GIS based Morphometric Analysis of Gagadio River Watershed of Shetrunji Basin

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Abstract—The watershed is a geo-hydrological area on which the precipitation occurs and drains towards the common outlet and there is a harmony among the soil, water, land-use and geomorphology. So it's more significant to take the watershed as a development unit. The morphometric characteristics are commonly used to develop regional hydrological models particularly in the case of unguaged catchment. The morphometric analysis is carried out for Gagadio watershed having 521.55km^2 area located in Amreli district of Gujarat. Gagadio river is a major left bank tributary of Shetrunji river. Using GIS techniques, the basic parameters (basin area, basin perimeter, basin length, total number and length of streams of each order), linear parameters (bifurcation ratio, drainage density, stream frequency, texture ratio, length of overland flow) and shape parameters (form factor, shape factor, elongation ratio, circulatory ratio, compactness coefficient) are calculated. Gagadio watershed is of 6thorder and it has parallel drainage pattern. Mean bifurcation ratio (4.02) indicates geologically controlled drainage pattern. Drainage density (2.04) and stream frequency (1.86) are moderate. Texture ratio (4.11) indicates moderate drainage texture and length of overland flow is 1.02. The shape parameters indicate elongated shape of watershed & correspondingly low peak discharges and less erodibility.

Keywords: GIS, morphometric, geo-hydrological, erodibility

I. Introduction

Morphometry is a field related to study the variation in size and shape of the objects in a simple way. Morphometric analysis is defined as the analysis showing quantitative details of basin geometry (Strahler, 1964). So morphometry provides quantitative information to the descriptions therefore the comparisons can be done in more significant way. Thus comparison does not depend on the interpretation of descriptive words. The areas of basin where the changes have been concentrated can also be identified and corrective measures can be carried out.

In the 1930s and 1940s, R.E.Horton initiated a fundamental change in hydrologic studies. Horton was the first to study the formation of streams and basins in a quantitative way. Morphometric parameters have been used in various studies of geomorphology and surface-water hydrology, such as flood characteristics, sediment yield and evolution of basin morphology. Studies of drainage basins were primarily descriptive before the second world war. The modern quantitative geomorphology has born with the use of Horton's mathematical description. These quantitative description, have longer been used to describe and predict stream network behavior for surface flow systems. Remote sensing along with GIS techniques has been proved efficient tool for watershed delineation and morphometric analysis. (Thakkar and Dhiman, 2007). Sharma et al. (2010) carried out morphometric analysis and prioritization of subwatersheds of Uttala river watershed using GIS. Magesh et al. (2012) used SRTM data and GIS techniques for analysing basin morphometry. Nooka Ratnam et al (2013) used remote sensing and GIS techniques for morphometric analysis of micro-watersheds of Sarada river basin. Patel et al. (2015) carried out GIS based morphometric analysis for prioritization of subwatersheds of Hathmati watershed of Sabarmati basin.

II. Study Area

Gagadio is a major tributary of Shetrunji river. Gagadio watershed has drainage area of 521.55 km^2. It lies between 71^{0}13'48" to 71^{0}27'36" E longitude and 21^{0}28'12" to 21^{0}51'36" N latitude. It is located in Amreli district of Gujarat. It falls in SOI toposheets 41 O 1, 2, 3, 5, 6, 7. Most part of study area is having clayey montmorillonitic soil and of deccan plateau geomorphic unit. Geologically, the area is situated in basaltic lava flow and some part is of flood plain deposit. The average rainfall over Gagadio watershed is 604.52 mm. The monsoon season starts around second week of June and withdraws by the first week of October. About 90% of total rainfall occurs during the months of July and August. In winter season, the temperature varies from 6^0 to 18^0 and in summer season, the variation is from 35^0 to 45^0.

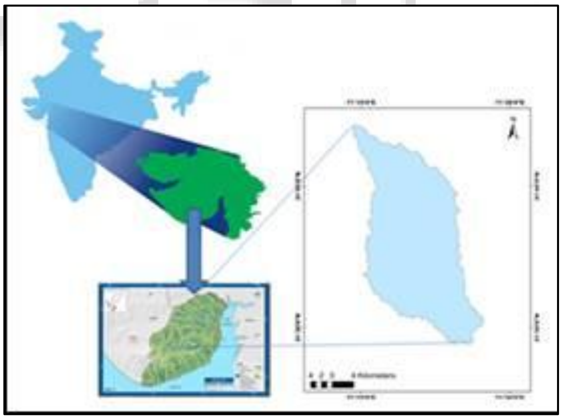

Fig. 1: Shetrunji and Other Rivers of Saurastra Flowing Towards Eastward & Location of Gagadio Watershed

III. Methodology

The Shuttle Radar Topography Mission(SRTM) data (http://srtm.csi.cgiar.org) were used to derive the Digital elevation model (DEM) of the Gujarat state having 90 m spatial resolution. From the DEM of Gujarat, DEM covering the study area was extracted by extraction tool of ArcGIS. The drainage network was extracted from DEM by terrain pre-processing with Arc hydro tool and validated by comparing it with georeferenced SOI toposheets number 41 O 1, 2, 3, 5, 6, 7. Using watershed processing tools of Arc Hydro, Gagadio watershed was delineated. For stream ordering, Strahler's method was used in spatial analyst tools. The stream network was in polyline feature and the stream order was represented by grid code. The number of streams and stream length were calculated in attribute table of polyline feature. The area and perimeter of watershed were calculated in attribute table of polygon feature class. Basin length was calculated with watershed processing tool of Arc Hydro.

IV. RESULTS AND DISCUSSIONS

A. *Basic Morphometric Parameters:*

Stream order	No. of streams	length(km)
1	734	510.32
2	182	340.56
3	43	102.78
4	6	65.95
5	2	23.84
6	1	21.88
Total	968	1065.32

Table 1: Number of Streams and Stream Length

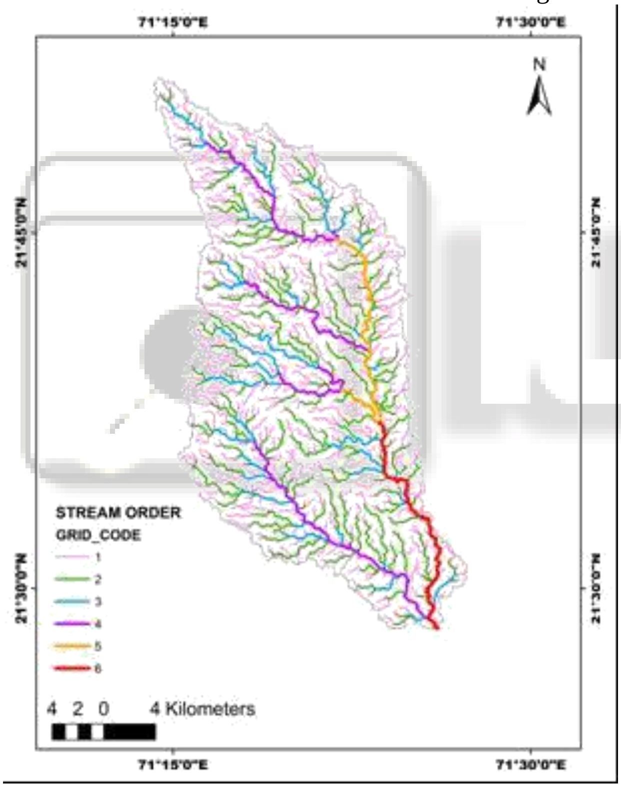

Fig. 2: Drainage Pattern of Gagadio Watershed

- Basin area A : 521.55 Km2
- Basin perimeter P : 178.38 km
- Basin length Lb : 45.85 km
- Total number of streams : 968
- Total length of streams : 1065.32 km

1) *Basin Area (A):*

It is the most important basin parameter and affects the volume of water produced due to rainfall. It is the first step to compute the average depth of rainfall over the basin. The volume of water produced is the product of the area of watershed and the rainfall depth. Area of Gagadio watershed is 521.55 km^2.

2) *Basin Perimeter (P):*

It is the length of the boundary line of the basin by which basin is delineated and it represents watershed size and shape. The perirmeter of Gagadio watershed is 178.38 km.

3) *Basin length (L_b):*

It is defined as the longest dimension of basin parallel to its principal drainage channel (Schuman, 1956). It is proportional to basin area. Basin length of Gagadio watershed is 45.85 km.

4) *Total number (N) & total length (L) of all streams of all orders:*

These are calculated for Gagadio watershed & its subwatersheds. (Table 1) Gagadio watershed is 6^{th} order basin and has parallel drainage pattern. (Fig. 2)

B. *Linear Morphometric Parameters:*

Mean bifurcation ratio R_b : 4.09
Drainage density D_d : 2.04 km / km^2
Stream frequency F_u : 1.86
Texture ratio T : 4.11
Length of overland flow L_o : 1.02 km

1) *Bifurcation ratio (R_b):*

It is expressed as the ratio of the total no. of streams of any paticular order (N_u) to the total no. of streams of next higher order. (Schumn, 1956)

$R_b = N_u / N_{u+1}$, where, N_u is total no. of streams of particular order & N_{u+1} is total no. of streams of next higher order. Lower values of bifurcation ratio (3 to 5) indicate less structural disturbance and less distorted drainage pattern while its higher values indicates higher structural disturbance (Strahler,1964). Mean bifurcation ratio (4.02) indicates less structural disturbance in drainage pattern of Gagadio watershed.

2) *Drainage density (D_d):*

It is defined as the total length of all streams of basin per unit area of the basin. (Horton, 1945) $D_d = L / A$, where L is the total length (km) of all streams, A is the area of basin (km^2). It represents the drainage efficiency of the basin and the response to the storm. It is a good quantitative indication of the dissection and analysis of a landform. Drainge density gives idea about the volume of water and sediments produced from watershed. Here, the value of drainage density is 2.04 which is called moderate drainage density.

3) *Stream frequency (F_u):*

It is expressed as the total number of streams per unit area of the basin. (Horton, 1945) $F_u = N / A$, where N is the no. of streams, A is the area of basin (km^2). It mainly depends on topographical features and drainage network of the area. Lower values of stream frequency indicate lower volume of surface runoff. Higher stream frequency is related to impermeable sub-surface material, sparse vegetation, high relief condition and low infiltration capacity. Here, stream frequency value in Gagadio watershed is 1.86 which is moderate.

4) *Texture ratio (T):*

It is the ratio of total number of first order streams to the basin perimeter. (Horton, 1945) $T = N_1 / P$, where N_1 is the number of first order streams, P is basin perimeter (km). It is one of the important morphometric parameter shows relative spacing of drainage channels. The texture ratio is associated with underlying lithology and relief aspect of the basin. High texture ratio shows the higher relief. Smith (1950) classified the drainage texture in five catagories as very course (<2), course (2-4), moderate (4-6), fine (6-8) and very fine (>8). Here the texture ratio in Gagadio watershed is 4.11, which shows moderate drainage texture.

5) Length of overland flow (L_0):

It is defined as the maximum length of surface flow occurred by rain water before it gets localized in definite channels. (Horton 1945) $L_0 = 0.5 \times D_d$, where L_0 is the length of overland flow (km), D_d is drainage density. Here, the length of overland flow is about 1 km.

C. Shape parameters:

- Form factor R_f : 0.248
- Shape factor B_s : 4.031
- Elongation ratio R_e : 0.562
- Circulatory ratio R_c : 0.206
- Compactness coefficient C_c : 2.203

1) Form Factor (R_S):

It is defined as the ratio of average width of basin to basin length. Form factor represents shape characteristics. (Horton, 1932) $R_f = B / L_b = A / L_b^2$, where L_b is basin length, B is the average width defined as the ratio of the area to the basin length. ($B = A / L_b$) The value of form factor should always be greater than 0.78 for a perfectly circular basin. The basins with higher form factors are usually more circular and have higher peak discharges of shorter durations, while its lower values indicates elongated basins and lower peak discharges of longer durations. Form factor of Gagadio watershed is 0.248 which reflects elongated shape.

2) Shape Factor (B_S):

It is obtained by dividing the square of the basin length to the basin area. (Horton 1945) $B_s = L_b^2 / A$, where L_b is the basin length, A is basin area. Shape factor is inversely related to form factor. Higher values of shape factor indicate elongated basin shape and correspondingly having a lower potential for confluence effects. Shape factor of Gagadio watershed is 4.031.

3) Circulatory Ratio (R_c):

It is expressed as the ratio of basin area to the area of a circle whose perimeter is equal to the basin perimeter (Miller, 1953). $R_c = 4\pi A / P^2 = 12.57A / P^2$, where A is basin area, P is basin perimeter. Higher values of R_c represents more circularity in shape of a basin. Lower value of circulatory ratio indicates less circular shape of a basin, slower discharge and possibility of erosion is less. Circulatory ratio of Gagadio watershed is 0.206, which reflects elongation in shape.

4) Elongation Ratio (R_e):

It is defined as the ratio of the diameter of a circle having the same area as the basin to the basin length. (Schuman, 1956) $R_e = (2 / L_b) (A / \pi)^{0.5}$. The elongation ratio is equal to 1 for a perfectly circular basin. If the basin is elongated, elongation ratio will be less than 1. Based on elongation ratio, the watersheds can be classified in five classes, named, 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). Here, value of elongation ratio is 0.562 which shows elongated shape.

5) Compactness Coefficient (C_c):

It is defined as the ratio of basin perimeter to the circumference of a circle having area equal to basin area. $C_c = P / 2\Pi r = 0.2821 (P / A^{0.5})$. This parameter is indirectly related with the elongation of the basin. Lower values of it indicate more elongated basin and lower values of peak discharges and less erosion, while higher values indicate less elongation in shape, higher values of peak discharges and more erosion. Here, compactness coefficient value is 2.203.

V. CONCLUSION

The study demonstrates that the morphometric analysis with help of SRTM data and topographical maps along with GIS software, is convenient to carry out accurately and reliably. The conventional methods for watershed delineation and morphometric analysis are time-consuming, cumbersome and error prone. Using ArcHydro tools, the watershed and sub-watersheds can be accurately delineated from SRTM image. Further, the evaluation of morphometric parameters assist us to understand the drainage pattern, structural disturbance, infiltration capacity, surface runoff production and erodibility. The value of mean bifurcation ratio is 4.02 indicates less structural disturbance in drainage pattern. Drainage density and stream frequency values are nearly 2.0 is moderate, drainage texture value is moderate and length of overland flow is about 1 km. Values of form factor (0.248), circulatory ratio (0.206), shape factor (4.031), elongation ratio (0.562), compactness coefficient (0.203) reflect elongated shape of watershed and slower response to rainfall event, lower peak discharge and less erodibility.

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