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RESEARCH ARTICLE

# Morphometric analysis of upper part of Pambar watershed, Ponnaiyar river basin, Tamil Nadu, India using Geographical Information System

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## Abstract

Geographical Information System is proved to be a professional tool in morphometric studies for analyzing their properties. It is an advanced technique which can efficiently store, update, manipulate, analyze and display the database to acquire effective management of groundwater. The study area is a part of Pambar watershed covering Vellore and Krishangiri districts of Tamil Nadu. It covers an area of 737 Sq. kms. The watershed is occupied by crystalline metamorphic rocks. The watershed is of sixth-order and the drainage pattern is dendritic type. The morphometric study is been carried out using GIS evaluating linear, areal and relief aspects. The study reveals that the morphometric attributes are very helpful for a drainage basin study. The values of form factor and elongation ratio show that the watershed is elongated and the terrain is low relief. It is observed that the drainage density is low for the hard rock region. The circularity ratio also indicates that the watershed is elongated in shape.

**Keywords:** Morphometric analysis, Pambar watershed, Ponnaiyar river basin, drainage pattern, GIS.

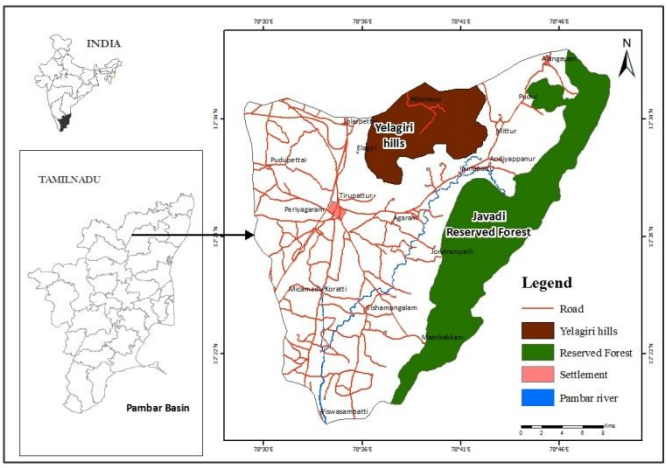
## Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy *et al.,* 2002). Drainage basin is the basic unit of fluvial investigation. The drainage is divided into stream lines into a network stream lines. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1957, 1964). The morphometric analysis is a quantitative method which describes various topographic parameters. It is also useful for statistical and comparative study using GIS and remote sensing for the morphometric study. The perspective study is taken for quantitative analysis of drainage system. The drainage pattern of the watershed is delineated using survey of India toposheets (scale 1:50,000). The morphometric parameters are computed using Arc GIS software. The present study reveals the stream order, number, frequency, density, and bifurcation ratio which are categorized by the linear, areal and relief properties. The morphometric parameters are also a helpful tool for identifying potential zonation.

## Materials and methods

Study area: The study area taken for morphometric investigation is Pambar watershed of Ponnaiyar river basin which covers an area of 737 Sq. kms in Vellore and Krishnagiri districts, Tamil Nadu, India (Fig. 1). The area is covered by the structural hill Yelagiri in the northern part and Javadi reserved forest in the eastern side of the study area.

Fig. 1. Location map of the study area.




The area is underlain by crystalline metamorphic rocks of pre-cambrian age which comprise charnockites and intrusive of dolerite and emplacement of ultramafic rocks. The Yelagiri hill is a ring complex with the rocks associated with Dunite-Pyroxenite-Syenite-Carbonatite. The drainage pattern is dendritic and the flow direction of the streams is southerly direction and controlled by the N-S trending shear zone. The streams originating in the Javadi reserved forest disappear in the colluviums of the bazada zones which is the characteristic feature of the drainage system. The total area of the basin is 737.11 Sq. kms and the total number of streams renowned in the area are 1505 of which 74.09% of streams is of first order 19.20% second order 4.72% third order 1.33% fourth order 0.60% fifth order and 0.07% sixth order.

Table 1. Morphometric parameters and its formula with reference.

| Parameters | Formulae | Reference |
|---|---|---|
| Linear aspects | | |
| Stream Order (U) | Hierarchial Rank | Strahler (1964) |
| Stream Length (Lu) | Length of the stream | Horton (1945) |
| Mean Stream Length (Lsm) | Lu/Nu | Strahler (1964) |
| Bifurcation Ratio (Rb) | Nu/Nu+1 | - |
| Mean bifurcation Ratio (Rbm) | - | Strahler (1957) |
| Areal aspects | | |
| Drainage density (Dd) | Dd=Lu/A | Horton (1945) |
| Drainage texture (T) | T=DdxFs | Smith (1950) |
| Stream frequency (Fs) | Fs=Nu/A | Horton(1945) |
| Elongation Ratio (Re) | Re=2SQRT(A/π)/Lb | Schumm (1956) |
| Circulatory Ratio (Rc) | $Rc=4\pi A/P^2$ | Strahler (1964) |
| Form Factor (Ff) | $Ff=A/L^2$ | Horton (1945) |
| Length of overland flow (Lg) | Lg=1/Dd*2 | Horton (1945) |
| Relief aspects | | |
| Relief (R) | R=H-h | Hadley and Schumm (1961) |
| Relief Ratio (Rr) | Rr=R/L | Schumm (1963) |
| Gradient Ratio (Gr) | Gr=H-h/L | Sreedevi *et al.* (2005) |

Table 2. Linear aspects of the drainage basin.

| Stream order | No. of streams | % of No. of streams | Total length (Km) | Mean length (Km) | Length Ratio | Bifurcation ratio | Log (Nu) | Log (Lu) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1115 | 74.09 | 710.67 | 0.64 | - | - | 3.05 | 2.85 |
| 2 | 289 | 19.20 | 298.94 | 1.03 | 1.62289 | 3.86 | 2.46 | 2.48 |
| 3 | 71 | 4.72 | 126.73 | 1.78 | 1.72562 | 4.07 | 1.85 | 2.10 |
| 4 | 20 | 1.33 | 90.46 | 4.52 | 2.5339 | 3.55 | 1.30 | 1.96 |
| 5 | 9 | 0.60 | 55.38 | 6.15 | 1.36051 | 2.22 | 0.95 | 1.74 |
| 6 | 1 | 0.07 | 0.64 | 0.64 | 0.10479 | 9.00 | 0.00 | -0.19 |
| | **1505** | - | **1282.82** | - | Mean Rb | **4.54** | - | - |

The first and second order streams are located in the higher elevation areas and most dominant streams in the area are first and second order. The morphometric analysis of the Pambar watershed was prepared based on the published topographic maps on a 1:50,000 scale. The drainage map was digitized from satellite imageries data of the year 2006. The satellite imageries had been geo-referenced and merged using the image processing software ERDAS imagine 8.6. The drainage pattern has been digitized based on topographic maps for reference. The morphometric parameters were classified in to three categories, Linear, Areal and Relief aspects were analyzed through GIS using ArcGIS software which are computed on the formulas given in Table 1.

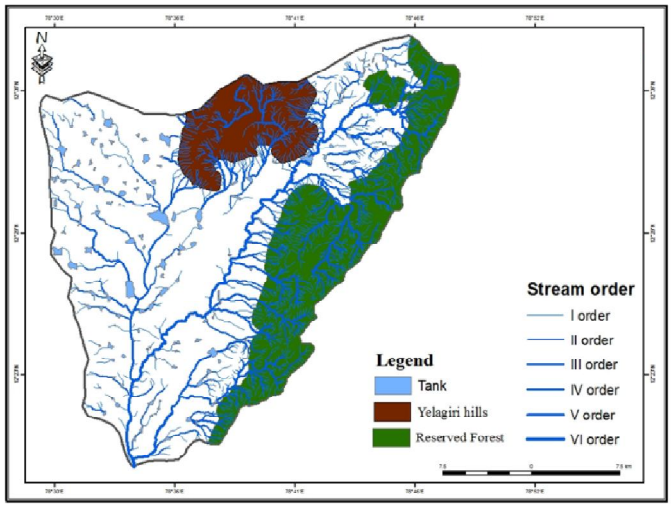
## Results and discussion

*Linear aspects of the drainage system*: The linear aspect describes the components of a typical drainage basin as stream order, stream number, bifurcation ratio, stream length and stream length ratio.

*(i) Stream order (u):* The designation of stream order is done following Strahler's method (Strahler, 1964), in which two first order streams join a stream segment of order 2 is formed; where two of orders 2 join a segment of order is 3 and so on.

The highest order is referred as the stream which all discharge of water and sediment is passed. The highest order in the study area is 6 (Fig. 2).

Fig. 2. Drainage map of the study area.




*(ii) Stream number (Nu):* The drainage network is assigned by their order numbers, the segment of each order are counted to get the stream number (Nu). The number of segments in each order is counted and given in Table 2.

The graphical representation of the data for stream order and Log of stream number is shown in Fig. 3.

Fig. 3. Graphical representation of the plot for stream order.

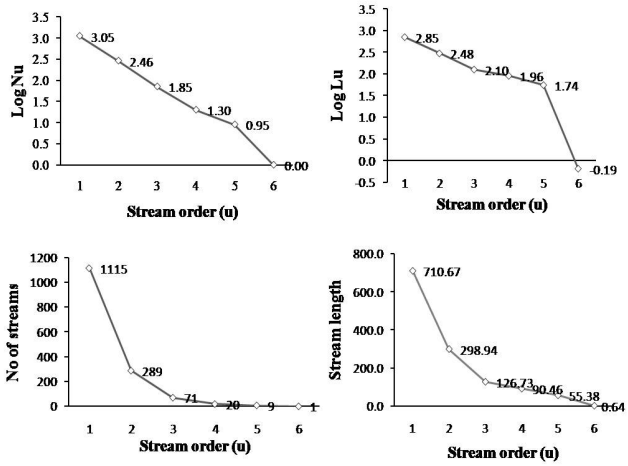



Table 3. Areal and relief aspects of the drainage basin.

| Areal aspects | Values |
|---|---|
| Area (A) (Sq. kms) | 737.11 |
| Perimeter (P) (Km) | 123.09 |
| Basin length (Lb) (Km) | 42.9 |
| Drainage density (Dd) | 1.74 |
| Drainage texture (T) | 3.55 |
| Stream frequency (Fs) | 2.04 |
| Elongation ratio (Re) | 0.714 |
| Circulatory ratio (Rc) | 0.611 |
| Form factor (Ff) | 0.40 |
| Length of overland flow (Lg) | 1.15 |
| Relief aspects | |
| Relief (R) | 6060 |
| Relief ratio (Rr) | 141.26 |

*(iii) Stream length (Lu):* Stream length of various orders has been computed based on the law given by Horton (1945). The length was determined using GIS software after digitizing the complete drainage pattern. The drainage network in the study area taken is a sixth order watershed and the length calculated is given in Table 2. Mean length of segments of a channel segment is obtained, as the total length is divided by the number and segments of that order.

*(iv) Stream length ratio:* Stream length ratio is defined as the ratio of mean length of segments of order u to mean length of segments of the next lower order (Lu-1).Stream length ratio ranges from 0.1 to 2.5 for the watershed. It is noticed that the RL between successive stream orders of the basin vary due to differences in slope and topographic conditions (Sreedevi *et al.,* 2005).

*(v) Bifurcation ratio (Rb):* The ratio of number of stream segments of a given order (Nu) to the number of segments of the higher order (Nu+1) is termed as Bifurcation ratio. Bifurcation ratio ranges between 2.22 to 9.

The average bifurcation ratio for the area is 4.54. Higher bifurcation ratio generally indicates some sort of geologic control (Agarwal, 1998). Normally if the bifurcation ratio is low, the basin produces a sharp peak of discharge and if the bifurcation ratio is high, the basin yields low but extended peak flow (Agarwal, 1998).

*Areal aspects of the drainage basin:* The areal aspects such as elongation ratio, form factor, drainage density, and circularity ratio are given in Table 3.

*(i) Basin area (A):* Area and perimeter of the basin are essential parameters for the quantitative analysis. The area of the basin is defined as the total area contributing flow to the channel of the given order and including all tributaries of lower orders. The area of the watershed is measured to be 737.11 Sq. kms. Perimeter is defined as the length of the boundary of the basin which can be drawn from topographical maps.

*(ii) Elongation ratio (Re):* The ratio between the diameter of a circle of the same area as the basin and the maximum length of the basin (Schumm, 1956). The elongation ratio ranges between 0.6 to 1.0 over a wide climatic conditions and geologic types. Values near to 1 are typical of regions of very low relief, whereas values in the range from 0.6 to 0.8 are generally associated with strong relief and steep ground slope. The elongation ratio for the study area is 0.71. The elongation ratio of indicates that low relief of terrain and elongated in shape.

*(iii) Form factor (Rf):* Form factor is defined as the ratio of the area of the basin (A) to the square of the length of the basin. The value of form factor would be less than 0.78 for a perfectly circular basin. The smaller value of 0.40 for the study area taken is elongated basin which has a flatter peak flow of longer duration.

*(iv) Circularity ratio (Rc):* The circularity ratio is defined as the ratio of the basin area to the area of circle having the same perimeter as the basin. The basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials (Miller, 1953). The circulatory ratio calculated for the study area is 0.61 indicates that the basin is elongated in shape.

*(v) Drainage density:* This is defined as the ratio of total channel segment length cumulative for all orders within the basin to the basin area. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure for the basin. The drainage density for the Pambar watershed is 1.74 km/Sq. km. The rock type affects drainage density tends to occur in hard rock region. The chief rock type in the study area is crystalline metamorphic rocks.

*(vi) Stream frequency:* Stream frequency is defined as the number of stream segments per unit area (Horton, 1945). The stream frequency value of the basin is 2.04. It mainly depends on the lithology of basin and reflects in the texture network.

*(vii) Drainage texture:* Drainage texture is calculated by the product of drainage density and stream frequency. The drainage density less than 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 greater than 8 is very fine drainage texture. The drainage texture for the area is 3.55.

*Relief aspects of the drainage system:*

*(i) Relief:* Relief is the difference between reference points defined in any one of several ways. Maximum relief within a region of given boundary is simply the elevation difference. Basin relief is an important factor in understanding the denudational characteristics of the basin. The maximum height of the basin is 6400 m and lowest is 340 m. Thus, the relief of the study area taken is 6060 m.

*(ii) Relief ratio:* Relief ratio is defined as the ratio between the relief and the length of the basin can be defined as the relief ratio which was proposed by Schumm (1965). The relief ratio for the watershed taken is 141.26.

## Conclusion

Following are the conclusions drawn out of the study:

1. The quantitative analysis of morphometric parameters evaluated using by GIS is found to be of enormous value in river basin study.
2. Based on the drainage orders the Pambar watershed has been classified as sixth order exhibiting dendritic pattern.
3. The drainage density of the study area is low and characteristic for texture of coarse drainage.
4. The circularity ratio shows that watershed is having low relief of terrain and elongated in shape.
5. Bifurcation ratio of 4.54 reveals that the drainage network in the study area is well developed stage.
6. The study reveals that the drainage area of the basin is passing through an early mature stage to old age stage of fluvial geomorphic cycle.

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