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A Comparative study on GIS based Morphometric and Hypsometric analysis

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Abstract : Watershed is a region bounded peripherally by a divide and draining to a particular water body. Each watershed varies in shape, size and its characteristics. Morphometric analysis is helpful in understanding and comparing the features within watershed. Two watersheds are considered for the present study. First watershed is a part of Arkavathi river of Cauvery basin and the second watershed is the part of Ponniyar river of South Pennar basin. Both watersheds having a common divide. SRTM DEM is used and Arc GIS is a tool for the study. The 1st and 2nd watersheds are having areas 857.9 km^2 and 1718.49km^2 and perimeters 142.39 km and 224.47 km respectively. The highest stream order is 7 for both watersheds and the drainages form dendritic pattern. Linear, areal and relief aspects of the watersheds are found out. Both the watersheds are having coarse texture based on the drainage density. The basin is more elongated and having low stream frequency. Hypsometric analysis is a useful tool to assess the erosion status of the watershed. From the hypsometric curve and hypsometric integral, it is observed that the watershed is having an equilibrium or mature stage of erosion.

Index Terms: Morphometric Analysis, Hypsometric Analysis

Key Words: Watershed, Drainage Density

I. INTRODUCTION

A watershed is the important unit of the hydrology. It is defined as a region bounded peripherally by a divide and draining to a particular water coarse or body of water. Each watershed differs in their characteristic features like size, shape, drainage pattern etc which makes it ultimately difficult for analysis and comparison. Morphometric analysis is a set of mathematical relationships between various attributes of the watershed. The term Morphometry is having Greek origin; which means measurements of earth features. Morphometric analysis is having 3 aspects which are linear aspects which mainly depends upon the length of streams, areal aspects which depends upon area and perimeter of watershed and relief aspects which depends on elevation difference between the remotest point and the discharging point of the watershed. Being dimension less parameter it makes the task of comparison of watershed much easier.

Processes such as weathering, stream erosion and sediment transportation make considerable changes to the watershed by means of land degradation and topographical changes. These processes are complex in nature, makes it extremely difficult to quantify. An area- elevation analysis called hypsometric analysis gives a solution for the same. It differentiates the erosional landforms at different stages of its evaluation. Hypsometric curve and hypsometric integral are very useful to differentiate the landform to youth, mature and old stages. Hypsometric curve is a plot which represents how much percentage land exists under various elevations.

These two methods are widely used and acceptable for the analysis and comparison of watersheds. These serve as the basis of any hydrologic related decision-making process.

Two watersheds are considered for the present study. First watershed L_Arkavathi_2 which is situated between latitude 12^{0}37'3.66'' N and 13^{0}02'26.36'' N and longitude 77^{0}20'40.50'' E and 77^{0}35'56'' E is a part of Arkavathi river of Cauvery basin and the second watershed U_Ponniyar_1 extending from latitude 12^{0}38'42.84'' N and 13^{0}12'56'' N and longitude 77^{0}32'3.30'' E and 77^{0}58'17.41'' E is the part of Ponniyar river of South Pennar basin. Both watersheds having a common divide. The area and perimeter of L_Arkavathi_2 watershed and U_Ponniyar_1 watershed is 857.9 km^2 and 142.39 km and 1718.49 km^2 and 224.47 km respectively.

II. METHODOLOGY

For the morphometric analysis, SRTM DEM is downloaded from the USGS digital elevation model platform Earth Explorer. Arc GIS tool is used for it. Small imperfections of the DEM had been eliminated using fill tool. Flow direction in the study area is created and accumulated flow also calculated using the software. The streams are selected whose flow accumulation is greater than the selected weight and stream order is found out.

There are 3 different morphometric aspects; linear aspects, areal aspects and relief aspects. The linear aspects mainly depend upon the length and number of segments of streams. The following linear aspects were considered for the study; stream order and number of stream segments, mean stream length, bifurcation ratio, stream length ratio, drainage pattern and length of overland flow. Strahler's method is adopted for the calculation of stream order. Number of segments of streams and length of each stream order is also calculated. Generally, number of segments of streams and length of streams decreases as the stream order increases. The mean stream length is the ratio between the total stream length of any order to the number of segments of steams of that order. Stream length ratio (R_L) is the ratio of mean stream length of a given order to the mean stream length of next lower order. The R_L value gives an idea about how the slope and topography are varied within a basin. Bifurcation ratio can be defined as the ratio between number of stream segments of given order to the number of stream segments of the next higher order. It shows the degree of bifurcation of streams. Drainage pattern is the planimetric arrangements of streams within a watershed. Different drainage patterns are trellised, rectangular, parallel, dendritic, deranging and radial. Length of overland flow (L_o) is defined as the flow of water over the surface before it comes concentrated in definite stream channels. If the L_o value is less, more quickly the surface runoff occurs from the stream.

The areal aspects considered in the study are watershed shape factor, form factor, elongation ratio, circularity ratio, drainage density, constant of channel maintenance, stream frequency and compactness coefficient. Form factor is calculated by dividing the basin area by the square of basin length. If the form factor is less, more elongated the basin will be. Shape factor is the reciprocal of form factor. Compactness is calculated using the expression:

$$Compactness\ coefficient = \frac{P}{2\sqrt{\pi A}}$$

where,

P = perimeter of the basin (km), A = area of the basin (km^2).

Circularity ratio can be expressed by the equation. The value commonly ranges from 0.2 to 0.5.

$$R_C = \frac{4\pi A}{P^2}$$

where,

R_c = Circularity ratio, A = watershed area (km^2), P = perimeter of watershed (km)

Elongation ratio is calculated using the formula:

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

where

R_e = Elongation ratio, A = watershed area (km^2), L = length of the watershed (km)

The value generally ranges from 0.6 to 1.0. Drainage density can be defined as the degree of closeness of spacing between channels. It is expressed in km/km^2. Based on the drainage density we can express the texture of the watershed. The inverse of drainage density is the constant of channel maintenance. It can be defined as how much area of water is required to sustain one linear 'km' of channel. Stream frequency is defined as the number of streams per 'km' of area.

Relief aspects are the indicators of flow directions of the water within the basin. Watershed relief, relief ratio, relative relief and Ruggedness number are the four major relief aspects considered for the study. Watershed relief is defined as the difference in elevation between the remotest point and the discharge point of the watershed. Relief ratio can be calculated by dividing the maximum relief by the horizontal distance along the longest dimension of the watershed parallel to the principle drainage line. Relative relief is the ratio of maximum watershed relief to the perimeter of the watershed. Ruggedness number is the product of watershed relief and drainage density where both are in same units.

Hypsometric analysis is also performed to the watersheds. It gives the clear idea about how much percentage of land is existing under various elevations. For the hypsometric analysis also clipped DEM was used. After filling the DEM, maximum and minimum elevation is noted and using GIS tool it is reclassified into different classes of equal intervals. The minimum, mean and maximum elevations are noted. The area under each elevation classes is noted from the GIS analysis. Relative elevation and relative area are also calculated and relative elevation Vs relative area graph is plotted. This plot is called as hypsometric curve. Hypsometric integral is also calculated using the expression:

$$E \approx H_{si} = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}}$$

Where E is the elevation- relief ratio equivalent to hypsometric integral H_{si}. Observing and comparing the hypsometric curve pattern and hypsometric integral value with the reference curve the geologic stage of the watershed is estimated.

III. RESULTS AND DISCUSSIONS:

The watersheds were analysed based on the above methodology and the following observations are made. Both the watersheds having dendritic drainage pattern and the maximum stream order is found to be 7. The area of the L_A_2 watershed is 857.9 km^2. Length and width are observed as 48.86 km and 29.35 km respectively. Perimeter is determined as 142.39 km. U_P_1 watershed is having an area of 1718.49 km^2. Length, width and perimeter are 64.48km, 53.09km and 224.47km respectively. Linear, Areal and relief aspects are tabulated as below:

Table 1. Linear Aspects: L_A_2 Watershed

Stream order	No. Of streams	Total length of streams (km)	Cumulative length (km)	Mean stream length (km)	Bifurcation ratio (km)	Length ratio
1	2296	877.44	877.44	0.38		
2	525	479.24	1356.67	0.91	4.37	2.39
3	113	214.52	1571.19	1.90	4.65	2.08
4	29	138.85	1710.04	4.79	3.90	2.52
5	6	52.23	1762.27	8.71	4.83	1.82
6	2	50.83	1813.10	25.41	3.00	2.92
7	1	5.22	1818.31	5.22	2.00	0.21

Drainage density	2.12	km/km^2
Length of overland flow	0.24	

Table 2. Areal Aspects

Compactness coefficient	1.37
Circularity ratio	0.53
Constant channel maintenance	0.47
Stream frequency	3.46
Form factor	0.36
Elongation ratio	0.68
Shape factor	2.78

Table3. Relief Aspects

Relief ratio	0.007879
Relative relief	0.002704
Ruggedness number	0.816008
Watershed relief	0.39

Table 4. Linear Aspects: U_P_1 Watershed

Stream order	No. Of streams	Total length of streams (km)	Cumulative length (km)	Mean stream length (km)	Bifurcation ratio (km)	Length ratio
1	5810	2314.50	2314.50	0.40		
2	1239	963.72	3278.22	0.78	4.69	1.95
3	271	460.25	3738.47	1.70	4.57	2.18
4	59	212.88	3951.35	3.61	4.59	2.12
5	12	115.39	4066.74	9.62	4.92	2.67
6	3	59.26	4126.00	19.75	4.00	2.05
7	1	56.08	4182.08	56.08	3.00	2.84

Drainage density	2.43	km/km^2
Length of overland flow	0.21	

Table 5. Areal Aspects

Compactness coefficient	1.53
Circularity ratio	0.43
Constant channel maintenance	0.41
Stream frequency	4.30
Form factor	0.41
Elongation ratio	0.73
Shape factor	2.42

Table 6. Relief Aspects

Relief ratio	0.002699
Relative relief	0.000775
Ruggedness number	0.423443
Watershed relief	0.17

The observed drainage density indicates that both the watershed texture is coarse. Stream frequency is found to be low. Circularity ratios correspond to the mature stage of the cycle of the tributary watershed of the region.

Hypsometric integral values fall under the category of equilibrium or mature stage of watershed. Hypsometric curve also shows an ‘S’ curve plot which also says that watershed is in mature stage or equilibrium stage for soil erosion.

IV. CONCLUSIONS:

Morphometric analysis is very helpful in understanding and comparing the watershed as it gives each parameter as dimensionless quantities. Remote sensing and GIS serve as a major useful platform for the morphometric analysis of the watershed. The hypsometric analysis is a useful technique to evaluate the state of watershed and its susceptibility towards soil erosion. Hence a combined study of morphometry and hypsometry is very much useful to make decisions regarding constructing hydraulic structures to manage soil erosion.

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