	Mean Bifurcation Ratio (Rbm)	see Table 1	Strahler (1964)	3.98
10	Weighted Mean Bifurcation Ratio (Rbwm)	see Table 1	Strahler (1953)	3.91
11	Main Channel Length (Cl) Kms	GIS Software	-	32.52

		Analysis		
12	Valley Length (Vl) Kms	GIS Software Analysis	-	26.07
13	Minimum Aerial Distance (Adm) Kms	GIS Software Analysis	-	25.24
14	Channel Index (Ci)	Ci = Cl / Adm (H & TS)	Miller (1968)	1.28
15	Valley Index (Vi)	Vi = Vl / Adm (TS)	Miller (1968)	1.03
16	Rho Coefficient (ρ)	ρ = Lur / Rb	Horton (1945)	0.52
B	**Basin Geometry**			
17	Length from W's Center to Mouth of W's (Lcm) Kms	GIS Software Analysis	Black (1972)	12.93
18	Width of W's at the Center of Mass (Wcm) Kms	GIS Software Analysis	Black (1972)	9.03
19	Basin Length (Lb) Kms	GIS Software Analysis	Schumm(1956)	26.07
20	Mean Basin Width (Wb)	Wb = A / Lb	Horton (1932)	11.10
21	Basin Area (A) Sq Kms	GIS Software Analysis	Schumm(1956)	289.41
22	Mean Area Ratio (Arm)	see Table 3		4.51
23	Weighted Mean Area Ratio (Arwm)	see Table 3		4.24
24	Basin Perimeter (P) Kms	GIS Software Analysis	Schumm(1956)	90.68
25	Relative Perimeter (Pr)	Pr = A / P	Schumm(1956)	3.19
26	Length Area Relation (Lar)	$Lar = 1.4 * A^{0.6}$	Hack (1957)	41.97
27	Lemniscate's (k)	$k = Lb^2 / A$	Chorley (1957)	2.34
28	Form Factor Ratio (Rf)	$Ff = A / Lb^2$	Horton (1932)	0.42
29	Shape Factor Ratio (Rs)	$Sf = Lb^2 / A$	Horton (1956)	2.34
30	Elongation Ratio (Re)	$Re = 2 / Lb * (A / \pi)^{0.5}$	Schumm(1956)	0.73
31	Elipticity Index (Ie)	$Ie = \pi * Vl^2 / 4 A$		1.85
32	Texture Ratio (Rt)	Rt = N1 / P	Schumm(1965)	9.11
33	Circularity Ratio (Rc)	$Rc = 12.57 * (A / P^2)$	Miller (1953)	0.44
34	Circularity Ration (Rcn)	Rcn = A / P	Strahler (1964)	3.19
35	Drainage Texture (Dt)	Dt = Nu / P	Horton (1945)	12.06
36	Compactness Coefficient (Cc)	$Cc = 0.2841 * P / A^{0.5}$	Gravelius (1914)	1.51
37	Fitness Ratio (Rf)	Rf = Cl / P	Melton (1957)	0.35
38	Wandering Ratio (Rw)	Rw = Cl / Lb	Smart & Surkan (1967)	1.24
39	Watershed Eccentricity (τ)	$\tau = [(\lvert Lcm^2 - Wcm^2 \rvert)]^{0.5} / Wcm$	Black (1972)	0.81
40	Centre of Gravity of the Watershed (Gc)	GIS Software Analysis	Rao (1998)	78.68 E & 23.86 N
41	Hydraulic Sinuosity Index (Hsi) %	Hsi = ((Ci - Vi)/(Ci - 1))*100	Mueller (1968)	88.59
42	Topographic Sinuosity Index (Tsi)	Tsi = ((Vi - 1)/(Ci	Mueller (1968)	11.41

	%	- 1))*100		
43	Standard Sinuosity Index (Ssi)	Ssi = Ci / Vi	Mueller (1968)	1.24
44	Longest Dimension Parallel to the Principal Drainage Line (Clp) Kms	GIS Software Analysis	-	30.14
C	**Drainage Texture Analysis**			
45	Stream Frequency (Fs)	Fs = Nu / A	Horton (1932)	4.35
46	Drainage Density (Dd) Km / Kms^2	Dd = Lu / A	Horton (1932)	2.79
47	Constant of Channel Maintenance (Kms^2 / Km)	C = 1 / Dd	Schumm(1956)	0.35
48	Drainage Intensity (Di)	Di = Fs / Dd	Faniran (1968)	1.55
49	Infiltration Number (If)	If = Fs * Dd	Faniran (1968)	12.13
50	Drainage Pattern (Dp)		Horton (1932)	Dn&Ra
51	Length of Overland Flow (Lg) Kms	Lg = A / 2 * Lu	Horton (1945)	0.17
D	**Relief Characterizes**			
52	Height of Basin Mouth (z) m	GIS Analysis / DEM	-	447.00
53	Maximum Height of the Basin (Z) m	GIS Analysis / DEM	-	621.00
54	Total Basin Relief (H) m	H = Z - z	Strahler (1952)	174.00
55	Relief Ratio (Rhl)	Rhl = H / Lb	Schumm(1956)	0.006
56	Absolute Relief (Ra) m	GIS Software Analysis		621.00
57	Relative Relief Ratio (Rhp)	Rhp = H * 100 / P	Melton (1957)	0.19
58	Dissection Index (Dis)	Dis = H / Ra	Singh & Dubey (1994)	0.28
59	Channel Gradient (Cg) m / Kms	Cg = H / {(π/2) * Clp}	Broscoe (1959)	1.83
60	Gradient Ratio (Rg)	Rg = (Z - z) / Lb	Sreedevi (2004)	0.006
61	Watershed Slope (Sw)	Sw = H / Lb		0.0067
62	Ruggedness Number (Rn)	Rn = Dd * (H / 1000)	Patton & Baker (1976)	0.48
63	Melton Ruggedness Number (MRn)	MRn = H / $A^{0.5}$	Melton (1965)	10.22
64	Total Contour Length (Ctl) Kms	GIS Software Analysis	-	1591.54
65	Contour Interval (Cin) m	GIS Software Analysis	-	10.00
66	Length of Two Successive Contours (L1+L2) Km	GIS Software Analysis	Strahler (1952)	194.38
67	Average Slope Width of Contour (Swc)	Swc = A / {(L1+L2) / 2}	Strahler (1952)	2.98
68	Slope Analysis (Sa)	GIS Analysis / DEM	Rich (1916)	$2^0$0'-$7^0$2'
69	Average Slope (S) %	S = (Z * (Ctl/H)) / (10 * A)	Wenthworth's (1930)	1.96
70	Mean Slope Ratio (Sm)		Wenthworth's (1930)	2.03
71	Weighted Mean Slope Ratio (Swm)		Wenthworth's (1930)	2.64

72	Mean Slope of Overall Basin (Θs)	Θs = (Ctl * Cin) / A	Chorley (1979)	0.54
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 (Hi) %	Hypsom Curve h/H & a/A	Strahler (1952)	36.00
76	Erosional Integrals (Ei) %	Hypsom Curve h/H & a/A	Strahler (1952)	64.00
77	Clinographic Analysis (Cga)	Tan Q = Cin / Awc	Strahler (1952)	2.98
78	Erosion Surface (Es) m	Superimposed Profiles	Miller (1953)	490-500
79	Surface Area of Relief (Rsa) Sq Kms	Composite Profile	Brown (1952)	289.41
80	Composite Profile Area (Acp) Sq Kms	Area between the Composite Curve and Horizontal Line	Pareta (2004)	289.41
81	Minimum Elevated Profile Area as Projected Profile (App) Sq Kms	Area between the Minimum Elevated Profile as Projected Profile and Horizontal Line	Pareta (2004)	236.43
82	Erosion Affected Area (Aea) Sq Kms	Aea = Acp - App	Pareta (2004)	52.98
83	Longitudinal Profile Curve Area (A_1) Sq Kms	Area between the Curve of the Profile and Horizontal Line	Snow & Slingerland (1987)	85.34
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)	157.88
85	Concavity Index (Ca)	$Ca = A_1 / A_2$	Snow & Slingerland (1987)	0.54

5. Land Use and Land Cover

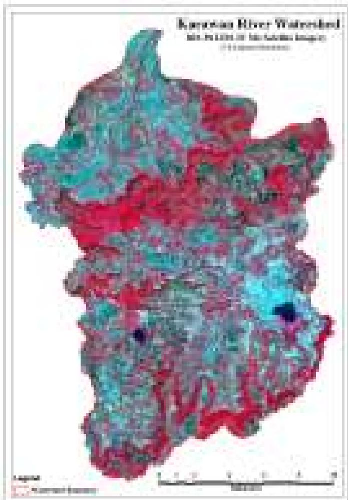

Figure 7: IRS-P6 LISS-IV Mx Satellite Imagery

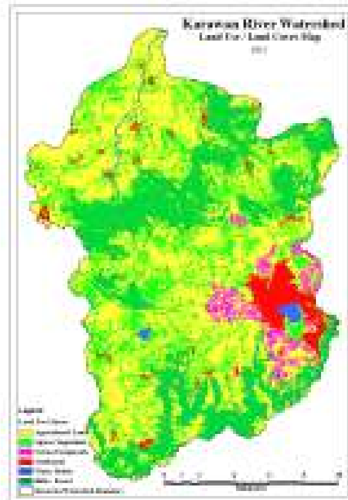

Figure 8: Land Use / Land Cover Map

Land is the most important natural resource, which embodies soil, water and associated flora and fauna involving the total ecosystem (Rao et al., 1996). Comprehensive information on the spatial distribution of land use/land cover categories and the pattern of their change is a prerequisite for management and utilization of the land resources of the study area. The land use pattern of any terrain is a reflection of the complex physical processes acting upon the surface of the earth. These processes include impact of climate, geologic and topographic conditions on the distribution of soils, vegetation and occurrence of water. For better development and management of the watershed areas, it is necessary to have timely and reliable information on geomorphological as well as environmental status.

Keeping the above views in mind, the authors have prepared a land use/land cover map (Figure 8) using IRS-P6 LISS-IV Mx data (Figure 7). This figure depicts that there are four units of land cover/land use pattern in the study area, which are given below and shown on the map.

6. Conclusion

The study reveals that remotely sensed data (ASTER-DEM) and GIS based approach in evaluation of drainage morphometric parameters and their influence on landforms, soils and eroded land characteristics at 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 ASTER (DEM) data with 30 m spatial resolution, and GIS software. 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 variation in stream length ratio might be 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 Karawan watershed is less elongated. Hence, from the study it can be concluded that ASTER (DEM) data, coupled with GIS techniques, prove to be a competent tool in morphometric analysis.

Acknowledgement

The author is grateful to Mr. Kapil Chaudhery, Director Spatial Decisions New Delhi for providing the necessary facilities to carry out this work. I am also thankful to my Guru Ji Prof. J. L. Jain for the motivation of this work.

7. References

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

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

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

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

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

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

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

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

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

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

11. Horton, R.E (1945), “Erosional Development of Streams and their Drainage Basins”, Bulletin of the Geological Society of America, 56, pp-275-370.

12. King, C.A.M (1966), “Techniques in Geomorphology”, Edward Arnold, (Publishers) Ltd. London, pp 319-321.

13. Pareta, K (2003), "Morphometric Analysis of Dhasan River Basin, India", Uttar Bharat Bhoogol Patrika, Gorakhpur, 39, pp 15-35.

14. Pareta, K (2004), "Hydro-Geomorphology of Sagar District (M.P.): A Study through Remote Sensing Technique", Proceeding in XIX M. P. Young Scientist Congress, Madhya Pradesh Council of Science & Technology (MAPCOST), Bhopal.

15. Pareta, K (2005), "Rainfall-Runoff Modelling, Soil Erosion Modelling, Water Balance Calculation, and Morphometric Analysis of Molali Watershed, Sagar, Madhya Pradesh using GIS and Remote Sensing Techniques", Proceeding in 25th International Cartographic Congress, INCA.

16. Pareta, K (2011), "Geo-Environmental and Geo-Hydrological Study of Rajghat Dam, Sagar (Madhya Pradesh) using Remote Sensing Techniques", International Journal of Scientific & Engineering Research, 2(8) (ISSN 2229-5518), pp 1-8.

17. Pareta, K. and Koshta, Upasana (2009), "Soil Erosion Modeling using Remote Sensing and GIS: A Case Study of Mohand Watershed, Haridwar", Madhya Bharti Journal, Dr. Hari Singh Gour University, Sagar (M.P.), 55, pp 23-33.

18. Richards, K.S. Arnett, R.R. and Ellis, J (1985), "Geomorphology and Soils", George Allen and Unwin, London, pp 441.

19. Scheidegger, A.E (1965), "The Algebra of Stream Order Number", U.S. Geological Survey Professional Paper, 525B, B1, pp 87-89.

20. Schumm, S.A (1954), "The relation of Drainage Basin Relief to Sediment Loss", International Association of Scientific Hydrology, 36, pp 216-219.

21. Schumm, S.A (1956), "Evolution of Drainage Systems & Slopes in Badlands at Perth Anboy, New Jersey", Bulletin of the Geological Society of America, 67, pp 597-646.

22. Schumm, S.A (1963), "Sinuosity of Alluvial Rivers on the Great Plains", Bulletin of the Geological Society of America, 74, pp 1089-1100.

23. Shreve, R.L (1966), "Statistical Law of Stream Numbers", Journal of Geology, 74, pp 17-37.

24. Smith, G.H (1939), "The Morphometry of Ohio: The Average Slope of the Land (abstract)", Annals of the Association of American Geographers, 29, pp 94.

25. Strahler, A.N (1952), "Hypsometric Analysis of Erosional Topography", Bulletin of the Geological Society of America, 63, pp 1117-42.

26. Strahler, A.N (1956), "Quantitative Slope Analysis", Bulletin of the Geological Society of America, 67, pp 571-596.

27. Strahler, A.N (1964), "Quantitative Geomorphology of Drainage Basin and Channel Network", Handbook of Applied Hydrology, pp 39-76.

28. Thornbury, W.D (1954), “Principles of Geomorphology”, John Wiley and Sons, London.
29. Wentworth, C.K (1930), “A Simplified Method of Determining the Average Slope of Land Surfaces”, American Journal of Science, 21, pp 184-194.
30. West, W.D. and Choubey, V.D (1964), "The Geomorphology of the Country around Sagar and Katangi (M.P.)", Journal of Geological Society of India, 5, pp 41-55.
31. Woldenberg, N.J (1967), “Geography & Properties of Surface”, Handward Paper in Theoretical Geography, 1 pp 95-189.
32. Young, A (1972), "Slope", Oliver & Boyd, Edinburgh, pp 5.
33. Zwnnitz, E.R (1932) "Drainage Pattern and their Significance", Journal of Geology, XL(6), pp 498-521.