The Pharma Innovation Journal 2022; SP-11(11): 1135-1139

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(11): 1135-1139

www.thepharmajournal.com
Received: 03-08-2022
Accepted: 08-09-2022

Morphometric analysis of Chatav watershed using GIS techniques

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Abstract
A Watershed is an ideal unit for the management of resources like land and water for mitigation of the impact of natural disasters for achieving sustainable development. SRTM DEM data at 30m spatial resolution have been used for the analysis. In the present study, RS and GIS technique is used to estimate the geomorphological parameters and delineation of the watershed. The research is carried out in the Chatav watershed in Khed tehsil of Ratnagiri district, Maharashtra. The study area is located between 17°45'28.8"N Latitude and 73°32'06.0"E Longitude. The total geographical area under study is 17700 ha. The average annual rainfall in the study area is 3511 mm and the mean temperature is 23.8 °C. Linear, areal, and relief aspects of the watershed were estimated. The results revealed that the basin has 4th order drainage network. The mean bifurcation ratio is 1.68 which indicates, the drainage pattern has strong structural control. The value of drainage density indicates the dense vegetation cover and low relief. The low relative relief indicates that peak discharge rates and catchment erosion are likely to be low. The study will be useful for the planning of watershed harvesting and groundwater recharge projects on a watershed basis.

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

Introduction
A Watershed is an ideal unit for the management of resources like land and water for mitigation of the impact of natural disasters for achieving sustainable development. The development of morphometric techniques is a major advance in the quantitative description of the geometry of the drainage basins and their network. The morphometric parameters are useful in characterizing river basins and comparing their characteristics. For the first time, it was proposed by Horton in 1945 [4]. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, and dimension of its landforms (Rai *et al.* 2014) [11].

Quantitative morphometric characterization of a drainage basin is considered to be the most appropriate method for the proper planning and management of the 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 *et al.* 2012) [9].

The measurement of these parameters is very laborious by the conventional methods, but by using the latest techniques like GIS, the morphometric analysis of natural drain can be better achieved. RS and GIS technique is used to estimate the geomorphological characteristics of the watershed. Various morphometric parameters need to measure in a drainage basin including stream order, stream length ratio, stream number, and basin area. Other 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 (Kandekar *et al.* 2021) [5].

Arc GIS is a powerful software to analyse, visualize, update geographical information and create quality presentations that brings the power of interactive mapping and analysis. Geomorphological analysis helps in a better understanding of the hydrological system of the watershed which is useful for carrying out management strategies (Bansod and Ajabe, 2018) [2]. The study will be helpful for the planning of water harvesting and groundwater recharge projects in the watershed.

Materials and Methods

Study area

In the Jagbudi river catchment, the Chatav watershed was selected as the study area for the present research. Jagbudi is the tributary of the Vashishti River and it meets Vashishti near Bahiravali. It originates from Khopi in the Ratnagiri district. The watershed is located at Chatav in Khed tehsil and district Ratnagiri of Maharashtra state. It lies between 17°45'28.8"N Latitude and 73°32'06.0"E Longitude. The total area of the watershed is 17700 ha. The average annual rainfall in the study area is 3511 mm and the mean annual temperature is 23.8 °C. The Jagbudi river basin has witnessed high rainfall and consequent floods of various intensities during recent years.

Data used and Methods

The boundary of the watershed is demarcated on Survey of India toposheet No. 47 G / 9 and 47 G / 10 (1:50,000). Digital Elevation Model (DEM) represents the relief of a surface between points of known elevation at a specific spatial resolution. The morphometric parameters were estimated using the SRTM DEM to an accuracy of 30 m. DEM data have been processed by the hydrological tool as in ArcGIS 10.4 software. Watershed delineation is carried out under the following steps fill, flow direction, flow accumulation, creation of outlet, snap pour point, and then watershed delineation.

A. Linear Aspects of Drainage Networks

It is concerned with the streams and their network. Linear aspects of the basins are closely linked with the channel patterns of the drainage network wherein the topological characteristics of the stream segments in terms of open links of the network system are analyzed (Afreeda and Kannan, 2018) [1]. It includes a one-dimensional component. These are one-dimensional properties as mentioned below.

Stream order

Stream order is the ranking of a stream channel segment in a drainage network (Salunke and Wayal, 2021) [12].

Stream number

The number of stream channels in their order is known as the stream number.

Bifurcation ratio (R_b)

Bifurcation ratio, defined as the ratio of the number of streams in N^{th} order to $N + 1^{th}$ order (Horton, 1945) [4], is an important parameter describing stages of river development. Strahler (1957) [14] observed that R_b characteristically ranges from 3 to 5 for the watershed in which geologic structures do not distort the drainage pattern.

$$R_b = \frac{N_u}{N_{u+1}} \qquad (2.1)$$

Where,
R_b= bifurcation ratio
N_u = number of streams of order u
N_{u+1}= number of streams of order u+1

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

The mean stream length is defined as the summation of the total length of all streams to the number of streams (R. Suresh, 2019) [10]

$$\bar{L}_u = \frac{\sum_{i=1}^{N} L_u}{N_u} \quad (2.2)$$

Where,
$\bar{L}_u$ = mean length of the channel of order 'u',
N_u= total no. of stream segment of order 'u'.

Stream Length Ratio (R_L)

It is the ratio of the mean length of the stream (L_u) of a particular order to the mean stream length of the next lower order (L_{u-1}) (Horton, 1945) [4]

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}} \quad (2.3)$$

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

Stream Area Ratio (R_A)

The channel area of order, A_i is the area of the watershed that contributes to the channel segment of order i and all lower-order channels. It can be quantified as

$$R_A = \frac{\bar{A}_u}{\bar{A}_{u-1}} \quad (2.4)$$

Where,
$\bar{A}_u$= Average basin area of stream of order u
$\bar{A}_{u-1}$= Average basin area of stream of order u-1

B. Areal Aspects of Drainage Network

The areal aspect represents the characteristics of the catchment area and describes how the catchment area controls and regulates the hydrological behavior.

Form Factor (R_F)

It determines the shape of the basin. The form factor is defined as the ratio of the basin area to the square of the basin length (Horton, 1945) [4]

$$R_F = \frac{A_u}{{L_b}^2} \quad (2.5)$$

Where,
A_u = Area of the basin
L_b = Length of the basin

Circularity ratio (R_c)

The circulatory ratio is the ratio of the basin area to the area of the circle having an equal perimeter as the perimeter of a drainage basin.

$$R_C = \frac{A_u}{A_c} \quad (2.6)$$

Where,
A_u = basin area
A_c = area of a circle

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) [13]

$$R_e = \frac{D_c}{L_{bm}} \quad (2.7)$$

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

Drainage Density (D_d)
It is the ratio of the total length of channels of all orders in the basin to the drainage area of the basin (Horton, 1945) [4]. This term was first introduced by Horton (1932) [3]

$$D_d = \frac{\sum_{i=1}^{K}\sum_{i=1}^{N} L_u}{A_u} \quad (2.8)$$

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 the total length of all the channels, expressed as a square meter per meter. It is also equal to the reciprocal of drainage density.

$$C = \frac{1}{D_d} \quad (2.9)$$

Where,
D_d = Drainage density

Length of Overland Flow (L_g)
The length of overland flow is approximately equal to half of the reciprocal of drainage density (Horton, 1945) [4]. It is the length of water over the ground before it gets concentrated into definite stream channels.

$$L_g = \frac{1}{2D_d} \quad (2.10)$$

Where,
D_d = Drainage density

C. Relief Aspects of Drainage Network
Linear and areal features have been considered as the two-dimensional aspect lying on a plan. The third dimension introduces the concept of relief or altitude (Kandekar, 2021) [5].

Relief
It is the maximum vertical difference between the highest and lowest point in the watershed. Relief is indicative of the potential energy of a given watershed above a specified datum available to move water and sediment downslope.

Relief Ratio (R_r)
It is the ratio of relief (H) to the horizontal distance (L) on which relief was measured (Schumm, 1956) [13].

$$R_r = \frac{H}{L_h} \quad (2.11)$$

Relative Relief (R_R)
It is the ratio of maximum watershed relief to the perimeter of the watershed (Melton, 1957) [7].

$$R_R = \frac{H}{P} * 100 \quad (2.12)$$

Ruggedness Number (R_n)
Ruggedness number (RN) is a product of relief (H) and drainage density (D) in the same unit (Strahler 1957) [14].

$$R_n = H * D_d \quad (2.13)$$

Result and discussion
The Chatav watershed of the Jagbudi river basin has 4^{th} order drainage network. Linear, Areal, and Relief aspects of the drainage network are given in Tables 1, 2, and 3, respectively.

A. Linear Aspects of Drainage Networks

Table 1: Linear aspects of the drainage network

Stream Order (u)	No. of Streams (N_u)	Stream Length km	Mean Stream Length km	Mean Stream Area Km^2	Bifurcation Ratio (R_b)	Stream Length Ratio (R_L)	Stream Area Ratio(R_a)
1	93	80.245	0.862	0.965			
2	39	43.490	1.115	3.269	2.384	1.292	3.384
3	30	21.948	0.731	5.215	1.3	0.656	1.595
4	22	19.989	0.908	8.078	1.363	1.241	1.548
Average					1.68	1.06	2.17

Stream order
The study area has a 4^{th}-order drainage basin covering an area of 177 sq. km. There was a total of 184 streams, out of which 93 are of 1^{st} order, 39 are of 2^{nd} order, 30 are of 3^{rd} order and 22 are of 4^{th} order streams. The higher stream order of the watershed indicated the greater discharge and higher velocity of the stream flow. The channel segment of the drainage basin has been ranked according to the Strahler stream ordering method.

Stream number
It was revealed from Table 1, that number of streams of particular order decreases with an increase in stream order. It means that the number of streams of any given order was less than that of the immediate lower order but more than the next higher order. It is observed in the Strahler approach. The higher number of streams in lower order led to lesser permeability and infiltration. It was observed that maximum frequency was in the case of first-order streams. It indicates that there is the possibility of flash floods after heavy rainfall on the downstream side. As the stream order increased, a decrease in stream frequency was observed.

Stream length
One of the basin's most important hydrological parameters is stream length since it provides information about surface runoff. Sub-watersheds streams of various orders were counted and their lengths from mouth to drainage divide were

measured. Areas with greater slopes and finer textures tend to have streams that are somewhat shorter in length. The maximum total length of stream segments was observed in the first order i.e., 80 km, and decreases with an increase in the stream order. That means results show that the stream order increases with a decrease in stream numbers.

Bifurcation ratio (R_b)

The bifurcation ratio (R_b) of the watershed varied from 1.3 to 2.38. The bifurcation ratio depends upon the geological and lithological development of the drainage basin (Strahler, 1964) [15]. The R_b values of the study area (Table 1) indicated that there was a decrease in R_b values from the first-order streams to the third-order streams and again increase in the R_b values was noticeable from the third-order stream to the fourth-order stream. These differences are depending upon the geological and lithological development of the drainage basin (Strahler, 1964) [15]. The mean bifurcation ratio was 1.68 which indicates that the drainage pattern has strong structural control.

Mean stream length

Mean stream lengths of the first-order, second-order, third-order, and fourth-order streams were 0.8628 km, 1.1151 km, 0.7316 km, and 0.9086 km, respectively. This may be due to the geomorphologic, lithological, and structural control and contrast. The length of the highest-order channel causes a maximum effect on the peak of the GIUH. If the length of the highest-order stream is more, it is expected to produce higher runoff (Khalegi *et al*., 2011) [6].

Stream length ratio (R_L)

The stream length ratio (Rl) of the II / I order was 1.2923, III / II order was 0.6560, and the IV / III order was 1.2419. These differences in the ratio in the research area were brought on by variances in topography and slope. Out of all Horton's ratios, the stream length ratio has the greatest impact on the peak of the GIUH peak. Higher RL values would create favourable conditions for flooding in the downstream area. The RL values do not depend upon the size of the river basin but it is characterized by basin shape.

Stream area ratio (R_a)

Stream area ratio (R_a) of II / I order was 3.38, III / II order was 1.59, IV / III order was 1.54. The average stream area ratio for the Chatav watershed is 2.17, which is considered as low. At low values of the stream area ratio ($R_a < 6$) the peak discharge of the hydrograph decreases but at higher values of the area ratio ($R_a > 6$) the peak discharge of the hydrograph increases with an increase in area ratio.

Areal Aspects of Drainage Networks

The areal aspect represents the characteristics of the catchment area and describes how the catchment area controls and regulates the hydrological behaviour.

Table 2: Areal aspects of the drainage network

Sr. No.	Morphometric Parameters	Symbol	Value
1	Area (sq. km)	A	177.73
2	Perimeter (km)	P	72.54
3	Basin Length (km)	L_b	21.4
4	Form factor	R_F	0.388
5	Circulatory ratio	R_C	0.42
6	Elongation ratio	R_L	0.70
7	Drainage density (km / km^2)	D_d	0.932
8	Constant of channel maintenance (km^2 / km)	C	1.072
9	Length of overland flow (km)	L_g	0.53

Form factor

The results of the study show that the form factor was observed as 0.38. The lower value of the form factor indicates that the watershed is elongated in shape. An elongated basin with a low form factor indicated that the basin had a flatter peak for a longer duration. Flood flows in such elongated basins are easier to manage than in the circular basin because the whole volume of discharge does not get accumulated at the same time at an outlet like a circular basin.

Circularity ratio

The circulatory ratio of the Chatav watershed was 0.424. When the basin is shaped like a complete circle, the ratio is equal to one, falling to 0.785 when it is square, and continuing to fall until the basin is elongated (Miller, 1953) [8]. The current value of the circularity ratio indicated that the basin is elongated in shape, with high to moderate relief and a structurally controlled drainage system. Additionally, it showed that the basin has a low runoff discharge.

Elongation ratio

It is an important index for the analysis of basin shape. This parameter is used to determine whether the basin's shape is like a circular one. Roundness and a low level of integration within a basin are indicated by elongation ratio values between 0.1 and 0.6. Watershed shapes can be classified using the index of elongation ratio, which includes circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (less than 0.5). The elongation ratio of the watershed is calculated as 0.7. It is observed that the watershed is elongated in shape. It suggests that the watershed is seeing flatter peak flows over a longer period.

Drainage density

The drainage density indicates the closeness of the spacing of channels, for the whole basin. Based on drainage density, watersheds are classified as low (less than 2.0 km / km^2), moderate (2.0-2.5 km / km^2), high (2.5-3.0 km / km^2), or very high (greater than 3.0 km / km^2). The drainage density of the Chatav watershed is calculated as 0.93 km / km^2. It comes under the low drainage density which indicates that the watershed has dense vegetation cover and low relief.

Constant of channel maintenance

The constant of channel maintenance shows how many square kilometres of basin surface is needed to create and maintain a channel that is one kilometre long. It is the inverse of drainage density (Schumm, 1956) [13]. As a result, as drainage density increases, the constant of channel maintenance decreases and vice versa. The constant of channel maintenance was found as 1.07 indicating that the study area is under the influence of fewer structural disturbances.

Length of overland flow
The length of the overland flow is referred to as the distance that precipitated water must travel over the surface of the ground to reach a stream. It is a significant independent variable that has a significant impact on the amount of water needed to exceed a specified erosion threshold. A high value for the length of the overland flow indicates a high level of surface runoff, whereas a low value for the length of the overland flow indicates a low level of surface runoff. The length of the overland flow of the study area was 0.53 km^2 / km which indicates the high surface runoff.

Relief aspects of drainage network
The various factors of relief assessed in this study are explained as follows:

Table 3: Relief Aspects of the Drainage network

Sr. No.	Parameter	Value
1	Relief (km)	1.181
2	Relief ratio	0.055
3	Relative relief	1.628
4	Ruggedness number	1.098

Relief (H)
Relief is the vertical distance between the highest and lowest watershed. It is also known as the maximum watershed relief (H). The total relief for the Jagbudi river catchment was 1.18 km. The high value of relief led the low infiltration and high runoff from the catchment.

Relief ratio
The present study shows that the relief ratio for the Jagbudi river catchment is 0.0551. The presence of a hilly region in the catchment was indicated by this relief ratio value.

Relative relief
Relative relief for the watershed was found to be 1.628 which is considered to be low. These low relative relief values indicate that peak discharge rates and catchment erosion are likely to be low.

Ruggedness number (R_n)
The value of the ruggedness number was observed 1.09. R_n shows the structural complexity of the terrain in association with relief and drainage density. This provides an idea of the overall roughness of the water.

Conclusions
The morphometric characterization was achieved through the measurement of linear, areal, and relief aspects of the Chatav watershed using GIS techniques. For the analysis, the toposheet was used for the demarcation of the watershed boundary. The toposheet was downloaded from the Survey of India website (1:50,000 scale). SRTM DEM was used for watershed delineation and determination of morphological parameters. The Chatav watershed has 4th order drainage network and covers a total geographical area of 17700 ha. The total number of streams in the basin is 184. The number of lower-order streams is more than higher-order streams. The value for drainage density is 0.43 km / km^2 which indicates the dense vegetation and low relief. The bifurcation ratio, stream length ratio, and stream area ratio of the watershed is 1.68, 1.06, and 2.17, respectively. The value for the circulatory ratio and elongation ratio is 0.424 and 0.7 respectively which indicates the elongated shape of the basin. The relative relief of the watershed is 1.628. The Ruggedness number for the basin is 1.09 km.
The study will be helpful for the planning of water harvesting and groundwater recharge project on a watershed basis.

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