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MORPHOMETRIC ANALYSIS OF ADYAR WATERSHED

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ABSTRACT: *Remote Sensing and Geographical Information System (GIS) has become an efficient tool in delineation of drainage pattern and water resources management and its planning. Adyar watershed in the Chennai basin with an area of 686.13 Km^2 was taken up for the study. In the present study, with the aid of GIS several morphometric parameters were determined to understand the nature, landscape development and hydrologic responses of Adyar watershed. The Shuttle Radar Topographic Mission (SRTM) data is used for the morphometric analysis of the watershed to derive linear, relief, and aerial aspects. Strahler's stream ordering techniques and analysis were followed for further analysis. This study would be of assistance to utilize the resources for sustainable development of the watershed.*

Keywords: *Adyar watershed , Morphometry, SRTM., Terrain processing,*

I. INTRODUCTION

Most of the study in hydrology field takes a watershed as a basic unit for better understanding. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms. Morphometric analysis brings out the basic characters on the geometrical and mechanical aspects of the river basin which in turn would be helpful in understanding the hydrology, sediment and evolution of landscapes in the basins. 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 [13]. The morphometric analysis examines linear, geometric, relief and areal aspects of the drainage networks. Morphometric analysis requires measurement of the linear features, gradient of streams, and slopes of the drainage basin.

II. STUDY AREA & METHODOLOGY

The river Adyar originates from Adanur Tank near Guduvancherry, further a surplus arm from the Chembarambakkam Lake in Chengalpattu district joins the river and this forms into a river which finally drains into the Bay of Bengal. The river collects surplus water from about 200 tanks and lakes, with a combined catchment area of 686.13 Km^2. Extraction of stream network and assigning stream order from topographic map for a large area is a tedious task. In this study, morphometric parameter of the Adyar basin is extracted from the SRTM Digital Elevation Model (DEM) with a spatial resolution of 90 m. The pour point of the basin and the systematic geoprocessing techniques required for the extraction of the basin are shown in Fig.. 1. The contributing area above a set of cells in a flow direction raster will be the basin boundary.

III. RESULTS AND DISCUSSION

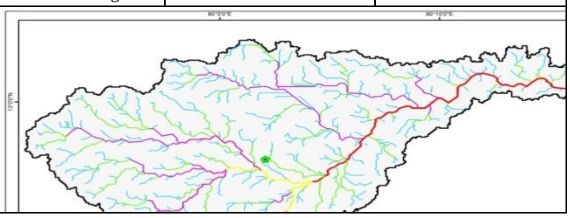
1.1. Stream Order (U):

The primary step in the drainage basin analysis is to determine the stream orders, which expresses the hierarchical relationship between stream segments, their connectivity and the discharge arising from contributing catchments. The stream order (U) is a dimensionless number, which can be used for comparison of geometry for drainage networks on different linear scales. Strahler [15] system has been followed because of its simplicity in the present study. Adyar stream is of 6.

1.2. Stream Number (N_u):

The properties of the stream networks are very important to study the landform making process [15]. The order wise total number of stream segment is known as the stream number. The statistics of the stream order in the Adyar basin is shown in Table 3. Mean stream number of Adyar sub basin is 82.5. Total log value is 6.803. The stream order and the total number of stream segments in each order for the basin are shown in the Table 2. The inverse geometric relationship is shown graphically in the form of a straight line with small deviation from a straight-line (Fig.3). The total length of individual stream segments of each order is the stream length of that order. Streams of relatively smaller lengths are characteristics of areas with larger slopes, longer lengths of streams are indicative of flatter gradients and where the rock formations are less permeable [8]

Table 1- List of various morphometric parameters derived

Parameter	Formula	Reference	Parameter	Formula	Reference
Linear Aspects of the Channel System			**Relief Aspects of Channel System**		
Stream Order (U)	Hierarchical rank	Strahler (1964)	Basin Relief (R)	R = H – h	Hadley and Schumm (1961)
Stream Number (N_u)	$N_u = N_1+N_2+\ldots N_n$	Horton (1945)	Relief Ratio (R_h)	$R_h = \left(\frac{H}{L_b}\right)$	Schumm (1963)
Stream Length (L_u)	Length of the stream	Horton (1945)	Relative Relief (R_{hp})	$R_{hp} = \left(\frac{H*100}{P}\right)$	Melton (1957)
Mean stream length(L_{sm})	$L_{sm} = \left(\frac{L_u}{N_u}\right)$	Strahler (1964)	Ruggedness number (N)	$N = D_d * \left(\frac{H}{1000}\right)$	Strahler (1957)
Stream Length Ratio (R_l)	$R_L = \left(\frac{L_u}{L_{u-1}}\right)$	Horton (1945)	Gradient ratio(G_r)	$G_r = \left(\frac{H-h}{L_b}\right)$	Sreedevi et al (2004)
Bifurcation ratio (R_b)	$R_b = \left(\frac{N_u}{N_{u+1}}\right)$	Schumn (1956)	**Aerial Aspects of Channel System**		
Basin shape/Shape factor ratio (B_s)	$B_s = \left(\frac{L_b^2}{A}\right)$	Horton (1945)	Stream Frequency (F_s)	$F_s = \left(\frac{N_u}{A}\right)$	Horton (1945)
RHO coefficient	$RHO = \left(\frac{R_L}{R_b}\right)$	Horton (1945)	Drainage Density (D_d)	$D_d = \left(\frac{L_u}{A}\right)$	Horton (1945)
Geometric Aspects of Channel System			Channel Maintenance (C)	$C = \left(\frac{1}{D_d}\right)$	Schumm (1956)
Length of the sub basin (L_b)	Maximum length of the basin $L_b=1.312*A^{0.568}$	Kanth et al (2012)	Infiltration Number (I_f)	$I_f = F_s * D_d$	Faniran (1968)
Length area relation (L_{ar})	$L_{ar} = 1.4*A^{0.6}$	Hack (1957)	Length of Overland Flow (L_g)	$L_g = \left(\frac{1}{2D_d}\right)$	Horton, 1945
Lemniscate (k)	$k = \left(\frac{L_b^2}{A}\right)$	Chorley (1957)			
Form factor ratio (R_f)	$R_f = \left(\frac{A}{L_b^2}\right)$	Horton (1945)			

Elongation ratio (R_e)	$R_e = \left(2\sqrt{\frac{A}{\pi}} \Big/ L_b \right)$	Schumm (1956)	*Figure 2. Drainage order map of the study area*

3.3. Stream Length (L_u):

In Adyar sub basin, 1st order streams have the maximum length of 383.14 km compared to that of other orders. The stream length of various orders is presented in the Table.3.

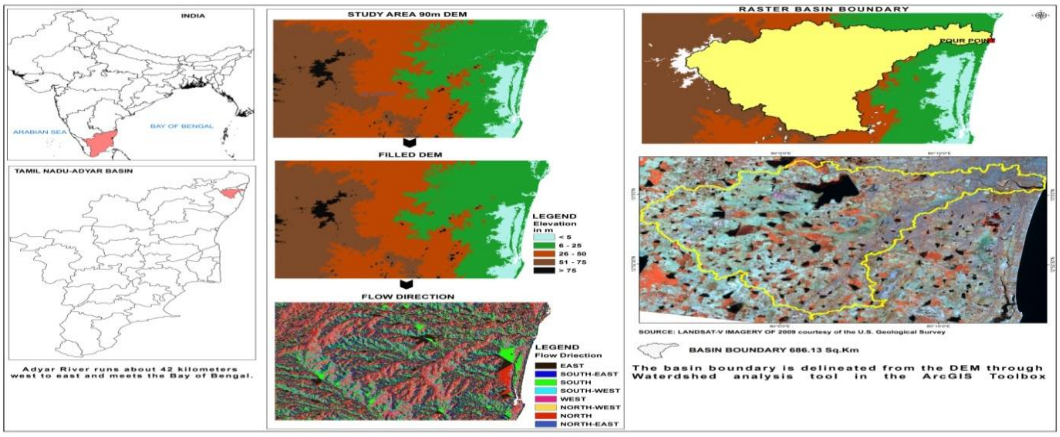


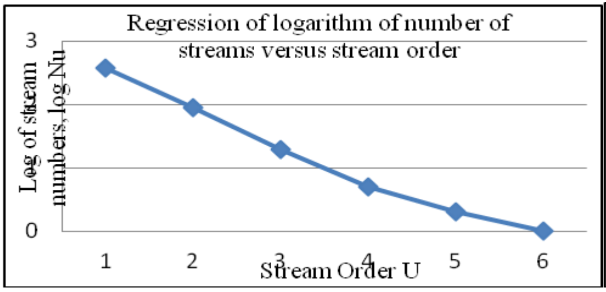
Figure 1. Study Area

3.4. Mean stream length (L_{sm}):

It is seen that, L_{sm} values for Adyar basin exhibit a variation from 1.01 to 31.86 for L1to L6 (TABLE 3). It is observed that, Mean length of channel segments of a given order is greater than that of the next lower order but less than that of the next higher order.

Table 2. Stream Number

	Number	% of Total	Logarithm
Number of 1st order streams (N_1)	380	76.77	2.579783597
Number of 2nd order streams (N_2)	88	17.78	1.944482672
Number of 3rd order streams (N_3)	19	3.84	1.278753601
Number of 4th order streams (N_4)	5	1.01	0.698970004
Number of 5th order streams (N_5)	2	0.4	0.301029996
Number of 6th order streams (N_6)	1	0.2	0
Total	**495**	**100**	**6.80301987**



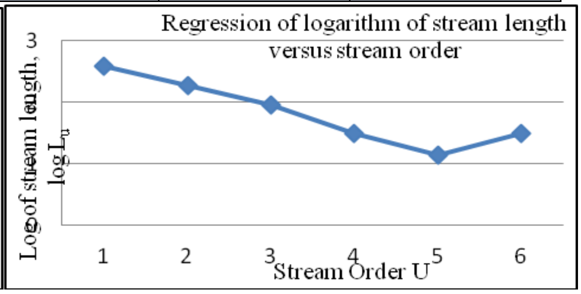


***Figure* 3. Plot of stream number vs. stream order Figure.4 Plot of stream length vs. stream order**

Generally higher the order, larger mean stream length is noticed in nature. The mean length of a channel is a dimensional property and reveals the characteristic size of drainage network components and its contributing basin surface [15]. Table.3 indicates that the total L_{sm} value of the basin is 53.05. The change in the mean stream length ratio is an indicator of the changes in the slope and topography, which in turn determine the age of the basin [10].

3.3. Stream Length Ratio (R_L):

Stream length ratio (R_L) is the ratio between mean stream length of a given order and its next lower order. In this study, R_L ranges from 1.11 to 4.58.Table.4 reveals that there is a variation of R_L in basin. The variation might be due to change in slope and topography.

Table 3. Stream Length

	Length	Mean stream	Cumulative mean	% of	Logarithm
Length of 1st order streams	383.14	1.01	1.01	51.62	2.5833545
Length of 2nd order streams	191.34	2.17	3.18	25.78	2.2818105
Length of 3rd order streams	90.66	4.77	7.95	12.21	1.9573956
Length of 4th order streams	31.38	6.28	14.23	4.23	1.4966214
Length of 5th order streams	13.91	6.96	21.19	1.87	1.1433975
Length of 6th order streams	31.86	31.86	53.05	4.29	1.5033005
Total	**742.29**	**53.05**	**100.61**	**100.00**	**10.965880**

The stream length ratio (R_L) shows an important relationship with discharge of the surface flow, erosional and depositional stages of the basin. More specifically, variation indicates if there is a major change in the hydrological characteristics of the underlying rock-surface over the areas of consecutive stream orders [8]. The R_L between streams of different orders in the Adyar water shed indicates its late youth stage of geomorphic development [12]

Table.4 Stream length ratio and Bifurcation ratio of the study area

Stream Length Ratio (R_L)	
2nd order/1st order	2.16
3rd order/2nd order	2.19
4th order/3rd order	1.32
5th order/4th order	1.11
6th order/5th order	4.58
Mean Stream length ratio(R_L) = 2.27	

Bifurcation Ratio (R_b)	
1st order/2nd order	4.32
2nd order/3rd order	4.63
3rd order/4th order	3.80
4th order/5th order	2.50
5th order/6th order	2.00
Mean Bifurcation Ratio(R_{bm})= 3.45	

3.4. Bifurcation ratio (R_b):

The bifurcation ratio (R_b) is dimensional parameter which is the ratio between stream numbers of an order and its next higher order [11]. The R_b is important parameter that articulates the degree of ramification of the drainage network and an indicator of the complexity and degree of dissection of a drainage basin. Here the R_b ranges between 2.0 to 4.63. Generally, bifurcation ratios range between 2.0 to 5.0 for sub basins in which the geologic structure does not exercise a dominant influence on the drainage pattern and indicates that the basin is falling under normal basin category [15]. It is seen that relatively high R_b of lower order streams in the Adyar basin indicates the presence of high and young relief. The mean bifurcation ratio (R_{bm}) is 3.45 for the study area (TABLE 4.), which indicates that geological structure are less disturbing the drainage pattern.

3.5. Basin shape/Shape factor ratio:

Basin Shape is the ratio of the square of basin length (L_b) to the area of basin (A). Adyar Catchment has a Shape Factor of 4.18. This indicates that the basin is neither too elongated nor too circular. Hence the basin has moderate time of concentration of flood waters.

3.6. RHO coefficient:

RHO coefficient is the ratio between the stream length ratio (R_L) and the bifurcation ratio (R_b). The computed value of RHO coefficient for the study area is 0.658. It is an important parameter that determines the relationship between the drainage density and the physiographic development of the basin, and allows the evaluation of the storage capacity of the drainage network [4]. It is influenced by climatic, geologic, biologic, geomorphologic and anthropogenic factors.

3.7. Area (A) and Perimeter (P) of the basin:

The area of the Adyar basin determined by the series of terrain processing procedures in SRTM DEM of 90m resolution is 686.13 sq.km. If the basin size is small, it is likely that rainwater will reach the main channel more rapidly than in a larger basin. Lag time will be shorter in the smaller basin, which is a key parameter for flood modeling purpose. Basin perimeter is the outer boundary of watershed. The perimeter of the Adyar basin are 229.42 Km.

3.10**. Length of the sub basin (L_b):**

Horton [3] defined basin length as the straight-line distance from a basin mouth to the point on the water divide intersected by the projection of the direction of the line through the source of the main stream, parallel to the principal drainage line. The length of the Adyar basin is arrived as 53.58km.

3.11. Length area relation (L_{ar}):

Hack [2] found that for a large number of basins, the stream length and basin area are related as L_{ar} = 1.4*A^0.6. The length area relation of the Adyar basin is 70.47.

3.12. Lemniscate (k):

Lemniscate value is used to determine the slope of the basin. A formula is proposed by Chorely [1], which gives the relation that 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 basin is 0.626.

3.13. Form factor ratio (R_f):

Form factor ratio (R_f) predicts the flow intensity of a basin of a defined area. The R_f of a drainage basin is expressed as the ratio between the area of the basin (A) and the square of the basin length (L^2). For a perfectly circular basin the form factor would always be less than 0.754. Form factors are large for short-wide basins. The lower R_f value of 0.238 for the study area suggests that it is an elongated basin. The index of R_f shows the inverse relationship with the square of the axial length and has a direct relationship with peak discharge. Flood flows of elongated basins are easier to manage than those of the circular basins.

3.14. Elongation ratio (R_e):

Elongation ratio (R_e) is the ratio between the diameter of a circle of the same area as the basin (D) and basin length (L) [11]. For most of the basins the R_e values vary from 0.6 to 1.0. Values close to 1.0 have very low relief with circular shape and the value ranges from 0.6 to 0.8 have high relief. The elongation ratio of the study area is found to be 0.55 which shows that the basin is elongated but with moderate to low relief.

3.15. Basin Relief (H):

Basin relief is the difference in elevation between the highest and the lowest point of the basin. The Basin Relief is 157 m.

3.16. Relief Ratio (R_h):

Overall steepness of the drainage basin was measured using relief ratio (R_h). Rh is the dimensionless height–length ratio between the basin relief (R) and the basin length (L). It is also an indicator of intensity of erosion processes and sediment delivery rate of the basin [15][11]. The Rh is normally in increase with decreasing the drainage area and size of sub-basin of a given drainage basin. In relation to stream slope, the inclinations of the ground surface are closely tied with its channel gradients and relief.

3.17. Relative Relief (R_{hp}):

The maximum basin relief was obtained from the highest point on the watershed perimeter to the mouth of the stream. Using the basin relief =157 m, a relief ratio was computed as suggested by Schumm [11] by dividing it with computed length of basin, which is 0.029. Melton's [7] relative relief was also calculated using the formula: R_{hp} = (H*100) / P, where P is perimeter in meters. This comes to about 0.068 for Adyar watershed.

3.18. Ruggedness number (N):

Ruggedness index (N) is used to measure surface roughness or unevenness. N is measured by dividing the product of drainage density and relative relief by thousand. Adyar basin shows very low N of 0.17. Low N reveals less fragmentation of relief which implies highly eroded surface and gentle slope [9].

3.19. Gradient ratio:

Gradient ratio is an indication of channel slope from which the runoff [14] volume could be evaluated. The basin has a gradient ratio of 0.0029.

3.20. Stream Frequency (F_s):

Stream frequency or channel frequency (F_s) is defined as number of stream segments of all orders per unit drainage area [3]. A higher F reflects greater surface run-off and a steeper ground surface. According to Kale [6] flooding is more likely in basins with a high drainage and stream frequency. Reddy [9] stated that low values of stream frequency F_s indicate presence of a permeable subsurface material and low relief. The factors which influence F are rainfall amount, erodibility, permeability, structure of rock, basin shape, tectonic influences etc. The stream frequency of the basin is 0.72. This low value indicates the basin possesses low relief and the almost flat topography.

3.21. Drainage Density (D_d):

Drainage density (D_d) expresses total stream length per unit drainage area. It depends on climate (mainly rainfall), geology, vegetation cover, erosivity, infiltration capacity and permeability of underlying rock and soil, relief and slope aspect of the basin [3] [15]. With the progress of youth stage towards maturity, D_d increases rapidly; while towards old stage it decreases. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. In the study area, D_d is 1.08 Km/Km2 which are considered as low value.

3.22. Drainage Pattern (D_p):

Drainage pattern is a factor of slope lithology and structure and also it helps in identifying the stage of cycle of erosion. Howard [5] related drainage patterns to geological information. 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 pattern of the basin has been observed as mainly dendritic.

3.23. Constant of Channel Maintenance (C):

Constant of channel maintenance (C) is denoted as inverse of drainage density. It is expressed in Km2/Km. It depends on the lithology, permeability and infiltration capacity of surface material, climatic condition and vegetation [11]; hence it is a measure of basin erodibility. Low value of C indicates high density of drainage network and less area required to sustain 1 km of drainage and vice versa. In the study basin C is 0.92 which denotes 0.92 km2 of basin area is required to sustain 1 km of the channel.

3.24. Infiltration Number (I_f):

Infiltration number is determined by multiplying the value of drainage density (D_d) and stream frequency (F_s). It is expressed by formula If=D_d*F_s where, D is the Drainage density and F_s is the stream frequency. The Infiltration number of the Adyar water shed is 0.785. Higher the value of infiltration number indicates lower the infiltration capacity and higher run off [15].

3.25. Length of Overland Flow (L_g):

Length of the overland flow (L_g) is the length of sheet flow of water over the ground before it gets concentrated in to definite stream channels [4]. This factor relates inversely to the average slope of the channel. The length of overland flow (L_g) approximately equals to half of the reciprocal of drainage density. Lengths of overland flow thus calculated for basin is 0.46. Generally higher value of L_g is indicative of low relief and whereas low value of L_g is an indicative of high relief.

IV. CONCLUSION

The present study has demonstrated that GIS is a valuable tool for analysis of various morphometric parameters. The morphometric parameters evolved here will be of immense utility in river basin evaluation, flood management, watershed prioritization for soil and water conservation, and natural resources management at micro level. The geoprocessing techniques employed in this study will assist the administrator in planning and decision making in basin development and management studies.

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