# Topographic and Morphometric Analysis of Sinnar Taluka Through 3D GIS Modeling

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**Abstract**

This research presents a comprehensive topographic and morphometric analysis of Sinnar Taluka using 3D GIS modeling techniques. The study integrates Survey of India toposheets, CartoDEM data from the BHUVAN portal, and GIS-based hydrological tools to derive terrain and drainage characteristics. Digital Elevation Model (DEM) generation, contour digitization, stream extraction, and morphometric parameter estimation were performed using ArcGIS 10.3. Parameters including drainage density, stream frequency, bifurcation ratio, elongation ratio, form factor, relief ratio, ruggedness number, and basin relief were computed. A 3D terrain model was developed using TIN conversion in ArcScene for enhanced visualization of elevation and watershed characteristics. The results provide critical insights into runoff behavior, erosion potential, watershed prioritization, and sustainable land-use planning. This study demonstrates the effectiveness of GIS-based morphometric analysis in supporting watershed management, disaster mitigation, and infrastructure planning.

**Keywords:** Digital Elevation Model (DEM), GIS, Morphometric Analysis, 3D Modeling, Drainage Density, Watershed Management.

## 1. INTRODUCTION

- Land and water resources are critical components for sustainable development. Increasing urbanization, industrial growth, and climatic variability demand scientific terrain analysis for efficient resource management.
- Topographic and morphometric studies provide quantitative assessment of watershed characteristics, drainage patterns, and hydrological behavior.
- Traditional contour maps represent terrain in two dimensions, requiring interpretation to visualize elevation variations. However, 3D GIS modeling enhances spatial understanding by representing elevation in a realistic form.
- This study focuses on Sinnar Taluka and applies GIS-based terrain modeling and morphometric evaluation to understand its geomorphological characteristics.
- The integration of Digital Elevation Models (DEMs) and hydrological analysis tools allows extraction of drainage networks, slope, aspect, and watershed parameters efficiently and accurately.

### a) Problem Statement

- There is a demand for 3D modeling for various applications such as environmental modeling, urban planning, disaster management, etc.

- Comprehensive study of topographic data along with integration techniques are needed to solve practical problems.
- The study of morphometric parameters provides meaningful insights and solutions to specific applications.

### b) Objectives

- To analyze and interpret the topographic and morphometric characteristics of Sinnar Taluka using 3D GIS modeling techniques for better understanding of its terrain, drainage pattern, and watershed behavior.
- To prepare a Digital Elevation Model (DEM) of Sinnar Taluka and generate topographic features such as elevation, slope, aspect, and contour maps.
- To exact an analyse the drainage network using GIS tools and determine stream order.
- To compute key morphometric parameters (such as drainage density, stream frequency, bifurcation ratio, form factor, elongation ratio, and relief ratio) for quantitative analysis of the watershed.
- To develop a 3D GIS model for visualizing terrain relief and drainage characteristics of Sinnar Taluka.
- To provide baseline data and insights for watershed management, land-use planning, and sustainable development in the study area.

### c) Study Area

- Sinnar Taluka, located in the Nashik District of the Indian state of Maharashtra, is a region characterized by a mix of agricultural plains and gently undulating terrain. We selected Sinnar Taluka as our study area. Sinnar Taluka lies between approximately 19.85° and 19.95° North latitude and 74.00° and 74.15° East longitude in the southern part of Nashik District. It is bounded by Niphad Taluka to the north, Nashik Taluka to the northwest, Sangamner Taluka of Ahmednagar District to the south, and Kopargaon Taluka to the southeast. The taluka serves as an important agricultural and industrial zone. The taluka serves as an important agricultural and industrial zone, with fertile lands supporting diverse crops and the Sinnar MIDC (Maharashtra Industrial Development Corporation) area contributing to regional economic growth.

**Figure 1: Study Area**

### d) Scope of the Project

### 1. General

**This project is limited to**

- Sinnar Taluka as a Study Area.
- Survey of India Toposheets of scale 1:50000 are use for generating Taluka boundaries and Basic Morphometric Parameters.
- Landscape Morphometric Parameters are derived from toposheets generated D.E.M.
- ARC-SCENE is used for Developing 3D model

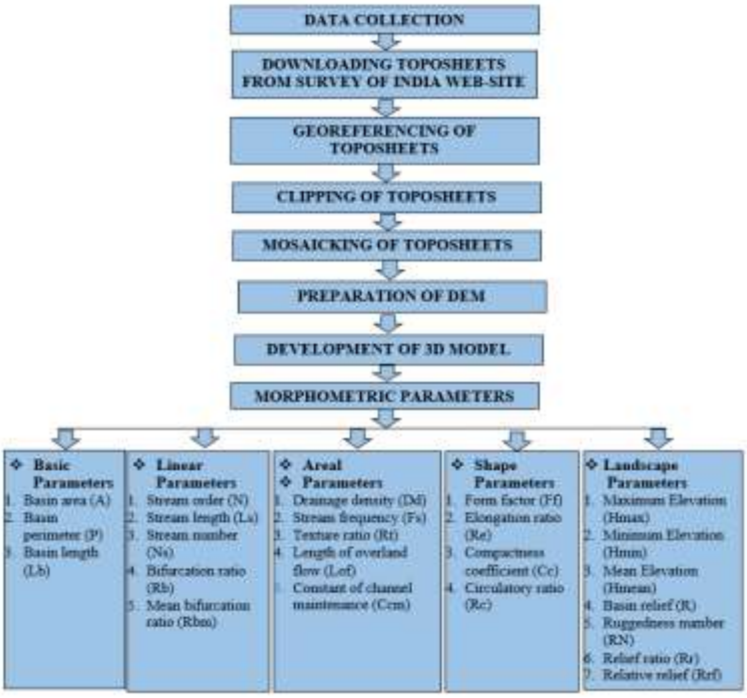
### 2. 3D Model Development

- Utilizing GIS software and tools, a high-resolution 3D model of the study area is developed based on the Digitized contours.
- The 3D model will accurately represent the terrain surface, including elevation, relief and ruggedness number parameters
- The 3D model and calculated morphometric parameters are visualized using GIS software, allowing for the creation of maps, graphs, and other visualizations to convey the results effectively.
- Various visualization techniques, such as contour maps, shaded relief maps, and 3D renderings, is employed to enhance the representation of the data.

## 2. Methodology

### a) Approach of Methodology

**Figure 2: Approach of Methodology**



### 1. Data Collection

- The data collection process involves obtaining the necessary spatial and topographic data for the study area. Toposheets of Sinnar Taluka are downloaded from the Survey of India website, while district and taluka boundary maps are collected from reliable sources. These toposheets serve as the primary data for generating the Digital Elevation Model (DEM) and conducting GIS-based analysis. Additional data, such as elevation points, drainage networks, and contour information, are also gathered to support accurate mapping, morphometric calculations, and 3D visualization of the terrain.

2. **Downloading Topoasheets from Survey of India Web-site**

- The toposheets required for the study are downloaded from the Survey of India website. The process begins by visiting the official website and signing up for an account. After logging in, users need to select the option "Open Series Map (Free PDF)". The appropriate map sheet can be located by entering the sheet number or by selecting the desired state and district information. Once the correct sheet is identified, it can be download by clicking on the "Download" button. Finally, after filling in the captcha verification, the download of the selected toposheets begins.

**Figure 3: Process of Downloading Topoasheets**

**Figure 4: Downloaded Toposheet**

### Georeferencing of Toposheet

- Georeferencing of topographic maps or toposheets is the process of aligning these paper or scanned maps with a known coordinate system in order to assign geographic coordinates to specific points on the map. This enables the map to be used in Geographic Information Systems (GIS) and other geospatial applications, allowing for accurate spatial analysis, data integration, and mapping. Georeferencing is a critical step when working with non-georeferenced or non- spatial maps

**Figure 5: Process of Georeferencing of Toposheet**

### Clipping of Toposheets

- Clipping of a toposheet, in the context of Geographic Information Systems (GIS) and geospatial data processing, refers to the process of selecting and extracting a specific portion or area of a toposheet or map while discarding the areas outside the selected boundary. This operation is commonly performed to isolate and work with a particular area of interest from a larger map.

**Figure 6: Process of Clipping of Toposheets**

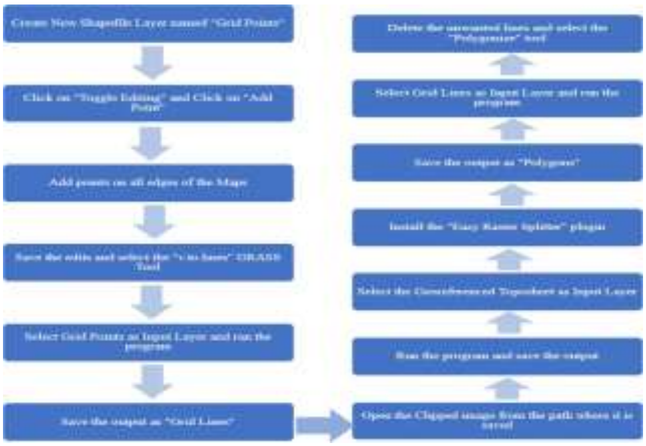


Figure 7: Clipped Toposheet

### Mosaicking of Toposheets

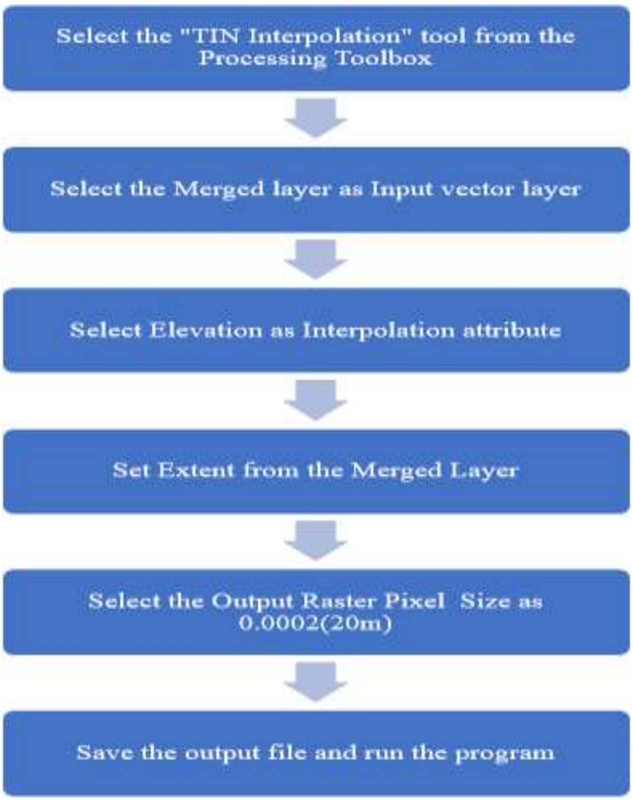
- Mosaicking of toposheets refers to the process of combining multiple adjacent or overlapping topographic maps, such as toposheets, into a seamless and continuous map. This operation is typically performed to create a unified and coherent representation of a larger geographic area by assembling individual maps into a single, composite map. Mosaiking can be an important step in cartography, Geographic Information Systems (GIS), and spatial data integration.

Figure 8: Mosaicked Toposheets

### Preparation of DEM

- A DEM, or Digital Elevation Model, is a digital representation of the topography, or the surface elevation, of a geographic area. It provides a structured grid of elevation values, typically in a raster format, where each cell in the grid represents the elevation at a specific location on the Earth's surface. DEMs are a fundamental component of geospatial data and are widely used in various fields, including geography, cartography, environmental science, engineering, and geographic information systems (GIS).

Figure 9: Process of Preparation of DEM



Select the "TIN Interpolation" tool from the Processing Toolbox

Select the Merged layer as Input vector layer

Select Elevation as Interpolation attribute

Set Extent from the Merged Layer

Select the Output Raster Pixel Size as 0.0002(20m)

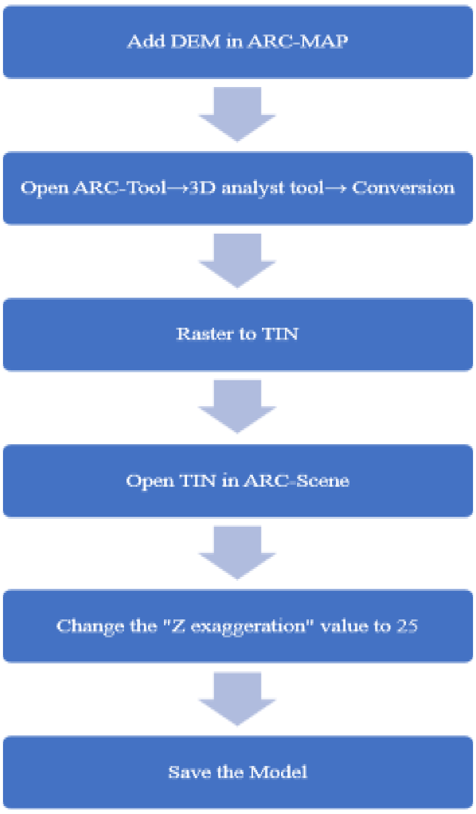
Save the output file and run the program

Figure 10: DEM of Sinnar

### Development of 3D Model

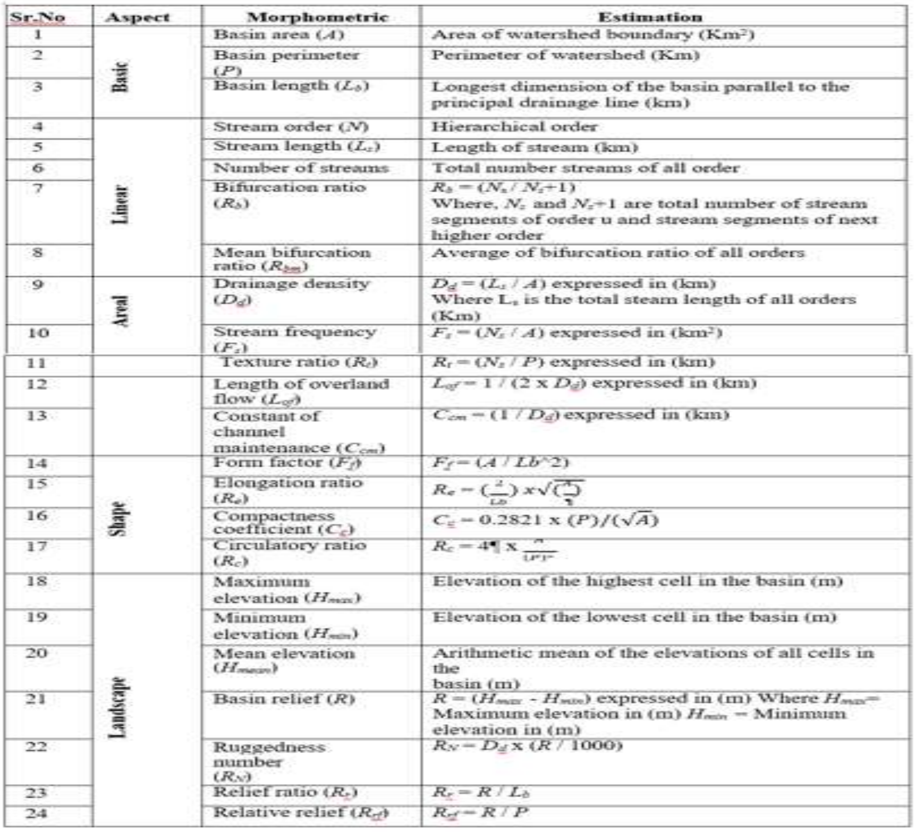
- A 3D model using GIS extends the capabilities of traditional GIS by adding the third dimension (elevation) to geographic data, enabling more accurate and comprehensive representations of the real world. This is particularly valuable in various fields, including urban planning, natural resource management, environmental analysis, and infrastructure management

Figure 11: Process of Development of 3D Model



## Morphometric Parameters

Table 1: Formulas for Morphometric Parameters Calculations



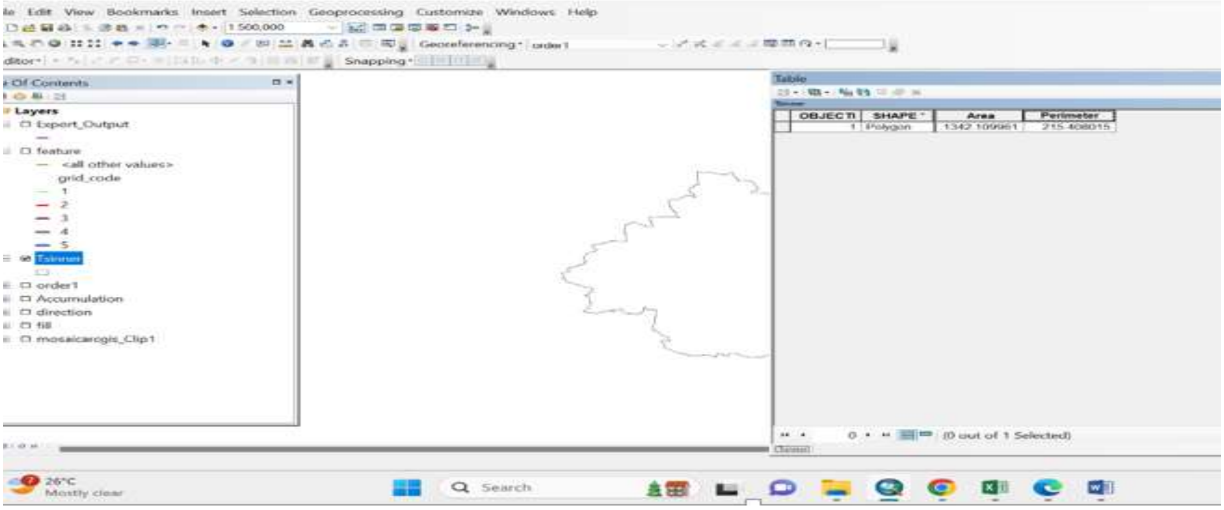
| Sr.No | Aspect | Morphometric | Estimation |
|---|---|---|---|
| 1 | Basic | Basin area ($A$) | Area of watershed boundary (Km²) |
| 2 | | Basin perimeter ($P$) | Perimeter of watershed (Km) |
| 3 | | Basin length ($L_b$) | Longest dimension of the basin parallel to the principal drainage line (km) |
| 4 | Linear | Stream order ($N$) | Hierarchical order |
| 5 | | Stream length ($L_s$) | Length of stream (km) |
| 6 | | Number of streams | Total number streams of all order |
| 7 | | Bifurcation ratio ($R_b$) | $R_b = (N_s / N_s{+}1)$<br>Where, $N_s$ and $N_s$+1 are total number of stream segments of order u and stream segments of next higher order |
| 8 | | Mean bifurcation ratio ($R_{bm}$) | Average of bifurcation ratio of all orders |
| 9 | Areal | Drainage density ($D_d$) | $D_d = (L_s / A)$ expressed in (km)<br>Where $L_s$ is the total steam length of all orders (Km) |
| 10 | | Stream frequency ($F_s$) | $F_s = (N_s / A)$ expressed in (km²) |
| 11 | | Texture ratio ($R_t$) | $R_t = (N_s / P)$ expressed in (km) |
| 12 | Shape | Length of overland flow ($L_{of}$) | $L_{of} = 1 / (2 \text{ x } D_d)$ expressed in (km) |
| 13 | | Constant of channel maintenance ($C_{cm}$) | $C_{cm} = (1 / D_d)$ expressed in (km) |
| 14 | | Form factor ($F_f$) | $F_f = (A / Lb\text{^}2)$ |
| 15 | | Elongation ratio ($R_e$) | $R_e = (\frac{2}{Lb}) x\sqrt{(\frac{A}{\pi})}$ |
| 16 | | Compactness coefficient ($C_c$) | $C_c = 0.2821 \text{ x } (P)/(\sqrt{A})$ |
| 17 | | Circulatory ratio ($R_c$) | $R_c = 4\pi \text{ x } \frac{A}{(P)^2}$ |
| 18 | Landscape | Maximum elevation ($H_{max}$) | Elevation of the highest cell in the basin (m) |
| 19 | | Minimum elevation ($H_{min}$) | Elevation of the lowest cell in the basin (m) |
| 20 | | Mean elevation ($H_{mean}$) | Arithmetic mean of the elevations of all cells in the basin (m) |
| 21 | | Basin relief ($R$) | $R = (H_{max} - H_{min})$ expressed in (m) Where $H_{max}$= Maximum elevation in (m) $H_{min}$ = Minimum elevation in (m) |
| 22 | | Ruggedness number ($R_N$) | $R_N = D_d \text{ x } (R / 1000)$ |
| 23 | | Relief ratio ($R_r$) | $R_r = R / L_b$ |
| 24 | | Relative relief ($R_{rf}$) | $R_{rf} = R / P$ |

## Results

### Basic Morphometric Parameters

**Table 2: Basic Parameters**

| Basic Morphometric Parameters | | |
|---|---|---|
| **Perimeter (P)** | **Area (A)** | **Length (Lb)** |
| **215.4 KM** | **1342.11 KM²** | **74.20 KM** |



| OBJECTI | SHAPE * | Area | Perimeter |
|---|---|---|---|
| 1 | Polygon | 1342.109961 | 215.408015 |

Figure 12: Basic Parameters From arc-GIS

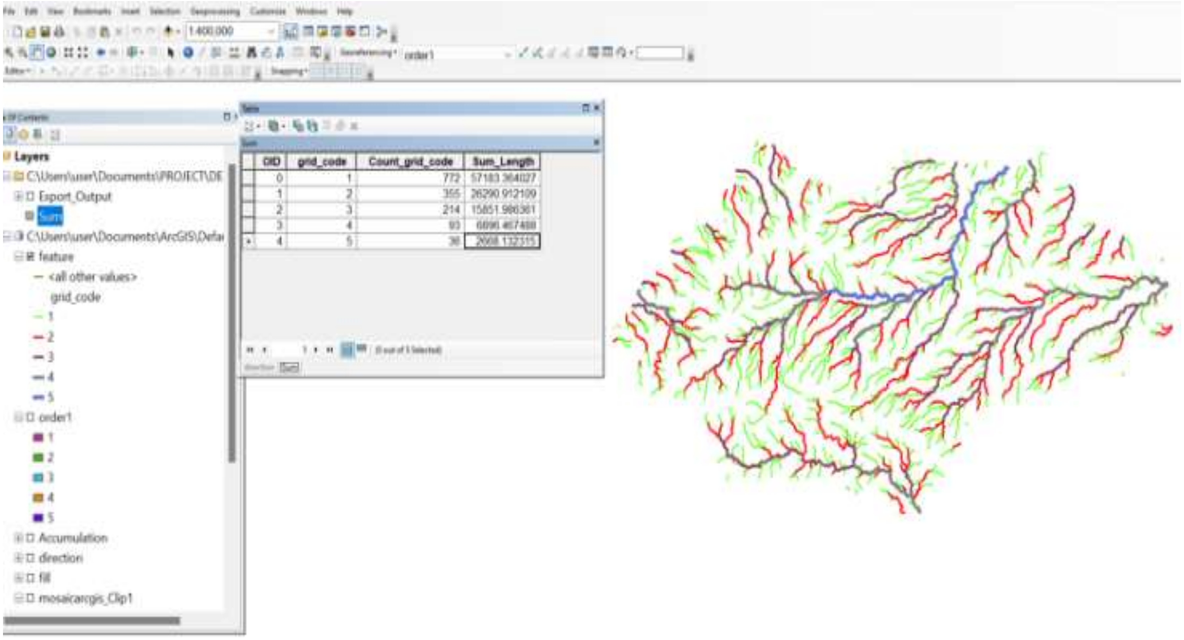
### Linear Morphometric Parameter

- The stream order, number of streams, and stream lengths are important parameters used in watershed analysis to characterize the hierarchical structure of river networks and understand the organization of drainage patterns. Stream orders are useful for characterizing the size and complexity of a river network. Strahler's stream ordering rule (1957) was used to determine stream orders. The stream order indicates the hierarchical level of streams in a watershed, with smaller streams having a lower order and larger streams having a higher order. Longer stream lengths are generally associated with flatter slopes, indicating slower flow velocities, while shorter stream lengths suggest steeper slopes and faster flow (Arabameri et al., 2020).

**Table 3: Linear Parameters**

| Linear Morphometric Parameters. | | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Stream Order** | | | | | **Total** |
| | **I** | **II** | **III** | **IV** | **V** | |
| No. of stream (Ns) | **772** | **335** | **214** | **93** | **36** | **1470** |
| Stream Length (Ls) in Km | **57.18** | **26.29** | **15.85** | **6.89** | **2.66** | **108.87** |

Figure 13: Linear Parameters From arc-GIS



| OID | grid_code | Count_grid_code | Sum_Length |
|---|---|---|---|
| 0 | 1 | 772 | 57183.364027 |
| 1 | 2 | 355 | 26290.912109 |
| 2 | 3 | 214 | 15851.986381 |
| 3 | 4 | 93 | 6896.467488 |
| 4 | 5 | 36 | 2068.132315 |

### Bifurcation Ratio

- Higher bifurcation (Rb) values can indicate higher runoff and lower permeability of the area. Lower Rb values suggest structurally less distributed area. The range of Rb values from **0.97 to 64.50** demonstrates the variability in the branching patterns of the area. The range of Rbm values from **1.68 to 14.27** highlights the diversity in erodibility and landscape stability across the study area.

**Table 4 : Bifurcation Ratio**

| **Bifurcation Ratio (Rb)** | | | | **Mean Bifurcation Ratio (Rbm)** |
|---|---|---|---|---|
| **(No. of streams in order 1) / (No. of streams in order 2)** | **(No. of streams in order 2) / (No. of streams in order 3)** | **(No. of streams in order 3) / (No. of streams in order 4)** | **(No. of streams in order 4) / (No. of streams in order 5)** | |
| 772/355 | 355/214 | 214/93 | 93/36 | (2.17+1.66 +2.30+2.58)/4 |
| **2.17** | **1.66** | **2.30** | **2.58** | **2.18** |

### Areal Morphometric Parameters

- Drainage density reflects the permeability of subsurface elements, vegetation type, and terrain relief. Lower Dd values (0.05 to 0.25 km/km²) indicate highly permeable subsoil and coarse drainage, suggesting conditions less prone to rapid erosion. Higher stream frequency indicates rocky surfaces and low permeability, while lower stream frequency suggests areas with agricultural land. Fs values range from 1.02 to 2.71. Fs has a direct relationship with erodibility. Texture ratio (Rt) is affected by the relief of the terrain. Higher values (6.44 to 15.77) indicate higher drainage texture, which implies softer rocks and lower soil erosion sensitivity. The length of overland flow (Lof) impacts hydrograph shape. Ccm, reflects continuous channel maintenance and is related to erodibility. It reflects the area needed for drainage and tests the eroding potential in the watershed. Higher Ccm values (7.5 to 15.16 sq.km/km) suggest higher infiltration rates and lower runoff rates.

**Table 5: Areal Morphometric Parameter**

| **Areal Morphometric Parameters** | | | | |
|---|---|---|---|---|
| Drainage density (Dd) | Stream Frequency (Fs) | Texture Ratio (Rt) | Length of overland flow (Lof) | Consant of channel Main. (Ccm) |
| **TLs/A** | **TNs/A** | **TNs/p** | **1/2*Dd** | **1/Dd** |
| 108.87/1342.11 | 1470/1342.11 | 1470/215.4 | 1/2*0.08 | 1/0.08 |
| **0.08** | **1.10** | **6.82** | **6.16** | **12.33** |

## Shape Morphometric Parameters

- High Ff values **(0.20 to 0.75)** indicate areas with high peak flows for a shorter period, while low Ff values suggest lower peak flows for longer durations. Ff values greater than **0.78** suggest circular basins. Re values in the range of **0.51 to 0.98** indicate the degree of elongation of the area. Cc values ranging from **1.51 to 2.18** provide insights into the hydrologic characteristics of the area. Lower Rc values indicate rapid discharge and increased soil erosion potential, while higher Rc values indicate lower discharge and reduced erosion potential. Lower shape parameter values indicate that the basin is elongated, whereas higher values indicate that the basin is circular.

**Table 6: Shape Morphometric Parameters**

| **Shape morphometric parameters** | | | |
|---|---|---|---|
| Form Factor (Ff) | Elongation Ratio (Re) | Compactness Coefficient (Cc) | Circulatory Ratio (Rc) |
| $A/Lb^2$ | $(2*Lb)*(\sqrt{A/\pi})$ | $0.2821*(P/\sqrt{A})$ | $4\pi*(A/P^2)$ |
| $1342.11/74.20^2$ | $(2*74.20)*$<br>$(\sqrt{1342.11/\pi})$ | $0.2821*(215.4/\sqrt{1342.11})$ | $4\pi(1342.11/215.4^2)$ |
| **0.24** | **0.56** | **1.66** | **0.36** |

## Landscape Morphometric Parameters

- Higher basin relief values (R) are associated with increased runoff and reduced infiltration, impacting erosion potential. While the ruggedness number (RN) Relief ratio (Rr) measures the steepness of the area and its impact on hydrological processes. High Rr values indicate hilly regions. Relative relief (Rrf) provides insight into the morphometric characteristics of the topography. The value of ruggedness number ranges from **0.03 to 1.34**. The relief ratio values varies from **4.21 to 38.50**. The range of relative relief value is from **0.96 to 8.38**.

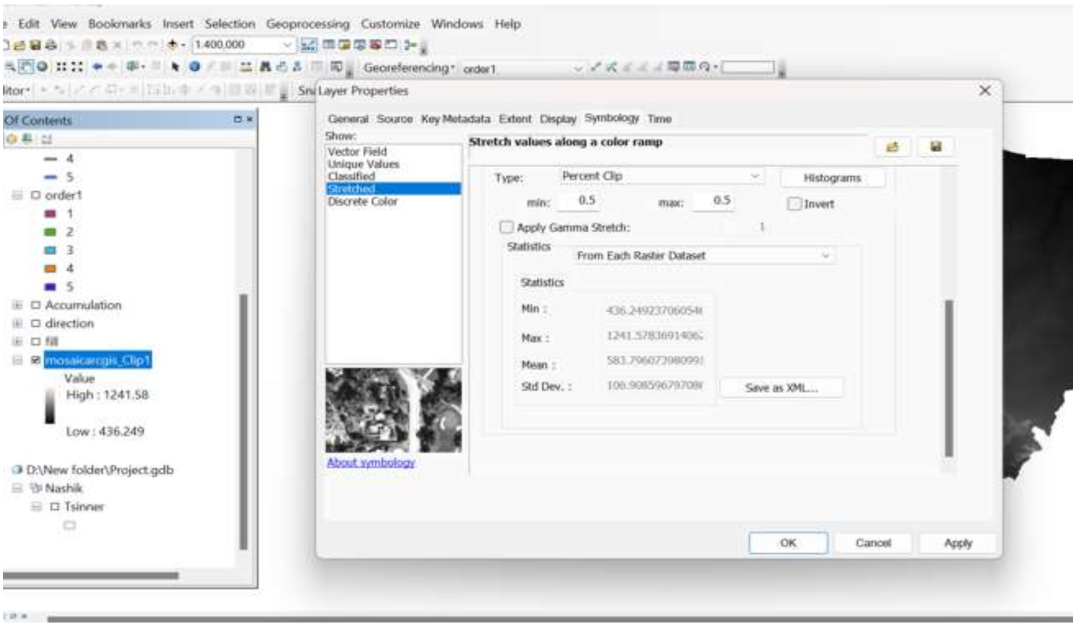
**Table 7: Landscape Morphometric Parameters**

| Landscape Morphometric Parameters | | | | | | |
|---|---|---|---|---|---|---|
| **Hmax** | **Hmin** | **Hmean** | **R** | **RN** | **Rr** | **Rrf** |
| - | - | - | **Hmax-Hmin** | **Dd*R/1000** | **R/Lb** | **R/P** |
| - | - | - | 1241.58-436.25 | 0.08*805.33/1000 | 805.33/74.20 | 805.33/215.4 |
| **1241.58** | **436.25** | **583.8** | **805.33** | **0.07** | **0.85** | **3.74** |

## 3D Model

- In ArcGIS, a 3D model refers to a representation of geographic features and spatial data in three dimensions (height, width, and depth). These models are used to visualize and analyze geographic information in a more realistic and immersive way than traditional 2D maps.

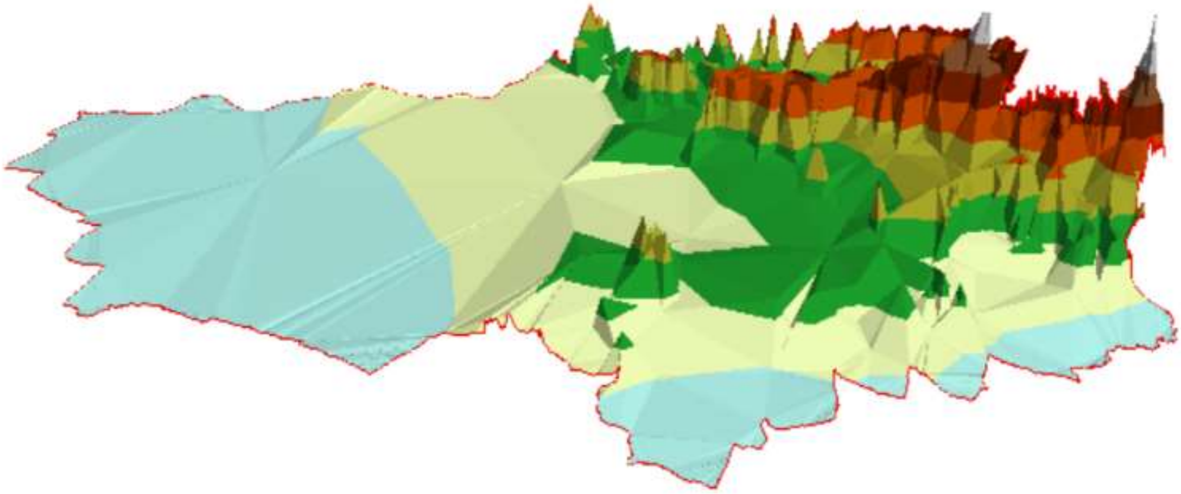
**Figure 14: 3D Model Development**



Value
High : 1241.58
Low : 436.249

Stretch values along a color ramp
Type: Percent Clip
min: 0.5 max: 0.5
☐ Invert
☐ Apply Gamma Stretch: 1
Statistics: From Each Raster Dataset
Statistics
Min : 436.24923706054
Max : 1241.5783691406
Mean : 583.79607398099
Std Dev. : 106.90859679708

**Figure 15: 3D Visualization of Sinnar Taluka**



## Conclusion

- In conclusion, the development of a 3D model and the calculation of morphometric parameters using GIS tools represent significant advancements in the field of civil engineering. Throughout this project, we have explored the capabilities of Geographic Information Systems (GIS) in not only visualizing geographical data but also in analyzing terrain characteristics with high precision.
- In summary, the development of 3D models and the calculation of morphometric parameters using GIS tools hold immense potential for advancing our understanding of terrain characteristics and their implications for various engineering and environmental applications. As we continue to refine and innovate in this field, we can expect to see even greater utilization of GIS technology in civil engineering projects, contributing to more sustainable and resilient infrastructure development

## Acknowledgement

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