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Morphometric analysis of a Semi Urban Watershed, trans Yamuna, draining at Allahabad using Cartosat (DEM) data and GIS

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-----ABSTRACT-----
Semi Urban Watershed is a constituent of the trans Yamuna River Basin, Allahabad District and covers an area of 289.41Km2, representing seasonally Semi humid tropical climate. To achieve the Morphometric analysis, Survey of India (SOI) topomaps in 1:50000 scales are procured and the boundary line is extracted by joining the ridge points. The analysis has revealed that the total number as well as total length of stream segments is maximum in first order streams and decreases as the stream order increases. The bifurcation ratio (Rb) between different successive orders is almost constant revealing the partial structural control. The drainage map is prepared with the help of Geographical Information System tool and morphometric parameters such as aerial and linear aspects of the watershed have been determined. These dimensionless and dimensional parametric values are interpreted to underst and the watershed characteristics. From the drainage map of the study area dendritic drainage pattern is identified. Strahler (1964) stream ordering method is used for stream ordering of the watershed. The drainage density of the watershed is 2.79 km/km2.Hence from the study it is clear that the Morphometric analysis based on GIS techniques is very useful to understand the prevailing geo hydrological characteristics and for watershed planning and Management.

Key words: *Morphometric analysis, linear parameters, areal parameters, Remote sensing, GIS and Semi Urban Watershed*

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I. INTRODUCTION

Morphometric is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998). A watershed is a natural or disturbed system that functions in a manner to collect, store, and discharges water from a common outlet, such as a larger stream and lakes. Watershed is the line separating neighboring drainage basins (catchments). Watersheds have been classified into different categories based on area viz Micro Watershed (0 to 10 ha), Small Watershed (10 to 40 ha), Mini Watershed (40 to 200 ha), Sub Watershed (200 to 400 ha), Watershed (400 to 1000 ha) and Sub basin (above 1000 ha). A watershed is the surface area drained by a part or the totality of one or several given water courses and can be taken as a basic erosional landscape element where land and water resources interact in a perceptible manner. In fact, they are the fundamental units of the fluvial landscape and a great amount of research has focused on their geometric characteristics, including the topology of the stream networks and quantitative description of drainage texture, pattern and shape (Abrahams, 1984). 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). The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at watershed level. 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). The influence of drainage morphometric is very significant in understanding the landform processes, soil physical properties and erosional characteristics. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1957, 1964; Krishnamurthy et al., 1996). Geographical Information System (GIS) techniques are now a days 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.

In the present study stream number, order, frequency, density and bifurcation ratio are derived and tabulated on the basis of areal and linear properties of drainage channels using GIS based on drainage lines as represented over the topographical maps (scale 1:50,000)

STUDY AREA

Allahabad is located at 25^0 27' N, 81^0 50' E; 25.45^0 N, 81.84^0 E in the southern part of the Uttar Pradesh at an elevation of 98 meters. The Indian longitude that is associated with Jabalpur also passes through Allahabad, which is 343 km north to Jabalpur on the same longitude. To its southwest, east and south west is the Bundelkhand region, to its north and north east is the Awadh region and to its west is lower Doab of which it is a part. It is the last point of the Yamuna River and is the last frontier of the Indian west. Ground water in the district occurs both in alluvium and in the weathered & jointed sandstones areas which are underlain by hard rocks. In the unconsolidated or alluvial formation ground water occurs under unconfined to confined conditions in the shallow and deeper aquifers respectively and depth to water ranges between 2 to 20 meters during pre-monsoon period, while in the post monsoon period it stands between 1 to 18.00 meters.

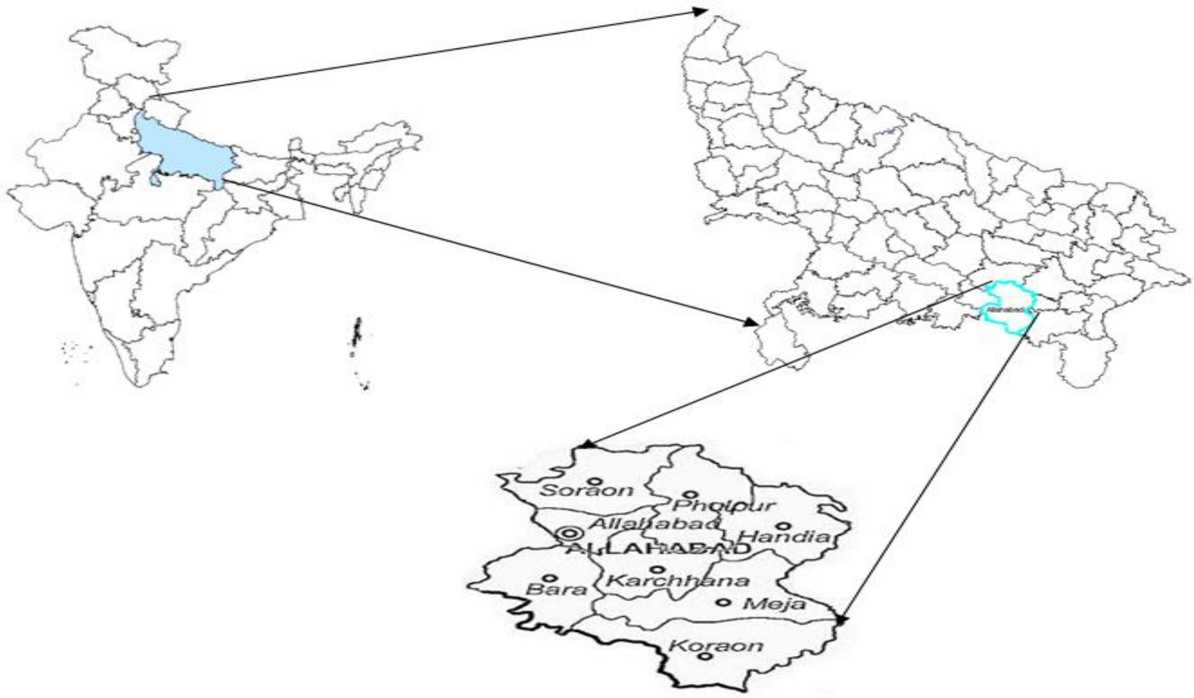

Fig-1: Location Map of study area

II. METHODOLOGY

In present study, morphometric analysis and priorization of basin is based on the integrated use of remote sensing and GIS technique. The remotely sensed data is geometrically rectified with respect to Survey of India (SOI) topographical maps at 1:50000.The digitization of dendritic drainage pattern is carried out in Arc GIS 9.3 software. For stream ordering, Horton's law is followed by designating an un-branched stream as first order stream, when two first order streams join it is designated as second order. Two second order steams join together to form third order and so on. The number of streams of each order are counted and recorded. The drainage map along with basin boundaries are digitized as a line coverage giving unique id for each order of stream. The digitized map is edited, and saved as line coverage in Arc GIS 9.3 Software. Morphometric parameters under linear and shape are computed using standard methods and formula (Horton 1932, 1945; Smith 1954; Strahler, 1964).The fundamental parameter namely; stream length, area, perimeter, number of streams and basin length are derived from drainage layer. The values of morphometric parameters namely; stream length, bifurcation ratio, drainage density, stream frequency, form factor, texture ratio, elongation ratio, circularity ratio and compactness constant are calculated based on the formula suggested by Horton (1945), Miller (1953), Schumn (1956), Strahler(1964), Nookaratm (2005) .

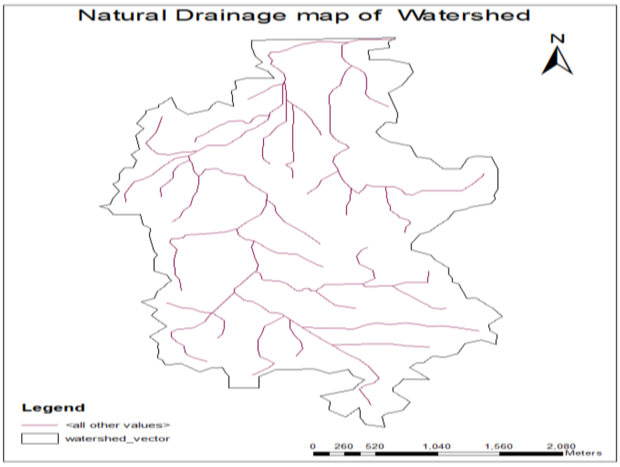

Fig-2: Natural drainage map of watershed

III. RESULTS AND DISCUSSION

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. This approach has recently been termed as Morphometric. The morphometric analysis of the Semi Urban watershed, trans Yamuna was carried out on the Survey of India topographical maps No. I43W06, I43W07, I43W10, and I43W11 on the scale 1:50,000 and CartoSAT-1 DEM with 30m spatial resolution. The lengths of the streams, areas of the watershed were measured by using ArcGIS-9.3 software, and stream ordering has been generated using Strahler (1952) system, and ArcHydro tool in ArcGIS-9.3 software. We have used several method for linear, areal and relief aspects studies i.e. Horton (1945, 32) for stream ordering, stream number, stream length, stream length ratio, bifurcation ratio, length of overland flow, rho coefficient, form factor, & stream frequency; Strahler (1952, 68) for weighted mean bifurcation ratio, mean stream length, ruggedness number, & hypsometric analysis; Wolman (1964) for sinuosity index analysis; Mueller (1968) for channel & valley index. Schumm (1956) for basin area, length of the basin, elongation ratio, texture ratio, relief ratio & constant of channel maintenance; Hack (1957) for length area relation; Chorely (1957) for lemniscate's; Miller (1960) for circularity ratio; Smith (1939) for drainage texture; Gravelius (1914) for compactness coefficient; Melton (1957, 58) for fitness ratio, & drainage density; Smart (1967) for wandering ratio; Black (1972) for watershed eccentricity; Faniran (1968) for drainage intensity; Wentworth (1930) for slope analysis, and Pareta (2004) for erosion analysis.

Linear Aspects

Linear aspects include the measurements of linear features of drainage such as stream order, bifurcation ratio, stream length, stream length ratio, length of overland flow etc. The linear characteristics of the drainage basin are discussed below.

IV. Stream Order (Su)

Stream Ordering is the first step of quantitative analysis .In this research stream order of Semi Urban Watershed, trans Yamuna has been found out by using ArcGIS-9.3 software. It has observed that first order channels join, a channel segment of order 2 is found. Where two of order 2 joins, segment of order 3 is formed; and so forth. The trunk stream through which all discharge of water and sediment passes is therefore the stream segment of highest order. Usefulness of the stream order system depends on the premise that, on the average, if a sufficiently large sample is treated, order number is directly proportional to size of the contributing watershed, to channel dimensions and to stream discharge at that place in the system. Because order number is dimensionless, two drainage networks differing greatly in linear scale can be compared with respect to corresponding points in their geometry through use of order number. After the drainage network elements have been assigned their order numbers, the segments of each order are counted to yield the number *Nu* of segments of the given order *u*

Stream Order of semi urban Watershed

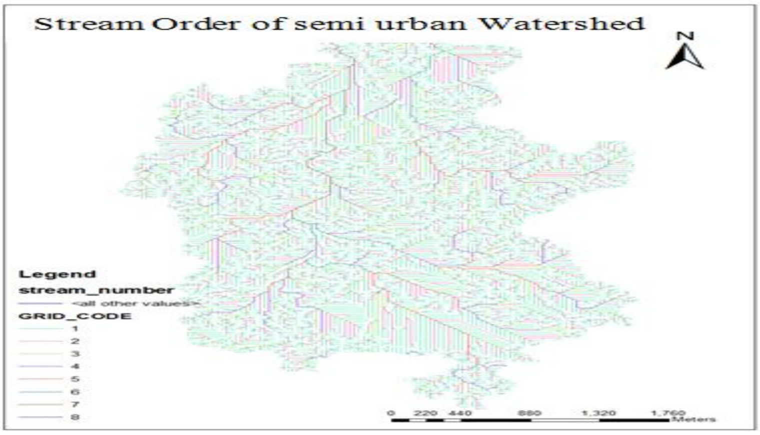

Fig-3: Stream order Map of Semi Urban Watershed, trans Yamuna

Bifurcation Ratio (Rb)

It is obvious that the number of stream segments of any given order will be fewer than for the next lower order but more numerous than for the next higher order. The ratio of number of segments of a given order *Nu* to the number of segments of the higher order Nu+1 is termed the *bifurcation ratio Rb*:

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

the bifurcation ratio will not be precisely the same from one order to the next, because of chance variations in watershed geometry, but will tend to be a constant throughout the series. Bifurcation ratio characteristically ranges between 0.9 and 15 for watersheds in which the geologic structures do not distort the drainage pattern. The theoretical minimum possible value of 2 is rarely approached under natural conditions. Because the bifurcation ratio is a dimensionless parameter, and because drainage systems in homogeneous materials tend to display geometrical similarity, it is not surprising that the ratio shows only a small variation from region to region. Abnormally high bifurcation ratios might be expected in regions of steeply dipping rock strata where narrow strike valleys are confined between hogback ridges. Average bifurcation ratio is calculated for the watershed as 4.04 (Table-1)

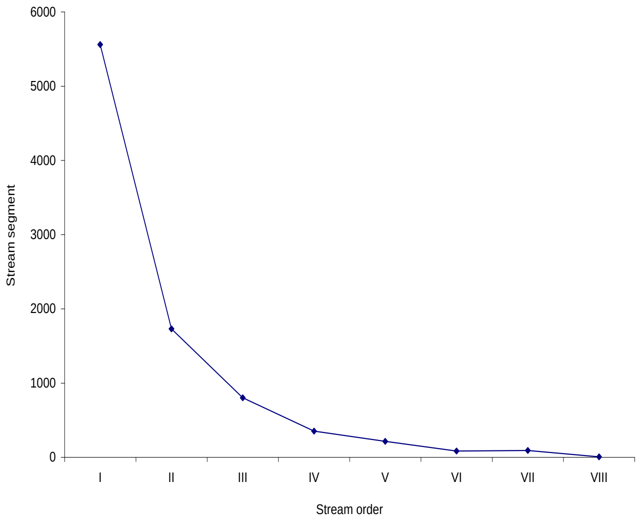

Fig-4: Regression of stream order on number of stream segments

Stream Lengths

Mean stream length Lu of a stream channel segment of order u is a dimensional property revealing the characteristic size of components of a drainage network and its contributing basin surfaces. Channel length is measured with the help of ArcGIS and QGIS softwares directly from the Stream Order map. To obtain the mean stream length of channel L_u of order *u*, the total length is divided by the number of stream segments *Nu* of that order, thus:

$$L_u = \frac{\sum_{i=1}^{N} L_u}{N_u}$$

Generally, The L_u increases with increase of order number. It can be seen from Table 1, that the mean length of channel segments of a given order is more than that of the next higher order. The total number of all stream segments *Nu* in a stream order, total stream length Lu in stream order u, mean stream length for the watershed are calculated and is shown in Table-2. Fig-5 shows that there is linear relationship between mean stream length and stream order.

V. Stream length ratio

Stream length ratio (RL) is defined as the average length of stream of any order to the average length of streams of the next lower order and it is expressed as;

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

Horton postulated that, the length ratio tends to be constant throughout the successive orders of the stream.

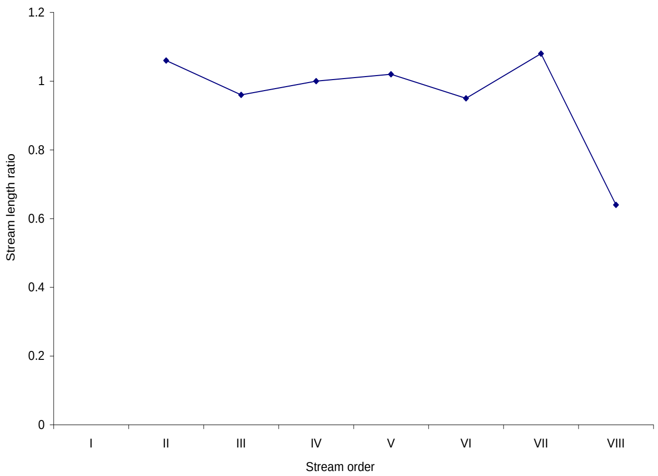

Fig-5: Regression of stream order on mean stream length

Length of overland flow

Horton defined length of overland flow Lo as the length of flow path, projected to the horizontal, non channel flow from a point on the drainage divide to a point on the adjacent stream channel. He noted that length of overland flow is one of the most important independent variables affecting both the hydrologic and physiographic development of drainage basins. During the evolution of the drainage system, Lo is adjusted to a magnitude appropriate to the scale of the first order drainage basins and is approximately equal to one half the reciprocal of the drainage density. The shorter the length of overland flow, the quicker the surface runoff from the streams. For a present study Length of Overland Flow is 0.17

Drainage pattern

In geomorphology, a drainage system is the pattern formed by the streams, rivers, and lakes in a particular drainage basin. They are governed by the topography of the land, whether a particular region is dominated by hard or soft rocks, and the gradient of the land. Geomorphologists and hydrologists often view streams as being part of drainage basins. A drainage basin is the topographic region from which a stream receives runoff, through flow, and groundwater flow. Drainage basins are divided from each other by topographic barriers called a watershed. A watershed represents all of the stream tributaries that flow to some location along the stream channel. The number, size, and shape of the drainage basins found in an area varies and the larger the topographic map, the more information on the drainage basin is available. A drainage system is described as accordant if its pattern correlates to the structure and relief of the landscape over which it flows. Following are the some of the drainage patterns in the world.

Dendritic drainage pattern

Dendritic drainage systems are the most common form of drainage system. In a dendritic system, there are many contributing streams (analogous to the twigs of a tree), which are then joined together into the tributaries of the main river (the branches and the trunk of the tree, respectively). They develop where the river channel follows the slope of the terrain. Dendritic systems form in V-shaped valleys; as a result, the rock types must be impervious and non-porous.

Parallel drainage pattern

A parallel drainage system is a pattern of rivers caused by steep slopes with some relief. Because of the steep slopes, the streams are swift and straight, with very few tributaries, and all flow in the same direction. This system forms on uniformly sloping surfaces, for example, rivers flowing southeast from the Aberdare Mountains in Kenya. Parallel drainage patterns form where there is a pronounced slope to the surface. A parallel pattern also develops in regions of parallel, elongate landforms like outcropping resistant rock bands.

Trellis drainage pattern

The geometry of a trellis drainage system is similar to that of a common garden trellis used to grow vines. As the river flows along a strike valley, smaller tributaries feed into it from the steep slopes on the sides of mountains. These tributaries enter the main river at approximately 90 degree angles, causing a trellis-like appearance of the drainage system. Trellis drainage is characteristic of folded mountains, such as the Appalachian Mountains in North America.

Rectangular drainage pattern

Rectangular drainage develops on rocks that are of approximately uniform resistance to erosion, but which have two directions of jointing at approximately right angles. The joints are usually less resistant to erosion than the bulk rock so erosion tends to preferentially open the joints and streams eventually develop along the joints. The result is a stream system in which streams consist mainly of straight line segments with right angle bends and tributaries join larger streams at right angles.

Radial drainage pattern

In a radial drainage system, the streams radiate outwards from a central high point. Volcanoes usually display excellent radial drainage. Other geological features on which radial drainage commonly develops are domes and laccoliths. On these features the drainage may exhibit a combination of radial patterns. (Subramanya K, 2012) The drainage pattern for the present study area is dendritic. The drainage pattern shows well integrated pattern formed by a main stream with its tributaries branching and rebranching freely in all direction. The dendritic pattern of drainage indicates that the soil is semi pervious in nature

.

Table 1 Linear morphometric parameters of Semi Urban Watershed, trans Yamuna

Stream Order	**No of Segments**	**Total length**	**Bifurcation Ratio**	**Mean Length**	**Length Ratio**
I	5560	266.38		0.047	
II	1730	88.15	3.21	0.050	1.06
III	802	39.17	2.15	0.048	0.96
IV	353	17.17	2.27	0.048	1.00
V	215	10.62	1.64	0.049	1.02
VI	84	4.0	2.55	0.047	0.95
VII	92	4.7	0.91	0.051	1.08
VIII	6	0.2	15.33	0.033	0.64

Areal aspects

Areal aspects (Au) of a watershed of given order u is defined as the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order. The watershed shape has a significant effect on stream discharge characteristics, for example, the elongated watershed having a high bifurcation ratio can be expected to have alternated flood discharge. But on the other hand, the round or circular watershed with a low bifurcation ratio may have a sharp peak flood discharge. The shape of a watershed has a profound influence on the runoff and sediment transport process. The shape of the catchment also governs the rate at which water enters the stream. The quantitative expression of watershed can be characterised as form factor, circularity ratio, and elongation ratio.

Form factor

Horton defines the form factor Rf as a dimensionless ratio of watershed area (A) to the square of the length of the watershed (L). The value of form factor would always be less than 0.7854 (for a perfect circular watershed). The watershed with higher form factor are normally circular and have high peak flows for shorter duration, whereas elongated watershed with lower values of form factor have low peak flows for longer duration. For the present study area form factor is 0.42.

$$R_f = \frac{A}{L^2}$$

Where R_f is the form factor, *L* is the total length of watershed and *A* is the total area of watershed.

Circularity ratio

Circularity ratio is the ratio between the areas of watershed to the area of circle having the same circumference as the perimeter of the watershed (Miller, 1953). The value ranges from 0.4 to 0.5, greater the value more is the circularity ratio. It is the significant ratio which indicates the stage of dissection in the study region. Its low, medium and high values are correlated with youth, mature and old stage of the cycle of the tributary watershed of the region, and the value obtained. For the present study area circularity ratio is obtained as 0.44.

$$R_c = \frac{4 \Pi A}{P^2}$$

Where R_c = Circularity ratio, A = Watershed area, P = Perimeter of watershed.

Elongation ratio

Elongation ratio is the ratio between the diameter of the circle having the same area as the watershed and maximum length of the basin (Schumn, 1956).

Smaller form factor shows more elongation of the basin. The watershed with higher form factor will have higher peak flow for shorter duration. Whereas elongated watershed with low form factor, will have a flatter peak of flow for longer duration.

$$R_e = \frac{2\sqrt{\frac{A}{\Pi}}}{L}$$

Where R_e is the Elongation ratio, *L* is the total length of watershed and *A* is the total area of watershed. The value of elongation ratio ranges from 0.6 to 1, lesser the value, more is the elongation of the watershed. For the present study area elongation ratio is calculated as 0.73.

Drainage density

Drainage density is the other element of drainage analysis which provides a better quantitative expression to the dissection and analysis of land forms, although a function of climate, lithology, structures and relief history of the region, etc. can ultimately be used as an indirect indicator to explain those variables, as well as the morphogenesis of landform. Drainage density (Dd) is one of the important indications of the linear scale of landform elements in stream eroded topography. It is defined as the total stream length of all stream order to the total area of watershed. The drainage density, which is expressed as km/Sq.km, indicates a quantitative measure of the average length of stream channel area of the watershed. Drainage density varies inversely with the length of the overland flow, and therefore, provides at least some indication of the drainage efficiency of the basin. Drainage density is mathematically expressed as:

$$D_d = \frac{\sum_{i=1}^{N} L_u}{A}$$

The measurement of drainage density provides a hydrologist or geomorphologist with a useful numerical measure of landscape dissection and runoff potential. On a highly permeable landscape, with small potential for runoff, drainage densities are sometimes less than 1 kilometer per square kilometer. On highly dissected surfaces densities of over 500 kilometers per square kilometer are often reported. Closer investigations of the processes responsible for drainage density variation have discovered that a number of factors collectively influence stream density. These factors include climate, topography, soil infiltration capacity, vegetation, and geology. The low value of drainage density influences greater infiltration and hence the wells in this region will have good water potential leading to higher specific capacity of wells. In the areas of higher drainage density the infiltration is less and surface runoff is more. The drainage density can also indirectly indicated groundwater potential of an area, due to its surface runoff and permeability. The value obtained (drainage density) was 1.697 Km/Sq.km for the present study. From this, it was inferred that the area is very coarser watershed. The drainage density obtained for the study area is low indicating that the area has highly resistant or highly permeable sub-soil material.

4.2.5 Constant of channel maintenance

The inverse of drainage density is the constant of channel maintenance (C). It indicates the number of Sq.km of watershed required to sustain one linear Km of channel.

$$C = \frac{1}{D_d}$$

It not only depends on rock type permeability, climatic regime, vegetation, relief but also as the duration of erosion and climatic history. The constant of channel maintenance is extremely low in areas of close dissection. Channel maintenance constant of the watershed is 0.35Kms2/Km

4.2.6 Stream frequency

Stream frequency may be expressed by relating the number of stream segments to the area drained. In other words, Stream frequency is the total number of stream segments in a watershed divided by the area of the watershed. Horton, 1932) introduced stream frequency or channel frequency as number of stream segments per unit area. For the present study, the stream frequency is 1.67.

$$S_f = \frac{\sum_{i=1}^{N} N_u}{A}$$

Where $\sum_{i=1}^{N} N_u$ = Total no. of stream segments

A = Total area of watershed (Sq. km).

Table 2 : Different Morphometric Parameters of Semi Urban Watershed, trans Yamuna.

Watershed Parameters	**Units**	**Values**
Watershed Area	Sq.km	289.41
Highest Stream Order	No.	8
Mean Bifurcation Ratio	Dimension less	4.00
Length of overland flow	Km	0.17
Form factor		0.42
Circularity Ratio		0.44
Elongation Ratio		0.73
Drainage density	Km/Sq.Km	2.79
Constant of channel maintenance		0.35

V. CONCLUSION

The study reveals that remotely sensed data i.e. CartoSAT-1 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 morphometric and properties of landforms, soils and eroded lands. Different landforms were identified in the watershed based on CartoSAT-1 DEM data with 30m 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. 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 Semi Urban Watershed, Trans Yamuna is less elongated to oval. Hence, from the study it can be concluded that CartoSAT-1 (DEM) data, coupled with GIS techniques, prove to be a competent tool in morphometric analysis.

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