Morphometric Study of Dhatarwadi River Basin Using RS and GIS Techniques

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Authors’ contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Morphometric study of Dhatarwadi river basin.
Place and Duration of Study: This study is a work done for the research work in Ph.D. degree at College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh, Gujarat, India.
Methodology: Morphometric analysis involved determination of linear, aerial and relief aspects of the Dhatarwadi river basin, which was carried out using 30 X 30 m SRTM DEM in ArcGIS 10.5 software using standard formulae.
Results: The obtained results revealed that the Dhatarwadi river basin is 6th order drainage basin. The total number of 1327 streams were identified out of which 1st, 2nd, 3rd, 4th, 5th and 6th order streams are counted as 1036, 239, 42, 7, 2 and 1 number, respectively. The mean bifurcation ratio value is 4.31 for the study area which indicates that the geological structures are not distorting the drainage pattern. Stream length ratio varies between 0.14 and 2.14 indicates late youth geomorphic stage. The length of overland flow was found as 0.3084 km which also indicates very less structural disturbance, low runoff conditions and having higher overland flow. The stream frequency of the

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basin is $1.5448 \text{ km}^{-2}$, indicates that this basin is having high permeable geology, low relief and the almost flat topography. The form factor, elongation ratio, circularity ratio and compactness coefficient are found as 0.3951, 0.7094, 0.3126 and 1.7882, respectively of the study basin is suggests that the Dhatarwadi river basin shape is elongated. The drainage texture is $7.1426 \text{ km}^{-1}$ which shows that the Dhatarwadi river basin has short duration for peak flow. The relief, relief ratio and relative ratio of the basin are found as 0.438 km, 0.009372 and 0.2352, respectively.

**Conclusion:** All these parameters indicate that the Dhatarwadi river basin is of flat terrain with small hillocks/inselbergs having low to medium runoff potential.

**Keywords:** Dhatarwadi; morphometry; runoff potential; river basin; linear aspect; aerial aspect; relief aspect.

1. INTRODUCTION

According to Clarke [1], morphometry is measuring and analyzing mathematically the geography of surface of the planet earth along with its shape and details of landforms. Hortan [2] had introduced “morphometry” [3]. Morphometric analysis of a river basin is generally required to understand evolutionary history of basin, study hydrological behaviour of basin, figure out runoff and groundwater potential, detect and evaluate seasonal changes occurring in characteristics of basin and know issues related to management of soil and water erosion due to the high flow occurrence [3-8]. The linear, areal and relief aspects of the basin are used for morphometric analysis [9,10]. The morphological characteristics of a basin govern its hydrological response to a considerable extent. Basin characteristics when measured and expressed in quantified morphometric parameters can be studied for their influence on runoff. Understanding drainage system of a watershed is vital, for which morphometric analysis is the key [11].

Remote Sensing (RS) and Geographical Information System (GIS) are the need of the time as they provide environment for data collection and their process on time with maximum possible accuracy. Morphometric analysis of river basin using RS and GIS techniques is being used many researchers as they are found precise and user friendly.

Choudhari et al. [12] studied morphometric parameters to evaluate soil erosion and groundwater potential zones for the Mula river basin of Pune, Maharashtra; they found morphometric parameters study using RS and GIS techniques as good option. Dsouza et al. [13] carried out a study to prioritize micro-watersheds in the Balekoppa located in the Sirsi taluk of Uttara Kannada district of Karnataka state of India based on erosion potential found out using morphometric study of the micro-watersheds using GIS environment. The proper use of RS and GIS techniques are found very much useful for morphometric study of Champua watershed of Upper Baitarani river basin, Odisha, India by Prabhakar et al. [14] to understand hydrologic performance of the basin. Mahala [3] found the remote sensing and GIS as a successful tool to understand the morphometric characteristics in two different morpho-climatic settings: the Kosi River basin of northern India for the mountain–plain tropical environment and Kangsabati River basin of eastern India for the plateau–plain sub-humid environment.

In present study, the important morphological parameters; linear, aerial and relief aspects were derived for Dhatarwadi river basin.

2. MATERIAL AND METHODS

2.1 Description of Study Area

The Dhatarwadi river basin is situated in Amreli district of Saurashtra region of Gujarat, India. The basin is located between $20^\circ 50'\text{ to } 21^\circ 20'$ North latitude and $71^\circ 05'\text{ to } 71^\circ 35'$ East longitude. Dhatarwadi river flows through Savarkundla, Khambha, Rajula and Jafrabad talukas of Amreli district encompassing tributaries namely Likhala, Sonardi and Surajwadi. The river basin covers an area of $85899 \text{ ha}$. The average annual rainfall in the Dhatarwadi river basin is $660 \text{ mm}$ (year 1988 to 2017). The winter season start from the month of November and ends in the middle of March with minimum temperatures being $19^\circ \text{C}$ and $20^\circ \text{C}$, respectively, during which the coldest month is January. The summer season comprises of the months from
middle of March to middle of June, mid April to mid of June being the hottest period during the year, during May month maximum temperature is recorded near about 42°C. The rainy season commences from the mid of June and ends in September or October are of seldom occurrence.
2.2 Data Sets Used

The toposheets of scale of 1:50000 were collected from Survey of India. The topographical maps were georeferenced in ArcGIS 10.5 software. The pre-processed Shuttle Radar Topography Mission (SRTM 30 m) Digital Elevation Model (DEM), the boundary of Dhatarwadi river basin and river body of Dhatarwadi was provided by BISAG, Gandhinagar for extraction and quantification of morphometric parameters.

2.3 Methodology

In the present study, the important morphological parameters i.e. linear, aerial and relief aspect parameters for Dhatarwadi river basin were derived using standard formula Table 1 shows the formulae used for quantitative determination.
3. RESULTS AND DISCUSSION

3.1 Linear Aspects of Dhatarwadi River Basin

The linear aspect consists of stream order, number of streams of respective stream order, total length of streams, mean stream length, length of overland flow, bifurcation number and stream length ratio. Linear parameters such as bifurcation ratio have direct relationship with erodibility. Greater values of linear parameters enhance the runoff potential and thereby the erodibility [19-22]. The linear aspects of Dhatarwadi river basin are presented in Table 2.

3.1.1 Stream order

Table 1. Mathematical formula to calculate morphometric parameters

| Morphometric Parameters | Formula | Reference |
|-------------------------|---------|-----------|
| Linear Aspects          |         |           |
| Stream order (u)        | Hierarchical rank | Horton (1945) [2] & Strahler (1964) [11] |
| Stream number (Nu)      | Number of streams | Horton (1945) [2] |
| Mean stream length (L̅u) | \( \frac{\sum_{i=1}^{n} L_{iu}}{N_u} \) | Horton (1945) [2] |
| Stream Length ratio (Rl) | \( R_l = \frac{L_u}{L_{u-1}} \) | Horton (1945) [2] |
| Bifurcation ratio (Rb)  | \( R_b = \frac{Nu}{Nu+1} \) | Schum (1956) [15] |
| Length of over Land flow (Lg) | \( L_g = 1/Dd^2 \) | Horton (1945) [2] |
| Aerial Aspects          |         |           |
| Drainage Density (Dd)   | \( Dd = \frac{L_u}{A} \) | Horton (1932) |
| Stream frequency (Fs)   | \( F_s = \frac{\sum_{i=1}^{K} N_u}{A} \) | Horton (1945) [2] |
| Circularity Ratio (Rc)  | \( R_c = 4\pi A/P^2 \) | Miller (1953) [16] |
| Elongation Ratio (Re)   | \( Re = \frac{2/Lb}{X(A/\pi)^{0.5b}} \) | Schum (1956) [15] |
| Form factor (Rf)        | \( R_f = \frac{A}{L_b^2} \) | Horton (1932) [39] |
| Compactness Coefficient (Cc) | \( Cc = 0.2821 P/A^{0.5b} \) | Strahler (1964) [11] |
| Drainage texture (Rt)   | \( Rt = Nu/P \) | Horton (1945) [2] |
| Relief Aspects          |         |           |
| Relief (H)              | \( H = h_1-h_2 \) | Hardley and Schum (1961) [17] |
| Relief Ratio (Rr)       | \( R_r = \frac{H}{L_b} \) | Schum (1956) [15] |
| Relative relief (Rr)    | \( R_r = \frac{H}{P} \) | Melton (1957) [18] |

Where, \( A \) = area of basin (km²), \( N_u \) = total number of stream segment of order ‘u’, \( L_u \) = total stream length of all order (km), \( P \) = perimeter of basin (km), \( L_b \) = Basin length (km), \( D_b \) = Diameter of circle having same area as that of watershed, \( L_m \) = Length of main channel (km), \( N_r \) = Total No. of Stream of all orders, \( h_1 \) and \( h_2 \) = Highest and lowest points on the valley floor of a watershed.

of morphometric parameters used in the present study. All the morphometric parameters analysis was performed in the Geographical Information System environment with the aid of ArcMap of ArcGIS 10.5 software. Fig. 2 and Fig. 3 shows DEM map and Slope map of the study area, respectively.

The study area is found out to be a 6th order drainage basin (Fig. 4). The total number of 1327 streams were identified out of which 1st, 2nd, 3rd, 4th, 5th and 6th order streams are counted as 1036, 239, 42, 7, 2 and 1 number, respectively. The first order stream has maximum number of streams in the study basin and with increase in order of stream there is a decrease in number of streams. Higher order stream is related with higher velocity with greater discharge [23]. The drainage pattern of stream network of the basin has been observed as mainly dendritic type which indicates that there is homogeneity in texture but lack of structural control [24]. This pattern may be well described as a tree or a fern like pattern with branches that are intersecting primarily at acute angles. While in some parts of the basin represent parallel pattern type indicating that the topographical features are dipping, folded and high in the hilly terrains. Tributaries having flow nearly parallel to one another and all the tributaries connected with approximately same angle to the main channel is considered as a parallel drainage pattern. Parallel drainage suggests that the area has gentle, uniform slopes and with less resistant bed rock [25].
3.1.2 Total stream length

The total length of the 1st order streams is highest i.e. 724.56 km and that of 2nd order is 356.16 km, 3rd order is 165.09 km, 4th order is 102.73 km, 5th order is 13.96 km (which is the lowest) and 6th order is 29.93 km. Generally, the total length of streams decreases with increase in stream order. In this study basin, fifth order streams are of little variation, this may be because of streams flowing from high altitude, moderately steep slope and lithological variation, implies that the geomorphic development in the streams of the study area is still in youth stage [26, 27].

3.1.3 Mean stream length

Strahler (1964) stated that the mean stream length is related with basin surface and is a dimensional property which is related to the components of drainage network. The mean stream length of the basin varies from 0.70 to 29.93 km which shows inverse trend with the total length of the streams, and Horton (1932) advocated that the number of streams decreases with the total length of the streams. This is because the number of streams decreases with increase in stream order. The basin length is 46.63 km and the area of basin is 858.99 km².

3.1.4 Bifurcation ratio

Bifurcation ratio of a basin is derived by total number of streams of any order divided by total number of streams of higher order. Therefore, it is a dimensionless parameter. Bifurcation ratio is classified into two class namely high (> 5) and low (< 5). Low class is referred when a drainage pattern is not under control of geologic structure, otherwise high class is considered [28, 24, 29]. The bifurcation ratio (Rb) ranging from 2.00 to 6.00 showed that the geologic structures are not disturbing the drainage pattern. The mean bifurcation ratio value is 4.31 for the study area which indicates that the geological structures are not distorting the drainage pattern [30].

3.1.5 Stream length ratio

Stream length ratio (RL) can be described as the ratio between the mean length of the one order and the next order of the stream segments. For study area it is varying between 0.14 and 2.14. The stream length ratio value with increase in stream order indicates that study area is in its late youth geomorphic stage [28].

3.1.6 Length of overland flow

Length of the overland flow represents the length of p/h that runoff water travel over the ground before it gets concentrated in to definite stream channels. It is one of the most important independent variables affects both to the hydrologic and physiographic development of watershed. Length of overland flow is classified in three classes viz., high value (>0.3), moderate value (0.2 to 0.3) and low value (<0.2) [29].

| Stream order | No. of streams | Total length of streams (km) | Mean stream length (km) | Length of overland flow (km) |
|--------------|----------------|------------------------------|-------------------------|-----------------------------|
| 1            | 1036           | 724.56                       | 0.70                    | 0.3084                      |
| 2            | 239            | 356.16                       | 1.49                    |                             |
| 3            | 42             | 165.09                       | 3.93                    |                             |
| 4            | 7              | 102.73                       | 14.68                   |                             |
| 5            | 2              | 13.96                        | 6.98                    |                             |
| 6            | 1              | 29.93                        | 29.93                   |                             |

A. Bifurcation ratio (Nu/Nu+1)

| Stream order | 1st/2nd | 2nd/3rd | 3rd/4th | 4th/5th | 5th/6th | Mean |
|--------------|---------|---------|---------|---------|---------|------|
|              | 4.33    | 5.69    | 6.00    | 3.50    | 2.00    | 4.31 |

B. Stream length ratio (Lu+1/Lu)

| Stream order | 2nd/1st | 3rd/2nd | 4th/3rd | 5th/4th | 6th/5th | Mean |
|--------------|---------|---------|---------|---------|---------|------|
|              | 0.49    | 0.46    | 0.62    | 0.14    | 2.14    | 0.77 |
Length of overland flow for Dhatarwadi basin was found as 0.3084 km which indicates the high stream frequency in the basin. As it is greater than 0.3 it comes under very less structural disturbance, low runoff conditions and having higher overland flow. A low value of over land flow suggests short flow path and steeper slopes; low infiltration and high runoff. A higher value of length of overland flow describes that slopes are gentle and flow paths are longer; infiltration is higher and runoff is lower [31].

3.2 Aerial Aspects of Dhatarwadi River Basin

The aerial parameter is comprised of drainage density, stream frequency, elongation ratio, form factor, circularity ratio, compactness coefficient and drainage texture. The parameters i.e. elongation ratio, form factor, circularity ratio and compactness coefficient are inversely proportional to the severity of soil erosion. As the values of these parameters increases the priority of the watershed decreases [32, 19, 33]. While the parameters drainage density, stream frequency and texture ratio are directly proportional to the severity of soil erosion. The parameters for Dhatarwadi river basin are presented in Table 2.

3.2.1 Drainage density

The drainage density of the basin is 1.6210 km/km². The drainage density is classified in five classes i.e. very coarse (< 2 km/km²), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (> 8). As it is less than 2 km/km², the Dhatarwadi river basin comes under low drainage density. Regions of highly permeable subsoil material under dense vegetative cover having low relief generally have low drainage density [30].

3.2.2 Stream frequency

Somashekar et al. [34] has given classes of stream frequency i.e. low (0-5 no. of streams/km²), moderated (5-10), moderated high
(10-15), high (15-20) and very high (20-25). The stream frequency of the basin is 1.5448 km² which comes under low class. Lower value of stream frequency indicates that this basin is having high permeable geology, low relief and the almost flat topography [35].

3.2.3 Form factor

The form factor value will always be more than 0.78 for perfectly circular basins. As it is smaller, the basin will be more elongated [36]. The form factor of the study basin is 0.3951 suggests that the basin shape is elongated and there will be less side flow for shorter duration and high main flow for longer duration [31].

3.2.4 Elongation ratio

Strahler [11] stated that the elongation ratio value may vary from 0.6 to 1.0. It is associated with a wide variety of climate and geology and can be grouped into three categories i.e. circular (greater than 0.9), oval (0.9 to 0.8) and less elongated (less than 0.8) as per [37]. The elongation ratio for Dhatarwadi river basin is 0.7094 indicating that it is less elongated.

3.2.5 Circularity ratio

According to Miller [16], the basin circularity ratio is the ratio of the basin area to the area of a circle having an equal perimeter as the basin. The circularity ratio of any basin ranging between 0.4 to 0.5 indicates that the basin is strongly elongated and highly permeable homogeneous geologic materials are present. The circularity ratio of the Dhatarwadi river basin is 0.3126 which is less than 0.4 indicating elongated in nature.

3.2.6 Compactness coefficient

The Compactness coefficient of a watershed as per Gravelius [38] is a ratio of watershed perimeter to the perimeter of a circle having equal area as of the watershed. A circular basin is the risky one when drainage is an important point since it will generate the shortest time of concentration before peak flow occurs in the basin. Compactness coefficient value equal to 1 indicates that the watershed behaves as a circular basin i.e. shortest time of concentration and value more than 1 indicates that behavior of watershed deviates from the circular basin nature [23]. The compactness coefficient of the basin was found as 1.7882 which shows that basin is elongated in shape.

3.2.7 Drainage texture

Drainage texture of a basin depends on the infiltration capacity of the basin [39]. The classification of drainage texture is the same with the classification of drainage density [27, 28, 24]. A watershed which has very fine texture or the higher value of drainage texture (>8) implies that it has more risk of soil erosion [31]. As per Altaf et al. [23] the basin having lower value of drainage texture has a longer duration to peak flow, while having higher value makes shorter duration to peak flow. For the present study area, drainage texture is 7.1426 km⁻¹ shows that the Dhatarwadi river basin has longer duration for peak flow.

3.3 Relief Aspects of Dhatarwadi River Basin

Relief aspects are important indicators of direction of water flow as it is an important factor to understand the extent of denudation process occurred within the basin [34]. Relief aspects consist of relief, relief ratio and relative relief. The values of the relief aspect are presented in Table 3.

3.3.1 Relief

The maximum basin elevation in the study basin is found as 438 m and the minimum elevation as 0 m because the Dhatarwadi river meets Gulf of Khambhat. The result showed that the relief of the basin is 0.438 km. Watershed relief is an indirect mean to know available potential energy in the drainage watershed. The forces of erosion acting on the watershed are always greater for greater relief [36].

Table 3. Aerial aspects of Dhatarwadi river basin

| Drainage density (km/km²) | Stream frequency (1/km²) | Circularity ratio | Compactness coefficient | Form factor | Elongation ratio | Drainage texture (1/km) |
|--------------------------|--------------------------|-------------------|------------------------|-------------|-----------------|------------------------|
| 1.6210                   | 1.5448                   | 0.3126            | 1.7882                 | 0.3951      | 0.7094          | 7.1426                 |
3.3.2 Relief ratio

The relief ratio of the basin is 0.009372. The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin as found by Schumn [15] stated that sediment loss per unit area was closely correlated with relief ratio. The low relief ratio of the Dhatarwadi river basin indicates low relief and slope in the basin [40].

3.3.3 Relative relief ratio

The relative relief was obtained as 0.2352. Nongkynrih and Husain [40] suggested that low relative relief ranges between 0 to 0.1 km, moderately between 0.1 to 0.3 and high above 0.3. The Dhatarwadi river basin has moderate relative relief which suggests that the basin is of flat terrain with small hillocks/inselbergs [41].

Table 4. Relief aspects of Dhatarwadi river basin

| Relief (km) | Relief ratio | Relative relief |
|-------------|--------------|-----------------|
| 0.438       | 0.009372     | 0.2352          |

4. CONCLUSION

Based on the study carried out using 30 m resolution DEM file following conclusion are derived,

- The Dhatarwadi river basin is found to be 6th order drainage basin. The total number of 1327 streams were identified out of which 1st, 2nd, 3rd, 4th, 5th and 6th order streams are counted as 1036, 239, 42, 7, 2 and 1 number, respectively.
- The mean bifurcation ratio value is 4.31 for the study area which indicates that the geological structures are not distorting the drainage pattern.
- Stream length ratio varies between 0.14 and 2.14 indicates geomorphic development is in late youth stage.
- The length of overland flow was found as 0.3084 km which indicates very less structural disturbance, low runoff conditions and having higher overland flow.
- The drainage density of the basin is 1.6210 km/km² indicates highly permeable subsoil material under dense vegetative cover having low relief.
- The stream frequency of the basin is 1.5448 km² indicates that this basin is having high permeable geology, low relief and the almost flat topography.
- The form factor, elongation ratio, circularity ratio and compactness coefficient are found as 0.3951, 0.7094, 0.3126 and 1.7882, respectively of the study basin is suggests that the Dhatarwadi river basin shape is elongated.
- The drainage texture is 7.1426 km¹ shows that the Dhatarwadi river basin has short duration for peak flow.
- The relief, relief ratio and relative ratio of the basin are found as 0.438 km, 0.009372 and 0.2352, respectively. All this parameter indicates that the Dhatarwadi river basin is of flat terrain with small hillocks/inselbergs.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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