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Morphometric analysis of Maun watershed in Tehri-Garhwal district of Uttarakhand using GIS

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ABSTRACT

Proper planning and management of available natural resources is necessary for progress and economic development in agriculture which are main stay of people leaving in the hilly region. The morphometric analysis of watershed coupled with soil, land use and slope can play a vital role in predicting the hydrological behavior of a watershed, engineering and site suitability aspect. An attempt has been made to study the morphometric characteristics of Maun watershed which is located in Tehri-Garhwal district of Uttarakhand. The study area is located between 78^{o} 22’ 28” to 78^{o} 24’ 57”E longitude and 30^{o} 17’ 19” to 30^{o} 18’ 52”N latitude and covers an area of 8.71 km^{2}. The qualitative analysis of the morphometric characteristics of the basin have been done and computed using GIS software. The drainage network in the study area is dendritic to sub-dendritic which indicates the influence of lithology and terrain on drainage pattern. The results clearly indicate relations among various morphometric attributes of the basin and help to understand their role in sculpturing the surface of the region.

Keywords: Drainage network, GIS, Landuse, Morphometric analysis, Tehri-Garhwal.

1. Introduction

Proper planning and management of available natural resources is necessary for progress and economic development in agriculture which are main stay of people leaving in hilly region. Water, which is precious natural resource, vital for sustaining all life on the earth is becoming scarce due to various reasons including reduction in infiltration rates, runoff, uneconomical use, overexploitation of the surface water resources etc; as result of change in land use patterns and degradation of land cover.

Quantitative morphometric characterization of a drainage basin is considered to be the most appropriate method for the proper planning and management of watershed, because it enables us to understand the relationship among different aspects of the drainage pattern of the basin, and also to make a comparative evaluation of different drainage basins, developed in various geologic and climatic regimes. A number of morphometric studies have been carried out in different Indian watersheds and subsequently used for water resources development and management projects as well as for watershed characterization and prioritization (Chalam *et al.*, 1996; Chaudhary *et al.*, 1998; Srinivasan *et al.*, 1999; Kumar *et al.*, 2001; Ali *et al.*, 2002; Singh *et al.*, 2003).

Pandey *et al.* (2004) studied morphometric characteristics of Karso watershed (Damodar Barakar catchment) and it's drainage pattern. Katpatal *et al.* (2004) conducted study on remote sensing and GIS application for monitoring and management of Pioli watershed near Nagpur urban area. Different parameters like geology, geomorphology, hydrology, land use/land cover were studied using IRS LISS III imagery of Indian Remote Sensing satellite.

The measurement of morphological parameters is laborious and cumbersome by the conventional methods, but using the latest technology like GIS, the morphometric analysis of natural drain and its drainage network can be better achieved. Morphometric parameters such as stream order, together with soil and land use, also play very important role in generating water resources action plan for location recharge and discharge areas. Nowadays, integration of Remote Sensing and GIS is helpful in planning and management of land and water resources for adoption of location specific technologies. In present study, Morphological characteristics of the Maun watershed were described and their inter-relationship was established. Accordingly, a water resource development plan has also been prepared by integrating land use/cover and slope with morphological parameters of the watershed under GIS environment. Drainage morphology along with slope map was also explored for locating and selecting the water harvesting structure like percolation tank, pond, check dams etc.

2. Study area

The study area is located in Tehri-Garhwal district of Uttarakhand and lying between 78^o 22' 28" to 78^o 24' 57" E longitude and 30^o 17' 19" to 30^o 18' 52" N latitude and covers an area of 8.71 km^2 (Figure 1). The elevation varies from 960 to 2000 m above mean sea level (MSL). The average annual rainfall in the study area varied from 1200 to 1400 mm, of which 70 to 80 % was received between June to September. The average temperature varied from 3^oC to 30^oC. The relative humidity at 8.30 hrs varied from 60 to 70 % in the northern hills and 30 to 40 % in the south-western dry areas. The soils of Maun watershed were brown to greyish brown and dark grey in colour, besides being non-calcareous and neutral to slightly acidic in reaction.

2.1 Data used and methodology

Detail flow chart of methodology adopted for data capture to output generation is presented in Figure 2. Survey of India (SOI) toposheet (53J/7) of the year 1960 on 1: 50,000 scale was used for morphometric analysis. The map sheet covering the study area was scanned in *tiff format* and translated to the *pix format* (PCIDSK format) using utility option of the software and geo- referenced using Ortho-Engine module of Geomatica version 9.1. The input data information was used to geo-reference the toposheet as: 1) Projection- UTM, 2) Zone and Rows- 44 (78^oE to 84^oE) and R (24^oN to 32^oN), 3) Datum- D076 Indian (India, Nepal) and 4) Resampling method- Nearest. Various thematic maps were geometrically registered with the base map and vector layers were generated. With the help of contour layer, digital elevation model (DEM) was prepared using algorithm VDEMINT available in Geomatica version 9.1 (Figure 3). Generally, it is used for topographic information, flow patterns, flood risk area identification and to determine accessibility. It is used to derive slope maps by means SLP algorithms (Figure 4). Slope is important as it has direct bearing on runoff and deciding suitable land use/land cover. Different classes of slope were made as per guidelines suggested by IMSD (1995) in Geomatica version 9.1 (table 1).

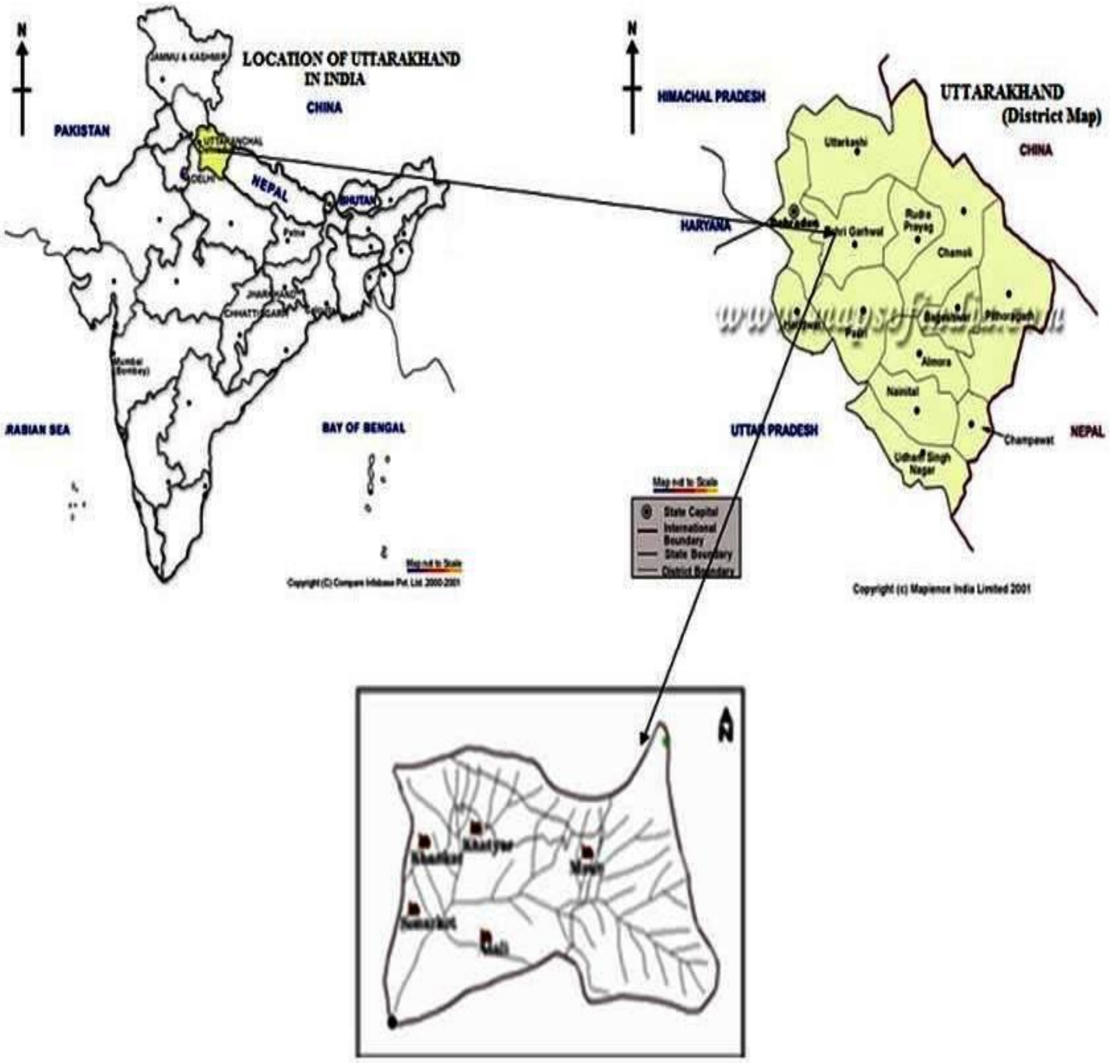

Figure 1: Index map of Maun watershed

These geo-reference maps were utilized to delineate the boundary of the watershed and drainage network with GIS environment of the SOI toposheet (Figure 5). Land use data of the year 1960 from SOI toposheet (Figure 6) and IRS LISS III data of 1: 25,000 scale for the year 2002 (Figure 7), procured from National Remote Sensing Centre (NRSC), Hyderabad was also digitized in a GIS environment by visual interpretation. Land use/land cover statistics for the selected watershed is presented in table 2 and table 3 respectively.

The qualitative analysis of the morphometric characteristics of the basin includes stream order, stream length, bifurcation ratio, drainage density, drainage frequency, relief measurements etc. These parameters were estimated from digitized coverage of drainage network map in the GIS environment. Morphological characterization is the systematic description of watershed's geometry. Geometry of drainage basin and it's stream channel system required the following drainage network: linear aspect of ratio, areal aspect of drainage basin, relief aspect of channel network and contributing ground slopes. Thus, it provides an effective comparison, regardless of scale. In the present study, for stream ordering Strahler (modified Horton's) method was adapted for quantitative analysis because of its simplicity and flexibility from subjective decisions.

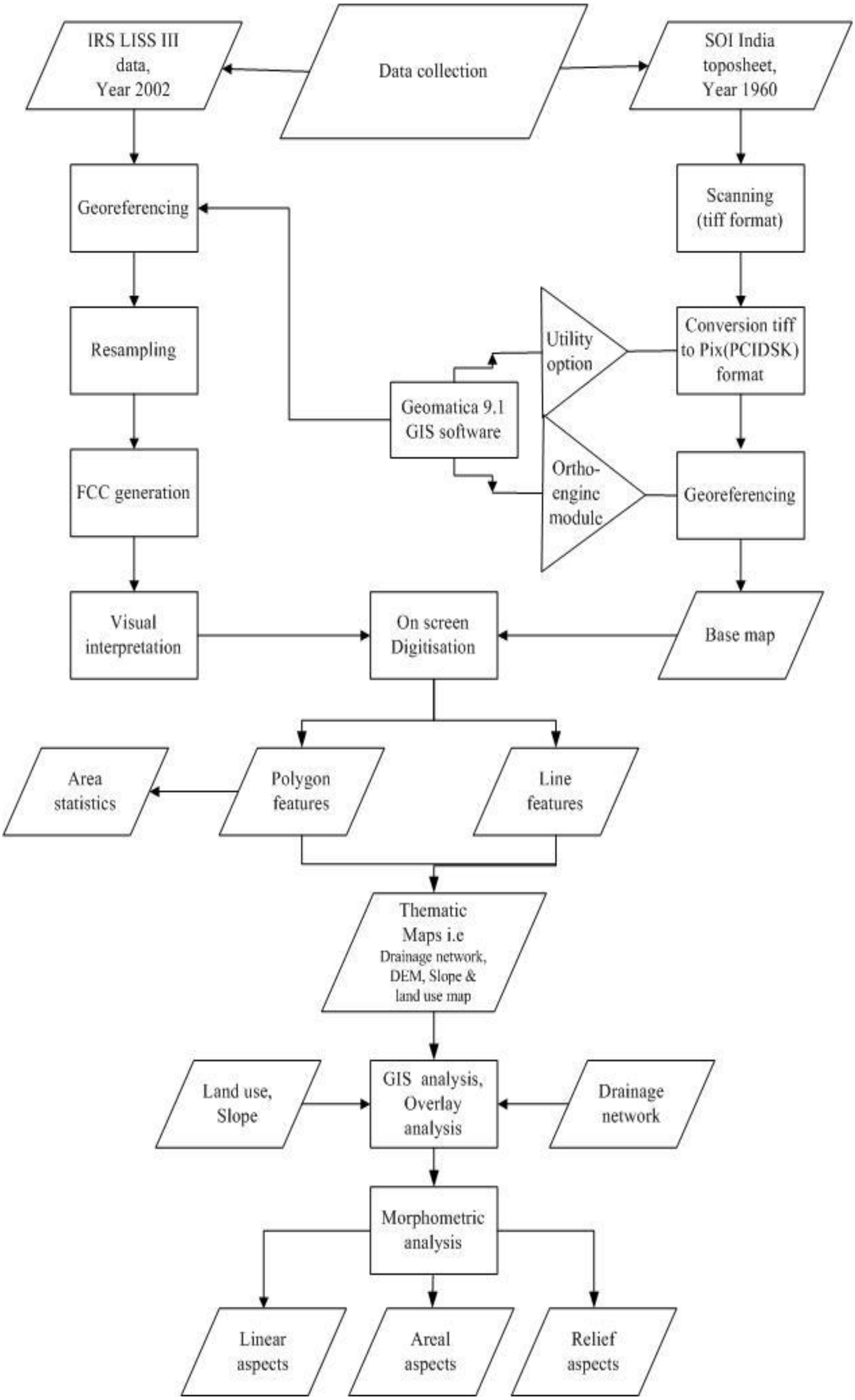

Figure 2: The detail flow chart of methodology adopted for morphometric analysis.

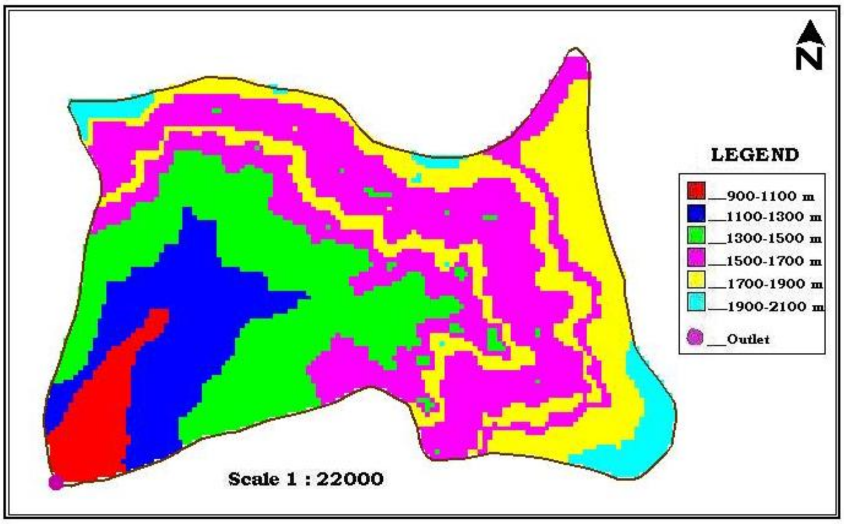

Figure 3: Digital elevation model of the study area.

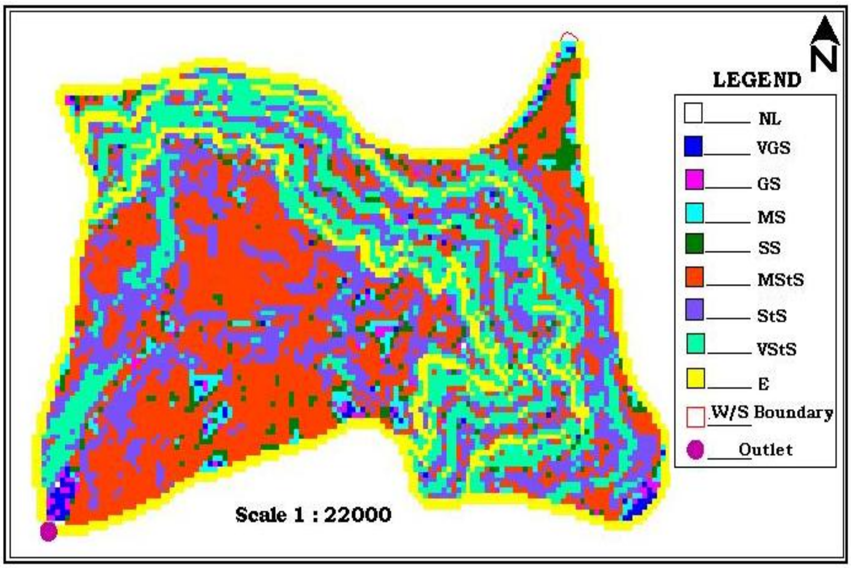

Figure 4: Slope map of Maun watershed.

Table 1: Areal extent of various slope classes in the study area

Slope categories	Slope as per IMSD classification (%)	Area (ha)	% Area
Nearly level (NL)	0-1	9.26	1.06
Very gently sloping (VGS)	1-3	16.73	1.92
Gently sloping (GS)	3-5	17.90	2.06
Moderately sloping (MS)	5-10	34.28	3.94
Strongly sloping (SS)	10-15	38.24	4.39
Moderately steep sloping (MStS)	15-35	264.05	30.32
Steep sloping (StS)	35-50	189.53	21.76
Very steep sloping (VStS)	50-75	169.55	19.47
Escarpment (E)	>75	131.48	15.10
	Total	871	100

2.2 Linear Aspect

The parameters representing length were considered in linear aspects.

2.2.1 Stream number (N_u)

The quantity N_u represents total number of all streams, counted as the stream segments, having the order 'u' present in the watershed. The number of streams of each order was an important concept in hydrologic synthesis. It is inversely proportional to the stream order.

2.2.2 Basin length (L_b)

Basin length was calculated as the distance between outlet and farthest point on the basin boundary. It is indicative of the contributing area of the basin of that order.

2.2.3 Basin perimeter (P)

Basin perimeter was taken as the lengths of watershed divide which surrounds the basin.

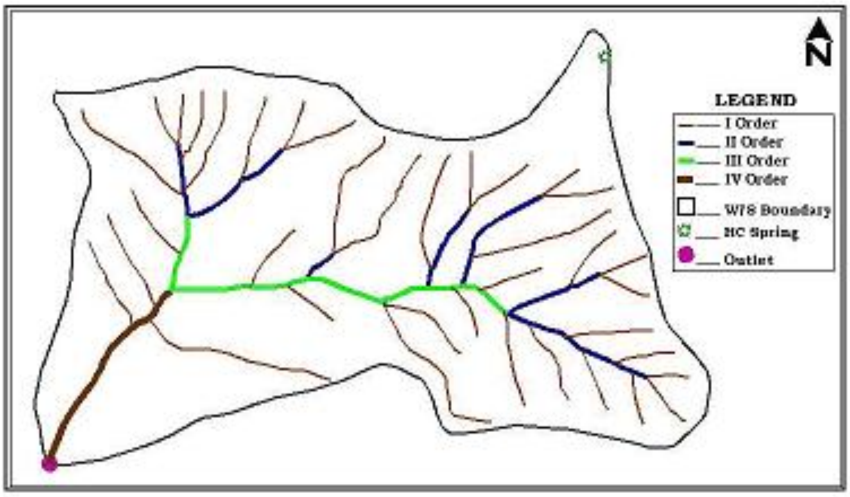

Figure 5: Drainage network in Maun watershed.

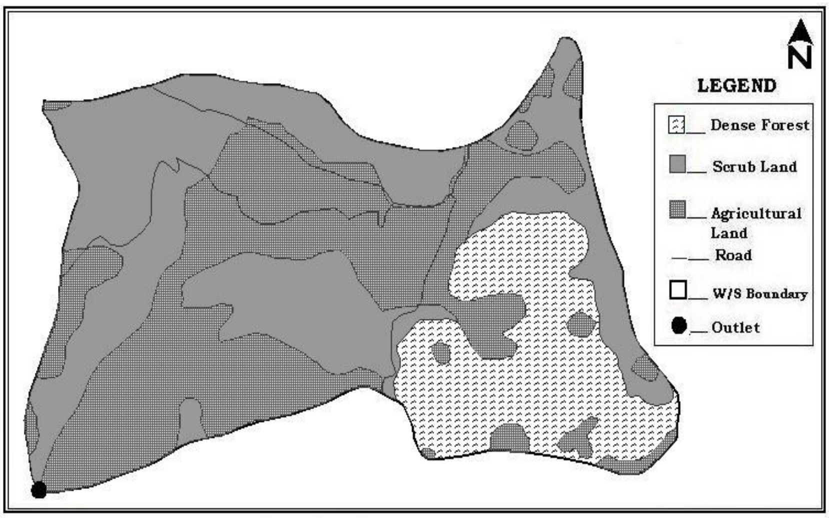

Figure 6: Land use/cover map based on the toposheet for the year 1960.

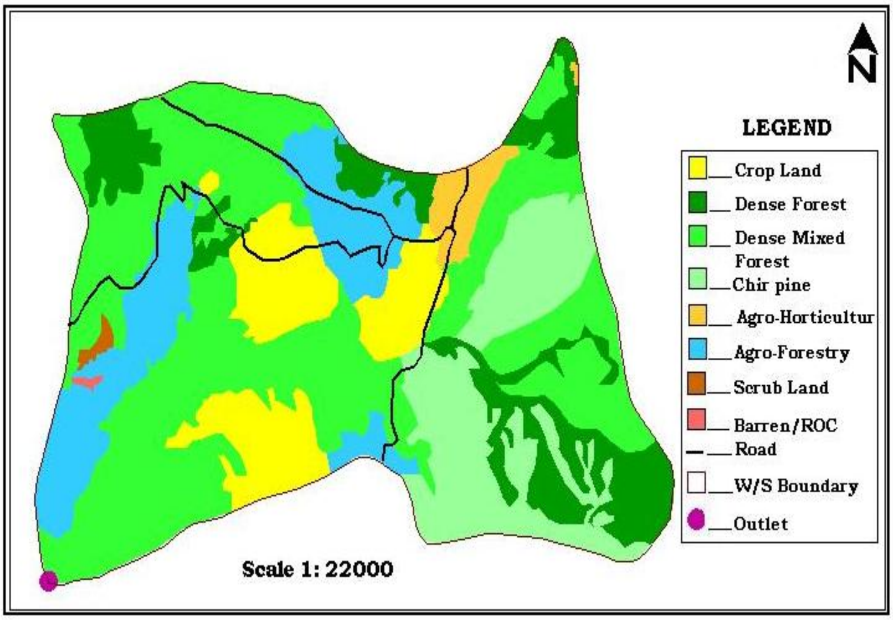

Figure 7: Land use on the basis of satellite imagery for the year 2002.

Table 2: Area covered under different land uses of the year 1960

Sl. No.	Land use/land cover	Area (ha)	Total area (%)
1	Agricultural land	351	40.30
2	Dense forest	343	39.38
3	Scrub land	177	20.32
	Total	871	100

Table 3: Areal extent under different land use of the year 2002

S No.	Land use	Area (ha)	% area
1	Agro - forestry	117.81	13.53
2	Agro - horticulture	31.91	3.66
3	Barren/ROC	15.65	1.80
4	Crop land	106.74	12.25
5	Chir pine	127.74	14.67
6	Dense forest	115.2	13.23
7	Dense mixed forest	338.83	38.90
8	Scrub land	17.15	1.97
	Total	871	100

ROC= Rock out crop

2.2.4 Main stream length (L_m)

This is the length along the longest water course from outflow point of designated sub basin to the upper limit of catchment boundary. The time of concentration along this stream is always maximum.

2.2.5 Mean stream length (L_{sm})

It is the total length of all streams of order 'u' in a given drainage basin divided by number of streams of order 'u'.

$$L_{sm} = \frac{\sum_{i=1}^{N_u} L_i}{N_u} \tag{1}$$

where L_i = length of ith stream of order 'u'

2.2.6 Bifurcation ratio (R_b)

The R_b was computed using Horton's law of stream numbers (Horton, 1945) which was stated as, "The number of stream segments of each order form an inverse geometric sequence with order number".

$$R_b = \frac{N_u}{N_{u+1}} \tag{2}$$

Where N_u = number of segments of order 'u', and
N_{u+1} = number of segments of higher order 'u+1'.

In general, the value of R_b normally varies in between 2 to 5 and tend to be more for elongated basins (Beaumont, 1975), and it is a useful index for hydrograph shape for watersheds similar in other respect. High value of R_b might be expected in region of steeply dipping rock strata. An elongated basin is likely to have high R_b, whereas a circular basin is likely to have low R_b.

2.2.7 Stream length ratio (R_L)

It is the ratio of mean stream length of order 'u' to the mean stream segment length of order (u-1).

$$R_L = \frac{L_u}{L_{u-1}} \tag{3}$$

2.2.8 Length of overland flow (L_g)

It was defined as the length of flow of water over the ground, before it becomes concentrated in defined stream channels (Horton, 1945). It is half the reciprocal of drainage density (D) for the average length of overland flow (L_g) for entire watershed.

$$L_g = \frac{1}{2 \times D} \tag{4}$$

2.2.9 Fineness ratio (R_{fn})

The fineness ratio (R_{fn}) was considered as the ratio of channel length to the length of the basin perimeter.

2.2.10 Areal Aspect

In areal aspects, different morphologic parameters were considered which represented the area.

2.2.11 Drainage area (A)

Drainage area (A) was represented by the area enclosed within the boundary of the watershed divide. It is the most important characteristic for hydrologic design.

2.2.12 Drainage density (D)

It was estimated as the ratio of total length of channels of all orders in the basin to the drainage area of the basin.

$$D = \frac{\sum_{i=1}^{w} \sum_{j=1}^{N_i} L_{ij}}{A} \qquad (5)$$

2.2.12 Constant of channel maintenance (C)

It was calculated as the ratio between the area of the drainage basin and total length of all the channels, expressed as square meter per meter. It is also equal to reciprocal of drainage density (D).

$$C = \frac{1}{D} \qquad (6)$$

2.2.13 Stream frequency (F_s)

It is calculated as the number of streams (N_u) per unit area.

$$F_s = 0.694 \times D^2 \qquad (7)$$

or

$$F_s = \frac{N_u}{A} \qquad (8)$$

2.2.14 Circulatory ratio (R_c)

Circulatory ratio (R_c) is estimated as the ratio of the basin area (A) to the area of a circle (A_c) having circumference equal to the perimeter of the basin (Millar, 1953). As basin shape approaches to a circle, the circulatory ratio approaches to unity.

$$R_C = \frac{A}{A_C} \qquad (9)$$

2.2.15 Elongation ratio (R_e)

It is defined as the ratio between the diameter of a circle (d_c) with the same area as the basin and basin length (L_b). The value of R_e approaches to 1 as the shape of the basin approaches to a circle and it varies from 0.6 to 1.0 over a wide variety of climatic and geologic regimes. Typical values of R_e are close to 1 for areas of very low relief and varies between 0.6 to 0.9 for regions of strong relief and steep ground slope. The elongation ratio was estimated by using equation 11.

$$R_e = \frac{2\sqrt{A/\pi}}{L_b} \qquad (10)$$

$$R_e = \frac{d_c}{L_b} \qquad (11)$$

2.2.16 Form factor (R_f)

The form factor (R_f) was calculated as the ratio of basin area (A) to the square of basin length (L_b) (Horton, 1932).

$$R_f = \frac{A}{L_b^{\ 2}} \tag{12}$$

2.2.17 Drainage texture ratio (R_t)

Drainage texture ratio (R_t) is the ratio of total number of stream segments (N_u) of all orders to the perimeter (P) of that area (Horton, 1945).

3. Relief Aspect

In basin relief aspects, the parameters were evaluated are given below in brief.

3.1 Total relief (H)

Total relief (H) is the maximum vertical distance between the lowest (outlet) and the highest (divide) points in the watershed. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope.

3.2 Relief ratio (R_h)

The relief ratio (R_h) was estimated as the ratio between the relief and the distance over which the relief measured (Schumn, 1956). It is an indicator of erosion process operating on the slopes of the basin. It measures the overall steepness of the watershed and can be related to its hydrologic characteristics.

3.3 Relative relief (R_p)

The relative relief is the ratio of basin relief (H) to the length of the perimeter (P). It is an indicator of general steepness of the basin from summit to mouth.

3.4 Ruggedness number (R_n)

Ruggedness number (R_n) is a product of relief (H) and drainage density (D) in the same unit. The areas of low relief but high drainage density are regarded as ruggedly textured as areas of higher relief having less dissection and computed as:

$$R_n = H \times D \tag{13}$$

In the present study, the morphometric characteristics of the basin includes stream order, stream length, stream length ratio, bifurcation ratio, fineness ratio, length of overland flow, drainage density, drainage frequency, constant of channel maintenance, form factor, relief ratio, elongation ratio and circularity ratio were computed using above equations and GIS software (Geomatica version 9.1). Thematic maps, such as land use/land cover, slope and drainage network maps were integrated by overlay technique in GIS for identifying the suitable site for soil conservation structures. 'Focus' module of GIS software Geomatica version 9.1 was used for digitization, computation and output generation of drainage network of watershed.

4. Results and discussion

The qualitative analysis of the morphometric characteristics of the basin (*i.e.,* stream order, stream length, bifurcation ratio, drainage density, drainage frequency, relief ratio, elongation ratio and circularity ratio etc.) has been carried out using the above equations from 1 to 14. In this section, the detail discussion of the results has carried out according to the linear, Areal and relief aspects. Further, a scope for water resources development in the selected watershed has been investigated.

4.1 Linear Aspect

The linear aspects of the channel system are stream order (U), stream length (L_u), stream length ratio, bifurcation ratio, length of main channel, basin length, basin perimeter, fineness ratio and length of overland flow. Classification of streams is important to index the size and scale of watershed.

The number of streams of various orders in watershed was counted and their lengths from mouth to drainage divide were measured with the help of GIS software. The statistics of drainage network of the watershed is shown in table 4. After analysis of the drainage network, it was found that Maun watershed is of 4th order and drainage pattern is dendrite. The total length of stream segments of 1st, 2nd and 3rd order streams were found to be 21.60, 4.82 and 1.35 km respectively. It also showed maximum total length of stream segments for 1st order streams (table 4). This is satisfying Horton's second law. The mean stream length of the watershed was found to be 0.58, 0.60 and 1.46 km for 1st, 2nd and 3rd order streams respectively. The stream length ratio (R_L) was estimated of 0.22, 0.61 and 0.497 for II/I, III/II and IV/III orders, respectively. The increasing trend in R_L from lower order to higher order indicates matured geomorphic stage and change from one order to another order indicated late youth stage of geomorphic development of streams (Singh and Singh, 1997).

Table 4: Statistics of drainage network

Parameters	Natural Drains			
	I order	II order	III order	IV order
Number of streams (N_u)	37	8	2	1
Minimum Length (km)	0.29	0.04	0.51	1.46
Maximum Length (m)	1.37	1.05	2.42	1.46
Mean stream length (L_{sm}), km	0.58	0.60	1.46	1.46
Standard Deviation (%)	0.26	0.33	2.93	0.00
Total Stream length (L_u), km	21.60	4.82	1.35	1.46

The natural drainage system of watershed was classified according to Strahler's system of stream ordering and the main stream was found as of 4th order. It shows that frequency in case of 1st order is 37 and for the 2nd and 3rd order, it is 1 and 8 respectively. It is also noticed that there is decrease in stream frequency with the increase in stream order (table 4). This satisfies the Horton's law of stream numbers. This stream order is used in the study of other characteristics of watershed. Horton (1945) considered the bifurcation ratio (R_b) as an index of relief and dissections. The value of Rb normally varies 2 to 5 and tends to be more for elongated basins (Beaumont, 1975). It is a useful index for hydrograph shape for watersheds similar in all other respects. In the present study, R_b varies from 2 to 4.63 with an average of 3.54. It was estimated of 4.63, 4 and 2 for I/II, II/III and III/IV orders, respectively. The high value of R_b indicates structural complexity and low permeability (Pankaj, 2009). It also indicates that the value of R_b is not same from one order to next order. The higher value of R_b indicated strong structural control on the drainage pattern. This shows it's usefulness for hydrograph shape for watersheds similar in other respect. An elongated watershed has higher bifurcation ratio than normal and approximately circular watershed (Singh, 2003). It is indicated that the watershed chosen for the study is not circular in shape and would produce delayed peak flow. The length of main channel, basin length and basin perimeter was found to be 5.32, 5.18 and 14.37 km respectively. Fineness ratio was found to be 0.36. Surface runoff follows a system of down slope flow path from the basin perimeter to the nearest channel. Horton (1945) defined length of over land flow as the length, projected to the horizontal, of non channel flow from a point on the drainage divide to a point on the adjacent stream channel. Length of over land flow is one of the most important independent variables, affecting both the hydrologic and physiographic development of drainage basin. The shorter the length of over land flow, the quicker will be surface runoff. Length of over land flow for Maun watershed was 0.14 km.

4.2 Areal Aspect

Areal aspect of morphometric study of the watershed includes the description of arrangement of areal elements, law of stream area, relationship between stream area and stream length, relation of area to the discharge, basin shape (form factor, circulatory ratio, and elongation ratio), drainage density etc. Drainage area represents the area enclosed within the boundary of the watershed divide. It is probably the single most important characteristic. The drainage density was found to be 3.54 km/km^2. The high drainage density indicates the region is weak and consists of impermeable surface materials, sparse vegetation cover and mountainous relief (Pankaj, 2009). Lower drainage density of the basin indicates towards coarse drainage pattern and humid climate of the study area. The coarse texture gives more time for overland flow and hence to ground water recharge. A low value of the drainage density indicates a relatively low density of streams and thus a slow stream response (Singh, 2004). Drainage texture is one of the important concepts of geomorphology which means the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. Horton defined drainage texture is the total number of stream segments of all orders per perimeter of that area. He recognized infiltration capacity as the single important factor which influences drainage texture. It includes drainage density and stream frequency. In the present study, drainage texture ratio is 3.34 which indicate the drainage is of coarse texture (Smith, 1950).

The constant of channel maintenance (C) was found to be 0.28 km which is the reciprocal of drainage density. It indicates that magnitude of surface area of watershed needed to sustain unit length of stream segment. The value of C indicated that Maun watershed is under the influence of high structural disturbance, low permeability, steep to very steep slopes and high surface runoff. Horton (1932) introduced stream frequency or channel frequency (F_s) which is ratio of the number of stream segments of all orders per unit area of the watershed. The stream frequency was found to be 8.68. The high value of F_s indicated the high relief and high infiltration capacity of the bed rocks pointing towards the increase in stream population which indicates erodibility of the rock surface as moderate to high nature (Pankaj, 2009). The circulatory ratio (R_c) was estimated to be 0.52 whereas, form factor and elongation ratio were found to be 0.32 and 0.64 respectively. The value of R_c is influenced by the length and frequency of streams, geological structures, land use/land cover and slope of the basin. Smaller the value of form factor more will be elongated basin and high peak flows of shorter durations (Javed, 2009). The value of elongation ratio varies from 0.6 to 1.0 over a wide variety of climatic and geologic regimes. Elongation ratio of 0.64 confirmed that the study area is having high relief and steep ground slope and having elongated shape (<0.7). The drainage area is characterized by high to moderate relief and the drainage system is structurally controlled (Pankaj, 2009). A circular basin is more efficient in the discharge of runoff than that of an elongated basin (Singh and Singh, 1997).

4.3 Relief Aspect

The relief ratio (R_h) was found to be 0.20. The R_h normally increased with the decreasing drainage area and size of the watersheds for a given drainage basin (Gottschalk, 1964). It measures overall steepness of watershed and also considered as an indicator for the intensity of erosion process occurring in the watershed. The high value of relief ratio is characteristics of hilly region. Strahler (1958) defined a dimensionless number, called ruggedness number (R_n), as a product of relief (H) and drainage density (D) in the same unit. The value of total relief (H) and relative relief was found to be 1.04 km and 0.28 respectively. The areas of low relief but high drainage density are regarded as ruggedly textured as areas of higher relief having less density. In the present study, R_n was found to be 3.67 km. This number represents that if drainage density is increased, keeping relief as constant then average horizontal distance from drainage divide to the adjacent channel is reduced. On the other hand, if relief increases by keeping drainage density as constant, the elevation difference between the drainage divide and adjacent channel will increase.

4.4 DEM, slope and Land Use/Land Cover change analysis

From DEM, It was found that maximum area of the Maun watershed is under the elevation of 1500 to 1700 m and elevation varies from 960 to 2000 m (Figure 3). Slope of a region are vital parameters in deciding suitable land use as the degree and direction of the slope to decide the land use that it can support. The dominant slope categories in the Maun watershed were moderately steep slope (30.32%) followed by steep sloping (21.76%). It was also noticed that slope of major area of agricultural land varied from very gently sloping to moderately sloping, whereas forest areas were mainly located on higher slope (Figure 4 and table 1). Land use land cover change analysis has been carried out using IRS LISS III data of 2002 and SOI toposheet of 1960. Dense forest was observed mainly in northern aspects and at higher altitude whereas, major agricultural activities were taken up mainly in southern aspects at the altitude of 1100-1400 m. The study observed that agricultural area had reduced up to 28.05% over a period of 42 years. At the same time, 13.53% area was occupied by agro-forestry in 2002 which was previously part of agricultural activity. The scrub land (Figure 6) converted into either dense forest or dense mixed forest by the year 2002 (Figure 7). This is due to the plantation made by the forest department. The cultivation had also been extended even to steep slope (35-50%). Morphometric parameters coupled with integrated thematic map of drainage density, land use and slope can help in decision making process for water resources management. Additional surface water resources can be developed by constructing different water harvesting structures under different land use/cover units and also by increasing the storage capacity of the existing major tanks within the watershed area. Apart from agriculture, care should also be taken in the waste land area to reduce the runoff rate and conserve the soil and water within the watershed. Small water harvesting structures, such as percolation tanks may be constructed to bring the waste land under cultivation and to improve the ground water recharge. Farm ponds can be constructed in areas having flat topography and locations having low soil permeability.

5. Summary and Conclusion

The morphometric characterization was achieved through the measurement of linear, areal and relief aspects of Maun watershed using GIS techniques. For determining the linear aspects such as stream order, bifurcation ratio, stream length and areal aspects such as drainage density, drainage texture and, relief aspects like total relief, relative relief, relief ratio and ruggedness number. The morphometric study of Maun watershed shows their relative characteristics with respect to hydrologic response of the watershed. Morphometric parameters coupled with integrated thematic map of drainage density, land use and slope can help in decision making process for water resources management. Additional surface water resources can be developed by constructing different water harvesting structures under different land use/cover units and also by increasing the storage capacity of the existing major tanks within the watershed area.

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