# Morphological Parameter Estimation Derived From ASTER-DEM Using GIS and Remote Sensing Techniques – A Study on Hosakote Watershed of Dakshina Pinakini River Basin, Karnataka, India

**K. Satish[1*] and H.C. Vajrappa[1]**

[1]Department of Geology, Jnanabharathi Campus, Bangalore University, Bangalore – 560 056, Karnataka, India.
*E-mail: geostish.k@gmail.com

**Abstract:**

*Study of groundwater potential zone and sites for groundwater recharge is most important in a watershed study. In order to locate the sites for groundwater recharge, morphometric analyses should carry out for a given watershed. For morphometric analyses, manual measurement of basin parameters is expensive and time consuming. Therefore, Advanced Spaceborne Thermal Emission and Reflection Radiometer Digital Elevation Model (ASTER-DEM) can be used as data source for extracting all complex morphometric parameters of the watershed. Morphological parameters such as stream order, number of streams of each order, stream length, bifurcation ratio, form factor, circularity ratio, elongation ratio and infiltration number have been estimated through DEM derived from ASTER (30 m) in GIS environment.*

**Keywords:**

ASTER-DEM, Circularity Ratio, Elongation Ratio, Infiltration Number, Groundwater Recharge

## Introduction

The morphometric studies involve the evolution of stream parameters through the measurement of various stream properties [1]. In this paper, an attempt has been made to evolute morphometric parameters derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer Digital Elevation Model (ASTER-DEM) (30 m). Modern technologies such as Geographic Information System (GIS), have gained significant importance over the last decade in their applications pertaining to distributed hydrologic modelling. GIS is suitable for the analysis of spatially referenced data. GIS can handle both spatial and aspatial data effectively and efficiently. Nowadays, GIS is widely used for resources planning in watershed [2, 3]. Using the presently available GIS techniques one has to go through tedious steps for generating these characteristics.

Since the mid-1980s digital elevation models (DEMs) have been used to delineate drainage networks [4, 5] and watershed boundaries, to calculate slope characteristics, and to produce flow paths of surface runoff [6, 7]. In this study, it has been found that ASTER-DEM can be very useful data to extract the morphometric characteristics of watersheds accurately in very less time, which helps in locate the sites for groundwater recharge and proper watershed planning.

## Study Area

The present study is conducted on Hosakote watershed of Dakshina Pinakini River – a tributary of river Cauvery, which falls between 77° 76′ and 77° 96′ N longitude and between 13° 04′ and 13° 17′ E latitude, covering an area of 161.3 $Km^2$ (Fig. 1).

## Materials and Methods

ASTER images obtained from the website *http://www.gdem.aster.ersdac.or.jp* are used. The drainage network from ASTER-DEM has been extracted, using the ArcGIS 9.3 (Fig. 1) adopting the standard procedures [8–11].

The steps are as follows to obtain watershed and streams derived from ASTER-DEM

Fill the sinks in the ASTER-DEM
Apply the flow direction function
Apply the flow accumulation
Apply a threshold condition
Obtain a streams grid
Obtain the stream links grid
Obtain watershed grid
Vectorize the streams grid
Vectorize the watershed grid.

## Morphometric Analyses

Morphometric analyses of the watersheds carried out by using three parameters viz, basic, derived and shape parameters.

## Basic Parameters

The perimeter (*P*) is the total length of the drainage basin boundary. The perimeter of the watershed is 59.19 Km. It is clearly noticed that the accurate delineation is possible when a higher resolution image is used. The total watershed area is 161.3 $Km^2$. The length of the watershed (*L*) measured parallel to the main drainage line. The values of basin length are shown in Table 1.

## Stream Order

Stream order or classification of streams is a useful indicator of stream size, discharge and drainage area [12]. The number of streams ($N$) of each order ($u$) is presented in Table 1. The watershed is fifth order basin, it is observed that decrease in stream frequency as the stream order increases (Fig. 2).

**Stream Length**

The number of streams of various orders in watershed is counted and their lengths are measured. The stream length characteristics of the watersheds confirm Horton's [13] second law "law of stream length" which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio. In general, the total length of stream segments is high in first order streams and decreases as the stream order increases (Fig. 3). In this case, the stream segments of various orders show variation from general observation. When stream length has been calculated for the watershed, it has been found that it follows a general pattern for ASTER, that is, stream length is maximum in the first order and decreases with the least at fifth order. The values of length ($L_u$) and total stream length ($L_t$) are shown in Table 1.

The maximum and minimum height ($H$,$h$) corresponds to the highest and lowest points of the basin. The maximum and minimum heights of watershed are 920 and 820 m, respectively.

***Derived Parameters***

**Bifurcation Ratio**

The bifurcation ratio ($R_b$) ranges between 3 and 4.33 when the influence of geological structures is negligible [14]. The mean $R_b$ may be defined as the average of bifurcation ratios of all orders (Table 1). In the present case the mean $R_b$ is 3.8, which indicates mature stage of development.

$$R_b = \frac{N_u}{N_u + 1}$$

Where, $N_u$=Total no. of stream segments of order 'u' and $N_{u+1}$=No. of segments of the next higher order.

**Drainage Density**

The value of $D_d$ is 1.57 Km/Km$^2$, which reveals that the watershed is composed of permeable subsurface material, vegetation cover and low relief. This reflects that this watershed has more infiltration capacity and is the good site for groundwater recharge (Table 1).

$$D_d = \sum \frac{L_u}{A_u}$$

Where, $L_u$=Total stream length of all the orders and $A$=Area of the Basin (Km$^2$).

**Stream Frequency**

Horton [15] introduced stream frequency ($F_s$) or channel frequency. The total number of stream segments of all orders per unit area. $F_s$ is related to permeability, infiltration capacity and relief of watershed. The watershed shows medium $F_s$ (1.64), which corresponds permeable strata.

$$F = \frac{N}{A}$$

where, $N$=Total no. of streams and $A$=Total area of the basin.

### Drainage Texture

The drainage texture ($D_t$) is an expression of the relative channel spacing in a fluvial dissected terrain. It depends on a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development of a basin [16]. The value of $D_t$ is 4.49, which indicates moderate drainage texture.

According to Horton [13], $D_t$ is the total number of stream segments of all orders per perimeter of that area. The drainage density <2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and >8 is very fine drainage texture.

$$R_t = \frac{N_u}{P}$$

Where, $N_u$=Total no. of streams of all orders and $P$=Perimeter (Km).

### Infiltration Number

Infiltration number is the product of the drainage density and stream frequency. It plays significant role in observing the character of basin. It is inversely proportional to the infiltration capacity of the basin. Result reveals that watershed has high infiltration capacity, composed of fractured subsurface and undulating to low relief (Table 1).

$$I_f = D_d \times F_s$$

Where, $D_d$=Drainage density and $F_s$=Stream Frequency.

### *Shape Parameters*

### Elongation Ratio

Schumm [17] defined elongation ratio ($R_e$) as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin ($L$). Result of $R_e$ exhibits that the watershed is more or less elongated in shape with the value of 0.6. A circular basin is more efficient in the discharge of run off than an elongated basin [18]. The value of $R_e$ varies from 0 (in highly elongated shape) to the unity, that is, 1 (in circular shape).

$$R_e = \frac{2\sqrt{A_u / \pi}}{L_b}$$

Where, $A$=Area of the Basin (Km$^2$); $\pi$=3.14; and $L_b$=Basin length.

### Circularity Ratio

Circularity ratio ($R_c$) is the ratio of the area of watershed to the area of a circle having the same circumference as the perimeter of the watershed [18]. $R_c$ is influenced by the length and frequency of streams, geological structures, land use/land cover, climate and relief of the basin. The $R_c$ of the watershed is 0.57. The result shows that the watershed is more or less elongated and characterized by moderate-to-low relief.

$$R_c = \frac{4\pi A}{P^2}$$

Where, $\pi$=3.14; $A$=Area of the Basin (Km$^2$) and $P^2$=Square of the perimeter (Km).

**Form Factor**

Form factor ($R_f$) is the ratio of the watershed area to the square of watershed length. It is used as a quantitative expression of the shape of watershed form. $R_f$ value indicates that the watershed is less circular in shape with lower value of 0.35, where we can expect more groundwater recharge.

$$R_f = \frac{A_u}{L_b{}^2}$$

Where, $A$=Area of the Basin (Km$^2$) and $L_b{}^2$=Square of Basin length.

**Results and Discussions**

The maximum frequency in case of first order stream is found in the watershed, that is 201 first, 48 second, 13 third, 3 fourth and 1 fifth order streams found in the watershed (Table 1). Furthermore, it is noted that $F_s$ decreases as the stream numbers increases. Plot of number of streams against the order of streams indicate linear correlations. It means that number of streams usually decreases in geometric progression as the stream order increases (Fig. 2). The variations in rock structures of watersheds are responsible for inequalities in stream frequencies of each order. The results show that the total length of stream segments is maximum in case of first order streams, that is, the first order has length of 147.5 Km, second order 54.2 Km, third order 29.7 Km, fourth order 12.3 and fifth order has length of 10.2 Km. This indicates that as the stream length decreases the order increases (Fig. 3). Thus, stream length characteristics of the watersheds confirm Horton's [13] second law "law of stream length". The value of drainage density 1.57 Km$^2$/Km indicates that region under this watershed is composed of permeable subsurface material, vegetation cover and low relief. This reflects that this watershed has more infiltration capacity and can be the good site for groundwater recharge. $F_s$ is related to permeability, infiltration capacity and relief of watershed. $F_s$ reveals that this watershed is covered by vegetation and having very good infiltration capacity. The $R_f$ value varies from 0 (in highly elongated shape) to the unity, that is, 1 (in perfect circular shape). Hence, higher the value of $R_f$ more circular the shape of the basin and vice-versa. The values of $R_f$, $R_c$ and $R_e$

obtained for this watershed indicate that the watershed is more or less elongated (Table 1). This is the indication of more ground water recharge and good site.

## Conclusion

The watershed shows dendritic drainage pattern. The $D_d$ of watershed reveals that the watershed is composed of permeable subsurface material, vegetation cover and low relief. The value of $F_s$ reveals that the watershed is covered by vegetation and having very good infiltration capacity. Results of $R_f$, $R_c$ and $R_e$ obtained for this watershed indicate that the watershed is more or less elongated. This reflects that the watershed has more infiltration capacity and can be considered as good site for groundwater recharge. If basin characteristics studied thoroughly, the groundwater recharge area can be located. Hence, a systematic analysis of morphometric parameters within the drainage network using ASTER data can provide significant value in understanding the basin characteristics. Overall results show that the morphometric parameters derived from the ASTER data provide good and satisfying results. The results will be more efficient when the DEM cell size is smaller or the resolution of the image is higher.

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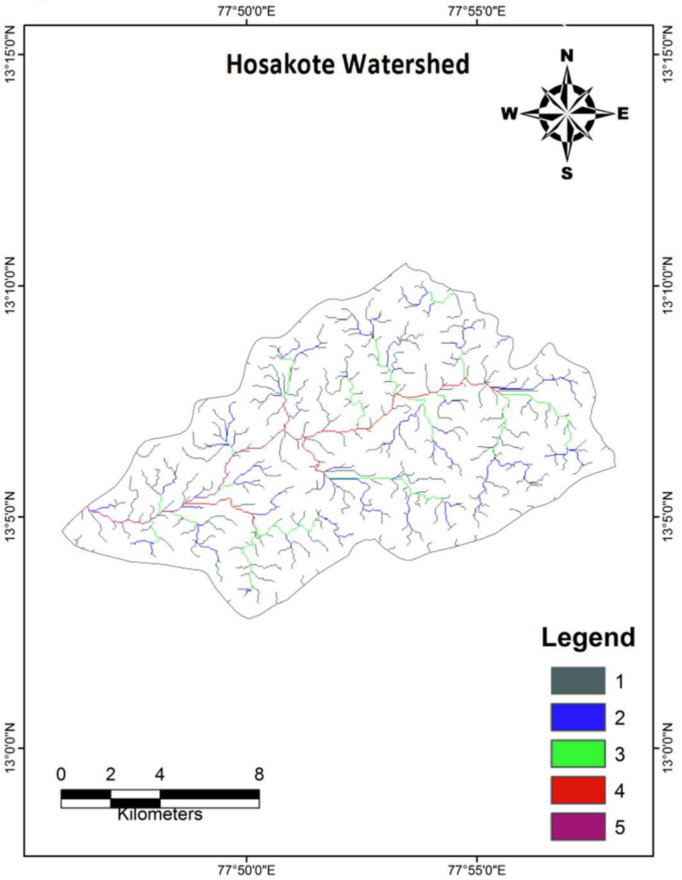


**Figure 1.** Drainage map of Hosakote watershed evoluted through ASTER-DEM.

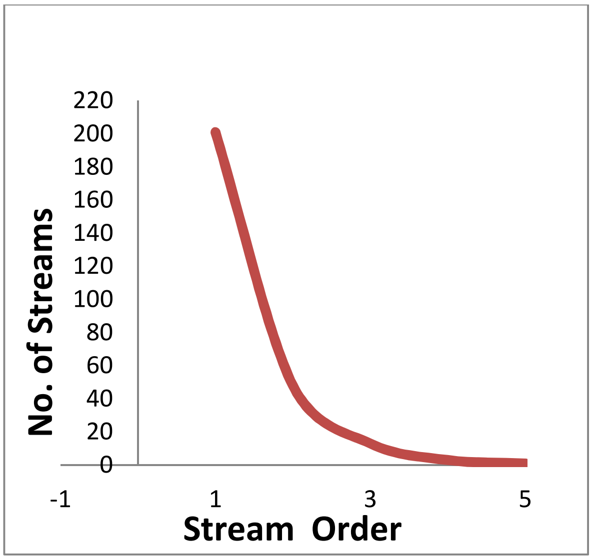


**Figure 2.** Relation of no. of streams to stream order.

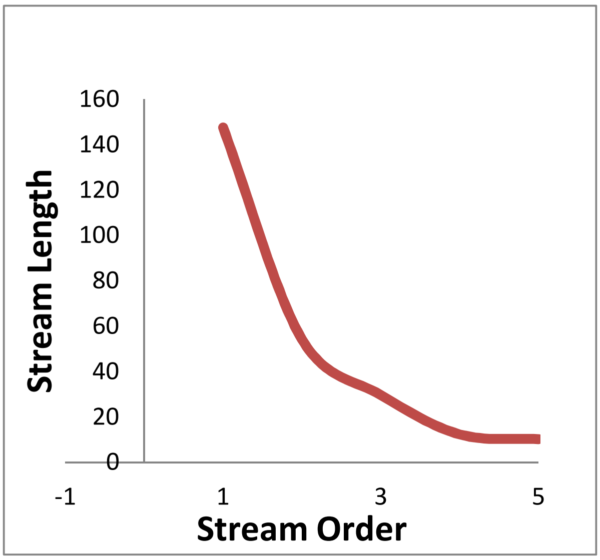


**Figure 3.** Relation of stream order to stream length.

**Table 1.** Morphometric analyses of the Hosakote watershed evoluted through ASTER-DEM.

| Stream Order | Stream Count | Total No. of Streams | Stream Length (Km) | Total Length (Km) | Mean Length (Km) | $R_b$ | $R_{bm}$ | $D_d$ (Km/Km$^2$) | $D_t$ | $F_s$ | $R_e$ | $R_f$ | $R_c$ | $I_f$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 201 | 266 | 147.52 | 253.94 | 0.73 | 4.18 | 3.8 | 1.57 | 4.49 | 1.64 | 0.66 | 0.35 | 0.57 | 2.59 |
| 2 | 48 | | 54.21 | | 1.12 | 3.69 | | | | | | | | |
| 3 | 13 | | 29.7 | | 2.28 | 4.33 | | | | | | | | |
| 4 | 3 | | 12.31 | | 4.1 | 3 | | | | | | | | |
| 5 | 1 | | 10.2 | | 10.2 | | | | | | | | | |