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Determination of geomorphological characteristics of asond watershed using GIS techniques

DR Patil, HN Bhange, BL Ayare, PM Ingle and MH Tharkar

Abstract
A Watershed is an ideal unit for management of resources like land and water for mitigation of the impact of natural disasters for achieving sustainable development. It provides a powerful study and management unit, which integrates ecological, geographical, geological, and cultural aspects of the land. GIS technique is used to estimate the morphological characteristics of watershed. Delineation of watershed using GIS is mainly based on the Digital Elevation Model (DEM) data. The study area, watershed, 510.76 ha was selected for study. The latitude 17º41' N and longitude 73º16'E are geocoordinates of Asond watershed which covered area 510.76 ha. Average annual rainfall of Wakavali is 2860 mm. Areal, linear and relief aspects of watershed were estimated. The parameters worked out includes Stream order, Stream length ratio, Bifurcation ratio, Basin length, Length of overland flow, Form factor, Circulatory ratio, Elongation ratio, Stream frequency, Drainage density, Constant of channel maintenance, Maximum relief, Relative relief, Relief ratio and Ruggedness number. 3rd order stream is trunk order. Total lengths of streams and total numbers of streams in each order are decreasing with increasing order. Bifurcation ratio for the watershed is 1.61. The form factor for the area is 0.44. From the value of elongation ratio 0.9, it is observed that the watershed is oval. The drainage density value for the basin area is 1.98 Km/Km^2 that is basin is poorly drained. The study will be useful for the planning of watershed harvesting and groundwater recharge projects on watershed basis.

Keywords: Watershed, morphometric analysis, GIS, asond, linear, areal, relief aspects

Introduction
A Watershed is an ideal unit for management of resources like land and water for mitigation of the impact of natural disasters for achieving sustainable development. It provides a powerful study and management unit, which integrates ecological, geographical, geological, and cultural aspects of the land. The watershed is also a useful concept for integrating science with historical, cultural, economic, and political issues. Water (movement, cycling, use, quality, etc.) provides a focus for integrating various aspects of watershed use and for making regional and global connections.

Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimension of its landforms. Morphometric methods, though simple, have been applied for the analysis of area-height relationships, determination of erosion surfaces, slopes, relative relief and terrain characteristics, river basin evaluation, and watershed prioritization for soil and water conservation activities in river basins.

Quantitative morphometric characterization of a drainage basin is considered to be the most appropriate method for the proper planning and management of watershed, because it enables us to understand the relationship among different aspects of the drainage pattern of the basin and also to make a comparative evaluation of different drainage basins, developed in various geologic and climatic regimes (Pingale S. M. *et al.*) [11].

The measurement of morphological parameters is laborious by the conventional methods, but using the latest technology like GIS, the morphometric analysis of natural drain and its drainage network can be better achieved. Various morphometric parameters needs to measure in a drainage basin include stream order, stream length, stream number, and basin area. Others morphometric parameters are basin shape factor (e.g. circularity ratio, elongation ratio, form factor and compaction ratio), basin perimeter, bifurcation ratios, drainage density, stream frequency and drainage intensity. Geographic Information Systems (GIS) technology has played critical roles in all aspects of watershed management, Basic physical characteristics of a watershed such as the drainage network and flow paths can be derived from readily available Digital Elevation Models.

DEM describes the elevation of any point in a given area at a specific spatial resolution.

For the present study Remote Sensing and Geographical Information System (GIS) is used as tools for managing and analyzing the spatially distributed information. Arc GIS is powerful software to analyze, visualize, update the geographical information and create quality presentations that brings the power of interactive mapping and analysis. Geomorphological analysis helps in better understanding of hydrological system of watershed which is useful for carrying out management strategies.

Materials and Methods

Site Description

Asond watershed is situated in Dapoli tehsil of Ratnagiri district, Maharashtra. The latitude 17º41' N and longitude 73º16'E are geocoordinates of Asond watershed which covered area 510.76 ha. Average annual rainfall of Wakavali is 2860 mm.

Data used

Topography is defined by a Digital Elevation Model (DEM) that describes the elevation of any point in a given area at a specific spatial resolution. The DEM is used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Hydrology tool under Spatial Analyst Tools in ArcGIS-10.5 software is used to extract drainage channels, and other parameters.

Linear Aspects of Drainage Network

The linear aspects of morphometric analysis of drainage basin includes stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio and length of overland flow.

Stream Order

The order of the stream is based on the connection of tributaries. In the present study, the channel segment of the drainage basin has been ranked according to Strahler's stream ordering system. According to Strahler (1957) [7], the smallest drainage lines are designated as first order. Two first order channels join with each other then a channel segment of second order is formed, where two second order stream join then a segment of third order is formed and so on.

Stream number

The number of stream channel in its order is known as stream number.

Stream Length

Stream length is the length of all the streams having order u^{th}. It indicates the contributing area of the basin of that order. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. (Bansod *et al.*, 2018) [2]

Mean Stream Length ($\bar{L}_u$)

The mean stream length defined as the summation of the total length of all streams to the number of stream (R. Suresh, 2012) [6].

$$\bar{L}_u = \frac{\sum_{i=1}^{N} Lu}{Nu}$$

Where, $\bar{L}_u$ = mean length of channel of order 'u',

Nu= total no. of stream segment of order 'u'.

Stream Length Ratio (R_L)

It is the ratio of mean length of stream (Lu) of particular order to the mean stream length of next lower order (Lu-1) (Horton, 1945)

$$R_L = \frac{\bar{L}u}{\bar{L}u-1}$$

Where, $\bar{L}_u$ = Average length of stream of order u

$\bar{L}_{u-1}$ = Average length of stream of order u-1

Bifurcation Ratio (R_b)

The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order (Horton, 1945)

$$R_b = \frac{Nu}{Nu+1}$$

Where, Rb = Bifurcation ratio

Nu = No of streams of order u

Nu+1= No of streams of order u+1

Length of overland flow

It is defined as the length of flow of water over the ground, before it becomes concentrated in defined stream channels (Horton, 1945). It is half the reciprocal of drainage density (Dd).

$$L_g = \frac{1}{2Dd}$$

Where, L_g = Length of overland flow

Dd = Drainage density

Areal Aspects of Drainage Networks

The areal aspects of morphometric characteristics of drainage basin includes form factor, circulatory ratio, elongation ratio, drainage density and constant of channel maintenance.

Form Factor (F_f)

It determines about the shape of the basin. Form factor is defined as the ratio of basin area to the square of the basin length (Horton, 1945)

$$F_f = \frac{Au}{Lb^2}$$

Where, A = Area of basin

L_b = Length of basin

Circulatory Ratio (R_c)

Circulatory ratio (Rc) is estimated as the ratio of the basin area (A_u) to the area of a circle (Ac) having circumference equal to the perimeter of the basin (Miller, 1953). The value of "C" generally changes from 0 (a line) to 1 (circle). The higher the value of "C" more the circular shape of the basin and vice versa.

$$R_C = \frac{Au}{Ac}$$

Where, Ac = Area of circle having equal perimeter as the perimeter of basin

A_u = Area of basin

Elongation Ratio (R_e)

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). High Re values indicate that the areas are having high infiltration capacity and low runoff. Values nearing 1.0 are typical of regions of low relief, whereas values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes.

$$R_e = \frac{Dc}{Lbm} = \frac{2 \times \sqrt{(A/\Pi)}}{Lb}$$

Where, D_C = Diameter of circle with the same area as the basin
L_{bm} = Maximum basin length

Drainage Density (D_d)
It is the ratio of total length of channels of all orders in the basin to the drainage area of the basin (Horton, 1945).

$$D_d = \frac{\sum_{i=1}^{K}\sum_{i=1}^{N} Lu}{Au}$$

Where, D_d = Drainage density
K = Principal order = highest order stream
L_u=Length of stream segments
A_u=basin area, km^2
N=total no. of streams

Constant of channel maintenance (C)
It is the ratio between the area of the drainage basin and total length of all the channels, expressed as square meter per meter. It is also equal to reciprocal of drainage density (Dd).

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

Where, D_d = Drainage density

Relief aspects of channel network
The relief aspects of morphological characteristics of drainage basin includes relief, relief ratio, relative relief, ruggedness number and length of overland flow (Bansod *et al.*, 2018) [2].

Maximum relief (H)
It is the maximum vertical difference between highest and lowest point in the watershed. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope.

Relief ratio (R_n)
It is the ratio of relief (H) to the horizontal distance (L) on which relief was measured (Schumm, 1956).

$$R_n = \frac{H}{Lh}$$

Where, H = Maximum relief
L_h = Maximum Length

Relative relief (R_{hp})
It is the ratio of maximum watershed relief to the perimeter of watershed (Melton, 1957).

$$R_{hp} = \frac{H}{P} \times 100$$

Where, H = basin relief
P = perimeter of basin

Ruggedness number (RN)
Ruggedness number (RN) is a product of relief (H) and drainage density (D) in the same unit (Strahler 1957) [7]. The areas of low relief but high drainage density are regarded as ruggedly textured as areas of higher relief having less dissection.

$$RN = H \times Dd$$

Where, Dd = Drainage density
H= Basin relief

Results and Discussions
Basic physical geomorphological characteristics of watershed such as drainage network, shape, size, etc. were derived from digital elevation model (DEM). The drainage pattern is dendritic in nature and it is influenced by general topography of area. Dendritic drainage pattern is mostly found in area having homogeneous rock.

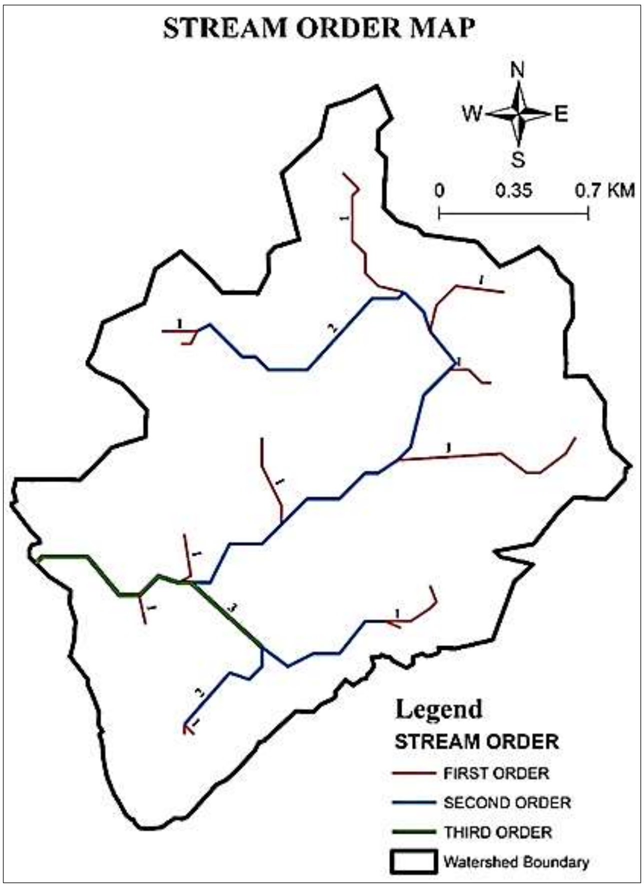

Fig 1: Stream order map

Linear Aspects
Stream number
Total 26 number of streams were identified in the watershed. Out of 26 streams, I^{st} order streams are 13, II^{nd} order streams are eight and five streams are of III^{rd} order. More 1^{st} order streams indicate that there was heavy runoff load to the down streams.

Stream order
The order of the stream is based on the connection of tributaries. In Study area, Stream network were identified to be up to III^{rd} order. Higher the stream order, higher is the watershed area. Fig 1. Shows stream order map of study area.

Stream length

The total length of all the streams was calculated with help of GIS. It was found to be 10.13 km. Total length of Ist order stream length was found to be 4.06 km. IInd order stream length was 4.73 km and IIIrd order stream length was 1.34 km. Similar results were also observed by Bansod *et al.*, 2018 [2].

Mean stream length ($\bar{L}_u$)

The mean stream length is found to be 0.312 km, 0.591 km and 0.268 km for Ist, IInd and IIIrd order streams, respectively. It is observed that length of IInd order stream is more than length of trunk order stream. The size of watershed area which contributes to drainage network can be revealed by mean stream length. Size of watershed was relatively small.

Stream length ratio (R_L)

The stream length ratio is estimated to be 1.16 and 0.28 for II/I, III/II orders respectively. Variations in stream length ratio exists between successive streams orders.

This variation are attributed mainly due to difference in slope and topographic conditions within the watershed.

Bifurcation ratio (R_b)

Bifurcation ratio is estimated 1.62 and 1.60 for I/II, II/III orders respectively. The average bifurcation ratio is calculated as 1.61. The high value of Rb means watershed has low permeability. It also indicated that drainage pattern has strong structural control.

Length of overland flow

The length of overland flow was calculated as 0.25 km. In the study, length of overland flow was more it means watershed has less structural disturbance.

Areal Aspects

Form factor (Ff)

For a perfectly circular watershed the value of form factor should be 0.754. Smaller the value, less circular or more elongated the watershed. High peak flows with short duration are common for the watershed with high form factors. Elongated watershed with low form factor indicates that flow for longer duration. In the present study, the form factor was 0.63 indicating sudden peak discharge at the outlet. Similar results were also observed and strongly supported by Adhikary *et al.*, 2018 [1].

Circulatory ratio (R_c)

Circulatory ratio is generally influenced by the stream length and frequency, geology, relief, land use and land cover and climatic condition of the basin. In this study, circulatory ratio is calculated as 0.44 which indicates elongated and highly permeable homogenous geologic materials.

Elongation ratio (R_e)

The elongation ratio of watershed is calculated as 0.89. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5). It is observed that the watershed is oval shaped. Similar results were also observed by Bansod *et al.*, 2018 [2].

Drainage density (D_d)

The drainage density of the watershed is calculated as 1.98 km/km^2. A low drainage density indicates permeable subsurface strata. It is a characteristic feature of coarse drainage which generally shows values less than 5.0. A low value of the drainage density indicates a relatively low density of streams and thus a slow stream response. Similar results were also observed by Bansod *et al.*, 2018 [2].

Constant of channel maintenance (C)

Value of Constant of channel maintenance(C) for the basin is 0.50 km which is reciprocal of drainage density. Higher is the average slope of the channel lower is the length of overland flow.

Relief Aspect

Maximum relief (H)

The maximum relief for the watershed is 105 m.

Relief ratio (R_n)

The relief ratio for watershed is 0.037. It measures overall steepness of watershed and also considered as an indicator for the intensity of erosion process occurring in the watershed. The high value of relief ratio is characteristics of hilly region. In the present study, relative relief was found to be low which represent the undulating surface with lower degree of slope. Similar results were also observed by Adhikary *et al.*,2018 [1].

Relative relief (R_{hp})

Relative relief can be used as an index of the relative velocity of vertical tectonic movements. The relative relief of the watershed was 0.913.

Ruggedness number (RN)

The Ruggedness number for the basin is 0.208 km. This value represents that if drainage density is increased, keeping relief as constant then average horizontal distance from drainage divide to the adjacent channel is reduced. On the other hand, if relief increases by keeping drainage density as constant, the elevation difference between the drainage divide and adjacent channel will increase. In the present study, value of ruggedness number is low i.e. it is less susceptible to soil erosion. Similar results were also observed by Bansod *et al.*, 2018 [2].

Table 1: Geomorphological characteristics of Asond watershed

A) Linear Aspects of Drainage Network			
Stream order	**Number of streams**	**Total stream length (km)**	**Mean stream Length (km)**
1	13	4.06	0.312
2	8	4.73	0.591
3	5	1.34	0.268
Bifurcation ratio			
1st order /2nd order	2nd order/3rd order	Bifurcation ratio	
1.63	1.6	1.61	
Stream length ratio	0.28		
B) Areal Aspects Of Drainage Network			

Form Factor	0.64
Circulatory ratio	0.45
Elongation ratio	0.90
Drainage density	1.98 km/sq.km
Constant of Channel maintenance	0.50 km
C) Relief aspects of drainage Network	
Relief	105 m
Relief Ratio	0.037
Relative Relief	0.913
Ruggedness Number	0.208 km
Length of overland flow	0.25 km

Total 26 number of streams were identified in the watershed. Out of 26 streams, 13 are Ist order streams, 8 are IInd order streams and 5 are IIIrd order streams. Stream network were identified to be up to IIIrd order. Bifurcation ratio is estimated of 1.62 and 1.60 for I/II, II/III orders respectively. The average bifurcation ratio is calculated as 1.61. The form factor was 0.63 indicating sudden peak discharge at the outlet. Circulatory ratio is calculated as 0.44 which indicates strongly elongated and highly permeable homogenous geologic materials. The elongation ratio of watershed is calculated as 0.90. It is observed that the watershed is Oval. The drainage density of the watershed is calculated as 1.98 km/km^2. The relief ratio for watershed is 0.0370. The relative relief of the watershed was 0.913. The Ruggedness number for the basin is 0.208 km.

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