Original Article

Indian Journal of Waste Management
Volume 1 Number 1, January - June 2017

Determination of Geomorphological Characteristics of Karpri-Kalu Watershed Using GIS Techniques

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Abstract

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. It provides a powerful study and management unit, which integrates ecological, geographical, geological, and cultural aspects of the land. GIS technique is used to estimate the morphological characteristics of watershed. Delineation of watershed using GIS is mainly based on the Digital Elevation Model (DEM) data. The study area, watershed, 8.04 Km^2, is located in Sangamner Tehsil of Ahmednagar district and lying between 74^0 20' 36'' E to 74^0 23' 6'' E longitude and 19^0 21' 34'' N to 19^0 23' 56'' N latitude. The average annual rainfall is 379 mm. Various operations were done to prepare contour and drainage maps. Areal, linear and relief aspects of watershed were estimated. The parameters worked out includes Stream order, Stream length ratio, Bifurcation ratio, Basin length, Length of overland flow, Form factor, Circulatory ratio, Elongation ratio, Stream frequency, Drainage density, Constant of channel maintenance, Maximum relief, Relative relief, Relief ratio and Ruggedness number. 4^{th} order stream is trunk order. Total lengths of streams and total numbers of streams in each order are decreasing with increasing order. Bifurcation ratio for the watershed is 3.166. The form factor for the area is 0.424. From the value of elongation ratio 0.734, it is observed that the watershed is less elongated. The drainage density value for the basin area is 2.024Km / Km^2 that is basin is poorly drained. The study will be useful for the planning of watershed harvesting and groundwater recharge projects on watershed basis.

Keywords: Watershed; Morphometric Analysis; GIS; Karpri-Kalu; Linear; Areal; Relief 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. It provides a powerful study and management unit, which integrates ecological, geographical, geological, and cultural aspects of the land. The watershed is also a useful concept for integrating science with historical, cultural, economic, and political issues. Water (movement, cycling, use, quality, etc.) provides a focus for integrating various aspects of watershed use and for making regional and global connections (Yongsheng Ma).

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

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). Morphometric methods, though simple, 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

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Received: March 01, 2017 | **Accepted:** March 04, 2017

prioritization for soil and water conservation activities in river basins (Kanth, T. A.).

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 S. M. *et al.*).

The measurement of morphological parameters is laborious by the conventional methods, but using the latest technology like GIS, the morphometric analysis of natural drain and its drainage network can be better achieved. Various morphometric parameters needs to measure in a drainage basin include stream order, stream length, 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 M. and F. Birajdar). Geographic Information Systems (GIS) technology has played critical roles in all aspects of watershed management, Basic physical characteristics of a watershed such as the drainage network and flow paths can be derived from readily available Digital Elevation Models (Tim U. S.).

DEM describes the elevation of any point in a given area at a specific spatial resolution. For the present study Remote Sensing and Geographical Information System (GIS) is used as tools for managing and analyzing the spatially distributed information. Arc GIS is powerful software to analyze, visualize, update the geographical information and create quality presentations that brings the power of interactive mapping and analysis.

Geomorphological analysis helps in better understanding of hydrological system of watershed which is useful for carrying out management strategies.

Study Area

The study area is located in Sangamner tehsil of Ahmednagar district and lying between $74^0$20'36'' E to 74^0 23' 6'' E longitude and 19^0 21' 34'' N to $19^0$23' 56'' N latitude. Area of watershed is 8.04 Km^2. The average annual rainfall is 379 mm. Watershed is found under water scarcity zone.

Data Used and Methodology

Topography is defined by a Digital Elevation Model (DEM) that describes the elevation of any point in a given area at a specific spatial resolution. The DEM is used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. The parameters such as slope gradient, the stream network characteristics such as channel slope, length, and width are derived from the DEM. The generation of depression less DEM is always the preparatory step for morphometric analysis of drainage basin. Hydrology tool under Spatial Analyst Tools in Arc GIS-10.1 software is used to extract drainage channels, and other parameters.

Linear Aspects

- *Stream Number and Stream Order*

The order of the stream is based on the connection of tributaries. Stream order is a fundamental 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 Strahler's stream ordering system. According to Strahler (1957), the smallest fingertip tributaries are designated as order 1. Where two first order channels join, a channel segment of order 2 is formed, where two of order 2 join, a segment of order 3 is formed and so forth. The trunk stream through which all discharge of water and sediment passes is therefore the stream segment of highest order (Vinoth M.).

- *Stream Length*

Stream length is the length of all the streams having order u. It indicates the contributing area of the basin of that order. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases (Soni S. et al). The extent of stream length in a watershed reveals the characteristics size of various components of drainage network and its contributing surface area.

- *Stream Length Ratio (Rl)*

It is the ratio of mean length of stream (Lu) of particular order to the mean stream length of next lower order (Lu-1) (Horton, 1945). It is expressed as,

$$Rl = \frac{Lu}{Lu - 1}$$

- *Bifurcation Ratio (Rb)*

The term bifurcation ratio (Rb) 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).

$$Rb = \frac{Nu}{Nu+1}$$

Where, Nu= No. of streams of particular order

Nu+1= No. of streams of next higher order.

- *Length of Overland Flow*

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 (Dd).

Areal Aspects

- *Form Factor (Ff)*

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).

$$Ff = \frac{Aw}{Lb2}$$

Where, Aw= basin area

Lb= basin length

- *Circularity Ratio (Rc)*

Circulatory ratio (Rc) is estimated as the ratio of the basin area (A_w) to the area of a circle (Ac) having circumference equal to the perimeter of the basin (Miller, 1953).

$$Rc = \frac{Aw}{Ac}$$

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.

- *Elongation Ratio (Re)*

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).

$$Re = \frac{Dc}{(Lb)max}$$

Where, Re = Elongation ratio, dimensionless.

Dc = Diameter of circle having same area as the given drainage basin, m.

Lb max. = Maximum basin length parallel to the principle drainage lines, m

High Re values indicate that the areas are having high infiltration capacity and low runoff. Values nearing 1.0 are typical of regions of low relief, whereas values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes.

- *Drainage Density (Dd)*

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

- *Constant of Channel Maintenance(C)*

It is the ratio between the area of the drainage basin and total length of all the channels, expressed as square meter per meter. It is also equal to reciprocal of drainage density (Dd).

- *Stream Frequency (Sf)*

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

$$Sf = \frac{\Sigma Nu}{Ab}$$

Where, Ó Nu = Total no of stream segment.

Ab = Basin area.

- *Drainage Factor (Df)*

It is ratio of stream frequency to the square of drainage density.

Relief Aspects

- *Maximum Relief (H)*

It is the maximum vertical difference between highest and lowest point in the watershed. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope.

- *Maximum Basin Relief*

It is elevation difference between basin outlet and

highest point located on the perimeter of basin.

- *Relief Ratio*

It is the ratio of relief (H) to the horizontal distance(L) on which relief was measured (Schumm, 1956).

$$Rn = \frac{H}{L}$$

Relative Relief (Rr)

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

$$Rr = \frac{H}{P} \times 100$$

Where, Rr = Relative Relief, %

H = Maximum basin relief, m

P = Basin perimeter, m.

Ruggedness Numbers (Rn)

Ruggedness number (Rn) is a product of relief (H) and drainage density (D) in the same unit (Strahler 1958). The areas of low relief but high drainage density are regarded as ruggedly textured as areas of higher relief having less dissection.

Rn = H×D

Result and Discussion

Linear Aspects

Total number of 29 streams are identified of which 22 are 1st order streams, 4 are 2nd order, 2 are 3rd order and one is indicating 4th order stream. Total length of 1st order streams is 7.143 Km, 2nd order streams 7.381 Km, 3rd order streams 1.726 Km and 4th order stream is 0.031 Km.The mean stream length of the watershed is found to be 0.324, 1.845 and 0.863 km for 1st, 2nd and 3rd order streams respectively. It is observed that total length of 2nd order streams is more and length of trunk order stream is very small.

Stream length ratio for the basin varies between 0.035 to 5.694. The stream length ratio (RL) is estimated of 5.694, 0.467 and 0.035 for II / I, III / II and IV / III orders, respectively.

In the present study, Rb varies from 2 to 5.5 with an average of 3.166. It is estimated of 5.5, 2 and 2 for I / II, II / III and III / IV orders, respectively. Rb is not same from one order to its next order. It is observed that watershed is neither elongated nor circular in shape. The high value of Rb indicates structural complexity and low permeability (Pankaj, 2009). It also indicates that the value of Rb is not same from one order to next order. The higher value of Rb indicated strong structural control on the drainage pattern. This shows it's usefulness for hydrograph shape for watersheds similar in other respect. An elongated watershed has higher bifurcation ratio than normal and approximately circular watershed (Singh, 2003). It is indicated that the watershed chosen for the study is not circular in shape and would produce delayed peak flow.

Basin length of basin is 4.355Km.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 0.2470. The watershed is having less structural disturbances, having higher overland flow.

Areal Aspects

The form factor for the study area is 0.424. For perfectly circular basin it should be greater than 0.78. Smaller the value of form factor more will be elongated basin and high peak flows of shorter durations.

The value of Circulatory ratio for the watershed is0.35. The value of Rc is influenced by the length and frequency of streams, geological structures, land use / land cover and slope of the basin.

The elongation ratio of watershed is 0.734. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5). It is observed that the watershed is less elongated.

The stream frequency of the watershed is 3.606**.** 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 of the watershed is 2.024Km / Km^2. A low drainage density indicates permeable subsurface strata and is a characteristic feature of coarse drainage which generally shows values less than 5.0. A low value of the drainage density indicates a relatively low density of streams

and thus a slow stream response (Singh, 2004). Drainage texture is one of the important concepts of geomorphology which means the relative spacing of drainage lines.

Value of Constant of channel maintenance(C)for the basin is 0.494Km which is reciprocal of drainage density.

Relief Aspects

The maximum relief for the watershed is 0.4846Km. Relative relief for the watershed is 0.352.

The relief ratio for basin is 0.0111. Watershed area indicates the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope.The Rh normally increased with the decreasing drainage area and size of the watersheds for a given drainage basin (Gottschalk, 1964). 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.

The Ruggedness number for the basin is 0.980Km. This number represents that if drainage density is increased, keeping relief as constant then average horizontal distance from drainage divide to the adjacent channel is reduced. On the other hand, if relief increases by keeping drainage density as constant, the elevation difference between the drainage divide and adjacent channel will increase.

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 and perimeter of basin is 8.042Km^{2}and 13.74Km. respectively. Basin length is 4.355Km and average basin width is 3.07Km. Total number of streams in the basin are 29. The highest order of stream is fourth order. The number of lower order streams are more than higher order stream. Both total lengths of streams and total numbers of streams in each order are decreasing with increasing order as explained by Horton (1945) and increasing mean stream length with increasing order as explained by Strahler (1964). From bifurcation ratio it is observed that there are less structural disturbances in the watershed. The length of overland flow is 0.2470. The drainage density value for the basin area is 2.024Km/ Km^2 that is basin is poorly drained. The Form factor and circulatory ratio for the watershed is 0.424 and 0.35 respectively. The circularity ratio is influenced by stream length, stream frequency (Fs), geological structures, land cover, climate, relief and slope of the basin. It is an important parameter, which indicates the stage of the basin. The elongation ratio of watershed is 0.734. The watershed has less elongated shape and having strong relief and steep ground slope. 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. Maximum relief and relative relief of the basin is 0.4846Km and 0.352 respectively. Relief ratio is 0.0111. According to Schumm (1956), there is direct relationship between the relief and channel gradient. There is also a correlation between hydrological characteristics and the relief ratio of a drainage basin. The study will be useful for the planning of watershed harvesting and groundwater recharge projects on watershed basis.

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