



Hypsometric Exploration of Five Sub-Catchments and Its Implication on Flood Management at Enyong Creek, Southern Akwa Ibom State, Nigeria

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ABSTRACT: The objective of this paper was to evaluate the hypsometric exploration of five sub-catchments and its implication on the flood management at Enyong Creek, Southern Akwa Ibom State, Nigeria using remote sensing. Result from the study shows that the hypsometric analysis of all the five sub-catchments of the Enyong Creek shows that the value of hypsometric integral (HI) ranges between 0.488-0.502 which indicates the Enyong Creek is at Equilibrium or Mature stage. Hydrologically, the result implies that the lower Enyong Creek sub-catchments are relatively mature and erosional processes have stabilized thus experiencing flooding. The study therefore illustrated the efficacy of GIS technology in hypsometric analysis of watershed as prerequisites for development of geological stages and it is also useful to undertake soil and water conservation measures.

DOI : <https://dx.doi.org/10.4314/jasem.v29i8.24>

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Cite this Article as: AUGUSTINE, C. U; OLATUNDE, B. O; SATURDAY, U; AWU, J. I (2025) Hypsometric Exploration of Five Sub-Catchments and Its Implication on Flood Management at Enyong Creek, Southern Akwa Ibom State, Nigeria. *J. Appl. Sci. Environ. Manage.* 29 (8) 2577-2590

Dates: Received: 30 May 2025; Revised: 11 June 2025; Accepted: 17 July 2025; Published: 01 August 2025

Keyword: Remote sensing; Hypsometric analysis; Flood management; Enyong creek

Hypsometric analysis is an assessment carried out to ascertain the susceptibility of a watershed to erosion, flooding, or any form of disaster as well as prioritize them for treatment. It was first introduced by Langbein (1947) to express the general slope and the forms of a drainage basin. Thus, hypsometric analysis represents a morphometric parameter, like the hypsometric integral, used to deduce its relationship with the area of watersheds. Most importantly, hypsometric analysis (area-altitude study) is beneficial in describing the stages of geomorphic development of a river basin. It deals with the measurement of the interrelationships between the basin area and the altitude of the basin, which has been used to understand the influence of climatic,

geologic, and tectonic factors on topographic changes. It is considered an effective tool for understanding the stages of geomorphic evolution and geological development of river catchments, and for the delineation of the erosional proneness of a watershed. The shapes and values of the hypsometric curve and hypsometric integral reveal the stage of development of the basin (Himadree and Sujit, 2019). It provides valuable information in deciding the geological stage of the development of a watershed. Strahler (1952) interpreted shapes of hypsometric curves by analyzing numerous drainage basins and classified the basins as youth (convex upward curves), mature (S-shaped curves which are concave upwards at high elevations and convex downwards at

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low elevations), and peneplain or old (concave upward curves). Meanwhile, there is frequent variation in the shape of the hypsometric curve during the early geomorphic stages of development followed by minimal variation after the watershed attains a stabilized or mature stage. The hypsometric integral is employed as an estimator of the erosion status of a drainage basin, and subsequent prioritization for taking up soil and water conservation activities (Hurtrez *et al.*, 1999b; Bishop *et al.*, 2002; Singh *et al.*, 2008). The hypsometric integral (Hsi) is also an indication of the cycle of erosion (Strahler, 1952a; Garg, 1983). Hypsometric integral, on the other hand, measures the percentage volume of earth material remaining after the erosion of an original landmass having a volume equal to the reference solid with a base equal to basin area and the height equal to the total height range in the basin. Strahler (1952) proposed the dimensionless hypsometric integral. This is used as a measure of landscape evolution. Strahler (1952) proposed the percentage hypsometric curve in which he showed concretely how a comprehensive analysis of the percentage hypsometric curve can provide vital indications of the stage of evolution of a particular drainage basin associated with uplift and denudation. Schumm (1956) also demonstrated the multiple possibilities of interpretation of hypsometric curves regarding the stage of basinal evolution. Hence, the objective of this study is to evaluate the Hypsometric

exploration of five sub-catchments and its implication on flood management at the Enyong Creek, Southern Akwa Ibom State, Nigeria.

MATERIALS AND METHODS

Study Area: The study area, Enyong Creek is located in Akwa Ibom State of Nigeria and has about five catchments' areas, namely; the Ito, Nkana, Nkwuot, Ntam Obu, Obio Usiere, respectively, as shown in Figure 1. The Enyong Creek lies between Latitude 5°12'51.903"N to 5°24'16.9"N and longitude 7°48'33.422"E to 7°58'3.775"E. Geologically, the study area is underlain by a wide range of diverse geological formations ranging from Asu River Formations, the Abakiliki Anticlinorium to the alluvium in the south. The area is well represented by structurally controlled ridges, denudational hills such as the 150m high of Obotme conical hill, steep-sided valleys, saddle and col at Obot Ito Ikpo. Also, it has an extensive wetlands and alluvial plains forming soil covers of silty clay, sandy and heavily weathered loamy and alluvium. The area enjoys tropical climate and the temperature ranges from 26 to 32° C. The level of humidity is high at the rate of 84% due to close proximity to the main Cross River Channel. The average annual rainfall in the basin is 2200mm with maximum contribution from southwest tropical maritime air-mass.

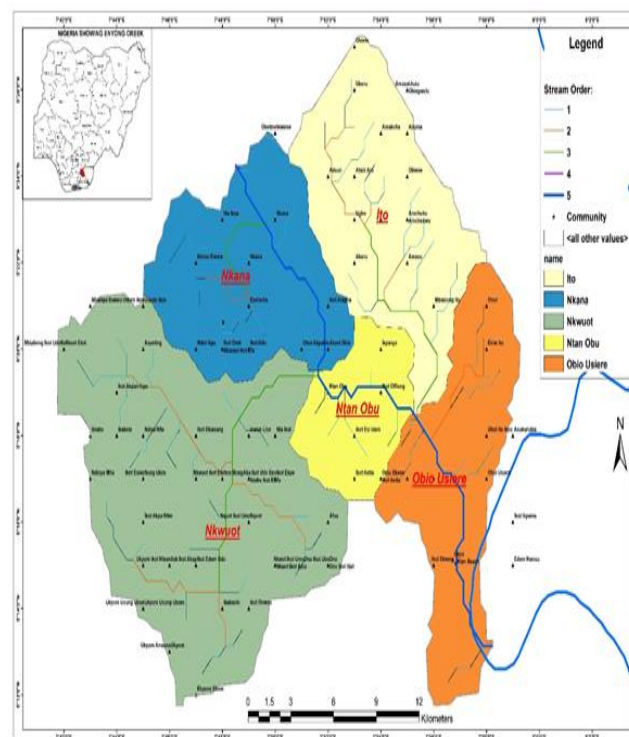


Fig 1: Map of Enyong Creek showing the five Sub-catchments (Source: Augustine, CU)

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Table 1: Hypsometric Integral Values of the Sub-Catchments

S/No.	Sub-Catchment	Max Elev	Min Elev	Mean Elev	Hypsometric integral (HI)	Stage of development
1	Nkwot	71.24	67.29	69.27	0.502	Equilibrium
2	Obio Usiere	67.93	64.05	65.94	0.4843	Equilibrium
3	Ntan Obu	55.48	52.43	53.91	0.4837	Equilibrium
4	Ito	88.18	83.16	85.61	0.488	Equilibrium
5	Nkana	63.18	59.80	61.49	0.500	Equilibrium

Data Collection and Processing: The study utilized two datasets which includes the remote sensing dataset and the climate dataset. The dataset was for 23 years period starting from year 2000 to 2023. The remote sensing data include Digital Elevation Model (DEM), Satellite Imagery, Land Cover, Soil Type, while the climate dataset comprises the rainfall and river discharge.

Digital Elevation Model (DEM); this was sourced from the USGS, 30m resolution and was used for the terrain analysis, watershed delineation, and hydrological modeling. It was processed through conversion, projection (WGS 1984 UTM Zone 32N), resampling, and sink filling.

Satellite Imagery: The satellite imagery used was obtained from the Landsat 8 with a 30m resolution. It was used for land cover and vegetation analysis, with preprocessing steps including conversion, radiometric correction, NDVI and EVI calculation, and alignment.

Land Cover: the land cover was obtained from the USGS NLCD, with a 30m resolution: Processed for spatial alignment, resampling, and accuracy verification using satellite imagery and field observations.

Soil Type: the soil type was sourced from the USDA SSURGO, with a 30m resolution. The soil type was processed through conversion, projection, resampling, and validation against field data for soil erosion modeling.

Climate data: The climate dataset which comprises the rainfall and river discharge data was sourced from the Nigerian Meteorological Agency (NiMet). The climate data was processed into a raster format, re-projected, resampled, and validated against historical records for accuracy in hydrological modeling.

Development of Hypsometric Analysis: This study employed a Geographic Information System (GIS)-based approach to perform hypsometric analysis on five delineated sub-catchments within the Enyong Creek. ASTER Digital Elevation Model (DEM) with a spatial resolution of 30 meters was utilized to extract elevation data necessary for the analysis. The

hypsometric curve was generated by plotting the relative area (a/A) along the x-axis and relative elevation (h/H) along the y-axis:

The Relative area (a/A) is the ratio of the area above a given contour to the total area of the sub-watershed, while, the Relative elevation (h/H) is the ratio of the height of a contour above the base to the total relief (maximum elevation minus minimum elevation) of the watershed.

The hypsometric integral (HI) was calculated using the elevation-relief ratio formula given by Pike and Wilson (1971), as shown as equation 1.

$$HI = \frac{\text{Mean Elevation} - \text{Minimum Elevation}}{\text{Maximum Elevation} - \text{Minimum Elevation}} \quad (1)$$

Where: Mean Elevation is derived from the elevation data of the delineated watershed.

Maximum and Minimum Elevation represent the highest and lowest points within each sub-catchment. The hypsometric curve, which is a normalized cumulative frequency distribution of elevation, and the HI values were analyzed to determine the stage of geomorphic development of each sub-catchment. Integration of the hypsometric curve yields the hypsometric integral (HI), which is indicative of the volume of material that remains in the basin relative to the total potential volume.

According to Strahler's classification (1952), the watershed development stages were interpreted using the following thresholds: as Youthful (in-equilibrium) stage when the $HI > 0.6$, Mature (equilibrium) stage when $0.35 \leq HI < 0.6$ and Old (monadnock) stage when $HI < 0.35$, respectively.

These classifications help assess the relative erosion status and evolutionary maturity of each watershed. GIS software (ArcGIS 10.8) was used for DEM processing, watershed delineation, and computation of hypsometric parameters.

RESULTS AND DISCUSSION

The result on the hypsometric analysis and its implication on flood management at lower enyong creek, of Akwa Ibom state is presented in two forms, namely; the hypsometric curve and integral for the five sub-catchments, respectively.

The hypsometric curve result: The hypsometric analysis results of the five sub-catchment (Nkwot, Obio Usiere, Ntan Obu, Ito, and Nkana) which represents the statistical distribution of elevations over the entire catchment are shown in Figures 2 to 6 and Table 1, respectively.

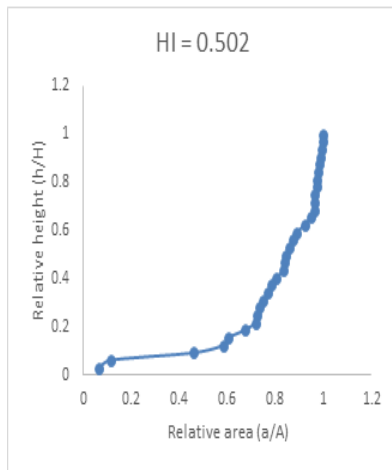


Fig 2: Hypsometric Curve of Nkwot Sub-Catchment

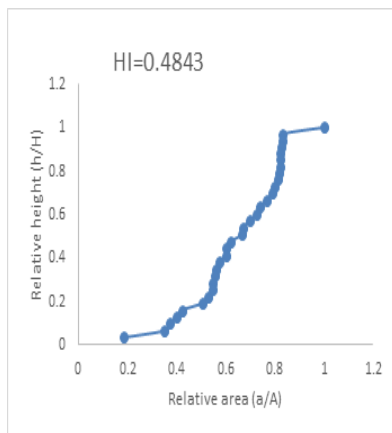


Fig 3: Hypsometric Curve of Obio Usiere Sub-Catchment

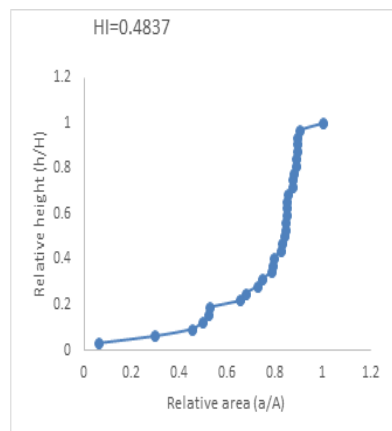


Fig 4: Hypsometric Curve of Ntan Obu Sub-Catchment

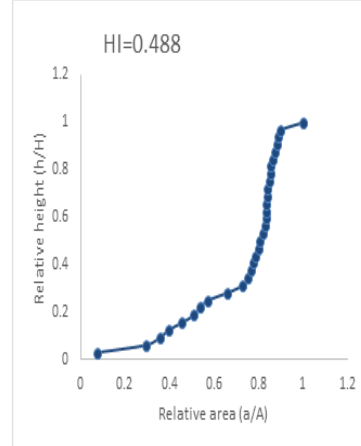


Fig 5: Hypsometric Curve of Ito Sub-Catchment

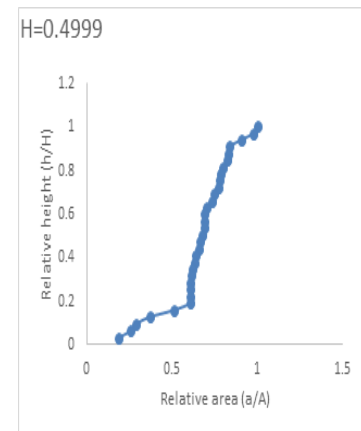


Fig 6: Hypsometric Curve of Nkana Sub-Catchment

The hypsometric curve results for the Nkwot sub-catchment, characterized by a maximum elevation of 71.24 meters, a minimum elevation of 67.29 meters, and a mean elevation of 69.27 meters, reveal important insights into the geomorphic state and evolutionary stage of the landscape. The calculated hypsometric integral (HI) value of 0.502 indicates a moderate degree of landform dissection. An HI value around 0.5 is typically associated with catchments in a mature or equilibrium stage of development, which aligns with the determined developmental stage for Nkwot. This result aligns with the findings of Strahler (1952), who established that HI values around 0.5 indicate a mature landscape where erosion and tectonic uplift are balanced. This equilibrium stage suggests that the sub-catchment has reached a balanced state between erosional and depositional processes, implying a relatively stable landscape where the rates of uplift and denudation are approximately equal. The landforms are neither in the youthful stage, characterized by active down-cutting and steep slopes, nor in the old stage, where most relief has been eroded away. Instead, the terrain

exhibits moderate relief and a smoother topographic profile, suggesting that substantial geomorphic evolution has occurred, and the landscape has been shaped by long-term fluvial processes that have gradually reduced elevation contrasts.

Likewise, the hypsometric curve analysis of the Obio Usiere sub-catchment, with a maximum elevation of 67.93 meters, a minimum elevation of 64.05 meters, and a mean elevation of 65.94 meters, provides valuable insight into the geomorphic status and evolutionary phase of the landscape. The hypsometric integral (HI) value of 0.4843 places the sub-catchment within the range typically associated with a mature or equilibrium landscape. This stage, confirmed by the recorded developmental classification, signifies that the sub-catchment is experiencing a balanced interplay between erosion and deposition, indicating a relatively stable geomorphological environment. This finding is supported by Pike and Wilson (1971), who indicated that HI values ranging from 0.45 to 0.50 are characteristic of equilibrium stages in landscapes with moderate relief. The HI value, being slightly below 0.5, suggests that while significant erosional processes have taken place over time, the area has not yet been fully degraded to a peneplain or an old-age topography. Instead, the sub-catchment is characterized by moderate dissection and relief, where erosional processes have smoothed the terrain but not eliminated it entirely. The close alignment of the mean elevation (65.94 meters) with the average of the maximum and minimum elevations further reinforces the interpretation of a mature landscape, pointing to a relatively even terrain with limited vertical differentiation. Similarly, the hypsometric curve analysis of the Ntan Obu sub-catchment, with a maximum elevation of 55.48 meters, a minimum elevation of 52.43 meters, and a mean elevation of 53.91 meters, offers important insights into the geomorphological condition and stage of landscape evolution. The hypsometric integral (HI) of 0.4837 situates the sub-catchment within the transitional range between youthful and old stages but is more closely aligned with the equilibrium or mature phase of development. This stage is marked by a relative balance between erosional forces and tectonic uplift or depositional processes, indicating that the landscape has evolved toward a stable form over geological time. These findings are consistent with Moglen and Bras (1995), who associated HI values close to 0.48 with equilibrium stages in fluvial-dominated terrains. The relatively low relief, as demonstrated by the narrow difference between the maximum and minimum elevations, suggests that the Ntan Obu sub-catchment has experienced prolonged

denudation and surface leveling processes. The mean elevation of 53.91 meters, which lies near the midpoint between the highest and lowest points, further confirms the subdued nature of the terrain and the dominance of mature fluvial processes that have eroded the steeper gradients and led to a more uniform topographic profile. More so, the hypsometric curve results for the Ito sub-catchment, which has a maximum elevation of 88.18 meters, a minimum elevation of 83.16 meters, and a mean elevation of 85.61 meters, offer a clear picture of the catchment's geomorphic condition and stage of development. With a hypsometric integral (HI) of 0.488, the sub-catchment falls within the range typically associated with a mature or equilibrium landscape, indicating that it has reached an intermediate stage in its geomorphological evolution. This stage reflects a balanced interaction between erosional forces and any tectonic or depositional influences, suggesting a landscape that has undergone substantial shaping over time but has not yet reached full degradation or old-age topography. This result agrees with the findings by Keller and Pinter (2002), who emphasized that landscapes with HI values between 0.45 and 0.50 reflect mature equilibrium conditions resulting from long-term erosional stability. The moderate difference between the maximum and minimum elevations highlights a relatively gentle relief, with the mean elevation closely approximating the average of the extreme elevation values. This points to a landscape that has been moderately dissected and smoothed by fluvial processes, resulting in a more uniform surface and reduced slope steepness. The HI value of 0.488, being slightly below 0.5, signifies a terrain where the majority of erosional activity has already occurred, yet some residual relief still exists. However, the hypsometric curve results of the Nkana sub-catchment, with a maximum elevation of 63.18 meters, a minimum elevation of 59.80 meters, and a mean elevation of 61.49 meters, provide important insights into the geomorphic condition and evolutionary status of the landscape. The hypsometric integral (HI) of 0.500 indicates that the sub-catchment is in a transitional but stable stage of development, classified as equilibrium. An HI value at or near 0.5 typically signifies a mature landscape that has undergone considerable erosional modification, yet retains enough relief to suggest that the terrain is neither youthful nor fully degraded. Strahler (1952) and subsequent studies such as Weissel *et al.* (1994) corroborate this view, describing HI values around 0.5 as indicative of dynamically stable terrains with balanced uplift and erosion. The narrow range in elevation, along with the proximity of the mean elevation to the midpoint

of the maximum and minimum values, reflects a landscape with moderate relief and a relatively smooth topographic profile. This suggests that the catchment has been shaped by prolonged fluvial processes that have progressively worn down the original steepness and irregularities, leading to a more uniform distribution of elevation. The equilibrium stage of development implies that the landscape has achieved a dynamic balance where the rates of erosion and deposition are relatively equal, and no dominant geomorphic process is drastically altering the landform at present. Generally, while all five sub-catchments fall within the equilibrium stage of development, the variation in their HI values and elevation ranges reflects different degrees of landscape maturity. Nkwot and the second Ito sub-catchment lean toward a slightly less eroded, more intact landscape, while Obio Usiere, Ntan Obu, and the first Ito sub-catchment show more advanced dissection and smoothing, typical of catchments that have undergone extensive geomorphic transformation but remain in a state of topographic balance.

Conclusion: The hypsometric analysis conducted across the five sub-catchments of the Lower Enyong Creek reveals that all the sub-catchments areas are in the equilibrium or mature stage of geomorphic development. This stage is characterized by a balance between erosion and deposition, indicating stable yet flood-prone landscapes. Findings from this study suggest that erosional processes have largely stabilized, making these areas vulnerable to surface runoff accumulation. The GIS approach proved effective in analyzing the terrain and providing insight into flood susceptibility. This analysis supports prioritization of soil and water conservation efforts for sustainable watershed management.

Declaration of Conflict of Interest: The authors declare that no known conflict of interest or personal relationships that could have influence the work reported in this paper.

Declaration of Data Availability Statement: Data are available upon request from the first author

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