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Hypsometric analysis of the Sankh river watershed using geospatial techniques

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Abstract

Hypsometric analysis is used to evaluate the distribution of elevations within the Watershed and understand the evolution of the landscape. This study uses a quantitative assessment of erosion status and landscape evolution. Remote sensing and GIS have been used to construct the hypsometric curve and Hypsometric Integral (HI). The Hypsometric curve is used to interpret the erosion status, and the hypsometric integral has been used to interpret whether the watershed is in the youth, mature, or old stage of development. For this purpose, the watershed has been divided into three sub-watersheds, namely SW-1, SW-2 and SW-3. The value of HI has been computed as 0.49 for all the sub-watersheds, which is an indicator that the whole watershed has attained a mature stage of development and homogeneous landscape evolution. Hypsometric analysis helps in understanding the terrain evolution and makes necessary sustainability planning strategies for the watershed management.

Keywords: Geomorphic, GIS, hypsometric, remote sensing, watershed

Introduction

A watershed is an area from which all the streams and precipitation are drained to a common outlet (Harsha *et al.*, 2020; Kumar *et al.*, 2016; Wang *et al.*, 2016) ^[1, 2, 3]. Hypsometric characteristics of a watershed provide important insights into its hydrological behaviour, erosion processes, and stage of geomorphic development (Yousaf *et al.*, 2018) ^[4]. Hypsometric analysis was initially introduced by Langebein (1947) to indicate the slope and forms of a drainage basin (Sharma *et al.*, 2013) ^[5] and later on interpreted by Strahler (1952) also found that HI has an inverse relation with the total relief, channel gradient, drainage density, and Slope steepness. It is also an indication of the cycle of erosion (Garg, 1991; Strahler, 1952) ^[6, 7]. The hypsometric curve is related to the volume of the soil mass within the basin and the extent of the erosion that took place in a basin relative to the residual mass (Hurtrez *et al.*, 1999; Marchi *et al.*, 2015) ^[8, 9]. Hypsometric analysis involves the estimation of the hypsometric interval and plotting hypsometric curves to identify the relationship between the relative area and the relative height of the watershed (Harsha *et al.*, 2020; Singh *et al.*, 2008; Walia *et al.*, 2018) ^[2, 10, 11]. These help in categorising watersheds into youthful, mature or old stages of geomorphic development (BALA, 2013; Jha *et al.*, 2022, 2022; Melesse *et al.*, 2003; Pande *et al.*, 2021) ^[12, 13, 14, 15]. High HI Values with a convex hypsometric curve indicate less eroded and tectonically active terrain, while lower HI values with a concave hypsometric curve indicate high erosion and a stable geomorphic unit (Ezati *et al.*, 2021; Haz & Pamumpuni, 2025; Strahler, 1952; Van Liem *et al.*, 2016) ^[7, 16, 17, 18].

Many researchers have used GIS for Hypsometric analysis (Das, 2014; Gajbhiye *et al.*, 2014; Harsha *et al.*, 2020; Markose & Jayappa, 2011; Sharma *et al.*, 2013; Shivaswamy *et al.*, 2019; Yousaf *et al.*, 2018) ^[2, 4, 5, 19, 20, 21, 22]. The integration of DEM digital elevation models with the GIS tool has enabled the automated extraction of watershed boundaries and the determination of stream networks (Melesse *et al.*, 2003) ^[14]. The objective is to conduct a hypsometric analysis of the Sank River Watershed to evaluate the erosion and evolutionary stages. This analysis will help to understand the level of erosion, landscape changes and implementation of plans for sustainable watershed management.

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2. Study Area

The study area is delineated from where the Sank River confluences with the South Koel to become part of the Brahmani River. The watershed area extends between longitudes 84°2'12" to 84°37'18" E and latitudes 22°0'41" to 23°21'27"N as shown in Figure 1. It has been divided into three sub-watersheds as SW-1, SW-2 and SW-3. The study area lies in Jharkhand, around 4410 sq km (64%), Odisha, 1330 sq km (19%) and Chhattisgarh, 1160 sq km (17%). It covers an area of around 6900 square kilometres

The climate of the study area lies in the tropical monsoon

climate zone. Sal tree is the most common tree found in this study area. The Chhotanagpur Granitic Gneiss complex (CGGC) forms the basement rock. Most of the study area consists of Batholith masses, which have undergone metamorphism and tectonic deformation. Pigmaitite veins are also most common, which have intruded into the basement rocks and other Granites (Patowarya *et al.*, 2023)^[23]. The landscape of the study area is characterised by undulating terrain with varying elevations ranging from 180 metres to 100 metres above sea level. The drainage pattern is mostly dendritic. The shape of the drainage is elongated.

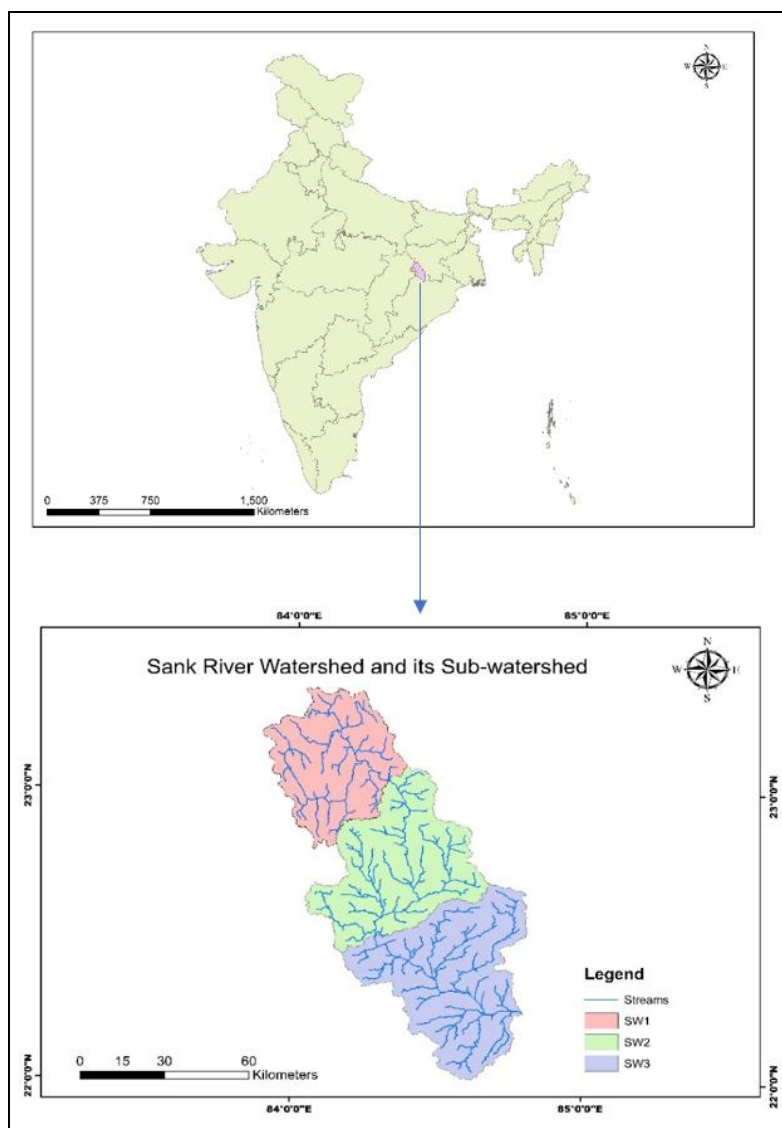


Fig 1: Map of Study area

3. Methodology

A geospatial technique with a quantitative approach has been used for hypsometric analysis of the study area. Initially, the digital data is acquired, then the watershed and sub-watersheds are delineated by processing data using different tools, and finally, the hypsometric parameters are computed for analysis. A 30-meter resolution SRTM DEM has been obtained from the website <https://earthexplorer.usgs.gov/>. The acquired DEM data is being processed in ArcMap 10.4. DEM data is processed using a specialist analysis hydrology tool, which involves fill, followed by the generation of flow direction and flow accumulation. Using the pour point, the Sankh River

watershed and sub-watersheds SW-1, SW-2, and SW-3 are delineated. Subsequently, the Sank River Watershed and sub-watersheds elevation range is reclassified into equal intervals, and finally, the Zonal Statistics table is used for the extraction of minimum, maximum, and mean elevation for the calculation of the Hypsometric Integral and the Hypsometric curve is plotted. The Hypsometry integral is calculated using the following equation.

$$HI = \frac{H_{mean} - H_{min}}{H_{max} - H_{min}}$$

Where:

- Hmean = Mean elevation of the watershed or sub-

watershed

- Hmin = Minimum elevation
- Hmax = Maximum elevation

The hypsometric curve is plotted between relative height h and H and relative area a and A . (Kumar *et al.*, 2016; Ritter

et al., 2002) [3, 24].

Where:

- h =height of given contour
- H = maximum basin elevation

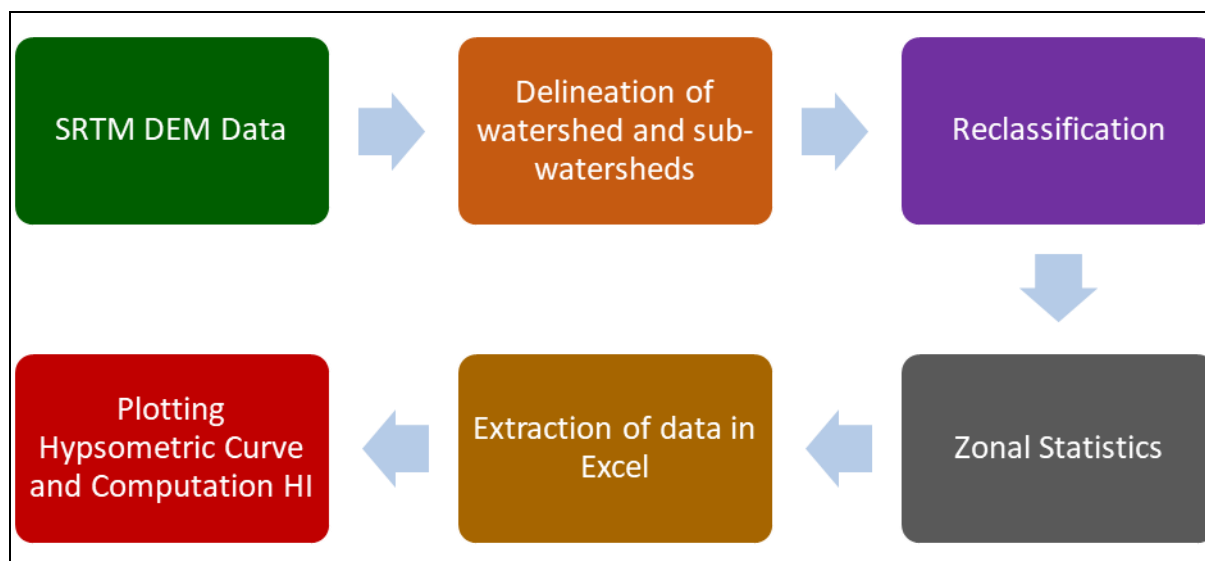


Fig 2: Flow chart of Hypsometric Analysis

4. Result

Sank River Watershed and its sub-watershed Hypsometric analysis have been done to understand the erosion status and landscape evolution. The value of HI ranges from 0 to 1 ((Kumar *et al.*, 2016; Markose & Jayappa, 2011) [3, 20].

Where:

- $HI > 0.6$ - Youthful stage (less eroded, tectonically active regions)

- $HI \sim 0.35-0.6$ - Mature Stage (Landscape evolution in process)
- $HI < 0.35$ - Old Stage (Highly eroded, Stable Landscape)

While the hypsometric curve shows:

Convex Shape - Youthful Stage

S-Shape - Mature Stage

Concave Shape - Old Stage

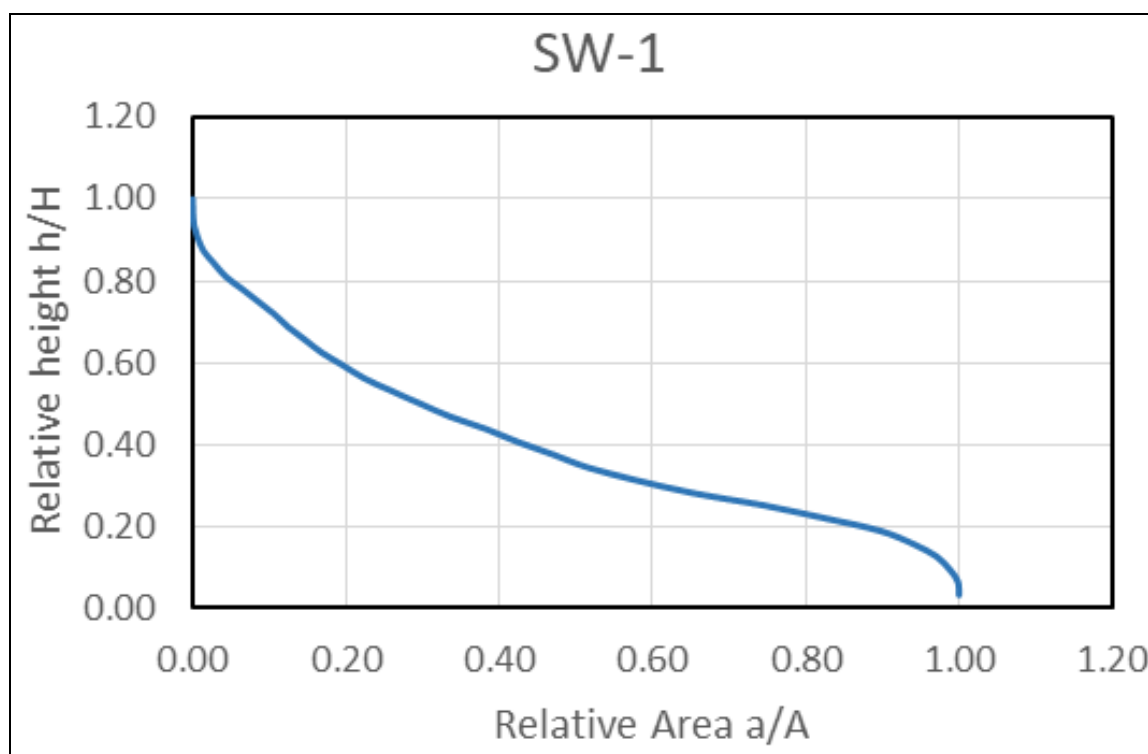


Fig 3: Hypsometric curve of Sub-watershed (SW-1)

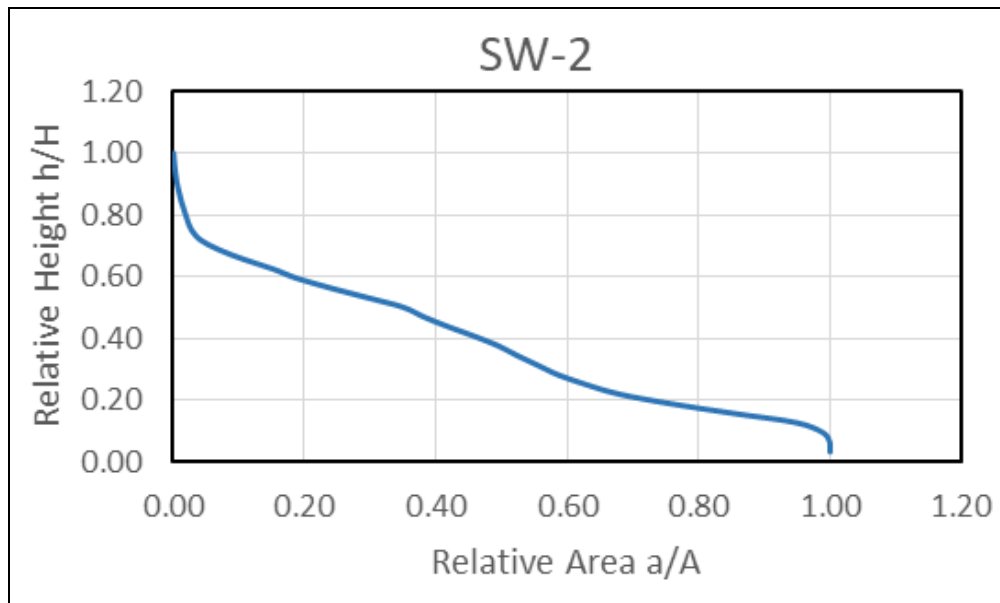


Fig 4: Hypsometric curve of Sub-watershed (SW-2)

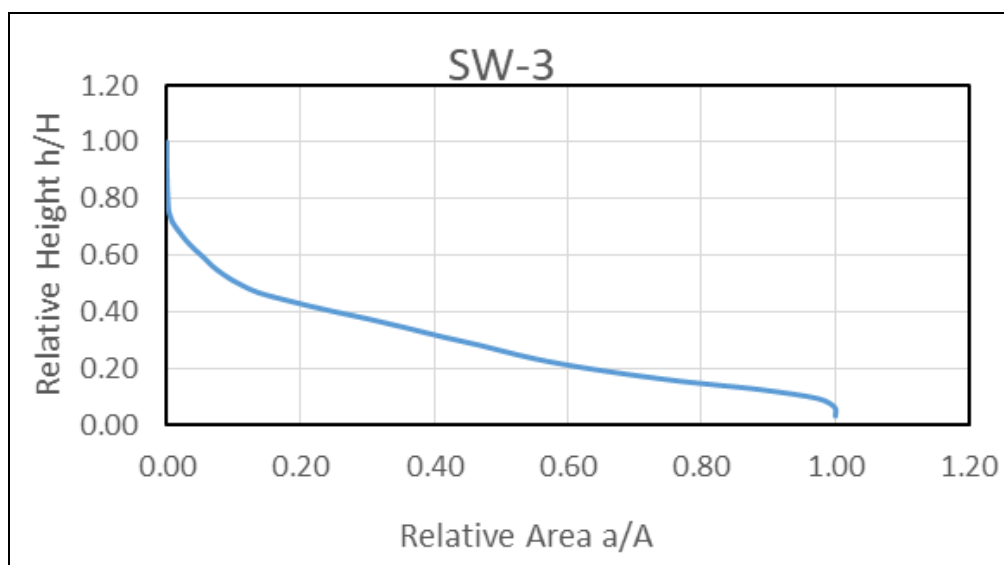


Fig 5: Hypsometric curve of Sub-watershed (SW-3)

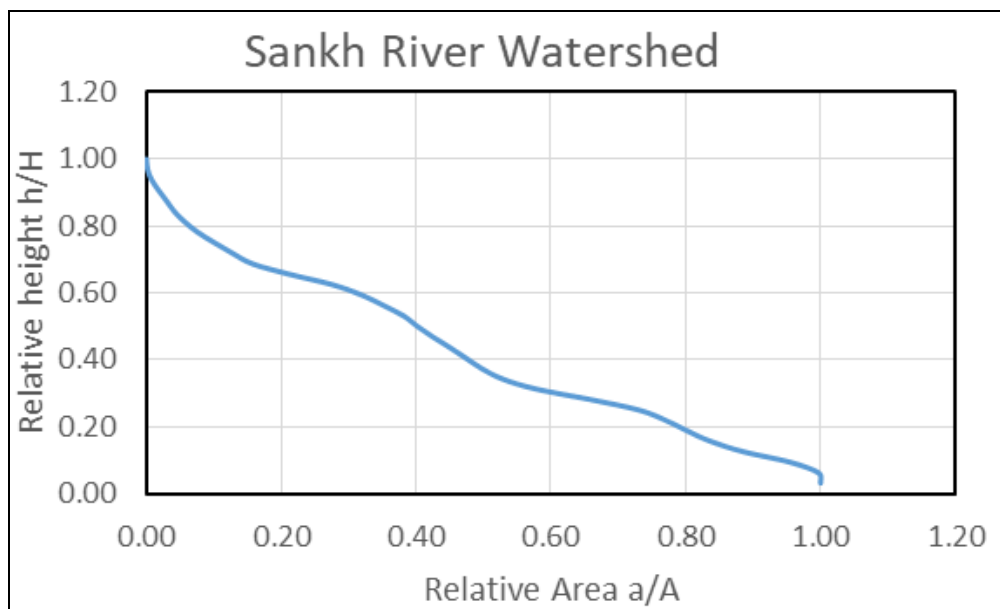


Fig 6: Hypsometric curve of Sankh River watershed

Table 1: Hypsometric Integral of watersheds

Watershed	Hypsometric Integral	Stage
SW-1	0.49	Mature
SW-2	0.49	Mature
SW-3	0.49	Mature
Sankh (whole)	0.49	Mature

- **SW-1:** The hypsometric curve shows a slight concave downward, and it is smooth. The HI value is calculated as 0.49, suggesting a balanced condition between erosion and slope decline, that is, the degradation and aggregation processes are active.
- **SW-2:** The Hypsometric curve is more curved compared to SW-1. HI Value is 0.49, which shows this watershed of mature stage, but is slightly more eroded than SW-1. Dissections are observed because in this watershed, there is a gradual decrease in the Elevation of the landscape. Terrain is changing towards the late mature stage
- **SW-3:** The Hypsometric curve is concave, and the HI value is 0.49. This shows the Sub-watershed has attained the strong mature stage, erosion intensity has increased and is approaching towards old stage, and terrain is slowly labelling.

Overall, the upper portion indicates a gentle slope that has less area at high elevation. In the middle portion, the slope has gradually declined, indicating the zone of active erosion. The lower portion of the surface relief is flat because of more sediment deposition.

5. Conclusion

The computed HI values of all the sub-watersheds, as well as that of the whole watershed, are 0.49, which indicates the whole basin has attained the maturity stage. Similar HI values also suggest homogeneity in geomorphic processes within the watershed. All sub-watersheds have uniform development, and basin evolution is homogeneous. All these results help in analysing plans for the watershed management. Sustainable use of groundwater and land use practices must be followed for the purpose of soil conservation. Contours bunding and Terracing on a moderate slope will help to reduce erosion. Check Dams and percolation tanks must be constructed within the watershed to increase the recharge of groundwater, since mature basins are sensitive to soil degradation. Thus, instead of constructing intensive structures, emphasis must be placed on maintaining the ecological balance and sustainable use of the landscape within the Watershed.

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