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BASIC MORPHOMETRIC ANALYSIS OF WATERSHED OR RIVER BASIN USING GIS: A REVIEW

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Abstract– Morphometric analysis of any watershed is a very crucial process. Use of remote sensing and GIS makes the analysis more accurate and fast. In this review paper 30 research papers were studied and methods, data, process and parameters are summarized. This study will be helpful for students of various fields who are going to work on watershed/river basin/drainage basin morphometric study.

INTRODUCTION

A watershed is defined as a land area which drains all precipitated water to a single point – a river, reservoir, stream or other water bodies (Flotemersch *et al.*, 2015). Watershed word is several times replaced with drainage basin. Singh (1994) classified watershed based on area as watershed (size: 50,000-2,00,000 ha), sub-watershed (size: 10,000 – 50,000 ha), mili-watershed (size: 1,000 – 10,000 ha), micro-watershed (size: 100 – 1,000 ha) and mini-watershed (size: 10 – 100 ha).

Morphometric analysis of a watershed is generally required to understand evolutionary history of a watershed, study hydrological behavior, figure out runoff and groundwater potential, detect and evaluate seasonal changes occurring in characteristics of a watershed and know issues related to management of soil and water erosion due to the high flow occurrence (Morisawa, 1985; Strahler, 1952; Chorley *et al.,* 1985; Chavare and Potdar, 2014; Sharma and Sarma, 2013; Mahala 2020). According to Clarke (1966), morphometry is measuring and analyzing mathematically the geography of surface of the planet earth along with its shape and details of landforms. Horton (1932) had introduced "morphometry" (Mahala, 2020). The linear, areal and relief aspects of the basin are used for morphometric analysis (Nag and Chakraborty, 2003; Manjre, 2015). Hydrological response of a watershed is always governed by its morphological characteristics to a considerable extent. Basin characteristics when measured and expressed in quantified morphometric parameters are used to study their influence on runoff generated in watershed. Understanding drainage system of a watershed is vital, for which morphometric analysis is the key (Strahler, 1964).

METHODOLOGY AND ANALYSIS

Morphometric parameters are an effective tool for the analysis of spatial information of a watershed, calculated with the help of GIS techniques.

A. **GIS environment used:** In all the research papers referenced use of ArcGIS software for analysis of raw data and ERDAS software for image processing or image improvement.
B. **Data set used:** Researches had used Survey of India (SOI) Toposheeton 1:25000 and 1:50000 scales, Advanced Space Borne Thermal Emission and Reflection (ASTER) DEM data (15 m resolution), Cartosat DEM data (30 m resolution), Shuttle Radar Topographic Mission (SRTM) DEM (30 & 90 m resolution), ASTER Global Digital Elevation Model (GDEM) of resolution 30 m × 30 m of National Aeronautics and Space Administration (NASA),

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Geologicalquadrangle map (1:250,000 scale), Satellite images of IRS-P6, IRS 1-C,IRS-ID LISS IIIand PAN digitalformat, LISS-4 sensor image, false color composite (FCC) of Landsat ETM+ data (30m resolution), LANDSAT 8 Imagery data (15 m resolution), were used as a raw data to calculate morphometric parameters.

C. **Process:** Morphometric analysis of drainage basin consists of delineation of watershed boundaries, drainage network and digitization of drainage basin using Arc GIS (hydrology tool), ERDAS IMAGINE or QGIS. There are number of tools and software's available for completing different steps of morphometric analysis. Fig. 1 shows different steps in calculation of morphometric parameters of watershed.

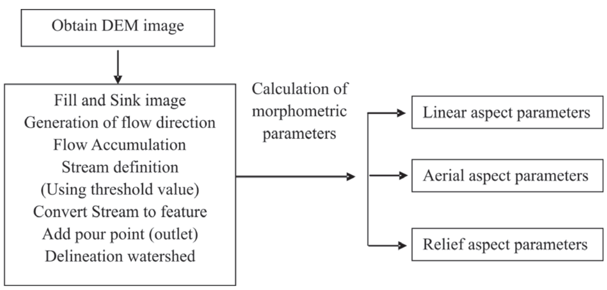

Fig. 1. Process flowchart for watershed delineation

D. **Commonly used parameters:** Mostly used morphometric parameters are listed in Table 1 with their mathematical formula.

Linear aspects of watershed

(a) Stream order

The stream order represents the degree of stream branching with watershed. Each length of stream is designated by its order. Generally, the n^{th} order stream is formed by two or more $(n-1)^{th}$ order streams and streams of lower orders. The highest order stream is known as trunk or principal stream through which all discharge of watershed passes through the outlet. The concept of stream order is used to calculate other indicators of drainage characters of watershed. Horton (1932, 1945), led to the development of law of drainage composition and Strahler (1964) suggested the stream ordering system. The designation of stream orders is the first step in drainage basin analysis and expresses the hierarchical relationship between stream segments,

Table 1. Mathematical formula to calculate morphometric parameters

Sr. No.	Morphometric Parameters	Formula	Reference
A.	**Linear Aspects**		
1	Stream order (u)	Hierarchical rank	Horton (1945) Strahler (1964)
2	Stream number (Nu)	Number of streams	Horton (1945)
3	Mean stream length ($\overline{L_u}$) Horton (1945)	$\overline{L_u} = \frac{\sum_{i=1}^{n} L_u}{N_u}$	
4	Stream Length ratio (RL)	RL=Lu/Lu-1	Horton (1945)
5	Bifurcation ratio (Rb)	Rb=Nu/Nu+1	Schumm (1956)
6	Length of over Land flow (Lg)	Lg=1/Dd*2	Horton (1945)
B.	**Aerial Aspects**		
7	Drainage Density (Dd)	Dd=Lu/A	Horton (1932)
8	Stream frequency (Fs)	$F_s = \frac{\sum_{i=1}^{K} N_u}{A_K}$	Horton (1945)
9	Circularity Ratio (Rc)	Rc = 4*pi*A/P2	Miller (1953)
10	Elongation Ratio (Re)	Re=(2/Lb)*(A/pi)0.5	Schumm (1956)
11	Form factor (Rf)	Rf =A/Lb2	Horton (1932)
12	Compactness Coefficient (Cc)	Cc = 0.2821*P/A0.5	Strahler (1964)
13	Drainage texture (Rt)	Rt = Nu/P	Horton (1945)
C.	Relief Aspects		
14	Relief (H)	H = h1-h2	Hardley and Schumm (1961)
15	Relief Ratio (Rh)	Rh = H/Lb	Schumm (1956)
16	Relative relief (Rp)	Rp = H/P	Melton (1957)

Where, A = area of basin (km^2), N_u = total number of stream segment of order 'u', L_u = total stream length of all order (km), P = perimeter of basin (km), L_b = Basin length (km), D_c = Diameter of circle having same area as that of watershed, L_m = Length of main channel (km), h_1 and h_2 = Highest and lowest points on the valley floor of a watershed.

their connectivity and the discharge arousing from contributing catchments.

(b) Stream number

The count of stream channels in each order is known as stream numbers (N_u). According to Horton's law (1945) of stream numbers, the numbers of streams of different order in a given drainage basin tend to approximate as inverse geometric sequences with the order number.

(c) Bifurcation Ratio

The bifurcation ratio (R_b) is defined as the ratio of the number of streams of any order to the number of streams of the next higher order. The value of R_b ranges from 2 to 4. Strahler (1957) demonstrated that bifurcation shows a small range of variation for different regions or for different environment except where the powerful geological control dominates.

(d) Length of overland flow

The overland flow refers to that flow of precipitated water, which moves over the land surface leading to the stream channels, while the channel flow reaching to the outlet of watershed is referred as surface runoff. The overland flow is significant in the smaller watershed, than runoff in bigger watershed. Horton (1945) defined length of over land flow as used the length of travel of the rainwater on the ground surface before it joins a definite channel.

(e) Stream Length

The extent of stream length on a watershed reveals the characteristics size of the various components of drainage network and its contributing surface area. Stream length is an important hydrological feature of the basin, as it provides information about surface runoff characteristics. The streams having relatively smaller length are formed in the areas with finer textures and larger slopes.

(f) Stream length ratio

The stream length ratio (R_L) is defined as a ratio of the average length of stream of any order to the average length of streams of the next lower order. Horton's law of stream length describes that "mean stream length segments of each of the successive orders of a basin tend to approximate a direct geometric series with stream length increasing towards lower order of streams".

D.2 Aerial aspects of watershed

(a) Drainage Density

Horton(1945) defined D_d as the total length of channels (Lu) in a catchment divided by the catchment area. Drainage density is a greater quantitative expression to the dissection and evaluation of landform, even though a operate of climate, Lithology and constructions and aid historical past of the area can lastly use as an oblique indicator to explain, these variables in addition to the morphogenesis of landform. In general, it has been observed over a wide variety of geologic and climatic conditions, that low drainage density is much more likely to happen in areas of exceedingly permeable subsoil material beneath dense vegetative cover, and where relief is low. In contrast, high D_d is favored in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief (Nag, 1998).

(b) Stream Frequency

The stream frequency (Fs) is defined as the total number of streams per unit area (Horton, 1945). It mainly depends on the lithology of the basin and reveals about the texture of drainage network. As the drainage density and stream frequency greater in a basin, faster will be the runoff therefore, flooding occurs most likely in to the basins with a high stream frequency and drainage density (Kale and Gupta, 2001). Stream frequency is related to infiltration capacity, permeability and relief of a watershed.

(c) Circularity Ratio

A dimensionless circularity ratio (Rc) is the ratio of basin area to the area of circle having the same perimeter as the basin. To derive, form of watershed Strahler (1964) and Miller (1953) used a quantitative method which is a dimensionless circularity ratio. It depends upon the length and frequency of streams, land use/ land cover, geological structures, relief, slope and climate of the watershed.

Elongation Ratio

The elongation ratio (Re) is defined as the ratio between a diameter of a circle having the same area as the basin and the maximum basin length (Schumm, 1956). This ratio ranges from 0.6 to 1.0 over a wide variety of climatic and geologic types (Strahler, 1965). It is an important parameter for the analysis of basin shape which helps to understand the hydrological character of a drainage basin.

Form Factor

Form Factor (R_f) is defined as the ratio of the basin area to the square of the basin length (Horton, 1932). For a perfectly circular watershed, the form factor would always be less than 0.754. As the value of form factor smaller, more elongated will be the watershed.

Compactness Coefficient

The compactness coefficient is the ratio of catchment perimeter to that of equivalent circle having area as that of the basin (Gravelius, 1914). The Cc is independent of size of watershed and depends only on the shape.

Drainage Texture

The drainage texture (T) depends upon various environmental factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. Drainage Texture is the total number of stream segments of all orders per perimeter of the area. Drainage texture is one of the important concepts of geomorphology which measures for the relive spacing of drainage lines. Drainage texture depends on the infiltration capacity, underlying lithology and relief aspect of the terrain. T is total number of stream segments of all orders per perimeter of that area (Horton, 1945).

D.3 Relief aspects of watershed

Relief

It is defined as the elevation difference between the reference points located in the drainage basin. Basin aid facets of the sub basins play a crucial function in drainage development, surface and subsurface water flow, permeability, landforms development and erosion properties of the terrain. Relief is an important attribute of terrain in general and the drainage watersheds is in particular. Strahler (1968) stated that relief is an indicative measure of the potential energy within the drainage basin because of its elevation above mean sea level.

Relief Ratio

The relief ratio is defined as the ratio of the total relief of a basin and the longest distance parallel to the main channel of the basin (Schumm, 1956). Schumm (1956) suggested the possibility of a close correlation between hydrologic characteristics and relief ratio of a basin, found relief ratio is closely correlated with sediments loose per unit area.

Relative Relief

It is defined as the ratio of total relief to the perimeter of basin. It is an essential morphometric variable used for the overall evaluation of morphological characteristics of a terrain. Melton (1957) suggested calculating the relative relief using the ratio of the difference between the highest and lowest elevation points in the basin and the basin perimeter.

CONCLUSION

Morphometric analysis of a watershed or river basin or drainage basinis the analysis of itsterrain characteristics like topography, shape and dimension of the landforms. Integration of morphometric analysis with watershed evaluation techniques would be helpful in the planning and management of the watershed. Different watershed problems like soil erosion, frequent flooding and draught conditions, development stage of the watershed can be identified using morphometric study of the watershed and it can be solved by taking precaution conservative measures. In all 30literatures, the researchers analyses the morphometric parametersof watershed using different sources viz., SOI Toposheet (1:50000), SRTM data (90 m) and ASTER data (30 m) in the GIS environment.From the review of various researchers, it is found that there is no any fix or strict value which reflects the behavior of watershed.According to the shape, the watershed is of two types circular and elongated. In circular watershed differences in the elevation is not much, so the relief aspect parameter having low value which suggested that high sensitive to flooding. While elongated watershed has high value of drainage density, stream frequency, and texture.

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