Morphometric Analysis of Wakawali Watershed using Remote Sensing and GIS.

Abstract:

Geographic Information Systems (GIS) and remote sensing are essential tools for collecting and analysing large amounts of geographic data. The morphometric analysis of the Wakawali watershed has been conducted using GIS techniques. The study has conducted in Wakawali in Dapoli tahsil of Ratnagiri district, Maharashtra. In this study the SRTM DEM was used to study the detailed morphometric characteristics of Wakawali watershed. The total area of Wakawali is 685ha. The total twenty morphometric parameter linear, aerial and relief aspect of watershed were calculated. The result revealed that the basin has 4th order drainage network. The mean bifurcation value of watershed was 1.95 which indicate that the drainage pattern has strong structural control. The value of drainage density which was 2.30 km/km^2, which falls in Coarse drainage structure, which denote that the gentle to steep slope terrain, medium dense vegetation, and less permeable with medium precipitation. Form factor and Circulatory ratio 0.56 and 0.25 indicate that the basin is in elongated in shape. The value of relief ratio of the watershed was 0.031 which indicating that the rolling and gentle slopes and the basin is less prone to erosion. This study helps in understanding the watershed hydrological behaviour, which directly influences runoff and soil loss.

Keywords: SRTM DEM, Morphometric parameter, Remote sensing and GIS.

1.Introduction:

In developing countries, problems with soil erosion and sedimentation threaten the sustainability of land management and the development of water resources. These problems lead to surface water pollution, dam and reservoir damage, and a loss of watershed storage capacity (Ninija 2017). In order to achieve sustainable development, a watershed is the ideal unit for managing resources like land and water to mitigate the impact of natural disasters. An understanding of the drainage network process in the watershed can be gained through a study of morphometric parameters. The mathematical calculations and measurements of the sizes and shapes of specific landforms on the surface of the earth are known as morphometric characteristics. In order to properly plan a watershed, a quantitative morphometric characterisation of a drainage basin is to be the most satisfactory method because it allows us to compare different drainage basins developed in different geologic and climatic regimes and comprehend the relationship between various aspects of the drainage pattern of the basin (Zende and Nagarajan, 2011). Geological structures, bedrock, and lithology are the main factors influencing morphometric parameters. Therefore, information about land use patterns, hydrology, geology, and geomorphology is very instructive for a reliable evaluation of the watershed's drainage pattern (Astras and Soulankellis, 1992). In the morphometric analysis of a drainage network, linear, areal, and relief aspects are taken into account. The linear aspect pertains to the number and length of stream segments, as well as the hierarchical streams order. According to (Khakhlari and Nandy (2016), the areal aspect comprises the analysis of basin parameters and basin shape, both topological and geometrical (stream frequency, drainage density) and the relief aspect the relief aspect comprises the study of basin relief and relative relief and ruggedness number. In India as well as around the world the use of remote sensing and GIS for the morphometric analysis is increasing day by day.It is a crucial tool for delineation and the computation of morphometric parameter in the watershed. The goal of morphometric analysis of the watershed is to gather the accurate and ideal information about the drainage system assessable stream network features. This study was conducted using RS and GIS techniques for the Wakawali watershed, with a focus on the significance of geomorphological parameters in the watershed.

2. Material and Method:

2.1Study Area:

Wakawali watershed is situated in Dapoli tehsil of Ratnagiri district, Maharashtra. It belongs to Konkan region. The total geographical area of Wakawali watershed which about 685ha. It is located between the 17^{o} 44' to 17^{o} 47' N and 73^{o} 16' to 73^{o} 18' E, having an elevation of 250 m of above the sea level. The area is recognized as having a hot and humid climate, with moderate temperatures ranging from as low as 11.9°C to as high as 37.3°C, and rainfall exceeding 3500mm, with over 90% of that falling between June and September. The location map of Wakawali watershed is as shown in Fig.1.

2.2Data used

The morphometric parameters of the watershed were analysed using an integrated remote sensing and GIS approach. Using remote sensing and GIS to analyse morphometric parameters (linear, areal, and relief), DEM has been utilised to extract drainage pattern. The DEM of Wakawali watershed was downloaded from https://Bhuvan nrsc gov.in portal having 30 m resolution. The processing of the DEM was done using QGIS software.

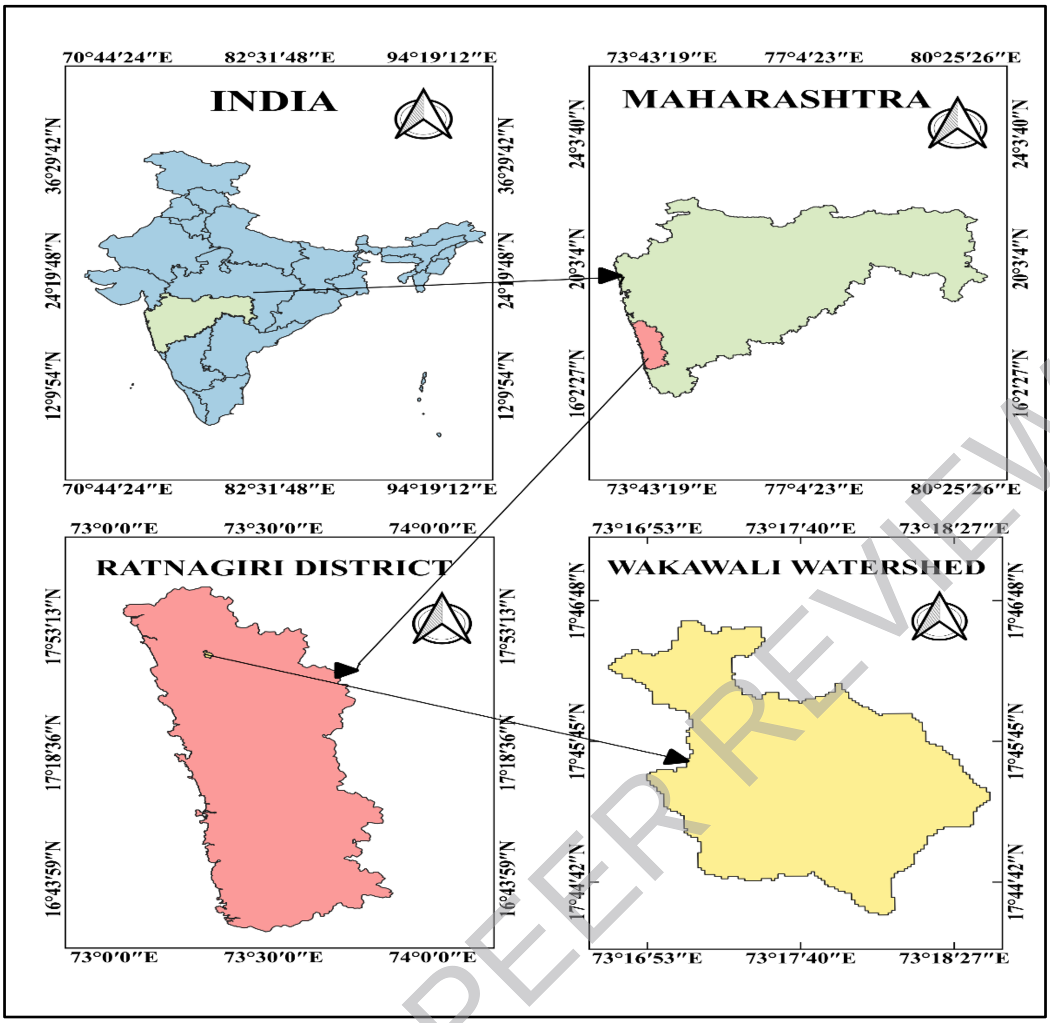

Fig.1: Location Map of Study Area

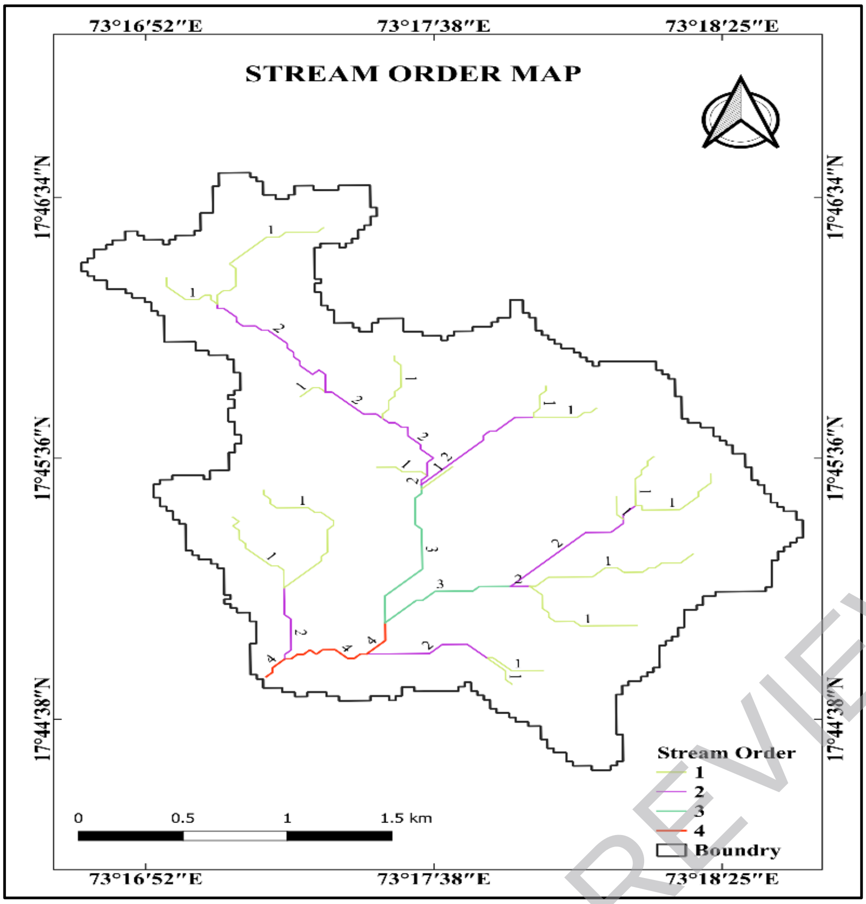

Fig.2: Stream Order Map of Wakawali Watershed

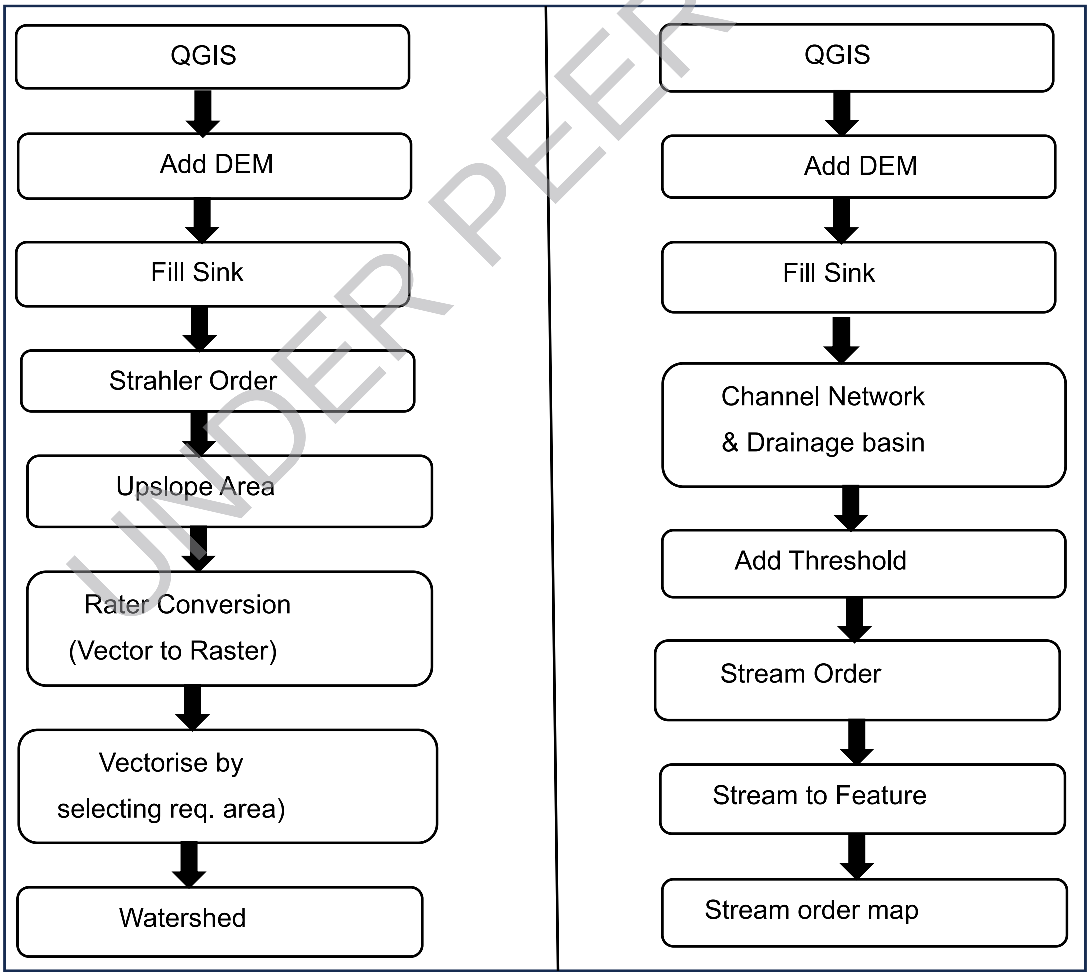

Fig 3: Flowchart for Preparation of Watershed and Stream Order

Table.1: Formulae of morphometric characteristics of linear, aerial and relief aspect

Sr. No	Morphometric characteristic	Formula	Units	Reference
Basic Parameter				
1.	Area of Basin (A)	QGIS Software	km^2	-
2.	Perimeter (P)	$L_b = 1.312 \times A^{0.568}$	km	-
3.	Length of Basin (L_b)	QGIS Software	km	Nookaratnam et al.(2005)
4.	Max. Elevation (H)	QGIS Software	m	-
5.	Min. Elevation (h)	QGIS Software	m	-
Linear Aspect				
6.	Stream Order (u)	Hierarchical rank	Dimensionless	Strahler (1964)
7.	Stream number (N_u)	Number of Stream of order u	Dimensionless	Horton (1945)
8.	Stream length (Lu)	$L_u=L_{u1}+L_{u2}+L_{u3}+\ldots+L_{un}$	m	Horton (1945)
9.	Stream Length Ratio (R_L)	R_L=Lu/Lu-1	Dimensionless	Horton (1945)
10.	Bifurcation Ratio (R_b):	R_b=Nu/Nu+1	Dimensionless	Schumm (1956)
Aerial Aspect				
11.	Drainage Density (D_d):	$D_d = \mathrm{Lu}/\mathrm{A}$	km/km^2	Horton (1945)
12.	Stream Frequency (F_s)	F_s =Nu/A	km^{-2}	Horton (1945
13.	Form Factor (R_f)	R_f =A/Lb^2	Dimensionless	Horton (1945)
14.	Circularity Ratio (R_c)	Rc=4πA/P^2	Dimensionless	Miller (1953)
15.	Drainage Texture(T)	T=Nu/P	km^{-1}	Smith (1950)
16.	Drainage intensity (D_i)	D_i= F_s/ D_d	km^{-1}	Faniran (1968)
Relief Aspect				
17.	Basin Relief(R)	R=H-h	m	Strahler (1952)
18.	Relief ratio (R_h)	R_h= H/L_b	Dimensionless	Schumm (1965)
19.	Relative Relief (R_r)	R_r=(H/P) ×100	Dimensionless	Melton (1957)
20.	Ruggedness Number (R_n)	R_n = H/D_d	Dimensionless	Strahler (1956)

3.Result and Discussion

Morphological characteristics

An essential part of quantitative geomorphology, is to examine the geometric properties of the landforms. Morphological characterization was systematic description of watershed ‘s geometry. The Wakawali watershed has 4th order drainage network. The linear, aerial and relief aspect of Wakawali watershed is as shown in Table 2 and 3.

3.1Basic Morphometric Parameter:

Basic aspects of watershed include Area of watershed (A), Perimeter of watershed (P) and Basin Length (L_b).

3.1.1Watershed Area (A):

Area of the Wakawali Watershed as determined by using QGIS software and it wasfound to be 685 ha.

3.1.2Perimeter of watershed (P)

The perimeter described as the watershed's outer periphery that includes the watershed area (A). The watershed's size and shape determined from the value of P (Schumm, 1956). QGIS software is used to calculate the watershed's perimeter. The perimeter of the Wakawali watershed is 18.61 km.

3.1.3Length of Basin (L_b):

The value of length of basin (L_b) for Wakawali watershed is 3.49 km.

3.2 Linear Aspects of Watershed:

Table 2: Stream order of watershed

Stream order(u)	No. of Streams (Nu)	Stream length km	Mean Stream Length (km)	Stream Length Ratio	Bifurcation ratio (Rb)
1	17	7.79	0.45	-	-
2	6	4.74	0.79	0.60	2.83
3	2	2.37	1.18	0.5	3
4	1	0.88	0.88	0.37	2
			Average	0.49	1.95

3.2.1Streamorder(u):

The first stage of morphometric analysis is known as "stream orders." There are no tributaries in the first-order streams. A second higher order stream gets generated when two first order streams merge. Third-order streams are generated when two second-order streams merge, and so forth. The Strahler (1964) method was used to perform the order of streams in this study. The highest order, a fourth-order stream network, was found in the Wakawali watershed. The stream order map is as shown in Fig.2.

3.2.2Stream Number (N_u):

Stream number is the total number of streams of each order in a particular watershed. According to Horton (1945), the number of streams is inversely proportional to the order of streams. Less permeability and infiltration resulted from the higher number of streams in lower order. (Dandekar et., al.2017.) In the Wakawali watershed the total number of streams found to be 26. There are 17 streams of I^{st} order, 6 streams of II^{nd} order, 2 streams of III^{rd} order and 1stream of IV^{th} order.

3.2.3Stream Length (L_u):

The total length of all streams of order 'u' is known as the stream length. The total stream length and mean of each order were calculated using QGIS. Stream order increases as stream length Decreases. Areas with finer textures and larger slopes tend to have streams of comparatively shorter lengths. In general, flatter gradients are indicated by longer stream lengths (Strahler 1964). The total Stream length of all the streams of Wakawali watershed was 15. 78 km.

3.2.4Stream Length Ratio (R_L):

According to Horton (1945), the stream length ratio is the ratio of the mean length of the stream segment (Lu) of order u to the mean length of the stream segment of next lower order (Lu-1). As increasing trend in stream length ratio from lower order to higher order indicate their geographic stage. Stream length ratio for Wakawali watershed varies from 0.37 to 0.60. The stream length ratio for order II/I was 0.60, III/II was 0.5, IV/III was 0.37.

3.2.5Bifurcation Ratio (R_b):

It is the ratio of total numbers all streams in one order (Nu) to total numbers of all streams in the next higher order (Nu + 1). The Rb value ranges between3.0 to 5.0. The value of bifurcation ratio is higher in elongated basins and lower in circular basins (Schumm, 1956). It could measure watershed hydrographs and surface water potential. Lower bifurcation ratio values indicate the watersheds' characteristics of the watersheds, which show that the drainage pattern has not been distorted and that there have less structural disturbances. The mean Rb value of watershed is to be 1.95 which shows the drainage pattern has strong structural control and have less structural disturbance.

3.3Areal Aspects of Watershed

3.3.1Drainage density (D_d):

The drainage density defined as the ratio of the total area of a watershed to the total length of all streams of all orders within that watershed. Drainage density is higher in regions with weak subsurface strata, high relief, and sparse vegetation. It is lower in regions with low relief and dense vegetation cover. Permeability, vegetative cover, and infiltration capacity are all inversely correlated with drainage density (Horton 1945). According to Strahler (1957) the Dd is classified into four different categorized: coarse (< 5 km^{-1}), medium (between 5.0 to 13.7 km^{-1}), fine (between 13.7 to 155.3 $km^{-1)}$, and ultra-fine (> 155 km^{-1}). Low drainage density results from a coarse drainage texture, while high drainage density results from a fine drainage texture. The Wakawali watershed has a drainage density of 2.30 km/km^2, falling within the coarse drainage structure, which denotes terrain with gentle to steep slopes, medium-dense vegetation, and less permeability with medium precipitation.

3.3.2Stream frequency (S_f):

The number of streams per unit area is known as the stream frequency or channel frequency. The drainage area has a direct impact on it (Horton, 1945). While it is directly correlated with runoff and the degree of dissection, it has an inverse relationship with mean annual rainfall and infiltration (Pankaj and Kumar 2009). Stream frequency (Fs) of Wakawali watershed is 3.79 km^{-2}.

3.3.3Form Factor (F_f):

According to (Horton,1945), Form factor is the ratio of the watershed area (A) to the square of watershed length (Lb). It is a shape of perimeter, which indicate that the watershed is elongated, oval or circular. For Wakawali watershed value of form factor is 0.56, which indicates watershed is elongated. An elongated basin with a low form factor indicated that the basin had a flatter peak for a longer duration. (Shinde et.al 2022)

3.3.4Circularity Ratio (R_c):

It is defined as the ratio of basin area to that of a circle with the same perimeter as that basin (Miller 1953). It is a dimensionless property. The range of circulatory ratio varies from 0 to1. The slope basin relief geologic structure and land use land cover all have impact on circulatory ratio. The Rc value for Wakawali watershed 0.25 which indicated elongated shape of watershed.

3.3.5Drainage texture (T):

According to (Horton, 1945), texture ratio is the ratio total stream number of all orders and perimeter of that area. Smith (1950) Drainage texture is influenced by the number of physical elements including factors like rainfall, type of soil, vegetative cover and relief. The drainage texture is categorized in drainage texture values in the five class, very fine (> 8), fine (6–8), moderate (4–6), coarse (2–4), and very coarse (< 2),(Smith 1950). The Drainage texture value of the watershed is 1.39 $km^{-1,}$ indicating that the watershed has very course drainage texture.

3.3.6Drainage intensity (D_i):

It is the ratio of stream frequency to the drainage density of basin. (Faniran 1968). Drainage intensity value is eventually reduced by Lower drainage density and stream frequency values. The drainage intensity of the study area was 1.64 km^{-1}, which is relatively low value. This implies that the watershed does not quickly remove the surface runoff and has good ability to absorb the water into the soil which helps in increase the ground water recharge. The low drainage intensity also implies the lower risk of flooding hence the water required more time to seep into the soil rather than the runoff on the surface. (Kumari et.al.2023).

3.4Relief Aspects of Watershed

3.4.1Basin relief (R):

The elevation difference between highest and lowest point located in drainage basin is known as basin relief. The basin topographic features including as slope, drainage patterns, and erosion potential is the difference in elevation between the highest and lowest points in a basin. In the present study, the Basin relief of the Wakawali watershed is 111.54 m which shows very low relief of watershed.

3.4.2Relief ratio (R_h):

The relief ratio is the ratio of the basin relief to the watershed's longest dimension parallel to the main flow path. A useful indicator of the watershed's gradient features, the relief ratio is a dimensionless ratio of basin length to basin relief (Schumm, 1956). It gives the information about the slope general steepness as well as the watershed slope that are prone to erosion. The watershed relief ratio 0.031 indicate that the basin has gentle, rolling slope making it less prone to erosion.

3.4.3Relative relief (R_r):

The ratio of basin relief to the perimeter of watershed is called relative relief (Melton1957). The relative relief is the variation in height. It displays the basin elevation from highest point to the outlet point. The Relative relief of the watershed is 0.59.This relative value suggest that the catchment erosion and peak discharge rate are likely to be low.

3.4.4Ruggedness number (R_n):

The drainage density is multiplied by relief gives the ruggedness number. The slope and drainage density determines the ruggedness number. While the watershed has high ruggedness number has steep long slope and high drainage density. A lower ruggedness number indicates a lower stream velocity, which suggests a lower susceptibility to soil erosion, (Strahler 1956). In this study the value of Rn obtained by 0.25 which recommends less prone to soil erosion.

Table3: Morphometric Parameter of linear aerial and relief aspect of watershed.

Sr. No	Morphometric characteristic	Units	Result
Basic Parameter			
1.	Area of Basin (A)	ha	6.85
2.	Perimeter (P)	km	18.61
3.	Length of Basin (L_b)	km	3.49
4.	Max. Elevation (H)	m	189.33
5.	Min. Elevation (h)	m	79.51
Linear Aspect			
6.	Stream Order (u)	Dimensionless	4th
7.	Stream number (N_u)	Dimensionless	26
8.	Stream length (L_u)	m	15.78
9.	Stream Length Ratio (R_L)	Dimensionless	0.37 to 0.60
10.	Bifurcation Ratio (R_b):	Dimensionless	1.95
Aerial Aspect			
11.	Drainage Density (D_d):	km/km^2	2.30
12.	Stream Frequency (F_s)	km^{-2}	3.79
13.	Form Factor (R_f)	Dimensionless	0.56
14.	Circularity Ratio (R_c)	Dimensionless	0.25
15.	Drainage Texture(T)	km^{-1}	1.39
16.	Drainage intensity (D_i)	km	1.64
Relief Aspect			
17.	Basin Relief(R)	m	111.54
18.	Relief ratio (R_h)	Dimensionless	0.031
19.	Relative Relief (R_r)	Dimensionless	0.59
20.	Ruggedness Number (R_n)	Dimensionless	0.25

4.Conclusion:

In conclusion, by applying GIS techniques, the morphometric characterization was done by measuring the linear, areal, and relief aspects of the Wakawali watershed. For the determination of morphological characteristics and watershed delineation the SRTM DEM was used. The Wakawali watershed covers 685 hectares area and has a fourth-order drainage network. The total number of streams of watershed are 26. As the stream order increases stream number decreases. The value of drainage density and Drainage texture for Wakawali watershed is 2.30 km/km^2,1.39Km which falling within the coarse drainage structure, which denotes terrain with gentle to steep slopes, medium-dense vegetation, and less permeability with medium precipitation. Shape factor like Circularity Ratio and Form Factor indicates that the watershed is elongated in shape. Analysing linear, aerial and relief parameters can help to understand the watershed's geomorphological characteristics and how they affect erosion processes. This study will be helpful in identifying areas that are prone to soil erosion, which is essential for implementing conservation measures.

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