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Morphometric Analysis of Kakan Watershed using Remote Sensing and GIS

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A B S T R A C T

In this study, remote sensing and GIS have been utilized for analyzing the morphometric characteristics of Kakan watershed. ALOS digital elevation model (DEM) of high spatial resolution (12.5 m) was used for preparation of stream network map and slope map of the study area. The Kakan watershed covers an area of around 47.44 km^2 and has fifth order trunk stream were computed using Arc-Map 10.8.Totally, 131.61 km stream length has been extracted from ALOS-DEM; about 77.51 km was in first order, 25.03 km was in second order, 15.15 km was in third order, 6.58 km was in fourth order and 7.35 km was in fifth order. Results from stream number and mean stream length were in accordance with the Horton's law of stream numbers and mean length. High drainage density (2.77 km/km^2) of Kakan watershed revealed the well-defined channel network and would produce more runoff. Elongation ratio (0.783) and bifurcation ratio (0.26) of Kakan watershed shows elongated shape and youth stage of tributaries. This study would help the watershed department for planning and designing of sol water conservation measures.

Introduction

In recent decades, Remote sensing and GIS have become efficient tools in watershed analysis and its conservation measures. The morphometric parameters are recognition tools used to analysis and assess the various aspects of the watershed such as lithological features, geomorphic landslides and hydrological behavior (Yadav *et al.,* 2018). The term morphometry signifies the meaning of measurement of form derived from a morpho means form and metric means measurement. The quantitative analysis of morphometric parameters is of immense utility in watershed evaluation, watershed prioritization for soil and water conservation and natural resource management at watershed level. Morphometric descriptors represent relatively simple approaches to describe basin processes and to compare basin characteristics (Mesa, 2006) and enable an enhanced understanding of the geological and geomorphic history of a drainage basin (Strahler, 1964). The morphometric assessment helps to elaborate a primary hydrological diagnosis in order to predict approximate behaviour of a watershed if correctly coupled with geomorphology and geology (Esper, 2008).The drainage basin analysis is important in any hydrological investigation for assessment of groundwater potential, groundwater management, pedology and environmental assessment. The hydrological response of a river basin can be interrelated with the physiographic characteristics of the drainage basin such as size, shape, slope, drainage density and length of steam segments etc. (Chorley, 1957). Hence, morphometric analysis of a watershed is an essential and foremost step toward basic understanding of watershed dynamics. Remote sensing and GIS are the most advance tools for morphological analysis of watershed.

The present study was an attempt to evaluate morphometric aspects of Kakan watershed and find out their different parameters using remote sensing and GIS.

Materials and Methods

Description of study area

The study area of Kakan falls under Jhadol block of Udaipur district in hard rock region of Rajasthan bounded by 24°17.67' to 24°12.06' N Latitude and 73°28.22' to 73°33.47' E Longitude. The total catchment area of Kakan watershed is 47.44 Km^2 with highest elevation of about 894 m and the lowest elevation is 504 m above the mean sea level. The climate of the study area is sub-humid to semi-arid characterized with dry hot in summer and extremely cold in winter season.

The mean annual rainfall of the Kakan watershed is 712.45 mm. May is generally the hottest month of the year with a mean daily maximum and minimum temperature of 40.5°C and 27.3°C respectively. Whereas January is the coldest month with daily maximum and minimum temperature of 22.2°C and 5.4°C respectively. The study area falls. The location map of the Kakan watershed is shown in Fig. 1.

Database and methodology

The data preparation for the morphometric analysis of the Kakan watershed was done using ALOS (Advanced Land Observing Satellite) DEM data with 12.5 m high resolution downloaded from Alaska satellite facility (https://asf.alaska.edu)and toposheet acquired from survey of India (SOI). The extraction of stream network was done from the ALOS-DEM with 12.5 m spatial resolution. The generation of depression less DEM is always the preliminary step for morphometric analysis of watershed. The stream network was generated by hydrology tool under spatial analyst tools in Arc-Map 10.8 (Fill DEM, calculation of flow direction, flow-accumulation, raster calculator condition and generate raster as stream order then converting into vector data). In the present study, Threshold value in flow accumulation was set more than 400 cells for the ALOS-DEM12.5 m high resolution. The total steam length of various orders was measured with the help of calculate geometry tool of Arc-Map 10.8. The various morphometric parameters come under linear, aerial and relief aspects of Kakan watershed were computed using mathematical formula given in Table 1. Methodological framework for extracting different geomorphological parameters has been given in Fig. 2**.**

Results and Discussion

Morphometric characteristics

The various morphometric parameters such as stream order, stream number, stream length, stream length ratio, bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio, constant of channel maintenance, watershed relief, relief ratio and ruggedness number were computed using Arc-Map 10.8. The morphological characteristics of the Kakan watershed have been presented in the Table 2.

Linear aspects of drainage network

Stream order

It is defined as measurement of stream position in the stream's hierarchy (Strahler, 1964). It is the first and foremost step of morphological analysis of watershed. In the present study, the stream segment of the drainage basin was ranked according to the method proposed by Strahler (1964). The Kakan watershed is of fifth order. Fig.3 showing the stream network map of Kakan watershed.

Stream number

The total number of streams present in given order is stream number. Totally, 216 streams were identified among which 172 were first-order streams, 33 were second-order streams. 8 were third-order streams, 2 were fourth-order streams and only1 was fifth-order stream. It was observed that the number of streams gradually decreases as the ordering of the streams increases. This is in accordance with the Horton's law of stream numbers (Horton, 1945).

Stream length

The total length of individual stream segments of each order is the stream length of that order. Totally, 131.61 km stream length extracted from ALOS-DEM; about 77.51 km was in first order, 25.03 km was in second order, 15.15 km was in third order, 6.58 km was in fourth order and 7.35 km was in fifth order, respectively. Law of stream length depicted negative relation of decreasing stream lengths with increasing stream order. Alteration from this law indicated the high or moderate gradient and upliftment of topography in watershed (Singh and Singh, 1997).

Mean stream length

Mean stream length is computed by dividing the total length of stream of a particular order by total number of streams of that order. In the present study, mean stream length for first order is 0.45, second order is 0.76, third order is 1.89, fourth order is 3.23 and for fifth order is 7.35. From the Table 2, it is observable that the mean length increases with increase in order. This result follows the Horton's law of stream lengths (Horton, 1945).

Stream length ratio

The stream length ratio is the ratio of the mean or average stream length of the given order to the mean or average stream length of next lower order and has an important relationship with surface flow and discharge (Horton, 1945). During the study it is found that the Kakan watershed has the stream length ratio in the range of 1.69 to 2.49.These difference in stream length ratio in the study area were due to variation in slope and topography(Sreedevi *et al.,* 2005).

Bifurcation ratio

Bifurcation ratio is the ratio of number of streams of given order to the number of streams of next higher order. Chow (1964) stated that the bifurcation ratio values lies between 3 and 5 for those watersheds where geological structures do not have much influence on the drainage pattern. In the present work, The values of bifurcation ratio of different order ranges from 2 to 5.21 (Table 2). However mean bifurcation ratio value is 5.67 for the study area which indicates that the geological structures are less disturbing the drainage pattern.

Aerial aspects of watershed

Drainage density

Drainage density is the ratio of total length of all stream segments of all order in watershed to the total watershed area. High drainage density is the resultant of impermeable subsurface material, sparse vegetation and mountainous relief resulting into higher slope categories (Strahler, 1964). The drainage density of study area is 2.77 km/km^2 indicating high drainage density. It signifies that Kakan watershed is predominated by impermeable sub surface materials indicating low recharge in the watershed.

Table.1 Formulas for calculation of morphological parameters

Morphological parameters	Methodology/Formula	References
Stream Order (Ou)	Hierarchical ordering (Ranking)	**A.N. Strahler (1964)**
Stream Length (Lu)	Length of the Stream segment of order u	**R.E. Horton (1945)**
Mean Stream Length (Lsm)	Lsm =Lu/Nu Where, Lu =Total stream length of order u (km),Nu =Total no. of stream segments of order u	**R.E. Horton (1945)**
Stream Length ratio (RL)	RL =Lu/Lu-1Where, Lu =Total stream length of the order u (km), Lu-1 =Total stream length of its next order	**R.E. Horton (1945)**
Bifurcation ratio (Rb)	Rb =Nu/Nu+1, Where, Nu =Total no. of stream segments of any given order u, Nu+1 =Number of streams of the next higher order	**R.E. Horton (1945)**
Mean Bifurcation ratio	R_{bm} =Average of Bifurcation ratios of all orders	**R.E. Horton (1945)**
Drainage Density (D)	$D = \sum Lu/Aw$ (km/km^2) Where, L_u =Total stream length of all orders (km), Aw = Area of the watershed (km^2)	**R.E. Horton (1945)**
Stream Frequency (Fs)	$Fs = \sum Nu/Aw$ (km^{-2}) Where, Nu =Total no. of streams of all orders, Aw = Area of the watershed (km^2)	**R.E. Horton (1945)**
Form Factor (Rf)	$Rf = Aw/(Lw)^2$ Where, A_w =Area of the watershed (km^2), Lw =Watershed length (km)	**R.E. Horton (1945)**
Circulatory Ratio (Rc)	$Rc = 4\times\pi\times Aw/P^2$ Where, Aw =Area of the watershed (km^2),P =Perimeter, π =3.14	**V.C. Miller (1953)**
Elongation ratio (Re)	$Re = \sqrt{(Aw/\pi)}/Lw$ Where. Aw =Area of the watershed (km^2) π =3.14**,** Lw = Watershed length (km)	**S.A. Schumn (1956)**
Constant of Stream maintenance (C)	C = 1/D (km^2/km) Where, D = Drainage density (km/km^2)	**S.A. Schumn (1956)**
Basin Relief (R)	R = H – h (m), where H is maximum elevation and h is minimum elevation within the watershed	**S.A. Schumm (1956)**
Relief ratio (Rr)	Rr = R/Lw Where, R =Basin Relief, Lw = length of watershed	**S.A. Schumn (1956)**
Ruggedness number (Rn)	**Rn = R×D** **Where, D =Drainage density, R =Basin Relief**	**A.N. Strahler (1957)**

Table.2 Morphological parameters of Kakan watershed

S. No.	Morphological parameters	Computed value
1	Area	**47.44 km^2**
2	Perimeter	**48.024 km**
3	Stream Order (Ou)	
	I	**172**
	II	**33**
	III	**8**
	IV	**2**
	V	**1**
4	Stream Length (Lu)	
	I	**77.51 km**
	II	**25.03 km**
	III	**15.15 km**
	IV	**6.58 km**
	V	**7.35 km**
5	Mean Stream Length (Lsm)	
	I	**0.45 km**
	II	**0.76 km**
	III	**1.89 km**
	IV	**3.29 km**
	V	**7.35 km**
6	Stream Length ratio (RL)	
	RL2	**1.69**
	RL3	**2.49**
	RL4	**1.74**
	RL5	**2.23**
7	Bifurcation ratio (Rb)	
	BR1	**5.21**
	BR2	**4.13**
	BR3	**4.00**
	BR4	**2.00**
8	Mean Bifurcation ratio	**3.068**
9	Drainage Density (D)	**2.77 km/km^2**
10	Stream Frequency (Fs)	**4.55 per km^2**
11	Form Factor (Rf)	**0.482**
12	Circulatory Ratio (Rc)	**0.26**
13	Elongation ratio (Re)	**0.783**
14	Constant of Stream maintenance (C)	**0.36 km^2/km**
15	Basin Relief (R)	**390 m**
16	Relief ratio (Rr)	**0.04**
17	**Ruggedness number (Rn)**	**1.08**

Fig.1 Location map of Kakan watershed (Study area)

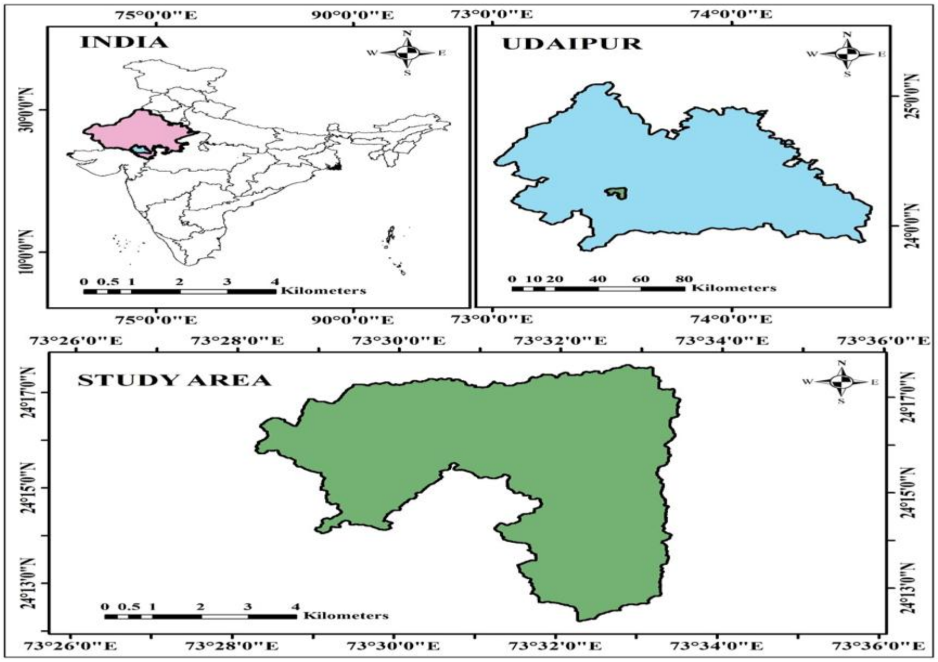


Fig.2 Methodological framework for calculating morphological characteristics of Kakan Watershed

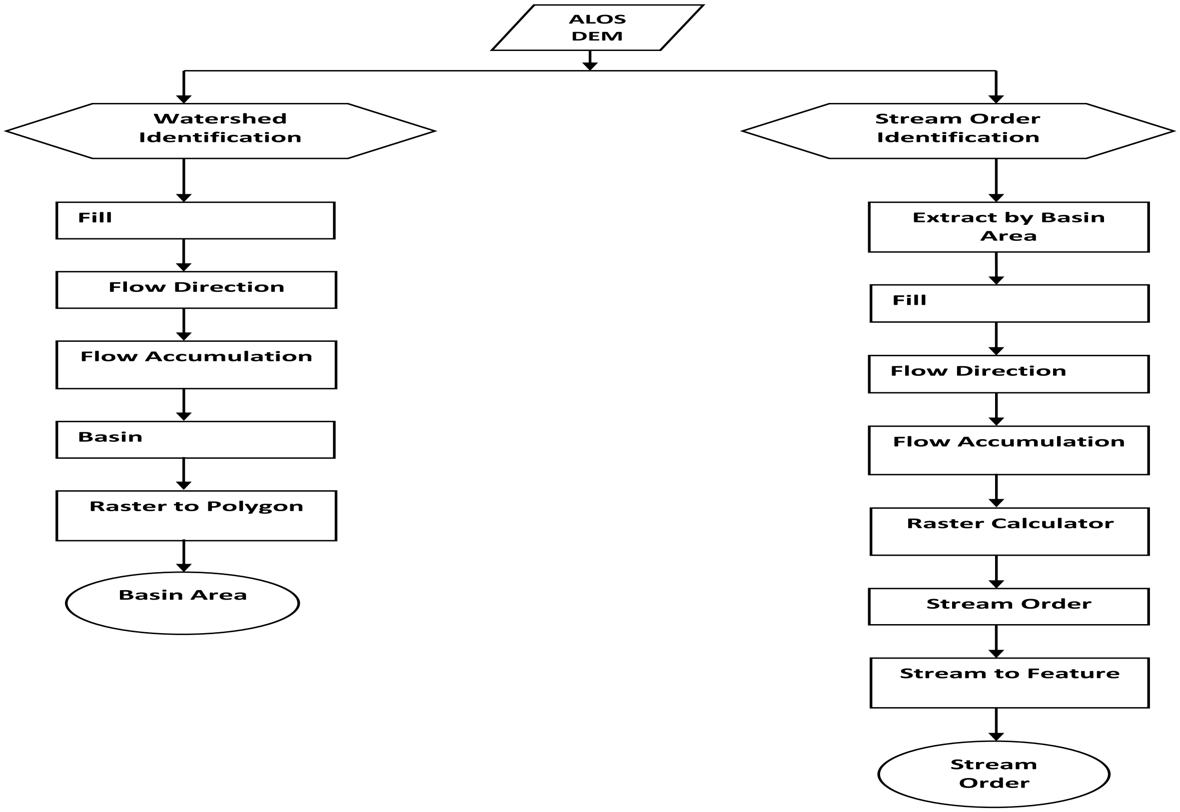


Fig.3 Stream network map of Kakan watershed

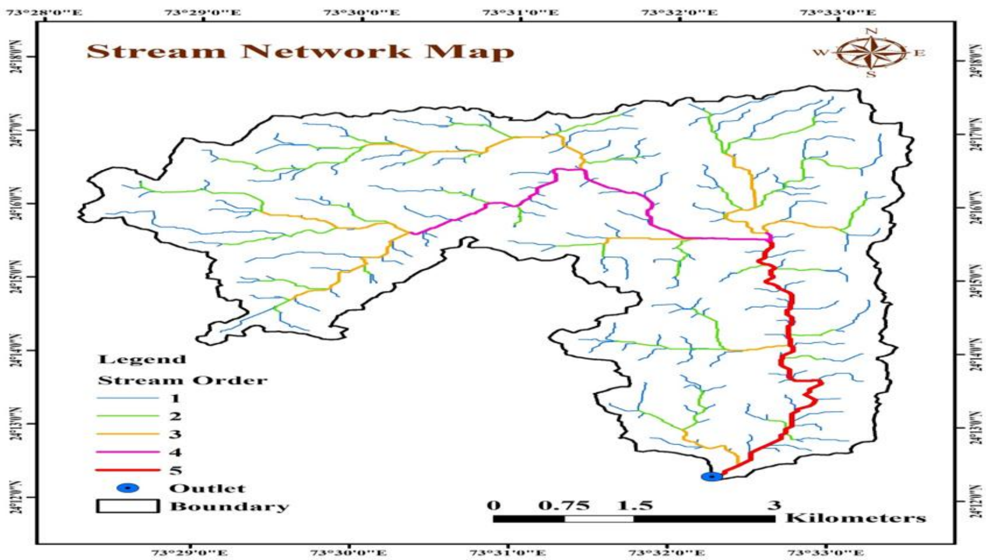
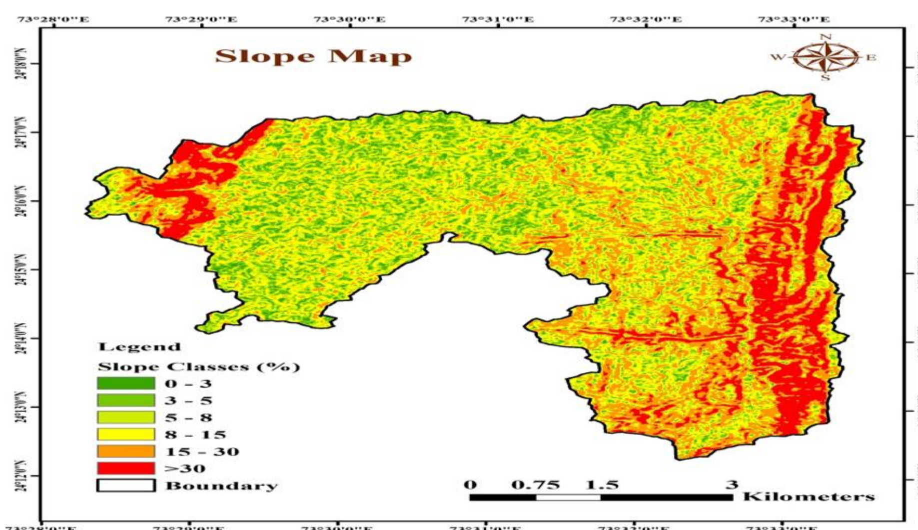


Fig.4 Slope map of Kakan watershed



Stream frequency

Stream frequency is expressed as ratio of total number of streams/channels of all order to the area of watershed. In the present study, the stream frequency of the Kakan watershed is 4.55 per km^2 indicates high stream frequency.

The stream frequency of the study area shows a positive correlation with the drainage density indicating that the stream population increases with the increase of drainage density. Generally, high value of stream frequency is related to impermeable sub-surface material, spare vegetation, high relief conditions.

Form factor

It is defined as the ratio of watershed area to square of watershed length. The value of form factor would always be greater than 0.78 for a circular watershed. Form factor value for the Kakan watershed is 0.482 (low) which suggests that watershed is elongated in shape. The elongated watershed indicated that the watershed may produce flatter peak flow for longer duration.

Elongation ratio

Elongation ratio is defined as the ratio of diameter of circle of same area as the watershed to the maximum watershed length. The elongation ratio is categorized into four classes as elongated (less than 0.7), less elongated (between 0.7 to 0.8), oval (between 0.8 to 0.9) and circular (more than 0.9).The elongation ratio of Kakan watershed is found to be 0.783 which shows that the Kakan watershed is less elongated in shape and also falls in category of high relief and steep land slope region.

Circulatory ratio

Miller (1953) defined circulatory ratio as the ratio of the area of the watershed to the area of the circle having the same circumference as the perimeter of the watershed. This ratio is more influenced by length, frequency and gradient of various orders rather than slope conditions and drainage pattern of the watershed.

The low, medium and high values of the circulatory ratio are indications of the youth, mature and old stages of the life cycle of the tributary watershed respectively. The low value of circulatory ratio for Kakan watershed (0.26) shows that the watershed is elongated and in youth stage.

Constant of channel maintenance

Schumm (1956) used the constant of channel maintenance as the inverse of drainage density. High value of constant of channel maintenance suggest more area is required to produce surface runoff which implies that part of water may get lost by evaporation, percolation etc. (Bhagwat *et al.,* 2011). The constant of channel maintenance for the study area is 0.36 km^2/km which is a low value indicates less chances of percolation and hence more surface runoff may observe in the Kakan watershed.

Relief aspects

Watershed relief

Watershed relief is the vertical distance between highest and lowest points in a watershed. In the current study, highest and lowest elevation was found to be 894 m and 504 m respectively. Therefore, the watershed relief of Kakan watershed is 390 m. This high value of watershed relief indicates low infiltration, high runoff and water flow under gravity.

Relief ratio

Schumn (1956) defined relief ratio as the ratio between the watershed relief to the longest length of the watershed parallel to the trunk stream line. It is a unitless morphometric parameter that successfully computed watershed slope aspects. Relief ratio is highly connected with the hydrologic character of the watershed. In Kakan Watershed, the value of relief ratio is 0.04 showed that it has hilly slope with less infiltration and more runoff.

Ruggedness number

Ruggedness number is the product of drainage density and basin relief (Strahler, 1957). This factor indicates structural complexity of the terrain, intensity of erosion within the basin. In the present study, ruggedness number for the watershed is 1.08 indicates that the area is rugged with strong relief and high stream density and susceptible to erosion.

In conclusions a study was carried out on Morphometric Analysis of Kakan watershed using ALOS DEM, RS and GIS. From the present study, it is concluded that the Kakan water is a fifth order drainage basin in which the number of stream segments decrease with the increase in stream order. The result of mean stream length follows the Horton's law.The variation in stream length ratio in the study area were due to variation in slope and topography. Low value of mean bifurcation ratio (3.068) indicates that the geological structures are less disturbing the drainage pattern. The elongation ratio (0.783), form factor (0.482) and circulatory ratio (0.26) represents elongated shape of watershed with high relief, steep land slope, flatter peak for longer duration.

The high value of stream frequency (4.55 per km^2) and drainage density (2.77 km/km^2) is due to the regions of low infiltration, sparse vegetation, impermeable sub surface material and mountainous relief. The low value of constant of channel maintenance (0.36 km^2/km) indicates less chances of percolation. The slope of the study area ranges between 0 to 88 percent with watershed relief (390 m), relief ratio (0.02) and ruggedness number (1.08) of study area reflects steep land slope, low infiltration, high runoff and rugged topography with high relief and high drainage density.

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