Research Article

DETERMINATION OF WATERSHED MORPHOLOGICAL PARAMETERS USING REMOTE SENSING AND GIS

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ABSTRACT
Drainage basin/watershed analysis based on morphometric parameters is very important for watershed planning and management. Morphometric analysis of watershed is the best method to identify the relationship of various aspects in the area. The application of Remote Sensing and Geographical Information System (GIS) for the analysis of morphometric parameters are found to be of immense utility in watershed for soil, water conservation and natural resources management. In the present study, the RS and GIS techniques were applied to evaluate linear, areal and relief aspects morphometric parameters of the Limkheda watershed, situated at upstream of Hadaf river basin, Gujarat, India. In this study, it is found that SRTM-DEM model has the capability to precisely delineate the watershed and to extract different morphological parameters, to characterize the watershed behaviour. The bifurcation ratio, form factor, elongation ratio and drainage density of the watershed are 0.58, 0.08, 0.33 and 0.35 respectively. The results of the study are useful for further hydrological investigations and the major inputs to various hydrological models.

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. The response of a particular watershed to different hydrological processes and its behaviour depends upon various physiographic, hydrological and geo-morphological parameters. Though these are watershed specific and thereby unique, the characterization of a watershed provides an idea about its behaviour.

Watershed geomorphology refers to the physical characteristics of the watershed. The morphometric studies involve the evolution of stream parameters through the measurement of various stream properties (Kumar *et al.,* 2000). Quantitative morphometric characterization of a drainage basin is considered to be the most appropriate method for the proper planning and management of watershed, because it enables us to understand the relationship among different aspects of the drainage pattern of the basin and also to make a comparative evaluation of different drainage basins, developed in various geologic and climatic regimes (Pingale *et al.,* 2012). Morphometric methods have been applied for the analysis of area-height relationships, determination of erosion surfaces, slopes, relative relief and terrain characteristics, river basin evaluation, and watershed prioritization for soil and water conservation activities in river basins (Kanth, 2012).

Modern technologies such as Remote Sensing (RS) and geographical information system (GIS) have gained significant importance over the last decade in their applications pertaining to watershed modelling. It found to be very effective in large area data collection and integration of spatial data to derive useful outputs through hydrologic modeling (Gupta and Srivastava, 2010; Pandey *et al.,* 2012; Thakur *et al.,* 2012). Some of the earlier studies on morphometric analysis using remote sensing technique were performed by (Srivastava, 1997; Nag, 1998; Srinivasa *et al*., 2004; Makwana and Tiwari, 2016; Premanand *et al.,* 2018; Hussain and Misra, 2018; Choudhari *et al.,* 2018).

In this study an agricultural watershed situated in the upper Hadaf river basin, is selected. The area is predominant with agricultural land and falls under semi-arid zone, where water resources planning and management is inevitable and critical issue. Considering the importance of water especially in semi-arid region, it is required to understand the watershed behaviour precisely. For this purpose Remote Sensing (RS) and Geographic Information System (GIS) analysis techniques were applied to evaluate linear, areal and relief aspects morphometric parameters of the watershed.

MATERIALS AND METHODS

Study Area

A Limkheda watershed located in the semi-arid middle region of Gujarat, India (Fig. 1) is selected in this study for calculating the morphological parameter. The total area of the Limkheda watershed is 220.86 km^2. The outlet of the study area is located at latitude 22° 49' 55" and longitude 73° 59' 15"at an elevation of 207 m. The study area attains maximum elevation of 490 m and a minimum of 196 m above mean sea level. The average annual rainfall for Limkheda watershed is 660 mm. A watershed mainly dominated with agriculture and forest land.

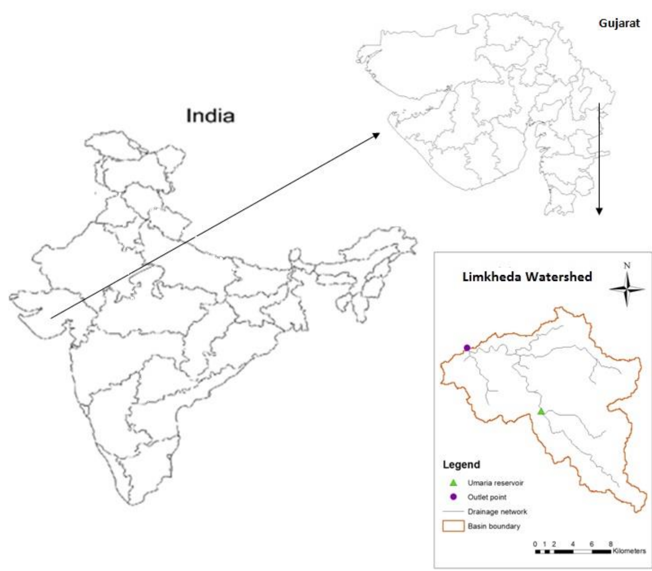

Fig.1. Location map of Limkheda watershed

Morphological Analysis

Morphologic characterization is the systematic description of watershed's geometry. Attempts were made to delineate watershed by using ArcGIS 10.0. Geometry of drainage basin and its stream channel system required the following measurements: (i) linear aspects of drainage network, (ii) aerial aspect of drainage basin, (iii) relief aspect of channel network and contributing ground slopes. The methodologies adopted for computation of morphologic parameters are follows:

Linear Aspects

Stream order: The order of the stream is based on the connection of tributaries. Stream order is a property of stream networks as it relates to the relative discharge of a channel segment. In the present study, the channel segment of the drainage basin has been ranked according to hierarchic ranking of streams proposed by (Strahler, 1964).

Stream length ratio (R_L): It is the ratio of mean length of stream (L_u) of particular order to the mean stream length of next lower order (L_{u-1}) (Horton, 1945). It is expressed as

$$R_L=L_u-L_{u-1}$$

Bifurcation ratio (R_b): The term bifurcation ratio (R_b) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order (Horton, 1945). Lower R_b values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Nag, 1998).

$$R_b=N_u/N_{u+1}$$

Length of overland flow (L_g): It is defined as the length of flow of water over the ground, before it becomes concentrated in defined stream channels (Horton, 1945). It is half the reciprocal of drainage density (D_d)

$$L_g=1/D_d\times2$$

Areal Aspects

Form factor (R_f): It determines about the shape of the basin. Form factor is defined as the ratio of basin area to the square of the basin length (Horton, 1932).

$$R_f = A/L_b^2$$

Circularity ratio (R_c): Circulatory ratio (R_c) is estimated as the ratio of the basin area (A) to the area of a circle (P) having circumference equal to the perimeter of the basin (Miller, 1953).

$$R_c = 4 \times pi \times A/P^2$$

*Fineness ratio (R_{fn})***:** The ratio of main channel length (L_b) to the length of the watershed perimeter (p) (Melton, 1957), which is a measure of topographic fitness.

$$R_{fn} = L_b/p$$

Elongation ratio (R_e): It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956)

$$R_e = (2/L_b) \times (A/pi)^{0.5}$$

Drainage density (D_d): It is the ratio of total length of channels of all orders in the basin to the drainage area of the basin (Horton, 1945).

$$D_d = L_u/A$$

Stream frequency (F_s): Stream frequency was introduced by Horton (1945). It is defined as the total number of stream segments of all orders per unit area.

$$F_s = N_u/A$$

Unity shape factor (R_u): The ratio of the basin length (L_b) to the square root of the basin area Horton (1945). In the present study area, unity shape factor is estimated

$$R_u = L_b/A^{0.5}$$

Watershed shape factor (W_s): The ratio of main stream length (L_m) to the diameter (D_c) of a circle having the same area as the watershed.

$$W_s = L_m/D_c$$

Compactness coefficient (C_c): It is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. The C_c is independent of size of watershed and dependent only on the slope. It is estimated as

$$C_c = 0.2821 \times P/A^{0.5}$$

Drainage texture (R_t): It is one of the important drainage parameters in morphometric analysis, which indicates relative spacing of drainage lines, which are more prominent in impermeable material compared to the permeable ones. Horton (1945) defined drainage texture as the total number of stream segments of all orders divided by the perimeter of the watershed. He also recognized infiltration capacity as the dominant factor influencing drainage texture which includes drainage density and stream frequency as well. Drainage texture (R_t) depends upon a number of natural factors such as climate, rainfall, vegetation, lithology, soil type, infiltration capacity, relief. In the Limkheda watershed the drainage texture is calculated as 0.16.

$$R_t = N_u/P$$

Relief Aspects

Basin relief (H): It is elevation difference between basin outlet and highest point located on the perimeter of basin (Hardley and Schumn, 1961).

$$H = h_1 - h_2$$

Relief Ratio (R_h): It is the ratio of relief (H) to the horizontal distance (L_b) (Schumn, 1956).

$$R_h = H/L_b$$

Relative relief (R_r): It is the ratio of maximum watershed relief to the perimeter of watershed (Melton, 1957).

$$R_r = H/P$$

RESULTS AND DISCUSSION

Digital elevation model

The Digital Elevation Model (DEM) is obtained from the remotely sensed imagery and prepared using the remote sensing and GIS software. DEM is well define the topography of the area by describing the elevation of any point at a given location and specific spatial resolution as a digital file. The watershed boundary demarcation or water delineation is generally carried out using topographical sheets. But this traditionally method is hectic and error prone therefore remote sensing imagery called DEM was used in this study. The DEM of the study area is obtained from shuttle radar topographic mission (SRTM), where elevation data at 90 x 90 m resolution are acquired. It is one of essential spatial to delineate the watershed on elevation. DEM was projected to Universal Transverse Mercator (UTM) under UTM zone 43, applicable for the study area before it is used. In the study area elevation varies from 196 to 490 m from the mean sea level, the mean. Elevation and Std. Deviation are 312.69 and 59.75 respectively. The DEM of the delineated watershed is shown in Fig. 2.

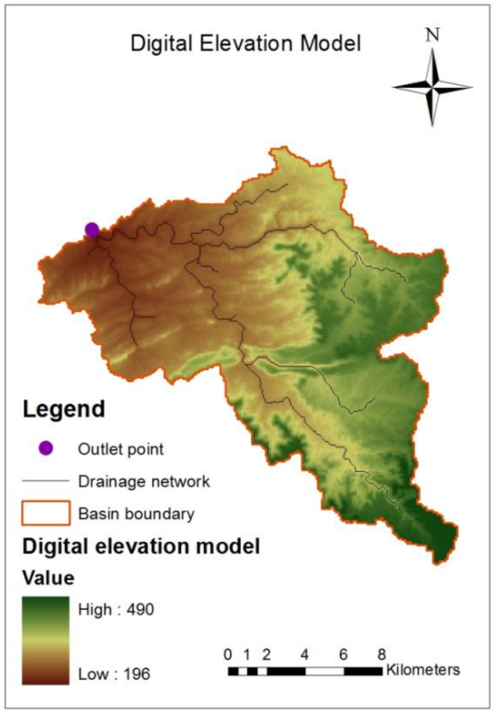

Fig. 2. Digital elevation model with drainage network of the Limkheda watershed

Calculations of Morphological Parameters

Morphological is a science that attempts to quantify the shape of drainage basin. Various parameters of Limkheda watershed were extracted the thematic maps. The morphological parameters for the watershed are calculated and presented here.

Linear Aspects

The highest order of the stream is third order. The total and mean stream length of the watershed is found to be 77.29 km and 4.06 km for all order streams respectively. Mean stream length ratio for the basin is 0.46.

In the present study, value of average R_b is 0.58. R_b is not same from one order to its next order. It is observed that watershed is elongated in shape. The high value of R_b indicates structural complexity and low permeability (Pankaj, 2009). The higher value of R_b indicated strong structural control on the drainage pattern. Basin length of basin is 50.46 km. It is the longest length of basin from the head water to the point of confluence. The term "length of overland flow" is used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels. The length of overland flow is 1.42.

Areal Aspects

The form factor for the study area is 0.08. For perfectly circular basin it should be greater than 0.78. Smaller the value of form factor more will be elongated basin. The value of circulatory ratio for the watershed is 0.21. The value of R_c is influenced by the length and frequency of streams, geological structures, land use/land cover and slope of the basin. The value of "C" generally changes from 0 (a line) to 1 (circle). The higher the value of "C" more the circular shape of the basin and vice versa.

The elongation ratio of watershed is 0.33. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (> 0.9), oval (0.9 - 0.8) and elongated (< 0.7). It is observed that the watershed is elongated. The stream frequency of the watershed is 0.08. The value of stream frequency (Fs) for the basin exhibit positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density. The stream frequency is dependent more or less on the rainfall and the temperature of the region.

The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. High drainage density is the result of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to course drainage texture while high drainage density leads to fine drainage texture (Strahaler, 1964). The drainage density of the watershed is 0.35 km/km^2. Drainage texture is one of the important concepts of morphology which means the relative spacing of drainage lines. The value of R_t is 0.16 for the watershed. Value of Constant of channel maintenance (C) for the basin is 2.17 km which is reciprocal of drainage density.

The fitness ratio, watershed shape factor and compactness coefficient for the watershed is 0.44, 1.92 and 2.17 respectively. The unity shape factor is 3.39 for the watershed. The R_u values < 2 of sub-watersheds indicates that have weaker flood discharge periods, whereas R_u value > 2 indicates that have sharp peak flood discharge.

Relief Aspects

The total relief for the watershed is 0.29 km. Relative relief for the watershed is 0.002. The relief ratio for basin is 0.005. The R_h normally increased with the decreasing drainage area and size of the watersheds for a given drainage basin. It measures overall steepness of watershed and also considered as an indicator for the intensity of erosion process occurring in the watershed. The high value of relief ratio is characteristics of hilly region.

SUMMARY AND CONCLUSION

Geographical Information System (GIS) tools are used in the drainage delineation and their updation. Morphometric analysis is carried out through updated drainage. Linear aspects, areal aspects and relief aspects of the basin are measured for the analysis. The number of streams of various orders in watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. Total area of basin is 220.86 km^2. The highest order of stream is third order. From bifurcation ratio it is observed that there are less structural disturbances in the watershed. The length of overland flow is 1.42. The drainage density value for the basin area is 0.35 km/km^2. The Form factor and circulatory ratio for the watershed is 0.08 and 0.21 respectively. The elongation ratio of watershed is 0.33. The watershed has elongated shape. Maximum relief and relative relief of the basin are 0.29 Km and 0.002 respectively. Relief ratio is 0.005. Overall results show that SRTM DEM model has the capability to precisely delineate the watershed and to extract different morphological parameters, to characterize the watershed behaviour. The study will be useful for the planning of watershed harvesting and groundwater recharge projects on watershed basis.

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