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DIGITAL DELINEATION OF WATERSHED AND ANALYSIS OF MORPHOMETRIC CHARACTERISTICS OF KUDAVALE MICRO-WATERSHED USING REMOTE SENSING AND GIS

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Abstract : Soil and water are the basic essentials for survival of life on the earth. The prosperity of nation depends on the quality of its land resources. Remote sensing and Geographic Information System (GIS) have become easier and efficient tools in the watershed development projects. Therefore, this attempt was made for digital delineation and analysis of morphometric characteristics for Kudavale micro-watershed using remote sensing and GIS. The watershed was delineated using digital elevation model in ArcGIS10.2. Digital Elevation Model (DEM) has been collected from ISRO's geoportal Bhuvan captured by Cartosat-1 satellite having spatial resolution of 2.5m. The analysis of morphometric characteristics showed that there were 43 streams present in watershed having fourth order as the highest stream order. The values of form factor, elongation ratio and circulation ratio were found 0.42, 0.73 and 0.51 respectively. From the analysis, it is found that the shape of Kudavale watershed is '+' type with N-S length slightly higher than E-W length. Also, watershed has dendritic type of drainage pattern with drainage density 2.17 km/km^2, which indicates gentle to steep slope terrain, medium dense vegetation, and less permeable with medium precipitation.

***IndexTerms* - RS and GIS, DEM, Digital Delineation, Morphometric Characteristics, ArcGIS.**

INTRODUCTION

Soil and water are the basic essentials for survival of human life on the Earth. With changing climate and growing demand of water for agriculture and urban development are increasing the pressure on water resources. The United Nations Environment Program (UNEP) estimates that more than two billion people will live under conditions of high water stress by 2050 which would be limiting factor for development in many countries around the world (Adham *et al.*, 2016). In fact every kind of activity is connected with land and prosperity of nation depends on the quality of its land resources.

In India, out of total geographical area of 328 million ha, 148.9 million ha representing 45% of total geographical area is subjected to soil erosion and land degradation. Water erosion alone is estimated to cause loss of 5334 million tonnes of top soil annually (Surya *et al.*, 2018). An average annual rainfall of India is 120 cm, which is among the highest for a comparable geographical area in the world. Despite India's vast water resources,droughts and famines are the common occurrence in many parts of country. Maharashtra contributes 9.4% geographical area of India, having net irrigated area 25.7 lakh ha. In the year 2019, the state has received 132.85 cm rainfall.

On the basis of geographical features, the state is divided into 3 natural regions, outof which Konkan region occupies the entire west coast of Maharashtra. Generally, climate of Konkan region is hot and humid. In Monsoon, from June to September, region receives rainfall between 3000 mm to 5000 mm.

Remote sensing (RS) is defined as science and art of collecting information about objects, areas and phenomena from a distance without being in contact with them. Geographic information system (GIS) is a system designed to capture, store, manipulate, analyse, manage and present spatial or geographic data. In the recent decades, Digital Elevation Model (DEM) and Geographic Information System (GIS) have become easier and efficient tools in the watershed analysis.

Traditionally, watershed delineation is done by drawing boundaries of watershed on topographic maps. In such maps, flow direction of water is decided with the help of contours and drainages depicted on the maps. This process is time consuming as well as requires large labour. In the modern approaches of watershed delineation, it requires only a Digital Elevation Model (DEM) as a base input. The watershed boundary is automatically derived from DEM following various steps such as sink removal, assigning flow direction andcalculation of flow accumulation (Kumar *et al.*, 2014). The DEMs are easily available and can be freely downloaded.

A particular watershed gives response to various hydrological processes in a different manner and its behaviour depends upon several physiographic, hydrological and geomorphological parameters. These responses are watershed specific but are very unique, thus the characterization of a watershed provides an idea about its behavior.. Various morphometric characters need to estimate of a watershed include linear aspects such as number of streams, stream order, stream length, stream length ratio andbifurcation ratio, areal aspects such as area, perimeter, drainage density, form factor, circulatory ratio and elongation ratio, relief aspects such as relief, relative relief, relief ratio and ruggedness number.

RESEARCH METHODOLOGY

3.1 Description of Study Area

Kudavale village, in Dapoli tehsil of Ratnagiri district of Maharashtra State, has been selected for the study. It is adopted village of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. It is situated 20 km away from Dapoli Campus and 150 km away from district headquarter Ratnagiri. The study area lies between 17º76' N lattitude and 73º17' E longitude. The total geographical area of Kudavale watershed is 1314.48 ha. The location map of the study area is shown in Figure 1.

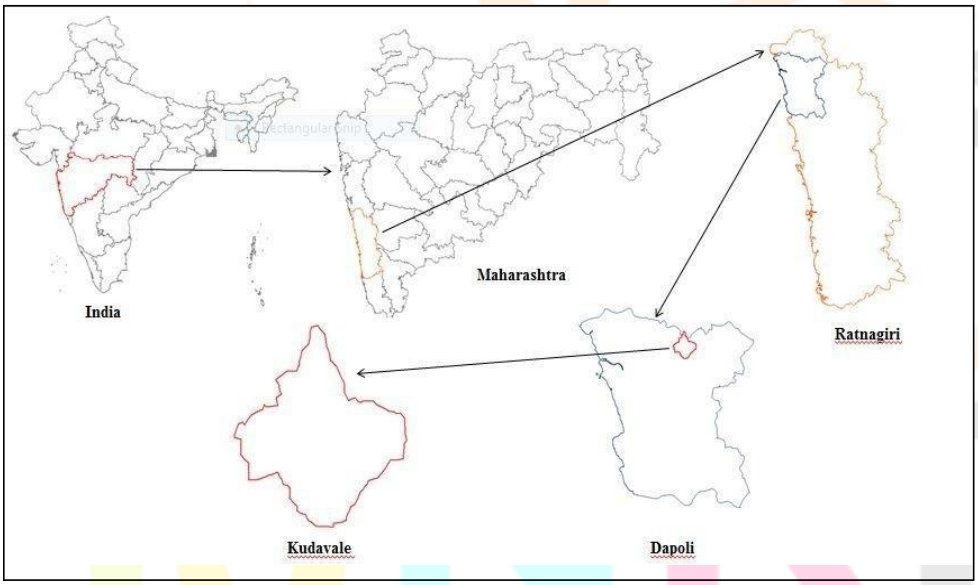

Fig.3.1 Location map of study area

3.2 Software Used

The software Arc GIS 10.2 which was available at Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, has been used for processing the remotely sensed data for delineating watershed and generating various maps like stream order map, land use land cover map, soil map, etc.

3.3 Data Collection

The various information required for the study was collected from various sources.

1. Digital Elevation Model (DEM) has been collected from ISRO's geoportal Bhuvancaptured by Cartosat-1 satellite having spatial resolution of 2.5m.
2. The village wise shape file and boundary of region has been extracted from diva gis website.

3.4 Procedure for delineation of watershed

Before watershed can be characterized, it needed to be delineated firstly. Watershed delineation is the process of identifying the drainage area of a set of points. Drainage divides are found along the highest point of the terrain. A Digital Elevation Model (DEM) is a representation of the bare ground topographic surface of the earth excluding trees, buildings and any other surface objects. The DEM can be created from a variety of sources. For delineation of watershed various operations were performed on DEM in ArcGIS software like fill, flow direction, flow accumulation, adding pour point, watershed andclipping the watershed from DEM. The flow chart of the procedure to delineate the watershed in ArcGIS software is given inFigure 2.

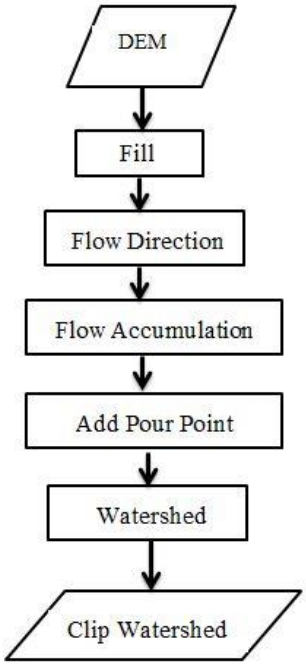

Fig. 2 Flow chart of procedure of watershed delineation

3.5 Morphometric Characteristics of watershed

The morphometric characteristics provide relevant information about terrain characteristics and hydrological behavior of the watershed. Morphometric characterizationis the systematic description of watershed geometry and its stream channel system to measure (I) Linear aspects of drainage network (II) Areal aspects of watershed and (III) Relief aspects of channel network. The parameters can be conveniently worked out from the delineated watershed obtained from DEM using the capability of GIS tools.

Table 1: Grouping of geomorphological parameters

Sr. No	Groups	Geomorphological Characteristics
1.	Linear aspects of Drainage networks (One dimensional)	Stream order, stream number, bifurcationratio, stream length, mean stream length,stream length ratio
2.	Areal aspects of watershed(Two dimensional)	Drainage density, form factor, circularityratio and elongation ratio
3.	Relief aspects of channel network (Three dimensional)	Relief ratio, relative relief, ruggednessnumber

3.6 Linear aspects of drainage network

The linear aspects are one dimensional components and deals with length parameters.

i. Basin Perimeter

It is defined as the length of the watershed divide that surrounds a basin. It is measured along a ridge line that separate one watershed along from other. It is estimatedusing ArcGIS software.

ii. Basin Length

It is defined as the length of the straight line from the mouth of the stream to thefarthest point of drainage divide. It was calculated as :

$$\text{Basin Length} = 1.312 \times \text{Area}^{0.568} \quad \text{\_\_\_(1)}$$

iii. Stream Order

The first step in a drainage basin analysis was designation of stream order. It is the method of ranking various streams on its size. It was introduced by Horton (1945). The smallest fingertip tributaries having no branches are designated as first order streams, where two first order streams join, a channel segment of second order is formed and so forth (Strahler, 1964). The generated network has maximum stream order of 6.

iv. Bifurcation Ratio (R_b)

The bifurcation ratio (Horton, 1945) is defined as the ratio of number of streams of one order (Nu) to the number of streams of next higher order (Nu+1). It varies with the stream order because of the changes in the watershed geometry (Strahler, 1964). The equation for law of stream numbers (Horton, 1945) is given below:

$$N_u = R_b^{(K-u)} \quad \text{\_\_\_(2)}$$

Where, K is highest stream order in watershed
u is stream order
R_b = Bifurcation ratio
Nu = No of streams of order u

v. Stream Length

The stream length of particular order is defined as the total of all streams of that order. It is used for the calculation of other parameters such as mean length, stream length ratio, drainage density, etc. The stream length decreases as the stream order increases. To find out the mean length of the channel of order u, the total length is divided by the number of segments (Nu) of that order, thus,

$$Lu = \frac{\Sigma Nu}{Nu} \quad \text{\_\_\_(3)}$$

Where,
Lu = mean length of channel of order 'u',
Nu = total no. of stream segment of order'u'.Stream Length Ratio (RL)

Horton (1945) defined the stream length ratio, RL, as the ratio of mean length, Lu ofsegments of order u to mean length of segments of the immediate lower order, $u-1$.

$$RL = Lu / Lu\text{-}1 \quad \text{\_\_\_(4)}$$

Where,
Lu = Average length of stream of order
Lu-1 = Average length of stream of order u-1

3.7 Areal aspects of watershed

It includes the description of areal elements such as watershed area,drainage density, form factor, elongation ratio, circulatory ratio, etc.

i. Area of the watershed (A)

Area of watershed is defined as the area contained within the vertical projection ofthe drainage divide on a horizontal plane. The area is expressed in hectares. It is estimated using ArcGIS software.

ii. Form Factor (Rf)

It is defined as the ratio of the watershed area (A) to the square of watershed length (Lb). It is a dimensionless number and will always be less than one. Smaller numerical value of form factor indicates more elongation of watershed.

$$\text{Form factor, } R_f = \frac{A}{Lb^2} \quad \text{\_\_\_(5)}$$

A = Area of watershed

L_b = Length of basin

iii. Circulatory Ratio (Rc)

Circularity ratio is defined as the ratio of watershed area (A) to the area of circle (A_C) having same perimeter as the perimeter of watershed. The numerical value may vary in between zero (in line) and one (in circle). It vary between 0.2 to 0.8.

$$R_C = A / Ac = 4A\Pi / P^2 \quad \_\_\_(6)$$

iv. Elongation Ratio (Re)

Elongation ratio, Rc, is defined as the ratio of the diameter of a circle (D_C) of thesame area as the watershed to the maximum length of the watershed (L_{bm}). The range of values of elongation ratio has been given in Table 3.2.

$$R_e = D_C / L_{bm} = 2 \times \sqrt{(A/\Pi)} / L_b \quad \_\_\_(7)$$

Where,

D_C = Diameter of circle with the same area as the watershed

v.Drainage Density

The drainage density (D_d) is defined as the ratio of the total length of all streams of all orders within a watershed to the total area of watershed (A). It provides us with an idea about the spacing between the streams. A higher density would suggest that the streams are closer and less density would mean that they are apart from each other. A higher drainage density also results in higher bifurcation ratio.

3.8 Relief aspects of channel network

Relief aspects are three dimensional properties of the watershed.

i. Maximum watershed relief (H)

Maximum watershed relief (H) is the elevation difference between basin mouth(discharge point) and the highest point on the basin perimeter. It is expressed in meter.

ii. Relative relief (RR)

Relative relief, R_R is the ratio of the maximum watershed relief to the perimeterlength. It is computed using following expression,

$$R_R = \frac{H}{L_p} \times 100 \quad \_\_\_(9)$$

Where,

H = Watershed relief

Lp = Length of perimeter

iii. Relief ratio (Rr)

The relief ratio (Rr) is defined as the ratio of maximum watershed relief divided bythe maximum watershed length. It is computed using following expression. High numeric value of relief ratio indicates the steep slope and vice versa.

$$Rr = H / Lb \quad \_\_(10)$$

Where,

H = Watershed relief

Lb = Basin Length

iv. Ruggedness number (RN)

The product of relief (H) and drainage density (Dd) is called ruggedness number.

$$RN = H \times Dd \quad \_\_\_(11)$$

Where,

Dd = Drainage density

IV. RESULTS AND DISCUSSION

4.1 Digital Delineation of Watershed

A digital watershed delineation procedure provides flexibility of delineating watersheds of various sizes by interactively choosing pour points along stream linkson either main stream or its branches. The procedure of delineation of watershed is depicted in section of materials and methods. The delineated watershed from the digital elevation model with ArcGIS is shown in Fig 3.

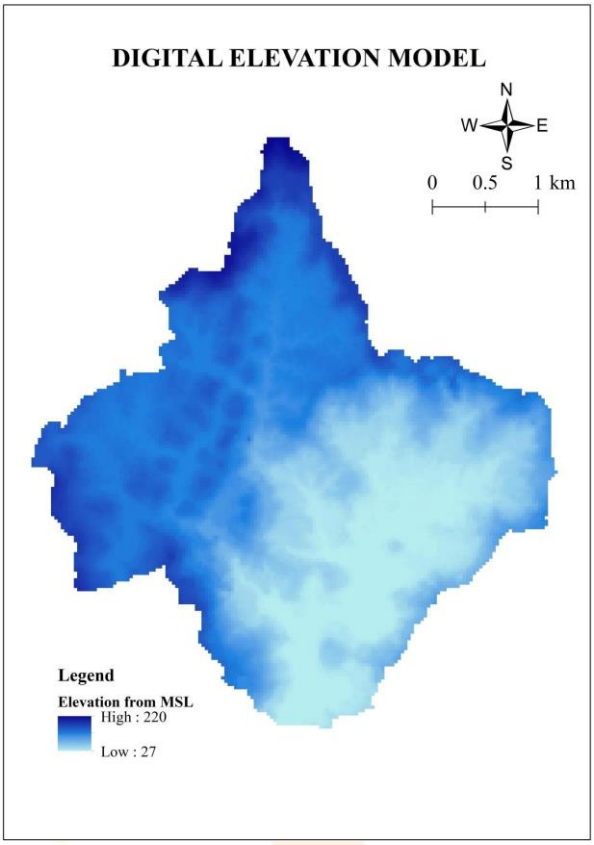

Fig 4.1: Digital Delineation of Kudavale Watershed using ArcGIS Software

4.2 Slope of Watershed

The slope map of Kudavale watershed using ArcGIS is shown in Fig 4. It indicates that slope of watershed varies between zero to more than 20 percent slope though the maximum area has slope below 5 %. Mostly mountainous area has slope greater than 20 % which is covered by forest. Average slope of watershed is 3.17%.

4.3 Contour Map of Watershed

Contour lines are the lines joining the points of equal elevation. The highest contour of watershed is 210 m and lowest contour is 30 m. The contour line map of Kudavale watershed is shown in Fig 5.

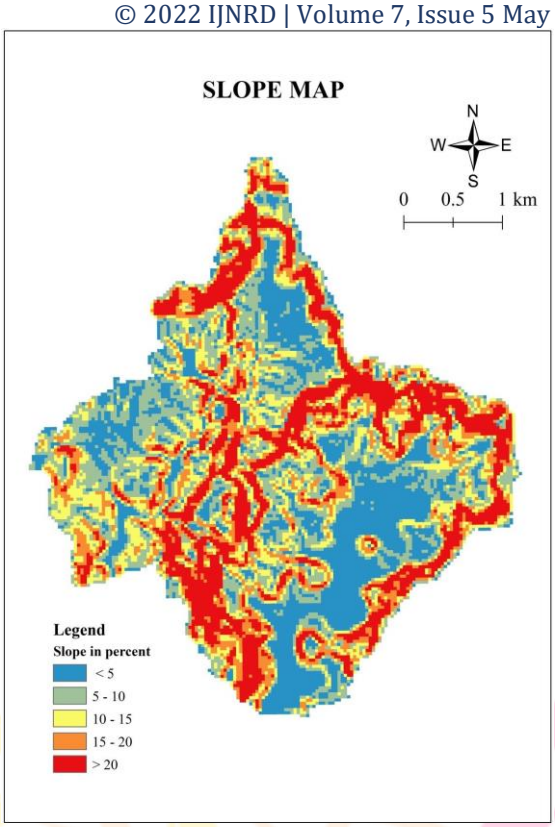

Fig 4.2: Slope Map of Kudavale Watershed using ArcGIS Software

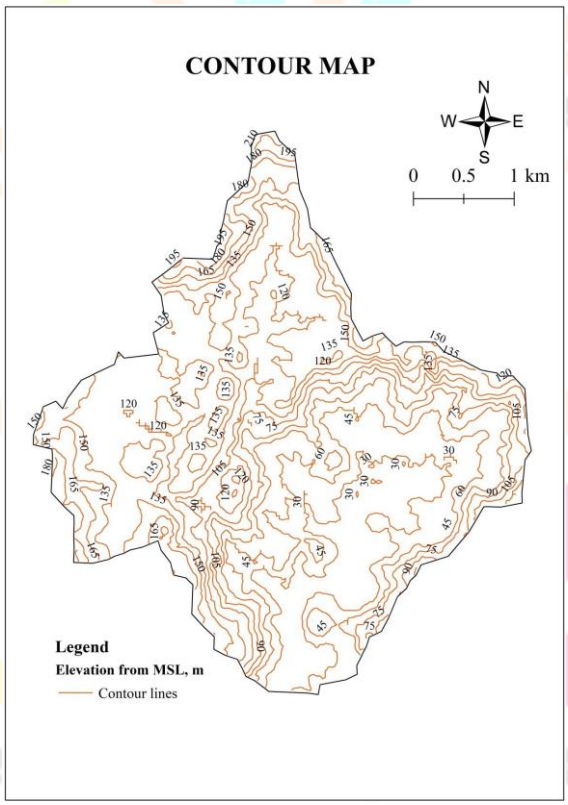

Fig 4.3: Contour Map of Kudavale Watershed using ArcGIS Software

4.4 Analysis of Morphometric characteristics of watershed

The morphometric analysis of the watershed was carried out to find thevarious geomorphic parameters. Morphometric analysis is carried out for quantitative evaluation of drainage basin and for planning and management of water resources. Three major aspects linear, areal and relief have been described for analysis. Linear aspect in morphometry is characterized by basin length, stream order, stream number, stream length and bifurcation ratio. Areal aspect represents the characteristics ofcatchment area and describes how catchment area controls and regulates the hydrological behaviour. Relief aspect defines terrain setup of the catchment andterrain characteristics.

4.4.1 Drainage pattern

Drainage pattern is expressed as a plan of a river system that reflects different types of information about geology and predominant slope of the drainage basin. The arrangement of streams in a drainage system constitutes the drainage pattern, which inturn reflects mainly structural or lithological controls of the underlying rocks. In Kudavale watershed, dendritic type of drainage pattern has been found. Dendritic drainage pattern shows homogenous and uniform soil and rocks. It shows that subsurface geology has a similar resistance to weathering so there is no apparent control over the direction the tributaries take. Drainage density map for Kudavale watershed is shown in Fig 6.

4.4.2 Linear Aspects of Drainage Pattern

Perimeter of watershed

Perimeter is calculated using the geometry of each layer in ArcGIS software.
The calculated perimeter of Kudavale watershed was 17.83 km.

Stream Order

In the present study, stream ordering has been carried out based on the methodproposed by strahler (1964). The total number of streams are 56. The smallestfingertip streams are designated as order 1. It reveals about size of stream, runoff, drainage area and its extent is directly proportional to the size of watershed (Soni, 2017).There are 43 streams of order I, 9 streams of order II, 3 streams of order III and 1 stream of order IV over the area of 13.15 km^2 . The number of streams of order I is more, it indicates that the land is undulating. Fig 7 shows the stream order map of the watershed.

Stream Length

The mean stream length and total stream length of each stream order is measured using ArcGIS software. It shows development of the stream segments and surface runoff characteristics. Streams having relatively smaller lengths indicate that the area is with high slopes. Longer stream lengths are indicative of flatter gradient. The total length of first order streams is 12561.86 m, second order is 8121.19, third order is 6287 m and fourth order is 1529.42 m. Stream length increases as the order number decreases.

Bifurcation Ratio

It is a measure of degree of distribution of stream network and influences the landscape morphometry. The value of bifurcation ratio ranges from 3.0 to 5.0 . The lower value of Rb indicates that the area has been less affected by structural disturbances. Values higher than 10 shows the structural controls play dominant role with elongate basins. The Rb values reflect shape of basin. Elongated basins have high Rb values while circular basins have low Rb values. The bifurcation ratio of watershed is 3.24. It indicates that the basin is elongated at upper half and circular in lower half and also the area is less affected by structural disturbances. The value of bifurcation ratio is given in Table 1.

Stream Length Ratio

The stream length ratio gives an idea about the relative permeability of the rock formation. The stream length ratios for first and second, second and third, third and fourth are 0.65, 0.74, 0.24 respectively. There is a variation in stream length ratio between streams of different order due to differences between slope and topography.

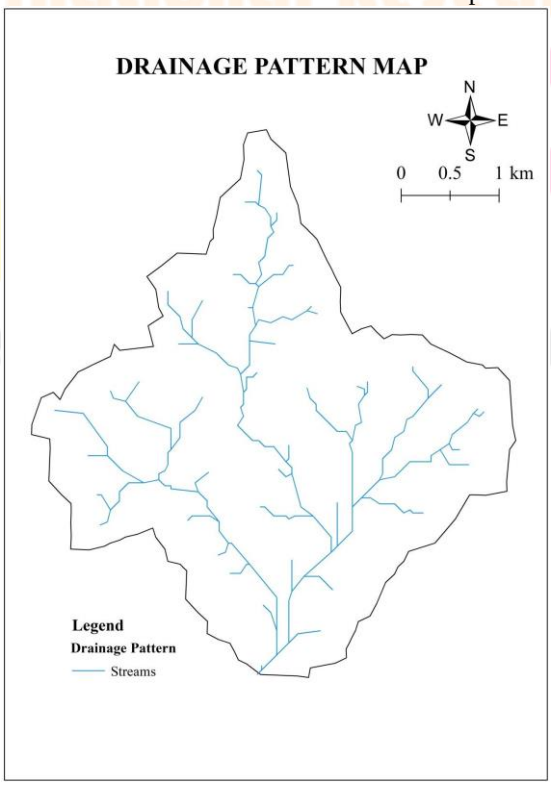

Fig 4.4: Drainage Density Map of Kudavale Watershed using ArcGIS Software

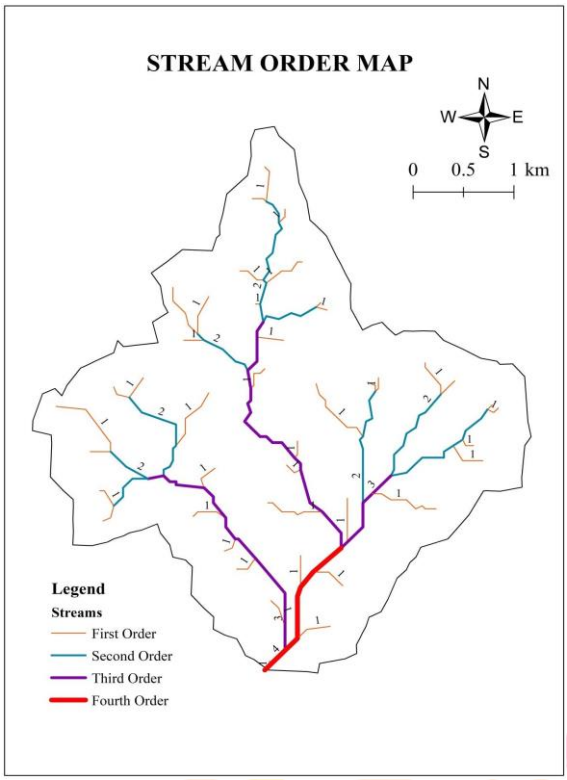

Fig 4.5: Stream Order Map of Kudavale Watershed using ArcGIS Software

4.4.3 Area of watershed

Area of Kudavale Watershed is found 1315.42 ha using ArcGIS software.

Drainage Density

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. While high drainage density is the resultant of impermeable subsurface material, sparse vegetation and mountainous relief (Soni, 2017). The drainage density for Kudavale watershed is 2.17 km/km^2, which indicates gentle to steep slope terrain, medium dense vegetation, and less permeable with medium precipitation. The drainage density map of Kudavale watershed using ArcGIS software is shown in Fig 8.

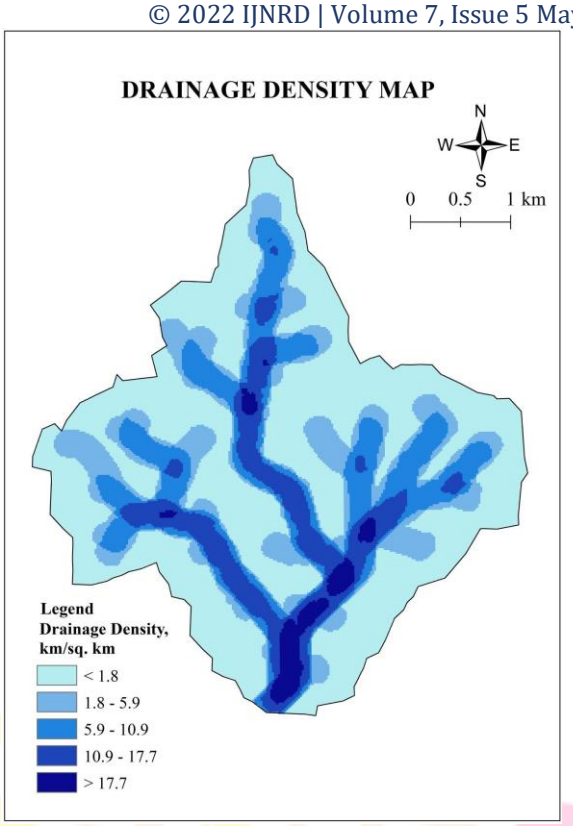

Fig 4.6: Drainage Density Map of Kudavale Watershed using ArcGIS Software

Form Factor

Form factor describes the shape of basin (Horton, 1932). The value of form factor varies from zero (highly elongated shape) to unity i.e. 1 (perfect circular shape).The form factor for Kudavale watershed is 0.42 which implies that watershed is less elongated.

Circulatory Ratio

It indicates the shape of basin. Circulatory ratio less than 0.5 indicates that it is elongated and highly permeable homogeneous geologic materials, whereas circulatoryratio greater than 0.5 indicates that the basin is circular in shape and characterised by high to moderate relief and drainage system is structurally controlled. The circulatory ratio of Kudavale watershed is 0.51. The shape of Kudavale watershed is some what '+' type with N-S length slightly higher than E-W length.

Elongation Ratio

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. It ranges from 0.6 to 1.0. Strahler (1964) classified elongation ratio as 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). The elongation ratio for Kudavale watershed is 0.73 which implies that watershed is less elongated.

4.4.4 Relief Aspects of Channel Network

Relief

Basin relief is responsible for the stream gradient and influences flood pattern and sediment volume that can be transported. The relief of Kudavale watershed is 180m which shows low relief of the area.

Relief Ratio

It shows overall steepness of a drainage basin. The relief ratio of Kudavale watershed is 0.032 which is relatively low (<0.1) suggesting gentle slope.

Relative Relief

The relative relief for Kudavale watershed is 1.01 %.

Ruggedness Number

This number represents that if drainage density is increased keeping relief as constant, the average horizontal distance from 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 goes on increasing. The ruggedness number for Kudavale watershed is 0.39. The Rn value is relatively low which suggests less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density (Paretha and Paretha,2012).

The values of different geomorphological parameters, calculated by using the methodology as discussed above. The calculated values are presented in the Table 1.

Table 1 Morphometric Characteristics of the Watershed under study

Sr. No.	Characteristics	Estimated Value
	Linear aspects	
1.	Basin perimeter	17.83 km
2.	Basin Length	5.67 km
3.	Stream Order	Number of Streams in given Order
	I	43
	II	9
	III	3
	IV	1
4.	Stream Order	Sum of length of streams of given order
	I	12561.86 m
	II	8121.19 m
	III	6287.00 m
	IV	1529.42 m
5.	Stream Order	Mean Stream Length
	I	292.14 m
	II	902.44 m
	III	2095.66 m
	IV	1529.42 m
6.	Stream Length Ratio	
	RL1	0.65
	RL2	0.74
	RL3	0.24
7.	Bifurcation Ratio R_b	3.24
	Areal Aspects	
8.	Area of watershed	13.15 km^2
9.	Form Factor	0.42
10.	Circularity Ratio	0.51
11.	Elongation Ratio	0.73
12.	Drainage Density	2.17 km/km^2
	Relief Aspects	
13.	Relief	180 m
14.	Relief Ratio	0.032
15.	Relative Relief	1.01%
16.	Ruggedness Number	0.39

SUMMARY AND CONCLUSION

In this study, the digital elevation model (DEM) was downloaded from ISRO's geoportal 'Bhuvan' which is captured by Cartosat 1 satellite having spatial resolution 2.5m. The digital delineation of the watershed is performed in Arc GIS 10.3 by using DEM. It gave a definite boundary of watershed depending upon the rainfall and runoff which contributes in the area. Digital delineation saves time, labour and money as well as it is an easy method. The drainage pattern of streams was of dendritic type pattern.. There were 43 streams present in the watershed with order IV as the highest stream order. The average bifurcation ratio (Rb) is 3.56. It indicates that the basin is elongated at upper half and circular in lower half and also the area is less affected by structural disturbances.

The drainage density for Kudavale watershed is 2.17 km/km^2, fells in its medium category which indicates gentle to steep slope terrain, medium dense vegetation, and less permeable with medium precipitation. The formfactor is 0.42 which implies that watershed is less elongated. The circulatory ratio and elongation ratio are 0.51 and 0.73 respectively. The relief of Kudavale watershed is 180m which shows low relief of the area. The relief ratio is 0.032 which is relatively low (<0.1) suggesting gentle slope. The ruggedness number is 0.39. The Rn value is relatively low which suggests less prone soiling erosion and having intrinsic structural complexity in association with relief and drainage density.

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