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VU Kandekar

M. Tech. Scholar, Dr. A. S.
College of Agril. Engineering and
Technology, MPKV, Rahuri,
Maharashtra, India

BK Gavit

Associate Professor, Dr. A. S.
College of Agril. Engineering and
Technology, MPKV, Rahuri,
Maharashtra, India

AA Atre

Professor, Dr. A. S. College of
Agril. Engineering and
Technology, MPKV, Rahuri,
Maharashtra, India

RD Bansod

Professor and Head, Agricultural
Engineering Section and Estate
Manager, College of Agriculture,
Pune, Maharashtra, India

CA Nimbalkar

Professor, College of Agriculture,
Pune, Maharashtra, India

Corresponding Author:**VU Kandekar**

M. Tech. Scholar, Dr. A. S.
College of Agril. Engineering and
Technology, MPKV, Rahuri,
Maharashtra, India

Morphometric analysis of Agadgaon watershed using remote sensing and geographic information system

VU Kandekar, BK Gavit, AA Atre, RD Bansod and CA Nimbalkar

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Abstract

Morphometry means measurement of earth features. This is important factor for planning any watershed development programme. RS and GIS technique is used to estimate the geomorphological characteristics of watershed. The area selected for the study is Agadgaon watershed in tehsil and district Ahmednagar of Maharashtra state. The area of watershed under study is 392 ha. The main watershed comprises of two sub-watersheds viz. W1 (296 ha) and W2 (96 ha). The Geomorphological characteristics of the watershed were extracted from DEM which was downloaded from United States Geological Survey's (USGS) official website, using RS data and GIS software, ArcGIS 10.2. The morphometric parameters considered for analysis include the linear, areal and relief aspects. It is third-order drainage watershed. The mean bifurcation ratio for W1 was 4 and 2.45 for W2 which shows that the basin was largely controlled by structures. Also both sub watersheds are elongated. The watershed is having high drainage density leads to fine drainage texture and indicates that the catchment area is more prone to flooding. Low values of relative relief indicate that peak discharge rates are likely to be low and low erosion from the catchment. Similarly, all morphometric parameters were calculated for both watersheds.

Keywords: Morphometry, Watershed, RS, GIS, DEM, Linear 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. Everywhere we can see land is a precious resource as it is the physical base of biomass on the earth. So conservation of such type of natural resources is very important to mitigate the increasing demand of land and mathematical analysis of the configuration of the earth surface, shape and dimension of its landforms (Agarwal, 1998) [2]. Morphometry means measurement of earth features. 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 (Clarke, 1966) [4]. This is important factor for planning any watershed development programme. Morphometric analysis provides detail information about physical characteristics of the watershed which are useful for environmental studies, such as land use planning, terrain elevation, soil and water conservation and soil erosion etc. The measurement of these parameters is very laborious by the conventional methods, but by using 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 watershed. Various morphometric parameters needs to measure in a drainage basin include stream order, stream length ratio, 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 (Shaikh and Birajdar) [19]. The study will be helpful for planning of water harvesting and groundwater recharge projects on watershed.

Radwan *et al.*, (2017) [14] carried out a morphometric analysis of catchment of the Wadibaish dam using an integrated GIS-based approach. The basin is having eighth stream order and relatively high value of bifurcation ratio (4.012) and this value of bifurcation ratio is consistent with the high drainage density value of 2.064 km/sq.km. Which confirms the impermeability of the subsurface material and mountainous relief in the basin.

Bansod and Ajabe (2018) [3] analyzed geomorphological characteristics of Karpri-Kalu watershed in Sangamner tehsil of Ahmednagar district Maharashtra using GIS techniques. Linear, areal, and relief aspects of the basin were estimated. Morphological characteristics show that watershed was having 4th order stream and from the value of elongation ratio (0.734) it was observed as less elongated.

The bifurcation ratio was found as 3.166 which indicates structural complexity and low permeability. The drainage density value for the basin area (2.024 km/km²), the basin was observed as poorly drained.

Rai *et al.*, (2019) ^[15] worked on the Varuna river basin in India for morphometric analysis using ASTER- DEM data using the GIS platform. Varuna river basin shows a dendritic drainage pattern and a very classic drainage texture. The value of the bifurcation ratio of the basin was observed as 3.92 which indicates that the basin is normal and the control of the drainage network is mainly pronounced by geomorphology. The elongation ratio of the Varuna basin was computed as 0.52 which represents the basin is elongated. Basin has moderate drainage density (0.37 km/km²) which is indicative of permeable material and vegetative cover having moderate to low relief. A low value of relief ratio (0.30) was observed due to the resistant basement rocks of the drainage basin and low degree of the gradient.

Varma *et al.*, (2020) ^[26] carried out a morphometric analysis of BarkhedaNathu watershed in Bhopal and Sehore district of Madhya Pradesh using GIS. The highest stream order observed in the watershed was 5 with a mean bifurcation ratio (3.345) suggests the lithological heterogeneity and smaller structural command in the area. The value of elongation ratio was found to be 3.56 which indicates relatively high infiltration capacity and low runoff. Drainage density was observed as 1.24 km/km² for the watershed under study.

Materials and Methods

Study Area

The watershed is located at Agadgaon in tehsil and district Ahmednagar of Maharashtra state. The watershed is located about 17 km away from Ahmednagar which lies between 74°48' and 74°52' E longitude and 19°8' and 19°9' N latitude and having 826.92 m above the mean sea level. The geographical area of watershed under study is 392 ha. The main watershed consists of two sub-watersheds viz. W1 (296 ha) and W2 (96 ha). Both the watersheds are demarcated on Survey of India toposheet No. 47 I/16 (1:50,000). The average rainfall of this region is 598.2 mm. According to census 2011, the population of Agadgaon village is 2557. The soils present in this area is mostly clay and clay loamy. Agadgaon watershed is located in the drought-prone semi-arid zone of Maharashtra. In general, the climate of the study area is very dry. The maximum temperature ranges between 40° C and 42° C during summer and minimum temperature ranges between 12° C and 13° C during winter. The rainfall is scanty, erratic, and unpredictable. Hence water for both agriculture and drinking is scarce. The area comes under agro-climatic zone no. IX as per the classification of the Agriculture Department, Govt. of Maharashtra. The location map of the study area as shown in Fig.1.

Watershed delineation: Watershed delineation plays an important role in the management of streams, rivers and wetlands. Arc-GIS 10.2 was used for the purpose of watershed delineation. ASTER DEM (30 m) data is used for delineation of watershed and Survey of India toposheet No.47 I/16 (1:50,000) of the study area was used for the base map preparation and validation purpose and extraction of the drainage network. Topo sheets provide information related to the location, drainage network and contours.

Geometry of drainage basin and its stream channel system required the following measurements):

1. The linear aspect of the drainage network

2. An areal aspect of the drainage basin
3. Relief aspect of channel network and contributing ground slopes

A. Linear Aspects of Drainage 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 (Afreena and Kannan, 2018) ^[1]. Linear The linear aspect in morphometry is characterized by basin length, stream order, stream number, stream length and bifurcation ratio, etc.

1. Stream order

The stream order represents the degree of stream branching with the watershed. Stream ordering is an important aspect for of drainage basin analysis. It is defined as a measure of the position of a stream in the hierarchy of streams (Horton 1945; Strahler 1957 ^[23]; Leopold *et al.*, 1964; Strahler 1964) ^[25] proposed a method of ranking of streams. The smallest fingertip tributaries are designated as first first-order streams. When two first first-order streams join, they form a second second-order stream and when two second second-order streams join, they form the third third-order stream. The order of stream will not change if the lower lower-order stream joins a higher order stream. Thus, when two streams of the same order join they form a stream of next higher order. The highest order stream carries discharge and sediments to the stream of the next order.

2. Stream number

The number of streams of each order in a given watershed is known as stream number. In the present study, the number of stream segment (Nu) of each stream order (u) of the watershed was counted and recorded.

3. Bifurcation ratio (R_B)

The bifurcation ratio is the ratio of the number of streams of any given order to the number of streams in the next higher higher-order (Schumm, 1956). It is a measure of the degree of distribution of stream network and influences the landscape morphometry. The R_B value ranges from 3.0 to 5.0 for networks formed on homogeneous rocks when the influences of geologic structures on the stream network is are negligible (Strahler, 1964) ^[25] and values higher than 10, where structural controls play a dominant role with elongate basins. The RB value ranges from 3 to 6 in almost all watersheds. The value 3 for high/ rolling topography and 6 for watershed controlled by geological structure, where the drainage network is highly distorted. It can be calculated by using the formula,

$$R_B = \frac{N_u}{N_{u+1}}$$

Where,

R_B = bifurcation ratio

N_u = number of streams of order u

N_{u+1} = number of streams of order u+1

4. Mean stream length (\bar{L}_u)

Length of stream is indicative of contributing area of the basin of that order. Generally, cumulative length of streams of particular order is measured and the mean stream length (\bar{L}_u) of that stream order is obtained by dividing cumulative stream

length by number of segment of that order N_u . The value of \bar{L}_u increases as the order number increases. The stream length is used to determine the basin parameter, the basin length, drainage density, etc. Stream length is defined as the ratio of summation of the total length of all streams to the number of streams.

$$\bar{L}_u = \frac{\sum_{i=1}^N L_{ui}}{N_u}$$

Where,

\bar{L}_u = mean length of the channel of order u

N_u = total number of stream segments of order u

5. Stream length ratio (R_L)

The law of stream length states that the mean length of a stream segment of each successive order of a watershed tends to approximate a direct geometric sequence in which the first term is the average length of segments of the first order.

$$\bar{L}_u = \bar{L}_1 \times R_L^{u-1}$$

Where R_L is stream length ratio which is defined as the ratio of mean length of u^{th} order stream to mean length of $(u-1)^{\text{th}}$ order stream. Taking log on both sides of equation and simplifying and then comparing it with the straight-line equation $y = a + bx$, we get

$$\log(\bar{L}_u) = \log\left(\frac{\bar{L}_1}{R_L}\right) + u \times \log(R_L)$$

$$R_L = 10^b$$

Where b is the regression constant of straight-line fitted between $\log(\bar{L}_u)$ and u .

6. Stream area ratio (R_A)

The law of stream area states that the mean basin area of the stream of each order approximates a direct geometrical sequence in which the first term is the mean area of the first order basin.

$$\bar{A}_u = \bar{A}_1 \times R_A^{u-1}$$

Where, R_A is the stream area ratio which is defined as the ratio of mean area of basin of order u to mean area of basin of order $(u-1)$. R_A is analogous to R_L . Taking log on both sides of equation, simplifying and comparing with the straight-line equation results in to

$$R_A = 10^b$$

Where b is the regression constant for straight-line equation between the log of the mean basin area and corresponding order.

B. Areal Aspects of Drainage Networks

The areal aspect represents the characteristics of the catchment area and describes how catchment area controls

and regulates the hydrological behavior. Areal aspects include drainage parameters such as drainage density, stream frequency, form factor, circularity ratio, length of overland flow constant of channel maintenance, etc. which is discussed below.

1. Form factor (F_f)

Horton (1932) [6] explained the basin shape through a dimensionless term called a form factor. It is the ratio of the basin area to the square of the basin length. The ratio was used in its inverted form shape index.

$$F_f = \frac{A_u}{L_b^2}$$

Where,

A_u = basin area (km^2)

L_b = basin length (km)

The form factor value varies from zero (in highly elongated shape) to the unity (in a perfect circular shape). Hence, a higher value of form factor indicates the circular shape of the basin and vice-versa. The higher value also indicates a higher sedimentation rate for the watersheds and vice-versa (Strahler, 1964) [25].

2. Shape Factor or Shape Index (SI)

The shape index is a dimensionless entity and is a reciprocal of form factor. It is greater than 1. The shape of watershed has a significant influence on the runoff as well on sediment transport phenomenon. An index of shape, basin shape factor as defined by Horton (1932) [6], is the ratio between square of maximum length of watershed and area of the watershed.

$$SI = \frac{1}{F_f}$$

Higher the shape index; more is the basin elongation and weak is the flood discharge.

3. Circularity ratio (R_c)

Miller (1953) [12] used this term to define the basin shape. The circularity ratio is the ratio of basin area to the area of a circle having equal perimeter as the perimeter of the drainage basin. R_c is computed by using the following formula.

$$R_c = \frac{A_u}{A_c}$$

Where,

A_u = basin area (km^2)

A_c = area of circle (km^2)

The value of the circularity ratio varies from zero (in a line) to one (in a circle). Higher the values of circularity ratio, more circular will be the shape of the basin and vice versa (Miller, 1953) [12].

4. Elongation ratio (R_e)

Schumm (1956) [18] used the elongation ratio as an index to mark the shape of the drainage basin. Elongation ratio is defined (Schumm, 1956) as the ratio of the diameter of a circle with the same area as a watershed to the maximum length of the watershed.

This parameter is used to assess whether the shape of the basin approaches a circle. The ratio ranges from 0.6 to 1.0 over a wide variety of climatic and geologic types. In an area of strong relief and steep ground slope, the elongation ratio ranges from 0.6 to 0.8. The varying slopes of a watershed can be classified with the help of the index of elongation ratio i.e. circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7) and more elongated (< 0.5) (Strahler, 1964) [25]. The elongation ratio is expressed by the following formula.

$$R_e = \frac{D_c}{L_{bm}}$$

Where,

D_c = diameter of circle (km)

L_{bm} = maximum basin length (km)

It is an important index for the analysis of basin shape. Analysis of elongation ratio indicates that the areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin (Singh and Singh, 1997) [21].

5. Compactness Ratio or Compactness coefficient (C_c)

Strahler (1964) [25] defined the compactness coefficient as the ratio of watershed perimeter to the perimeter of a circle of a watershed area. It is greater than or equal to unity. When C_c approaches to 1 basin shape approaches to that of the circle. It is given by

$$C_c = \frac{0.282P}{\sqrt{A}}$$

Where,

A = Area of the watershed (km^2)

P = Perimeter of the watershed (km)

6. Drainage density (D_d)

Drainage density is defined as the ratio of the total length of stream segment of all orders to basin area projected on a horizontal surface (Horton, 1945) [7],

$$D_d = \frac{\sum_{u=1}^k \sum_{i=1}^{N_u} L_{ui}}{A}$$

Where,

D_d = Drainage density (km per km^2)

L_{ui} = length of i^{th} stream segment of u^{th} order (km)

A = Area of the watershed (km^2)

Drainage density has dimension km/ km^2 . D_d is a numerical measure of landscape dissection and runoff potential. It shows the infiltration capacity of the land and vegetation cover of the catchment (Macka, 2001). The drainage density is considered as an important measure of the total length of the streams available to dispose runoff per unit area, indicating the degree of abstraction.

The watershed which is having high values of drainage density indicates a well-developed network and torrential runoff resulting in intense flood, while a low value indicates moderate and high permeability of the terrain (Strahler, 1964) [25]. The watershed can be grouped into four categories on the basis of drainage density (Malik *et al.*, 2011) [11] as, low

(below 2.0 km per km^2), moderate ($2.0\text{-}2.5 \text{ km per km}^2$), high ($2.5\text{-}3.0 \text{ km per km}^2$) and very high (above 3.0 km per km^2).

7. Constant of channel maintenance (C)

This parameter indicates the requirement of units of the watershed surface to bear one unit of channel length. Schumm (1956) has used the inverse of the drainage density having the dimension of length as a property termed constant of channel maintenance. The drainage basins having higher values of this parameter, there will be a lower value of drainage density. A higher value of C reveals strong control of lithology with a surface of high permeability and indicates relatively higher infiltration rates, moderate surface runoff, less dissection, and watershed is not influenced by structural parameters.

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

Where,

C = Constant of channel maintenance ($\text{km}^2 \text{ per km}$)

D_d = drainage density (km per km^2)

8. Average length of overland flow (L_o)

Horton (1945) [7] defined the average length of overland flow as the length of flow path projected on the horizontal plan of non-channel flow from a point on a drainage divide to the adjacent stream channel. It is one of the most important variables affecting both hydrologic and physiographic development of watershed basins.

The average length of overland flow is approximately half of the distance between the stream channels, i.e. approximately half of the reciprocal of drainage density. It is the length of travel of water over the ground before it gets concentrated into the mainstream which affects hydrologic and physiographic development of drainage basin (Horton, 1945) [7].

$$L_o = \frac{1}{2 \cdot D_d}$$

Where,

L_o = Length of overland flow ($\text{km}^2 \text{ per km}$)

D_d = drainage density (km per km^2)

9. Stream Frequency (S_f)

Stream frequency of a basin is defined as the number of stream segments of all orders per unit area (Horton, 1945) [7]. Stream frequency has dimension km^{-2} . The stream frequency is computed using the following formula:

$$S_f = \frac{\sum_{u=1}^k N_u}{A}$$

Where,

S_f = Stream frequency (km^{-2})

N_u = Number of streams of u^{th} order

A = Area of the watershed (km^2)

Low stream frequency indicates high permeable geology and low relief. Channel frequency density serves as a tool in establishing the erosional process operating over an area, to be more specific, the same in relation to the stream orders and their characteristics provide data which can throw light even on the sequences of relief developments and the degree of ruggedness in the area (Singh, 1980) [20].

A higher stream frequency points to larger surface runoff, steeper ground surface, impermeable subsurface, sparse vegetation, and high relief conditions.

C. Relief Aspects of Drainage Networks

Linear and areal features have been considered as the two-dimensional aspect lie on a plan. The third dimension introduces the concept of relief or altitude. The relief properties that have been used in the study are as follows:

1. Relief (H)

Relief is defined as the elevation difference between reference points located in the watershed (Schumm, 1956). Within the given boundary of the region, the elevation difference between the highest and lowest point is called maximum relief. Maximum basin relief is the elevation difference between the basin outlet and the highest point located on the perimeter of the basin. According to Rao *et al.*, (2010) [16], calculation of basin relief to show spatial variation is predominant. Basin relief is the maximum vertical distance between the lowest and the highest point of a basin. Basin relief is responsible for the stream gradient and influences flood patterns and sediment volume that can be transported (Hadley and Schumm, 1961) [5]. It is an important factor in understanding the denudation characteristics of the basin (Sreedevi *et al.*, 2009) [22]. Digital Elevation Model of the given watershed is shown in Fig. 2.

2. Relief ratio (R_H)

The ratio of relief (H) to the horizontal distance on which relief was measured is the relief ratio. Relief ratio is a dimensionless ratio of basin relief and basin length and effective measure of gradient aspects of the watershed (Schumm, 1956). It shows overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on slopes of the basin.

$$R_H = \frac{H}{L_h}$$

Where,

H = relief (m)

L_h = horizontal distance (m)

3. Relative relief (R_{HP})

It is defined as the ratio of maximum basin relief (H) to the perimeter (P) of the basin.

$$R_{HP} = \frac{H}{P} * 100$$

Where,

H = basin relief (m)

P = perimeter of basin (m)

4. Ruggedness number (R_n)

The product of relief (H) and drainage density (D_d) is called ruggedness number. It is a dimensionless entity. Strahler (1958) [24] defined ruggedness number as drainage density times relief. Any change in either value is important to slope length and steepness, and ultimately, erosion factors. It is computed from the following equation

$$R_n = H * D_d$$

Where,

H = basin relief (km)

D_d = drainage density (km/sq. km)

This number represented that if drainage density was increased and keeping relief as constant, the average horizontal distance from the drainage divide to the adjacent channel was reduced. On the other hand, if relief is increased by keeping drainage density constant, the elevation difference between the drainage divide and adjacent channel goes on increasing.

Results and Discussion

The linear and areal aspects of Agadgaon watershed i.e. W1 and W2 are extracted and presented in Table 1. The geomorphological characteristics of the two sub-watersheds W1 and W2 in Agadgaon watershed are tabulated in Table 2.

Linear Aspects of Drainage Networks

1. Stream order

The geomorphological characteristics of watershed showed that stream order of mainstream channel was 3 in both watersheds. For W1, a total of 19 streams was found, out of which 16 are of 1st order, 2 are of 2nd order, 1 of 3rd order. Similarly, it is observed as 6, 2, and 1 for 1st, 2nd, and 3rd order streams in W2. More number of streams in W1 can lead to a reduction in time of concentration and quick disposal of runoff generated in the watershed. Stream order map of the study area is shown in fig. 3.

2. Stream number

It was revealed from Table 2, 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 immediate lower order but more than the next higher order. It is observed in 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 a possibility of flash flood after heavy rainfall in the downstream side. It was noticed that there was a decrease in stream frequency as the stream order increases in both W1 and W2.

3. Stream length

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. The number of streams of various orders in a sub-watershed was counted and their lengths from mouth to drainage divide were measured. Streams of relatively smaller lengths are characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. The total length of stream segments in the study area was maximum in first-order streams and decreases as the stream order increases in both W1 and W2. The total length of streams was found to be 8.82 km in W1 and in the case of W2 it was observed as 3.22 km.

4. Bifurcation ratio (R_B)

The bifurcation ratio reflects the geological as well as tectonic characteristics of the watershed. Table 4.3 shows that the value of the bifurcation ratio for W1 is 4 and for W2 it is observed as 2.45. The results of the bifurcation ratio show that W1 has dominant overland flow resulting in an early peak in hydrograph, which further shows that high potential of

susceptibility to flash flooding during intense storm compared to W2. The high value of R_B in W1 also indicates good control of geological structures. Subwatershed W1 has a higher bifurcation ratio, suggesting that the channel network is well spread in the watershed.

5. Mean stream length (\bar{L}_u)

The results of the study show that mean stream lengths of the first order, second order, third order stream for W1 were 0.35 km, 1.02 km, and 1.18 km, respectively. Whereas it was observed as 0.26 km, 0.3 km, and 1.04 km for first order, second order, third order stream respectively in W2 watershed. 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) [8].

6. Stream length ratio (R_L)

Stream length ratio (R_L) for W1 watershed was observed as 1.836 and for W2 watershed it was 1.988. The observed variations in stream length ratio for the study area were due to variations in slope and topography of watershed. Higher values of R_L would make the condition favorable for flooding in the downstream region. The R_L values does not depend upon the size of the river basin but it is characterized by basin shape. Drainage network map is shown in Fig. 4.

7. Stream area ratio (R_A)

Table 2 shows that stream area ratio (R_A) for W1 was 1.283 and in the case of W2, it was 1.59 which is considered as low for both sub-watersheds. It was observed that area contributing to streams is decreasing as stream order increases in case of W1 but in case of W2 the area contributing to streams first decreases and in case of third-order stream area again it increased. This is due to the longer length of the third-order stream in W2. 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. Stream area map is shown in Fig. 5.

Areal Aspects of Drainage Networks

1. Form factor (F_f)

The results of the study show that form factor was observed as 0.4263 and 0.2866 for W1 and W2 watershed, respectively. The values of form factor for both watersheds are less than 0.7854 (the value corresponding to a perfectly circular basin), indicates that both watersheds are elongated in shape, which results in lower peak flows of longer duration. Both watersheds show a lower value of form factor which implies elongated basin with flatter peak of low flow for a longer duration, lower erosion, and sediment transport capacities and favors a diminution of floods because streams flow into the mainstream at greater time intervals and space which leads to groundwater percolation. Flood flows of such elongated watershed, are easier to manage than those of the circular basin.

2. Shape Factor or Shape Index (SI)

The shape of the watershed has a significant influence on the runoff as well on the sediment transport phenomenon. The shape index is a dimensionless entity and is a reciprocal of the form factor. Table 2 shows that the shape factor for watershed W1 is 2.3457 and for W2 it is 3.4891. Higher the shape index,

more is the basin elongation. Hence we can say that W2 is elongated in shape and weak is the flood discharge.

3. Circularity ratio (R_c)

The circularity ratio indicates the shape of the basin, it generally ranges between 0.4-0.5. The result shows that W1 is having a circularity ratio of 0.446 and 0.4184 for W2. In the present study value of circularity ratio for both watersheds indicated, that both watersheds are elongated in shape and are characterised by the high to moderate relief as well as drainage system were structurally controlled. It also indicates that watersheds have low runoff discharge.

4. Elongation ratio (R_e)

It is an important index for the analysis of basin shape. This parameter is used to assess whether the shape of the basin approaches a circle.

The watershed W1 has a value of elongation ratio as 0.7362 which indicates that watershed is less elongated and for W2 value of elongation ratio was 0.6038 which indicates an elongated shape of the watershed. It indicates that watershed is having a flatter peak flow for a longer duration.

5. Compactness Ratio or Compactness coefficient (C_c)

If the C_c value is 1.28 the basin is more square shape, while the basin is very elongated one, if the C_c is greater than 3. It can be seen from Table 2 that W1 is having a compactness coefficient as 1.496 and for W2 it is 1.545. As C_c value are near to two, it indicates that both watersheds are not square. The shape therefore can be slightly elongated which indicates the low peak flows for longer duration. Thus flood flow of these watersheds is easier to manage.

6. Drainage density (D_d)

The drainage density indicates the groundwater potential of an area, due to its relation with surface runoff and permeability. Low drainage density generally results in the areas of permeable subsoil material, dense vegetation, and low relief (Nag, 1998) [13]. While high drainage density is the resultant of impermeable subsurface material, sparse vegetation, and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture.

The drainage density indicates the closeness of spacing of channels, for the whole basin. The drainage density of W1 was 2.979 km/km² which is high and W2 has a drainage density of 3.354 km/km² which is very high as discussed in chapter 3. High drainage density leads to fine drainage texture (Strahler, 1964) [25] and indicates that the catchment area is more prone to flooding.

7. Constant of channel maintenance (C)

The constant of channel maintenance indicates the number of sq.km of basin surface required to develop and sustain a channel of length 1 km long. The constant of channel maintenance was found 0.356 km²/km for W1 and for W2 it was found as 0.298 km²/km. It indicated the magnitude of the surface area of the watershed needed to sustain the unit length of the stream segment.

8. Length of overland flow (L_o)

Table 3 shows that the length of overland flow for W1 was 0.168 km²/km and for W2, it was 0.149 km²/km. The high value of the length of overland flow is indicating high surface

runoff whereas the low value of the length of overland flow is indicating low surface runoff.

In the study area both watersheds having low values. The low value of the length of overland flow indicates the low surface runoff. In addition, it indicates that runoff will take very little time to reach the outlet (Romshoo *et al.*, 2012) [17].

9. Stream Frequency (S_f)

Stream frequency indicates the number of stream segments of all orders per unit area. The stream frequency observed for W1 as 6.41 streams/ sq.km and 9.375 streams/ sq.km for W2. This value of S_f is low for W1 as compared to W2. Hence W1 is having high permeable geology and low relief. Channel frequency density also serves as a tool in establishing the erosional process operating over an area.

Relief aspects of the drainage network

1. Relief (H)

It is the maximum vertical distance between the lowest and highest point of the watershed. It is also known as maximum watershed relief (H). The value of relief for W1 was 146 m while for W2 it was found 144 m. It is an important factor in understanding the denudation characteristics of the basin (Sreedevi *et al.*, 2009) [22].

Slope map of study area is shown in Fig.6 and area under each slope is tabulated in Table 3.

2. Relief ratio (R_H)

It measures the overall steepness of a drainage basin by considering the extreme elevation difference and is an indicator of the intensity of the erosion processes operating on the slopes of the basin. The present study shows that the relief ratio for W1 was observed as 0.058 and 0.0786 for W2.

3. Relative relief (R_{HP})

Relative relief for watershed W1 was found to be 1.599 and for W2 it was 2.681 which is considered low. These low values of relative relief indicate that peak discharge rates are likely to be low and low erosion from the catchment.

4. Ruggedness number (R_n)

The value of ruggedness number was observed 0.435 for W1 and for W2 this value was observed as 0.483. 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.

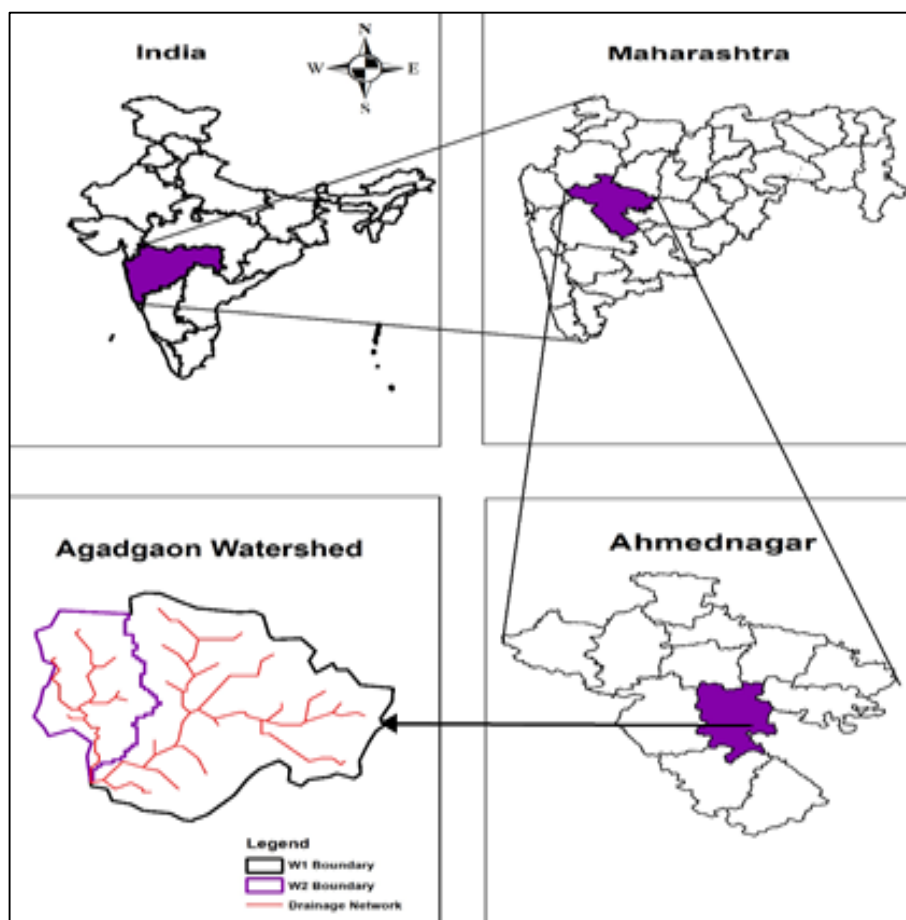


Fig 1: Location map of the study area

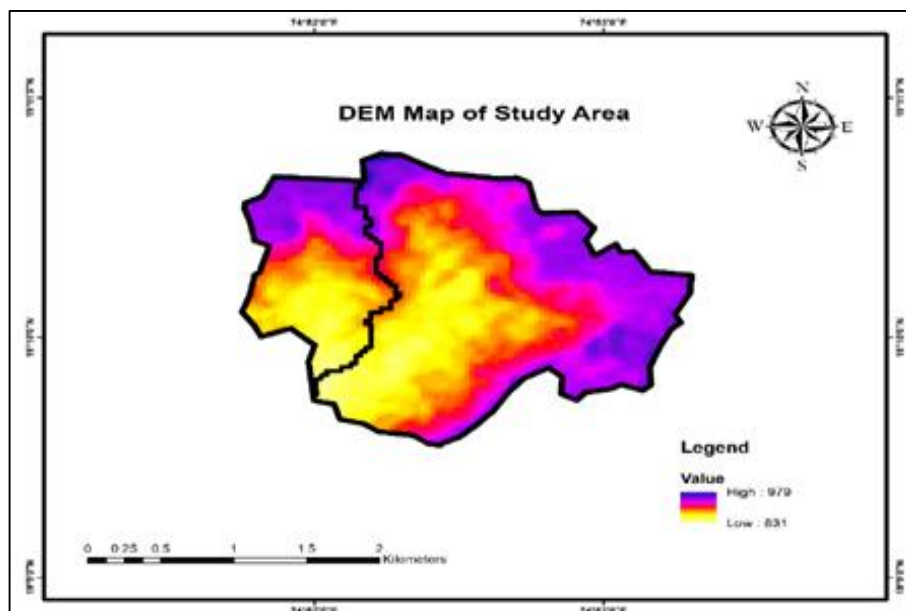


Fig 2: DEM map of the the study area

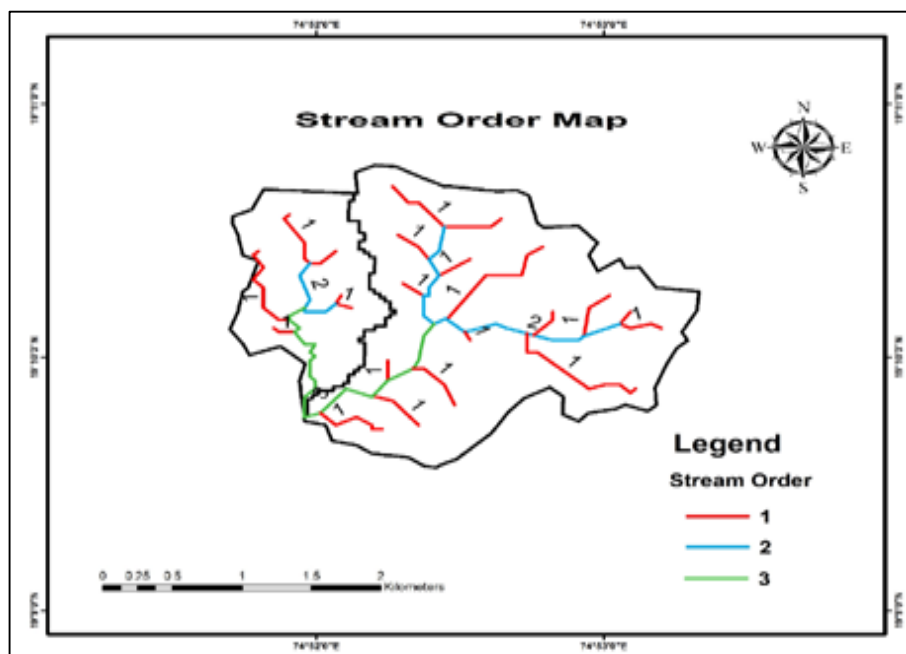


Fig 3: Stream order map of the study area

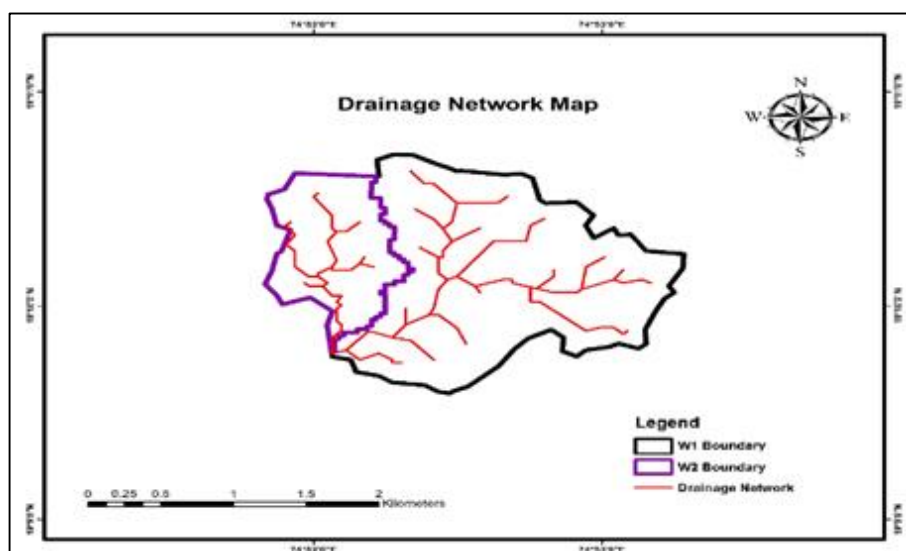


Fig 4: Drainage network map

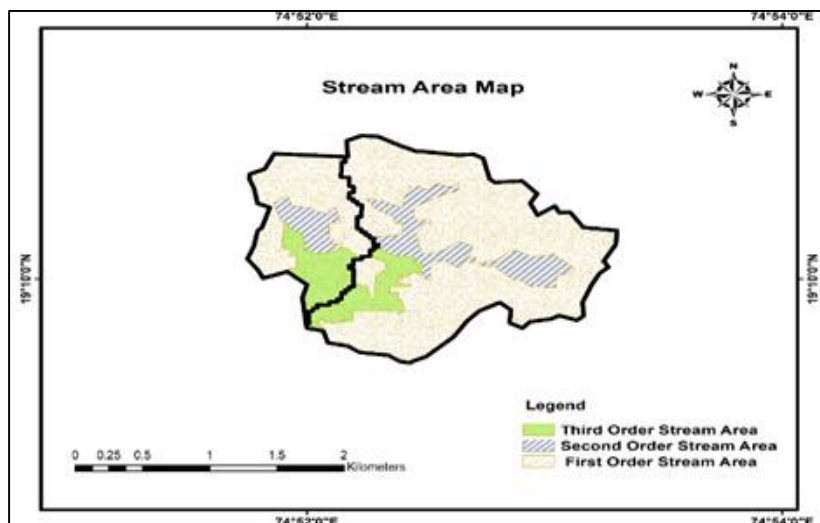


Fig5: Stream area map of the study area

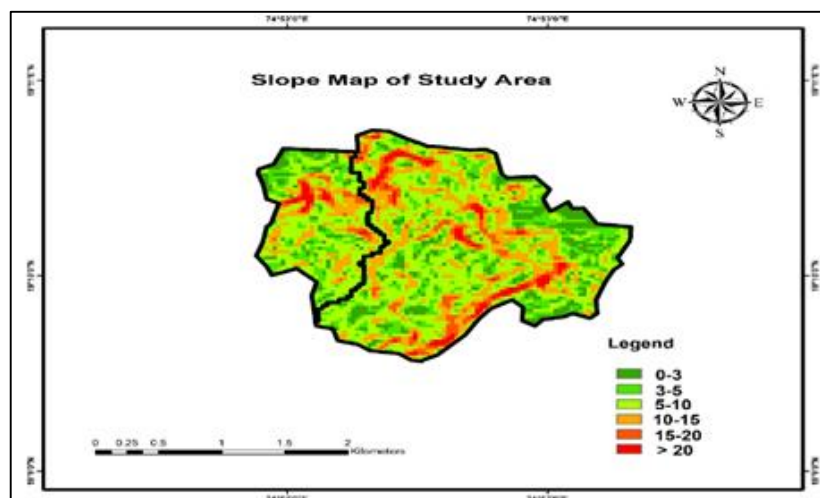


Fig 6: Slope map of the study area

Table 1: Linear and areal geomorphic parameters

Sr. No.	Watershed	Number of the stream in the order specified			Total no. of the stream ΣN_u	Stream length in the order specified, km			Mean Stream Length \bar{L}_u , km			Area of streams A_u , km ²		
		1 st	2 nd	3 rd		1 st	2 nd	3 rd	1 st	2 nd	3 rd	1 st	2 nd	3 rd
1.	W1	16	2	1	19	5.60	2.04	1.18	0.35	1.02	1.18	2.33	0.38	0.25
2.	W2	6	2	1	9	1.58	0.6	1.04	0.26	0.3	1.04	0.57	0.14	0.25

Table 2: Geomorphological characteristics of the watershed

Sr. No	Characteristic	W1	W2
1.	Length of Perimeter	9.13	5.37
2.	Drainage Area	2.96	0.96
3.	The maximum length of the watershed	2.48	1.70
4.	Main stream length	2.635	1.83
5.	Bifurcation ratio	4	2.45
6.	Stream length ratio	1.836	1.988
7.	Stream area ratio	1.283	1.59
8.	Form factor	0.4263	0.2866
9.	Shape index	2.3457	3.4891
10.	Circularity ratio	0.446	0.4184
11.	Elongation ratio	0.7362	0.6038
12.	Compactness coefficient	1.496	1.545
13.	Constant for channel maintenance	0.336	0.298
14.	Drainage density	2.979	3.354
15.	Stream frequency	6.41	9.375
16.	Avg. length of overland flow	0.168	0.149
17.	Relief	146	144
18.	Relief ratio	0.058	0.0786
19.	Relative relief	1.599	2.681
20.	Ruggedness no	0.435	0.483

Table 3: Area under different slope classes

Sr. No.	Slope (%)	Class	Area (ha)W1	Area (%)W1	Area (ha)W2	Area (%)W2
1.	0-3	Nearly level	37.26	12.59	12.51	13.03
2.	3-5	Gentle	47.52	16.05	18.33	19.09
3.	5-10	Moderately Gentle	115.37	38.98	39.51	41.16
4.	10-15	Steep	64.98	21.95	17.91	18.66
5.	15-20	Moderately steep	20.61	6.96	4.95	5.16
6.	>20	Steep	10.26	3.47	2.79	2.90
		Total area	296	100	96	100

Conclusions

An experiment was carried out for Morphometric Analysis of Agadgaon watershed using remote sensing and Geographic Information System. Watershed covers area 296 ha (W1) and 96 ha (W2) with third-order drainage basin.

The mean bifurcation ratio for W1 was 4 and 2.45 for W2 which shows that the basin was largely controlled by structures. For W1 and W2 form factor was observed as 0.4263 and 0.2866 respectively, which shows that both the watersheds are elongated in shape with low-form factor and hence experiences lower peak flows of longer duration. W1 has a value of elongation ratio as 0.7362 which indicates that watershed is less elongated and for W2 value of elongation ratio was 0.6038 which indicates an elongated shape of the watershed.

Bifurcation ratio, Stream length ratio, and stream area ratio of W1 were 4, 1.836, and 1.283 respectively and for W2 the values were 2.45, 1.988, and 1.59 respectively. The watershed is having high drainage density leads to fine drainage texture and indicates that the catchment area is more prone to flooding.

Low values of relative relief indicate that peak discharge rates are likely to be low and low erosion from the catchment. Similarly, all morphometric parameters were calculated for both watersheds. The study will be helpful for planning of water harvesting and groundwater recharge projects on watershed basis.

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