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International
Journal
Of Modern Engineering Research (IJMER)

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

Om Shankar Srivastava[1], D. M. Denis[2], Santosh Kumar Sirvastava[3]

[1-] *M.Tech.Student,Vaugh School of Agricultural Engineering & Technology, SHIATS, Allahabad*

[2-] *Professor & Head, Department of Soil Water Land Engineering & Management, SHIATS, Allahabad*

[3-] *Associate Professor, Department of Soil Water Land Engineering & Management, SHIATS, Allahabad*

Abstract: *In the present paper, an attempt has been made to study the Morphometric characteristic of a Semi Urban watershed, trans Yamuna at Allahabad, Uttar Pradesh, India. For detail study Survey of India toposheets at 1:50,000 scale and CartoSAT-1 DEM data with 30m spatial resolutions has been used. Watershed boundary, flow accumulation, stream number, stream ordering, stream length have been prepared using ArcGIS 9.3, Hydrotool. It has been found that the total length of all stream segments under stream order I to VIII is 266.38,88.15,39.17,17.17,10.62,4.0,4.7,0.2 Km respectively. The total length of Streams for the entire watershed has thus been found to be 430.39 Kms representing a dense drainage network. More than ten morphometric parameters of all aspects have been analysis. This study is very useful for planning rain water harvesting and watershed management.*

Key words: *Morphometric Analysis, Cartosat DEM, Remote Sensing and GIS*

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). Watershed has emerged as the basic planning unit of all hydrologic analyses and designs. Watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. 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). Watersheds can be delineated by several methods. One used extensively is hand delineation based on the contour information depicted on topographic maps. Even with the advent of GIS technology, this method is often still used prior to creating a digital watershed dataset. While this manual method can result in accurate delineations, it is a time-consuming and expensive task. The availability of digital topographic maps has made heads-up digitizing methods possible, but this method can also be slow and costly. Because the watershed delineation process is often a subjective one that depends not only on the hydrologic characteristics of a given location, but also on the requirements of the delineator, a fully automated system is not practical for many purposes. Effective management of water resources requires detailed information at micro level necessitating delineation of watersheds into sub watersheds and mini watersheds. The watersheds features should be stored and formatted in such a way that it can easily be made available for any water resources study such as watershed planning and management, estimating upland erosion and evaluating the impacts of mans activities on the quality and quantity of the streams. Geographical information systems (GIS) with its ability to gather spatial data from different sources into an integrated environment emerged as a significant tool for delineation of watersheds. Particularly, GIS provided a consistent method for watershed delineation using digital elevation models (DEM's) and based on the contour information depicted on toposheets. The Geographic Information System (GIS) has unique features to relate to the point, linear and area features in terms of the topology as well as connectivity (Murali Krishna, 2006). The morphometric analysis involves measurement of linear aspects of the watershed and slope contribution (Nag and Chakraborty, 2003). The morphometric characteristics of a watershed represent its attributes and can be helpful in synthesizing its hydrological behavior (Pandey etal., 2004). The watershed morphometric characteristics have been studied by many scientists using conventional (Horton, 1945, Smith, 1950, Strahler, 1957) and remote sensing & GIS methods (Biswas et al.,1999, Vittala *et al.*, 2004; Narendra and Nageswara Rao, 2006; Rudraiah *et al.*, 2008). 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 the manipulation and analysis of spatial information. In

the present study stream number, order, length, Rho coefficient and bifurcation ratio are derived and tabulated on the basis of Linear properties of drainage channels using GIS based on drainage lines as represented over the topographical maps (scale 1:50,000). Remote Sensing (Lillisand, Thomas, 2002) and Geographical Information System (GIS) will be used as tool for managing and analyzing the spatially distributed informations. Arc GIS 9.3 Software are powerful software to analyze, visualize, update the geographical information, and create quality presentations that brings the power of interactive mapping and analysis.

II. 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.

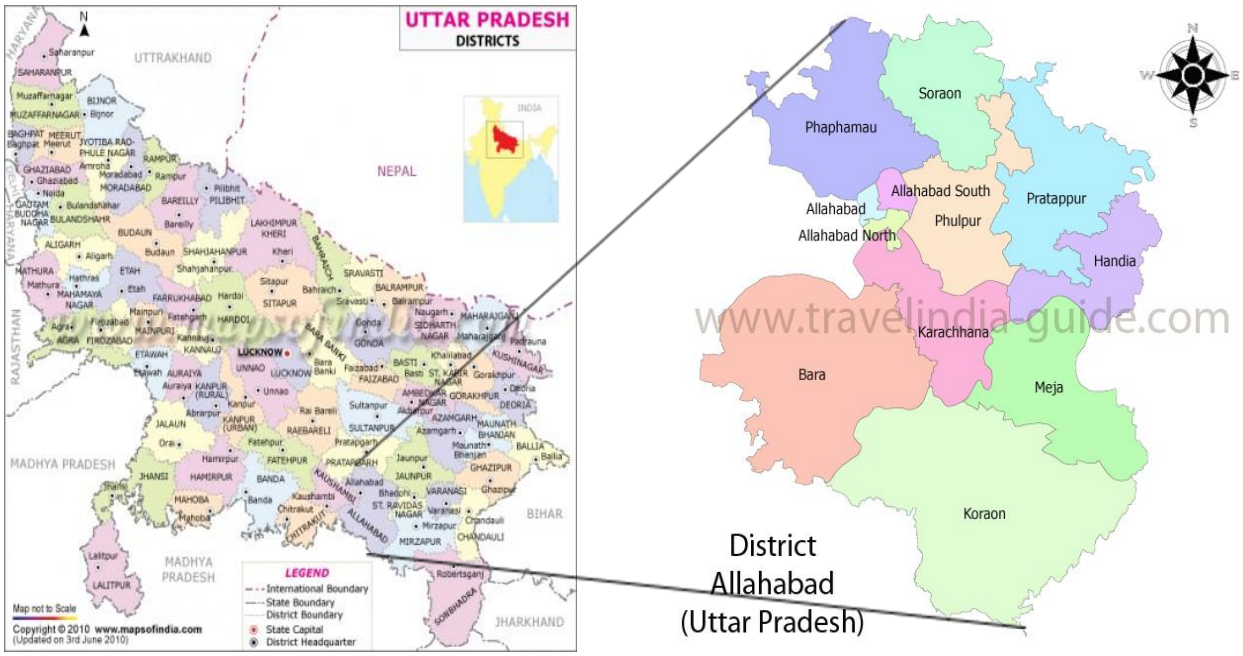

Fig:1 Location map of the study area

The land of Allahabad district that falls between the Ganga and Yamuna is just like the rest of Doab dominant with alluvial (Entisols), fertile but not too moist. The non-doabi parts of the district, the southern part and eastern part of the district are somewhat similar to those of adjoining Bundelkhand dry and rocky. Allahabad experiences all four seasons. The summer seasons are from April to June with the maximum temperatures ranging between 40^0C to 45^0C. Monsoon begins in early July and lasts till September. The winter seasons falls in the month of December, January and February. Temperatures in the cold weather could drop to freezing with maximum at almost 12^0C to 14^0C. The lowest temperature recorded, -2^0C and highest 48^0C. Rainfall and humidity are varies.

III. Materials And Methods

CartoSAT-1 DEM (30m) has been used in this study to extract watershed boundary, drainage network and analysis of morphometric parameters.

Extraction of drainage network from CartoSAT-1 DEM (30m)

The extraction of the drainage network of the study area carried out from CartoSAT-1 stereopair satellite imagery (26 September, 2011) based DEM, in raster format with a 30m*30m grid cell size, which was downloaded from Bhuwan site (www.nrsc.gov.in). Hydrology tool under Spatial Analyst Tools in ArcGIS-9.3 software was used to extract drainage channels, and other parameters. The automated method for delineating streams followed a series of steps i.e. DEM, fill, flow accumulation, watershed, and stream order.

Morphometric analysis has been done based on Cartosat(DEM) & different morphometric parameters have been generated in GIS environment.

The present study area of Semi Urban watershed, trans Yamuna boundary has been delineated using Cartosat (DEM). 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 (1953) system, and ArcHydro tool in ArcGIS-9.3 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). 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- 9.3 software.

Table 1:-Morphometric Analysis of Semi Urban Watershed, trans Yamuna-Comparative Characteristics

S.No.	Morphometric Parameter	Formula	Reference
A	Drainage Network		
1	Stream Order (Su)	Hierarchical Rank	Strahler(1952)
2	1st Order Stream (Suf)	Suf=N1	Strahler(1952)
3	Stream Number (Nu)	Nu=N1+N2+….Nn	Horton(1945)
4	Stream Length (Lu) Kms	Lu=L1+L2…….Ln	Strahler(1964)
5	Stream Length Ratio(Lur)	Lur=Su of II/Su of I	Strahler(1964)
6	Mean Stream Length Ratio (Lurm)	Lurm=Mean of Lur	Horton(1945)
7	Weighted Mean Stream Length Ratio(Luwm)	Luwm=Total of Lur*Lur-r/Total of Lur-r	Horton(1945)
8	Bifurcation Ratio(Rb)	Rb=Su of I/Su of II	Strahler(1964)
9	Mean Bifurcation Ratio	Mean of Rb	Strahler(1964)
10	Weighted Mean Bifurcation Ratio (Rbwm)	Total of Rb*(Nu-r)/Total of(Nu-r)	Strahler(1953)
11	Rho Coefficient (ρ)	ρ=Lur/Rb	Horton (1945)

IV. Results And Discussion

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 stream has maximum frequency followed by second order, third order, fourth order, fifth order, sixth order, seventh order, and eight order respectively which has been shown in table 2. it has also noticed that there is a decrease in stream frequency as the stream order increases.

Stream Number (Nu)

When two channel of different order join then the higher order is maintained. Stream number has been find out using ArcGIS9.3. Total 8842 streams were identified of which 5560 was found to be first order, 1730 second order, 802 third order,353 fourth order,215 fifth order,84 sixth order,92 seventh order and 6 eight order which is shown in table 2. The higher amount of stream order indicates lesser permeability and infiltration in this sub-watershed. (Strahler, 1964). Drainage patterns of stream network analysis have been observed as mainly of dendritic type which indicates that the homogeneity in texture and lack of structural control. The properties of the stream networks are very important to the study of Semi Urban watershed, trans Yamuna.

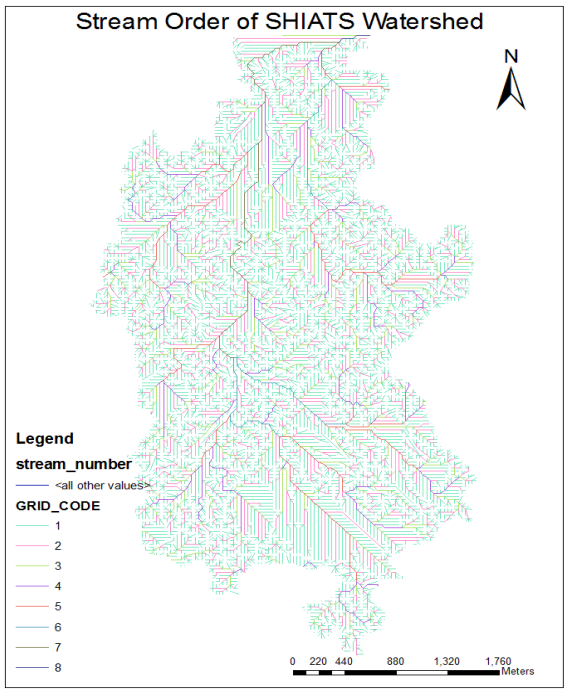

Fig.2 Stream ordering watershed

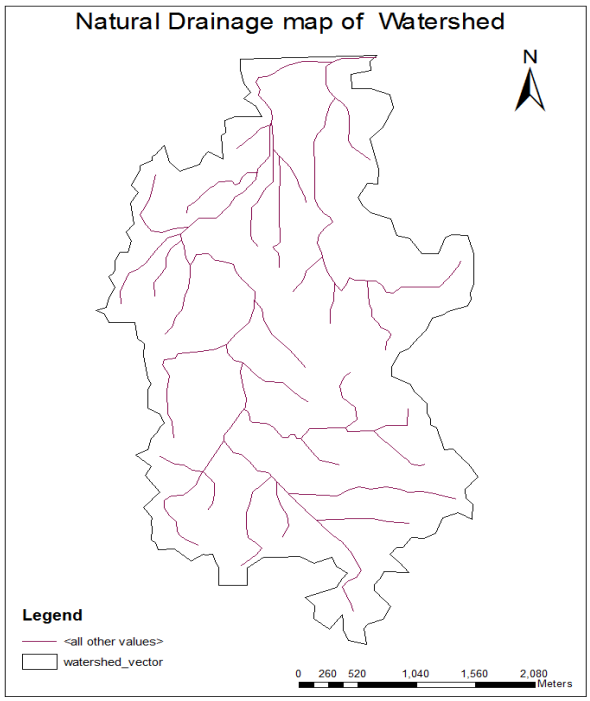

Fig3. Natural drainage map of watershed

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), which is shown in table3.1. The bifurcation ratio is dimensionless property. It has been found that range of bifurcation ratio vary from 0.9 to 15.0. 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. The lower values of Rb are characteristics of the watersheds, which have suffered less structural disturbances and the drainage pattern has not been distorted because of the structural disturbances. The highest Rb (15.33) is found between 7th and 8th order in Semi Urban watershed, trans Yamuna which indicates corresponding highest overland flow and discharge due to hilly metamorphic formation associated with high slope configuration. Also the higher values of Rb indicate strong structural control in the drainage pattern whereas the lower value indicates that the Semi Urban watershed, trans Yamuna is less affected by structural disturbances. The lowest Rb is found between 6th and 8th orders in Semi Urban watershed, trans Yamuna which indicates corresponding lower overland flow and discharge moderate slope configuration. The bifurcation ratio of different stream number and mean bifurcation ratio has been shown in table 2.

Table 2. Stream Order, Stream Number, and Biffurcation Ratio's in Semi Urban Watershed, trans Yamuna

Su	Nu	Rb	Nu-r	Rb*(Nu-r)	Rbwm
I	5560				2.89
II	1730	3.21	7290	23400.90	
III	802	2.15	2532	5443.80	
IV	353	2.27	1155	2621.85	
V	215	1.64	568	931.52	
VI	84	2.55	299	762.45	
VII	92	0.91	176	160.16	
VIII	6	15.33	98	1502.34	
Total	8842	28.06	12038	34823.02	
Mean	1105.25	4.00*			

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 ratio

Weighted Mean Bifurcation Ratio (Rbwm)

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. It has been observed that the mean bifurcation ratio is 4.00 of the Semi Urban watershed, trans Yamuna watershed Allahabad. The values of the weighted mean bifurcation ratio has been found to be very close to the mean value of bifurcation ratio in Semi Urban watershed, trans Yamuna. This is shown in table 2.

Stream Length (Lu)

The total length of the 1st order streams is highest, that is, 266.38 km, and that of 2nd order is 88.15 km, 3rd order is 39.17 km, 4th order is 17.17 km, 5th order is 10.62 km, 6th order is 4.0 km, 7^{th} order is 4.7 and the lowest is of 8th order of 0.2 km, respectively. Generally, the higher the order, the longer the length of stream is noticed in the nature. Longer length of stream is advantageous over the shorter length, in that the former collects water from wider area and greater option for construction of a bund along the length. Lower stream lengths are likely to have lower runoff (Chitra et al., 2011).Longer lengths of streams are generally indicative of flatter gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as stream order increases.

Ratio of stream length and stream order

Ratio of stream length and stream order for different stream order has been calculated for Semi Urban watershed, trans Yamuna. Highest value for Lu/Su has been found in the 7^{th} stream order whereas lowest Lu/Su has been found in the 8^{th} stream order.

Table 3: Stream Length and Stream Length Ratio in Semi Urban Watershed, trans Yamuna.

Su	Lu	Lu/Su	Lur	Lur-r	Lur*(Lur-r)	Luwm
I	266.38	0.047				1.02
II	88.15	0.050	1.06	354.53	375.80	
III	39.17	0.048	0.96	127.32	122.22	
IV	17.17	0.048	1.00	56.34	56.34	
V	10.62	0.049	1.02	27.79	28.34	
VI	4.0	0.047	0.95	14.62	13.88	
VII	4.7	0.051	1.08	8.7	9.39	
VIII	0.2	0.033	0.64	4.9	3.13	
Total	430.39	0.373	6.71	594.20	609.10	
Mean			0.95*			

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 Length ratio Stream.

Stream Length Ratio (Lur)

Stream Length Ratio is defined as the ratio of the mean (Lu) of segments of order (So) to mean length of segments of the next lower order (Lu-1). This tends to be constant throughout the successive order of Semi Urban watershed, trans Yamuna. After the calculation of stream length ratio it has been absorbed that stream length ration has been changed from one order to another which is shown in table 3. Change of stream length ratio from one order to another order indicating there late youth stage of geomorphic development (Singh and Singh 1997). The variation in stream length ratio might be due to change in slope and topography.

Stream Length used in the ratio (Lur-r)

Stream Length used in the ratio (Lur-r) is defined as the Sum of first order Stream Length and second order Stream Length. Lur-r value is calculated for all stream length which is shown in table 3.

Weighted Mean Stream Length ratio (Luwm)

Weighted Mean Stream Length ratio obtained by summation of Stream Length Ratio multiplied by Stream Length used in the ratio divided by Stream Length used in the ratio. It has been observed that the mean Stream length ratio is 0.95 of the Semi Urban watershed, trans Yamuna Allahabad which is shown in table 3

Rho Coefficient

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 Tundah watershed is 0.85 (Table 3). This is suggesting higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

Mean area calculation of Semi Urban watershed, Trans Yamuna

Stream order wise mean area and its ratio for Semi Urban watershed, trans Yamuna has been calculates and shown in the Table 4. Stream order wise mean area has been calculated by total number of stream divided by number of streams present in that particular stream order. Area ratio is calculated by stream order wise mean area divided by prior stream order wise mean area. All the calculated value has been shown in table 4.

Table 4: Stream Order, Stream Order wise Mean Area in Semi Urban Watershed, trans Yamuna

Su	Nu	Am	Ar
I	5560	0.15	
II	1730	0.50	3.33
III	802	1.10	2.20
IV	353	2.50	2.27
V	215	4.11	1.64
VI	84	10.52	2.55
VII	92	9.61	0.91
VIII	6	147.36	15.33
Total	8842	175.85	
Mean			

Su: Stream Order, Nu: Number of Streams
Am: Stream Orderwise mean area
Ar: Area ratio, Arm: Mean area ratio and Arwm: Weighted mean area ratio

V. Conclusion

This study addressed analysis of DEM to delineate Semi Urban watershed, trans Yamuna its morphometric analysis. Toposheets, Google earth data, and Semi Urban watershed, trans Yamuna boundary has been used in this study. The major findings are to evaluation morphometric parameters of watershed and their influence on landforms using Cartosat DEM and GIS based approach.

The analysis has revealed that the total number and 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 varies revealing the geostructural control. From this study it has been concluded that the higher values of Rb in Semi Urban watershed, trans Yamuna watershed shows strong structural control, while the lower values indicate that watershed are not affected by structural disturbances. The lower values of Rb are characteristics of the watersheds, which have suffered less structural disturbances and the drainage pattern has not been distorted because of the structural disturbances.

The study reveals that morphometric analysis based on GIS technique is a competent tool for geo-hydrological studies. These studies are very useful for identifying and planning the ground water potential zones and watershed management.

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