

# Morphometric Analysis of Olanthichira Watershed in Malappuram district, Kerala, using Geographic Information System

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## ABSTRACT

Morphometric analysis of watershed is important for understanding its geo-hydrological behaviour. The objective of this study is to determine morphometric parameters of Olanthichira watershed, Kuttipuram block, Malappuram district of state Kerala, India. The stream channels of the watershed were extracted from SRTM DEM and SOI topographical maps on 1:50,000 scale using Hydrology tools in Arc GIS software showing dendritic drainage pattern. Then morphometric analysis is carried out by determining parameters of linear, areal and relief aspects. Drainage density of 1.836 km/km<sup>2</sup> is moderate suggests semi-permeable rocks, moderate relief, and a balanced hydrological response. The drainage texture of watershed is 4.359/km indicates a moderate to fine drainage texture means the watershed has a fairly advanced drainage system, with a moderate number of stream channels with highest channel maintenance constant of 0.544 experiencing low runoff and fewer structural disruptions. The moderate bifurcation ratio of 3.68 in a drainage network suggests that the network's development is influenced by some degree of structural control. The areal aspects of the watershed point out elongated shape which possess lower erosion and sediment transport capacities and less prone to sudden floods but might require interventions to prevent sediment deposition in channels. The results of morphometric analysis along with slope map, aspect map and vegetation (NDVI) map are helpful for decision makers to implement soil and water conservation measures for sustainable management of the resources in watershed.

*Keywords: ArcGIS, Malappuram, Morphometric analysis, Remote sensing, SRTM DEM, Watershed characterization.*

## 1. INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, dimension of its landforms (Clarke, 1966). Morphometric analysis involves the characterization of a river basin or watershed through the quantitative measurement of various parameters including linear aspects, areal aspects, and relief aspects. Morphometric characteristics at the watershed scale can provide significant insights into its formation and development, as all hydrologic and geomorphic processes take place within the watershed (Pareta&Pareta, 2011). Morphometric analysis plays a critical role in watershed management by providing a scientific basis for understanding the physical characteristics of a watershed. These characteristics directly influence hydrological processes like surface runoff, infiltration, groundwater recharge, erosion, and sediment transport, which are key factors in managing watersheds effectively. It helps in planning water conservation, erosion control, flood mitigation, and sustainable resource utilization strategies.

Earlier, morphometric analysis was conducted manually using topographic maps to delineate watersheds and drainage networks. Measurements, such as stream lengths, drainage density, and basin areas, were calculated using tools like planimeters and curvimeters, while contour maps were analysed to estimate relief and slope. This process was labour-intensive, time-consuming and prone to human error, with limited accuracy due to the coarse resolution of maps and restricted data availability. These limitations have been overcome by the evolution of Geographic Information System (GIS) and Digital Elevation Model (DEM). GIS software enables efficient delineation of drainage networks, stream ordering, and watershed

boundaries, while DEMs provide high-resolution elevation data for precise terrain analysis. Integrating morphometric insights with modern tools like GIS ensures precision and efficiency in addressing watershed challenges.

Sreedevi et al. (2009) conducted a morphometric analysis of the Wailapalli watershed in South India using Shuttle Radar Topography Mission (SRTM) data and GIS techniques. The results indicated that the elongated shape of the basin is largely influenced by thrusting and faulting, with lower-order streams dominating the drainage system. Stream development is driven by rainfall, and the morphometric analysis suggests a drainage pattern minimally influenced by geological structures, characterized by high discharge capability but low groundwater potential. These findings provide valuable insights for designing rainwater harvesting systems and watershed management strategies. Mani et al. (2022) conducted a morphometric analysis of the Suswa River basin using geospatial techniques to study its hydrological characteristics. The research examined the relationship between water, soil, topography, and vegetation by utilizing SRTM-DEM data (30 m resolution) and ArcGIS software to delineate the basin and drainage network. The findings reveal a sub-dendritic to dendritic drainage pattern with an average drainage density of 2.84 km/km<sup>2</sup>. The basin's elongated shape and moderate relief are indicated by its elongation ratio. This study focuses on the morphometric analysis of the Olanthichira watershed, offering insights into its geo-hydrological characteristics. Additionally, the findings can serve as a valuable resource for decision-makers in promoting sustainable development.

## **2. MATERIAL AND METHODS**

### **2.1 Study area**

Olanthichira watershed is a micro-watershed of Bharathapuzha river basin, which spreads over an area of 814 ha in Edayoor and Melmuri villages of Marakkara and Edayoorpanchayats in Kuttippuram block of Malappuram District, Kerala. The watershed lies between 76° 02' 45" to 76°04'30" E longitude and 10° 55' 15" to 10° 58' 30" N latitude. The location map of study area map is shown in Fig. 1. Physio-graphically, it falls midland region with elevation ranges from 15 m to 150m above MSL. The general slope is towards South-West direction with average slope of 25%. The watershed has a humid tropical climate with an average annual rainfall of 2800 mm. The main drain of the watershed is Kannamkadavu Olanthithodu which originates from Parappur chola and other drainwise, Devar chola, Thengat chola, Nechikkatu chola, Ayanikkunduthodu, Parakkandamthodu and Moolam chola, joins to main drain at several points. The outlet is at Olanthichira. The main drain joins to Kunthippuzha then to Bharathapuzha.

### **2.2 Data and software used**

Survey of India (SOI) topographic map of 1:50,000 scale (C43K1) and Shuttle Radar Topography Mission (SRTM) DEM of 30m spatial resolution downloaded from USGS Earth explorer were used for delineation of Olanthichira watershed and morphometric analysis. Landsat 9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) with spatial resolution of 30m and spectral resolution of 11 bands was downloaded from USGS Earth Explorer for Land Use/Land Cover (LULC) mapping and NDVI mapping. Arc GIS software (10.7.1) was used to prepare different maps and conduct the morphometric analysis.

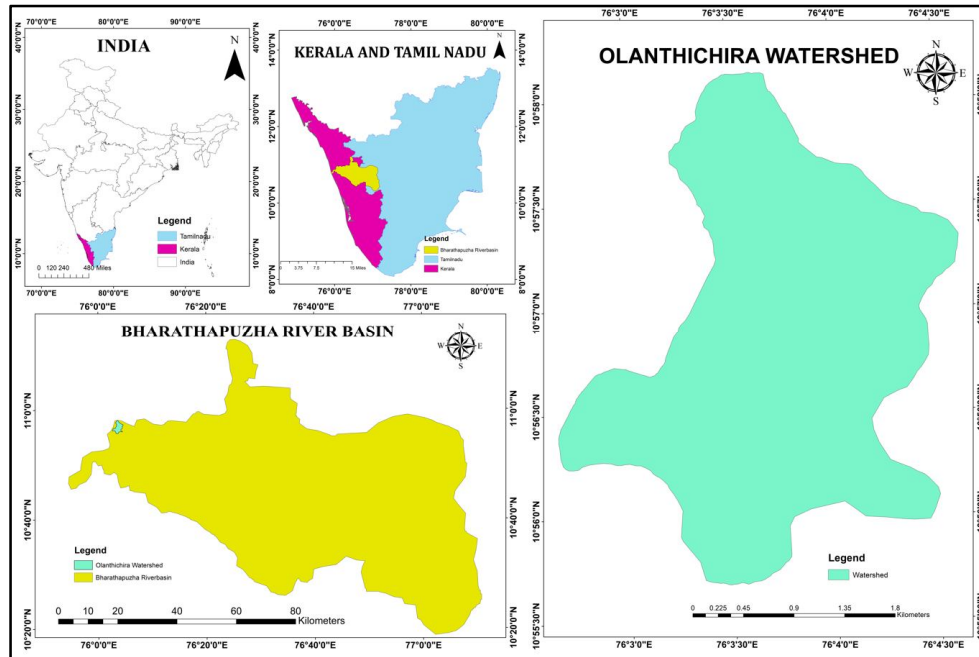


Fig. 1. Location map of Olanthichirawatershed, Malappuram

### 2.3 Methodology

The watershed was delineated using hydrology tools in ArcGIS. The process began with filling the SRTM DEM, followed by calculating flow direction and flow accumulation. Streams were then generated by applying threshold values to the flow accumulation data. The stream generated were verified using georeferenced topographic map. Finally, Olanthichira watershed was delineated by defining outlet point. The complete process was shown as flow chart in Fig. 2. Morphometric parameters represent the physical characteristics of a watershed and are primarily classified into three categories: linear, areal, and relief aspects. These parameters were determined using formulae mentioned in Table.1.

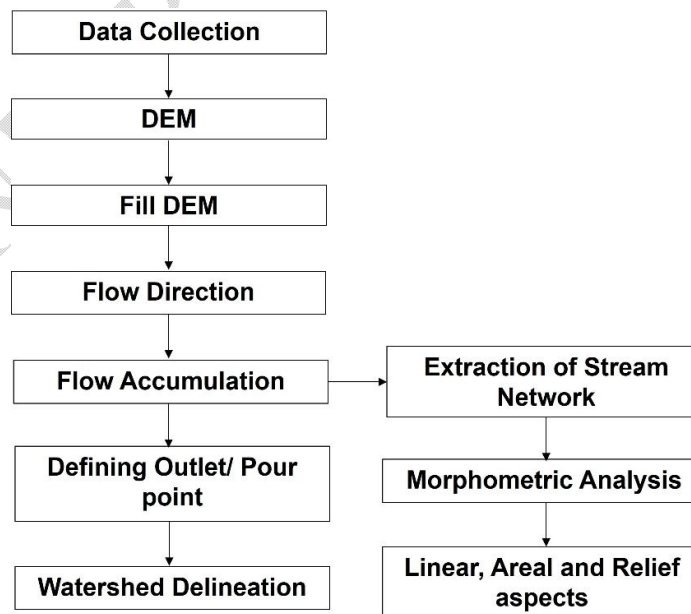


Fig. 2. Watershed delineation process

**Table 1. Mathematic equations for determining morphometric parameters**

Sl.No.	Morphometric Parameters	Formula/ Definition	References
<b>A Basin Parameters</b>			
1	Area (A)	GIS Analysis	
2	Perimeter (P)	GIS Analysis	
3	Basin length (L <sub>b</sub> )	$L_b = 1.312 A^{0.568}$	Schum (1956)
4	Mean basin width (W <sub>b</sub> )	$W_b = A / L_b$	Horton (1945)
5	Stream order (u)	Ranking hierarchically	Strahler (1952)
6	Stream number (N <sub>u</sub> )	$N_u = N_1 + N_2 + \dots N_n$	Horton (1945)
<b>B Linear Parameters</b>			
1	Stream length (L <sub>u</sub> )	$L_u = L_1 + L_2 + \dots L_n$	Strahler (1964)
2	Mean stream length (L <sub>sm</sub> )	$L_{sm} = L_u / N_u$	Strahler (1952)
3	Stream length ratio (L <sub>ur</sub> )	$L_{ur} = L_{smu} / L_{smu-1}$	Strahler (1964)
4	Mean stream length ratio (R <sub>slm</sub> )	$R_{slm} = \sum L_{ur} / n$	Schumm (1956)
5	Bifurcation ratio (R <sub>b</sub> )	$R_b = N_u / N_{u+1}$	Strahler (1964)
6	Mean bifurcation ratio (R <sub>bm</sub> )	$R_{bm} = \sum R_b / n$	Strahler (1964)
7	Rho coefficient (ρ)	$\rho = R_{slm} / R_{bm}$	Horton (1945)
8	Drainage density (D <sub>d</sub> )	$D_d = L_u / A$	Horton (1932)
9	Stream frequency (F <sub>s</sub> )	$F_s = N_u / A$	Horton (1932)
10	Drainage texture (D <sub>t</sub> )	$D_t = N_u / P$	Horton (1945)
11	Infiltration number (I <sub>i</sub> )	$I_i = F_s * D_d$	Faniran (1968)
12	Length of overland flow (L <sub>o</sub> )	$L_o = 1 / 2 D_d$	Horton (1945)
13	Drainage intensity (D <sub>i</sub> )	$D_i = F_s / D_d$	Faniran (1968)
<b>C Areal Parameters</b>			
1	Circularity ratio (R <sub>c</sub> )	$R_c = 4\pi A / P^2$	Miller (1953)
2	Elongation ratio (R <sub>e</sub> )	$R_e = D / L_b = 1.128 \sqrt{A} / L_b$	Schumm (1956)
3	Form factor ratio (F <sub>f</sub> )	$F_f = A / L_b^2$	Horton (1932)
4	Compactness constant (C <sub>c</sub> )	$C_c = 0.282 A / P^{0.5}$	Horton (1945)
5	Lemniscate's ratio (k)	$k = L_b^2 / 4A$	Chorley et al. (1957)
6	Shape factor (B <sub>s</sub> )	$B_s = L_b^2 / A$	Horton (1932)
7	Constant of channel maintenance (C)	$C = 1 / D_d$	Schumm (1956)
<b>C Relief Parameters</b>			
1	Elevation of basin outlet (h)	GIS analysis	
2	Maximum elevation of the basin (H)	GIS analysis	
3	Basin relief (R)	$R = H - h$	Strahler (1952)
4	Relief ratio (R <sub>n</sub> )	$R_n = R / L_b$	Schumm (1956)
5	Relative relief (R <sub>r</sub> )	$R_r = R / P$	Schumm (1956)
6	Ruggedness number	$H_d = D_d * R$	Strahler (1957)

Using Landsat 9 image, Normalised difference vegetation index (NDVI) map was prepared for 2023 to know the vegetation status of watershed using raster calculator in ArcGIS software. NDVI is a measure of the vegetation status of the study area and can be measured by calculating the difference of the Band 5 (NIR) and Band 4 (red) images of the TIRS Landsat imagery given in Equation 1 & 2 (Aravind, P et al. 2022).

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}$$

Thenslope map and aspect map of Olanthichira watershed were prepared in ArcGIS software.

### 3. RESULTS AND DISCUSSION

This study provided the morphometric analysis of Olanthichira watershed in three different aspects (Linear, Areal and Relief aspects). The slope, aspect, drainage density, vegetation (NDVI map), and soil characteristics of the watershed were analysed, providing a critical basis for understanding and managing the watershed. These aspects were determined based on various parameters outlined below.

#### 3.1 Basin Parameters

Drainage area (A) is a key watershed characteristic of hydrological analysis and design. Larger area and higher difference in elevation results in greater discharge (Sujatha et al., 2015). The elevation of Olanthichira watershed ranges from 18 to 146 m shown in Fig 3. The total area of Olanthichira watershed is 814 ha (8.14 km<sup>2</sup>) and the perimeter is 15.138 km. The basin length of watershed represents maximum length running parallel to the main drainage line which is 4.137 km. The basin width is 1.885 km which is the distance of line drawn perpendicular to basin length.

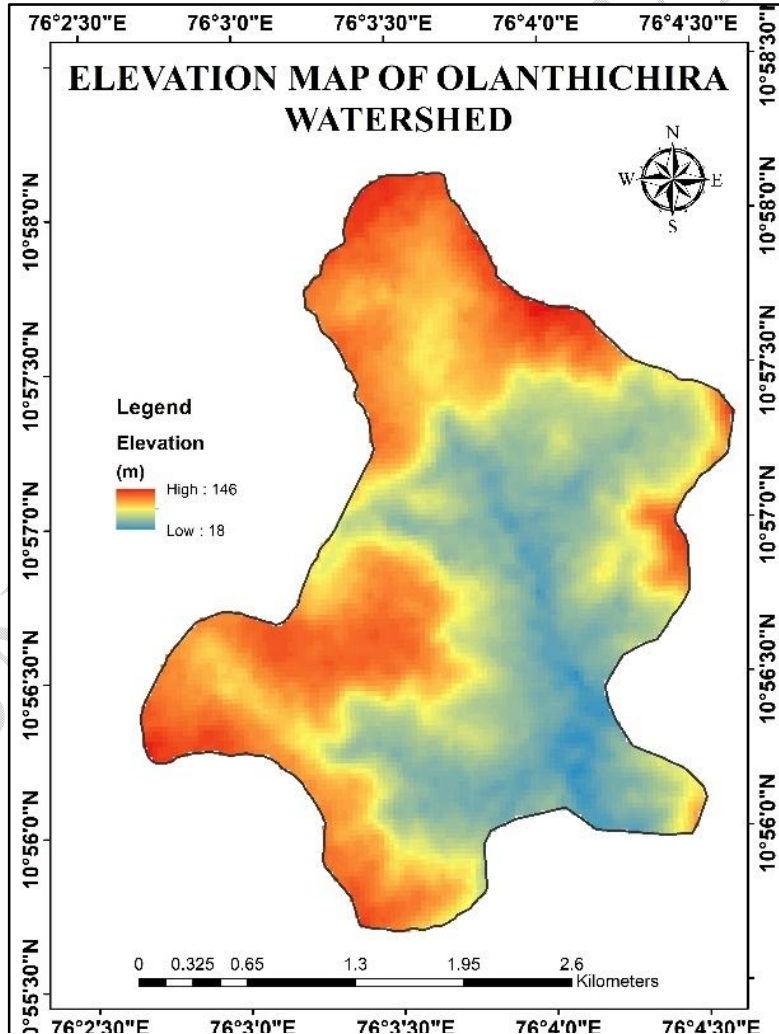


Fig.3. Elevation map of Olanthichirawatershed

### 3.2 Linear Parameters

#### 3.2.1 Stream Order and Stream Number

Stream ordering is the first step in morphometric analysis. Strahler's method of stream ordering has been adopted and found that the Olanthichira watershed is of fourth order drainage basin with dendritic drainage pattern which is shown in Fig.4. Stream numbers representing the number of streams in each order and the total number of streams in watershed is 66 given in table 2, which showed that the total number of streams decreases as the stream order increases.

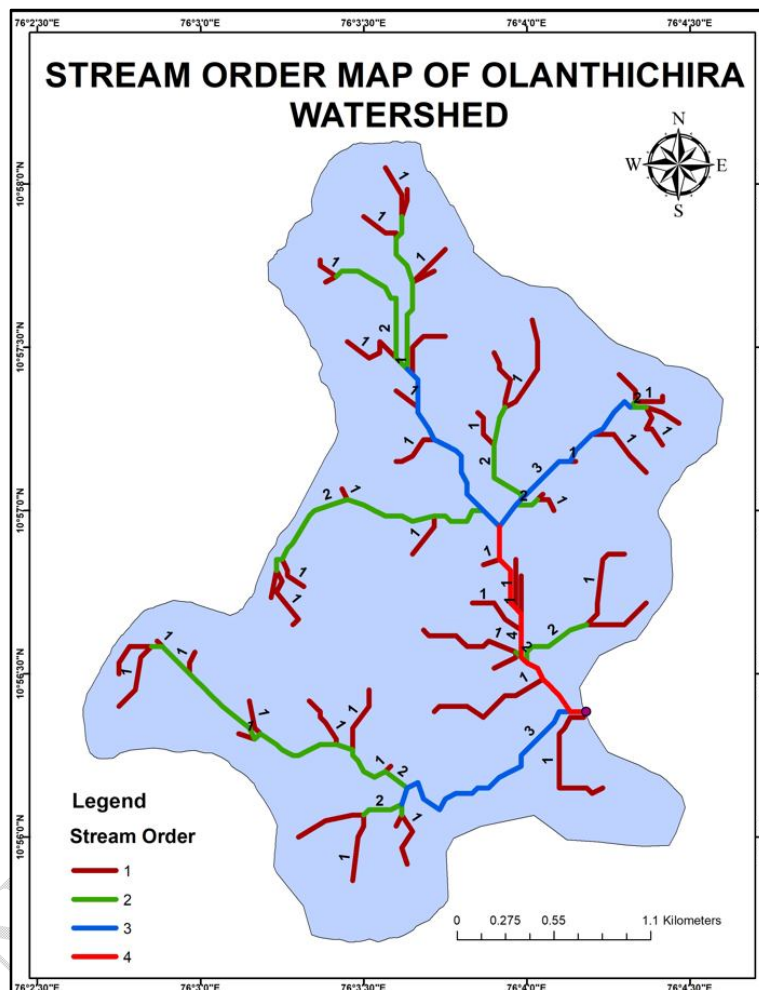


Fig. 4. Stream Order map of Olanthichirawatershed

Table 2. Stream length, Stream length ratio and Bifurcation ratio of Olanthichira watershed

Stream order (u)	Stream Number (N <sub>u</sub> )	Stream Length (L <sub>u</sub> )	Mean Stream Length (L <sub>um</sub> )	Stream Length Ratio (R <sub>l</sub> )	Bifurcation ratio (R <sub>b</sub> )
1	50	12.470	0.249	-	4.16
2	12	1.989	0.165	0.665	4
3	3	0.412	0.137	0.830	3

4	1	0.076	0.07	0.556	-
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### **3.2.2 Stream length, Mean stream length and Stream length ratio**

The total stream length of watershed is 14.95 km and the individual stream length of each order is given in table 2. The mean stream length ratio of this watershed is 0.683 and the stream length ratio of each order is given in table 2, an increasing stream length ratio from lower order to higher order indicates their mature geomorphic stage.

### **3.2.3 Bifurcation ratio and Mean bifurcation ratio**

In this Olanthichira watershed, the range of bifurcation is between 3 to 4.16 shown in table 2 and other parameters are shown in table 3. The mean bifurcation ratio of 3.68 is within the normal range (3–5) for natural drainage systems (Strahler, 1964). This ratio reflects a relatively moderate influence of geological structures on the drainage network. The rho coefficient of 0.183 indicates moderate branching but relatively shorter stream lengths for higher-order streams reflect a balanced system with neither rapid drainage nor excessive storage, favouring sustainable hydrological management.

**Table 3. Linear aspects of Olanthichira watershed**

<b>Parameters</b>	<b>Values</b>
Total stream length ( $L_u$ )	14.949 km
Mean stream length ratio ( $R_{slm}$ )	0.683
Mean bifurcation ratio ( $R_{bm}$ )	3.722
Rho coefficient ( $r$ )	0.183
Drainage density ( $D_d$ )	1.836 km/km <sup>2</sup>
Stream frequency ( $F_s$ )	8.108 streams/ km <sup>2</sup>
Drainage texture ( $D_t$ )	4.359 streams/ km
Infiltration number ( $I_i$ )	14.890
Length of overland flow ( $L_o$ )	0.91 km
Drainage intensity ( $D_i$ )	4.414 / km

### **3.2.3 Drainage density and Drainage texture**

The drainage density of this watershed is 1.836 km/km<sup>2</sup> falls in medium category which indicates moderately developed drainage network with gentle to steep slope terrain, medium dense vegetation, and less permeable for medium precipitation (Soni, 2017). A drainage texture value of 4.359/km indicates a moderate to fine drainage texture. This means the watershed has a relatively well-developed drainage network with a moderate number of stream channel (Soni, 2017). An infiltration number of this watershed is 14.89 suggesting that the soil has a high capacity to absorb water. This means water can enter the soil quickly, reducing surface runoff and potential erosion whereas 4.414 of high drainage intensity value typically points to higher potential for erosion.

### **3.2.4 Stream frequency**

A stream frequency of 8.108/ km<sup>2</sup> indicates a very high density of stream channels per unit area in the watershed, the watershed is likely to have a higher capacity for watershed drainage and runoff management (Shekar and Mathew, 2023).

### **3.2.5 Length of overland flow**

The length of overland flow of this watershed is 0.91km implying gentle slopes and longer flow paths, high infiltration, and reduced runoff (Sukristiyanti et al., 2018).

## **3.3 Areal Parameters**

Areal parameters such as circularity ratio, elongation ratio, form factor, compactness constant, lemniscate ratio, shape factor and compactness of channel maintenance were determined and given in table 4. These parameters focus on size and shape of watershed.

**Table 4. Areal aspects of Olanthichira watershed**

Parameters	Values
Circularity ratio ( $R_c$ )	0.446
Elongation ratio ( $R_e$ )	0.745
Form factor ratio ( $F_f$ )	0.436
Compactness constant ( $C_c$ )	1.500
Lemniscate's ratio ( $k$ )	0.570
Shape factor ( $B_s$ )	2.289
Constant of channel maintenance (C)	0.544 km <sup>2</sup> /km

### **3.3.1 Circularity ratio**

Circularity ratio ( $R_c$ ) value close to 1 indicates that the basin shapes are circular, allowing for consistent water infiltration providing more time for excess water to drain out of the basin (Soni, 2017). The  $R_c$  values of this watershed is 0.44 indicating of the lack of circularity characterized by medium to low relief. Such drainage systems are partially controlled by the structural disturbances (Kuntamalla et al., 2018).

### **3.3.2 Elongation ratio**

According to Pareta&Pareta(2011), the shape of a watershed is highly elongated ( $R_e < 0.5$ ), elongated ( $R_e = 0.5-0.7$ ), less elongated ( $R_e = 0.7-0.8$ ), oval ( $R_e = 0.8-0.9$ ) and circular ( $R_e = 0.9-0.10$ ). Since Olanthichira watershed has  $R_e$  value of 0.745, its elongated in shape.

### **3.3.3 Form factor**

If form factor is below 0.78, its elongated. If above 0.78, its circular (Singh et al., 2023). This watershed has a form factor of 0.436 signifying an elongated watershed which has low peak flows for longer duration.

### **3.3.4 Compactness constant**

A  $C_c$  value of 1.0 represents a perfectly circular catchment, whereas a  $C_c$  value greater than 1.0 indicates a significant deviation from a circular basin shape (Singh et al., 2023). The compactness constant of 1.5 suggests that this watershed is less compact and more elongated which typically have longer flow paths and may exhibit slower and more prolonged runoff response.

### **3.3.5 Shape factor**

Shape factor or shape index is the reciprocal of form factor (Vincy et al., 2012). This watershed has higher shape index of 2.289 indicating elongated shape tends to have longer flow paths and more prolonged runoff response compared to more compact watershed. Lemniscate ratio describes the shape of a watershed and a higher value (37.9) of this watershed suggests that the watershed is more elongated and less circular.

### **3.3.6 Constant of channel maintenance**

The constant of channel maintenance of this watershed is 0.544/km which comes under the low erodible category. These channels can accommodate sediment within the range of 0.4 to 0.5/km, indicating their ability to handle a moderate amount of sediment transport (Shekar and Mathew, 2023).

### 3.4 Relief Parameters

The relief aspects focus on topography and elevation surface of watershed and the results are shown in table 5.

**Table 5. Relief aspects of Olanthichira watershed**

Parameters	Values
Elevation of basin outlet (h)	21 m
Maximum elevation of the basin (H)	146 m
Basin relief (R)	125 m
Relief ratio ( $R_h$ )	0.0302
Relative relief ( $R_r$ )	8.257 m/ km
Ruggedness number	0.229

#### **3.4.1 Relief**

Basin relief represents the maximum vertical distance between the lowest and the highest point of a basin. It triggers stream gradient affecting flood pattern and amount of sediment that can be transported (Hadely& Schumm 1961). The basin relief of 125m of this watershed represents areas with moderate topographical variation, balanced runoff and erosion potential and a relief ratio of 0.0302 suggests that the watershed has a relatively gentle slope indicating area is in a region with low to moderate topographic variation.

#### **3.4.2 Relative relief**

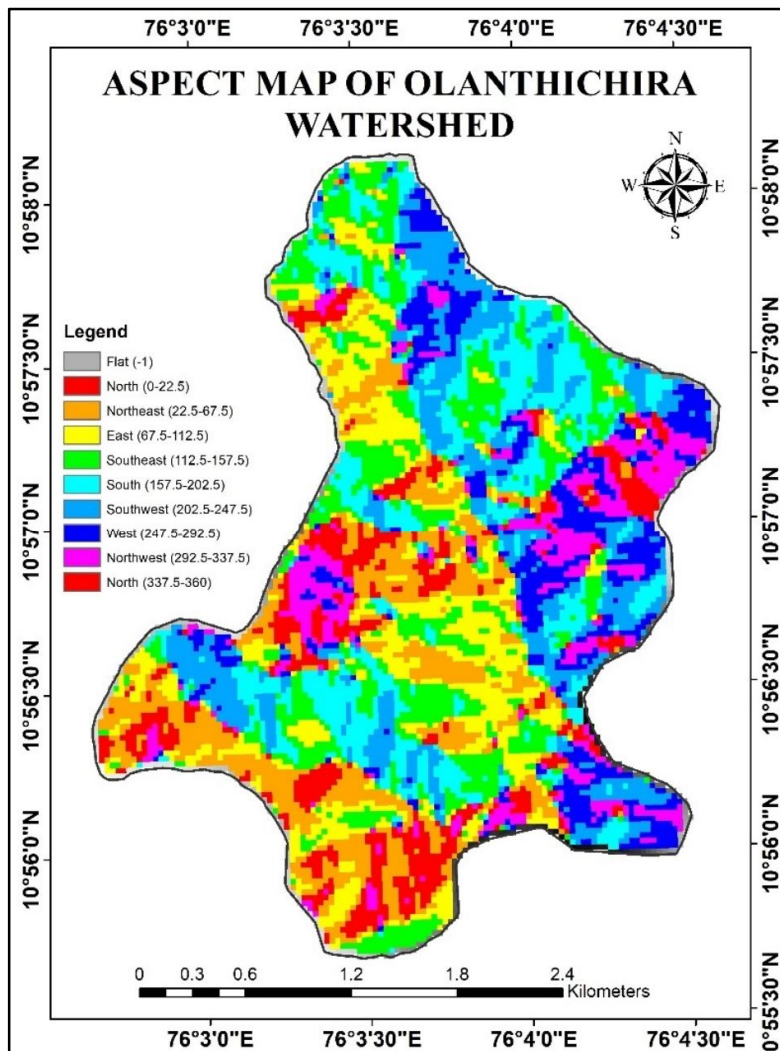
Relative relief of this watershed is 8.257 m/km. This low value suggests that the area has gentle slope means runoff will be slower and more controlled leading to lower runoff potential.

#### **3.4.3 Ruggedness number**

The ruggedness number of this watershed is 0.229 which hints watershed is less prone to erosion and have low to moderate complex structure related to relief and drainage density (Soni, 2017).

### 3.5 Aspect map

Aspect shows the direction of the slope. As of now, the direction of slope at  $0^\circ$  is north, at  $90^\circ$  it is east and so on. It strongly influences water flow across the watershed shown in Fig. 5. In this watershed, North-facing slopes may receive less direct sunlight, leading to lower evaporation and potentially greater soil moisture retention. Conversely, south-facing slopes may experience faster runoff due to higher solar exposure and reduced moisture.



**Fig. 5. Aspect map of Olanthichirawatershed**

### 3.6 Slope map

Slope of a watershed is important morphometric factor of hydrological as it influences the velocity of run-off and concentration time (Sujatha et al., 2015). The slope map of this watershed was prepared using DEM, it varies from 0° to 53°. The slope is classified into seven classes and shown in Fig. 6. The maximum area of watershed has slope of 15°–25°.

### 3.7 NDVI map

NDVI map of watershed was prepared using Landsat-9 image in ArcGIS shown in Fig. 7. The range of NDVI values 0.078–0.597 indicates a landscape with varied vegetation health and density, from degraded or bare areas to regions of dense, healthy vegetation. Higher NDVI zones (light green to green) are crucial for ecological and agricultural productivity, indicating areas with high biomass and strong vegetation health. Lower NDVI zones (red to orange) might represent regions requiring intervention, such as reforestation, irrigation, or land improvement, to enhance vegetation cover and productivity. This map can be used to identify priority areas for conservation or rehabilitation.

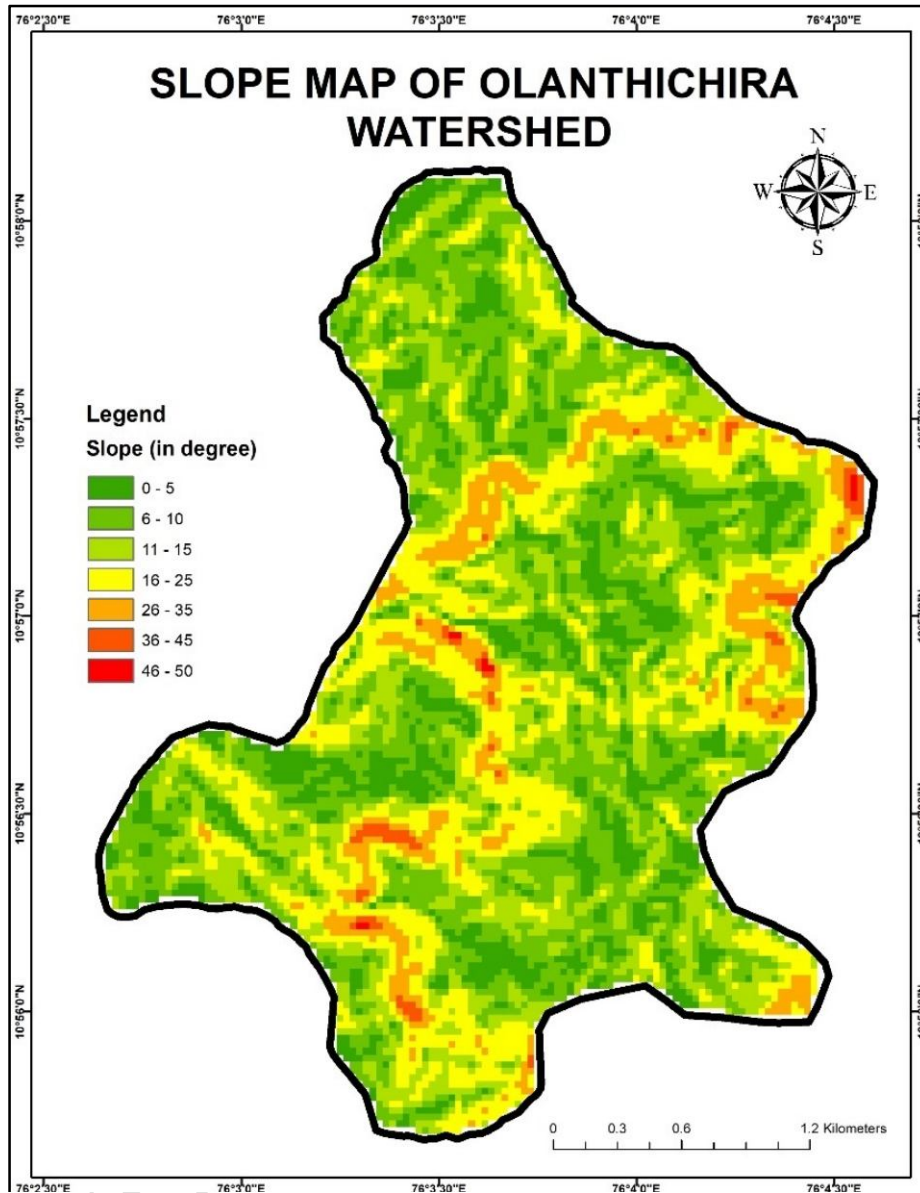


Fig. 6. Slope map of Olanthichirawatershed

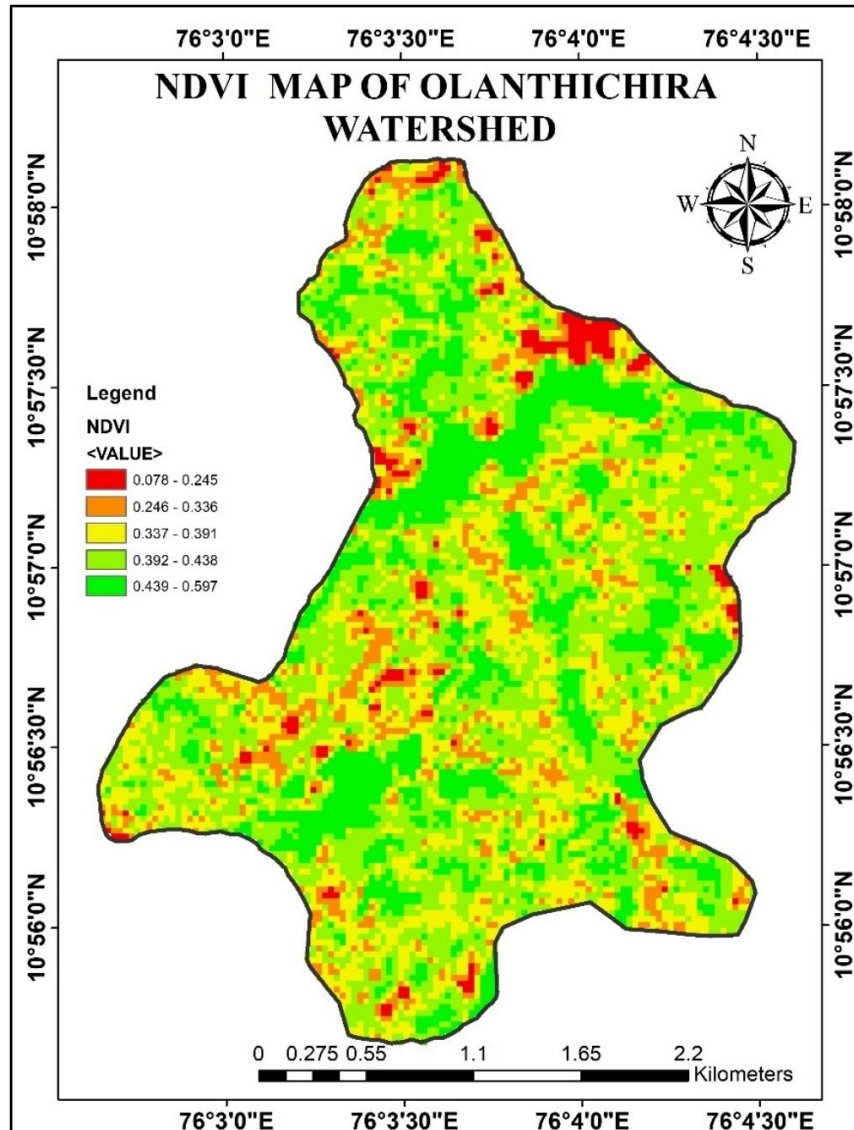


Fig. 7. NDVI map of Olanthichirawatershed

#### 4. CONCLUSION

Morphometric analysis gives a quantitative description of drainage basin which is very much useful in studies such as hydrologic modelling, watershed prioritization, natural resources conservation and management, and rehabilitation. GIS and remote sensing techniques found to be most effective for morphometric analysis compared to traditional approaches. Hence in this study, a quantitative morphometric analysis was done using geospatial technology. First using SRTM DEM and topographic map, Olanthichira watershed was delineated. Then by extracting drainage networks, morphometric parameters were calculated using mathematical equations. This micro watershed is classified as fourth-order watershed with dendritic drainage pattern. The bifurcation ratio of watershed suggests that drainage pattern is moderate influenced by geology and structural controls. Then the low drainage density, high infiltration number and length of overland flow indicates that watershed has low erosion potential. Form factor, elongation ratio, circularity ratio and compactness constant describe watershed in shape with smaller flood peaks and longer flood flows. These parameters describe geology, runoff characteristics, permeability of region in watershed whereas slope, aspect, NDVI and soil map provide effective information. The integration of these parameters with slope, aspect and NDVI map provides a comprehensive

approach for assessing a watershed behaviour and identifying optimal sites for soil and water conservation measures.

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