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Hypsometric Analysis of the River Digil Catchment in Mubi Adamawa State, Nigeria

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Abstract
Hypsometric analysis as a method of evaluating erosion proneness of river catchment areas has gained wider popularity in recent time. Assessment of the stage of evolution of a landscape is a necessary prerequisite for landuse planning, natural resources conservation and management. The main data for this study was Shuttle Radar Topography Mission-Digital Elevation Model (SRTM-DEM) downloaded from the USGS Earth Explorer Portal. The GIS Extensions-Arc Hydro was used to process the DEM and the derived digital layer was used to delineate the River Digil catchment. The Elevation–Relief Ratio method was adopted to analyse the hypsometric integral of River Digil catchment and its sub-basins. Results of the analyses revealed that the study catchment and its sub-basins are in the mature or equilibrium stage of geological development. The hypsometric integral value of the River Digil catchment was 0.48, implying that 48% of the original rock mass in the study area is still intact. This indicates that the River Digil catchment has attained a stable stage in erosional processes. There was little variation in hypsometric integral values among the five sub-basins, which values range from 0.47 to 0.49. The findings of this study provide additional information to stakeholders involved in planning for soil and water resources conservation in the study area. This study recommends the construction of reservoir upstream of the River Digil catchment to impound excess surface runoff for urban water supply and to mitigate the problem of soil erosion in the downstream sector.

Keywords: Hypsometric integral, *Hypsometric curve*, Equilibrium, Digil catchment, SRTM-DEM, Monadnock

Introduction

Water and land are very important natural resources that are becoming limited in both quantity and quality owing largely to environmental degradation. The availability of these two vital natural resources are being affected by growing population, diversification in human activities and advancements in technology. As the availability and access to fresh water and land are being reduced in different sectors, proper planning and management of these two important natural resources become increasingly necessary (Shivaswamy, *et al.*, 2019).

The River Digil is a tributary of the River Yedzeram. This important hydrological unit is located on the western segment of the Mandara Mountains. Here, the land is generally dominated by undulating plains whose adjoining hill slopes are prone to soil erosion. It has further been observed that the removal of vegetation on the hill slopes have caused sustained increase in surface runoff during intense rainstorms. It is therefore, imperative to assess the evolutionary status of the River Digil catchment with a view to providing information required for planning and management of land and water resources in Mubi town.

Watershed development and management plans are very important for surface and groundwater conservation. To prepare a watershed development plan, it becomes important to know the topography, lithology, erosional status and drainage pattern of the area (Pisal, *et al.*, 2020). Morphometric analysis, which reveals the river basin characteristics, usually lacks in-depth details of relief characteristics of the basin. Detailed analysis of geomorphic evolution history of a drainage basin and its relation to the tectonic uplift is more important in hydrological as well as erosion studies (Vijith, *et al*., 2017).

Hypsometric analysis is considered an effective tool for understanding the stages of geomorphic evolution and geological development of river catchment, and for the delineation of erosional proneness of watershed (Farhan *et al*., 2016). The hypsometric curve and hypsometric integral emerged as techniques for characterizing landforms in the nineteenth century. The approach came to prominence in the 1950s following the Quantitative Revolution in Geography. That was the first time concerted effort was made on obtaining quantitative information about properties of the Earth's surface in Geomorphology (Keylock, *et al.*, 2020).

Hypsometric analysis of drainage basins reveals the stage of geological development of a river catchment area and is a measure of its maturity, indicating the susceptibility of the watershed to erosion. Hypsometry reflects the interaction between tectonics and erosion and provide a valuable geomorphic index, which is expressed quantitatively as hypsometric integral (Sharma *et al*, 2016). Critical evaluation of hypsometric (area-altitude) parameters helps to differentiate between tectonically active and inactive areas in a basin (Vijith, *et al.*, 2017). Hypsometric analysis of river basin expresses the degree of denudation and rate of morphological changes. It is, therefore, useful to comprehend the erosion status of watersheds and prioritise them for undertaking soil and water conservation measures (Bora and Deka, 2019).

Materials and Methods:

This section consists of description of the study area, and procedures for estimating hypsometric integral and plotting of hypsometric curves.

The Study Area

The Digil River originates from the Mandara Mountains bordering Nigeria and the Republic of Cameroon south-east of Mubi town in Adamawa State. The entire catchment is located between Latitudes 10° 9' and 10° 21' north of the Equator, and Longitudes 13° 14' and 13° 31' east of the Greenwich Meridian as shown in Figure 1. The catchment covers an area of 261 km^2.

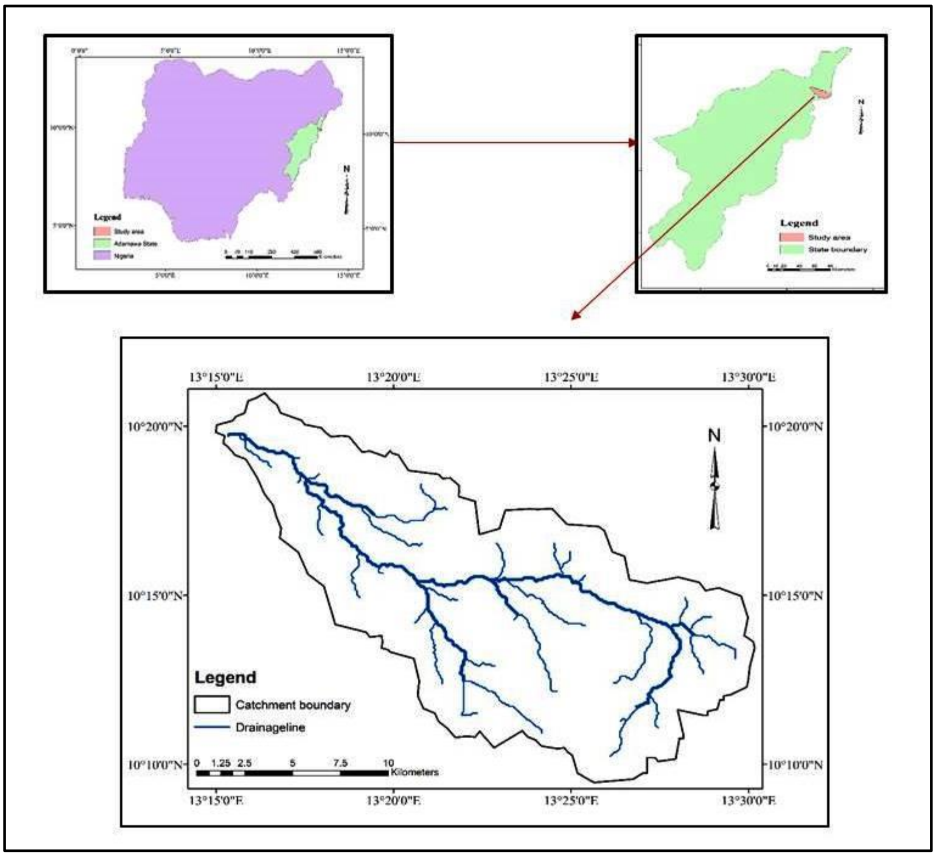

Figure 1: Location of the Study Area.

Geologically, the River Digil Catchment area falls within the Precambrian Basement Complex of northern part of Adamawa state, Nigeria. There are basically four types of rock formation in the study area, namely; Recent alluvium, Terraced alluvium, Migmatites and Granites. Occurrences of these different types of rocks were influenced by the degree of weathering and fluvial processes acting upon the parent material. Recent alluvium is confined to the river channels traversing the River Digil catchment, while terraced alluvium occurs on the floodplains adjoining the river channels. The lower and middle sections of the river catchment are dominated by the terraced alluvium. Migmatites are found in a small segment south west of the study catchment, while older Granites constitute greater proportion of area in upper course of the river. (Obiefuna, *et. al*, 1997).

Recent alluvium and terraced alluvium are loose textured rock materials derived from the weathering of the Basement Complex rocks uphill or in-situ. Since recent alluvium is not consolidated into solid rock, it is highly susceptible to erosion. In addition, the newly deposited alluvium often occur in stream beds, which predispose it to action of running water.

Terraced alluvium, though older and structurally more compacted than recent alluvium is liable to be eroded by running water due to its occurrence on valley slopes. This partly explains why terraced alluvium landscapes are dissected in river valleys characterized by steep slope.

Migmatites and older granites dominate the upper section of the study area. These rocks are resistant to erosion, hence are mainly confined to areas on higher elevation and as rock-outcrops in the river channels. There are also some lateritic concretions which Obiefuna, *et al*. (1997) aver must have been derived from weathering of the underlying basement complex rock.

Relief of the study area is closely related to the geology. The elevation is generally high, ranging from 552 meters at the river outlet to 1,492 meters in the south eastern part of the study area. The observed variation in relief configuration connotes high propensity for surface runoff. Relief of the study area is shown in Figure 2.

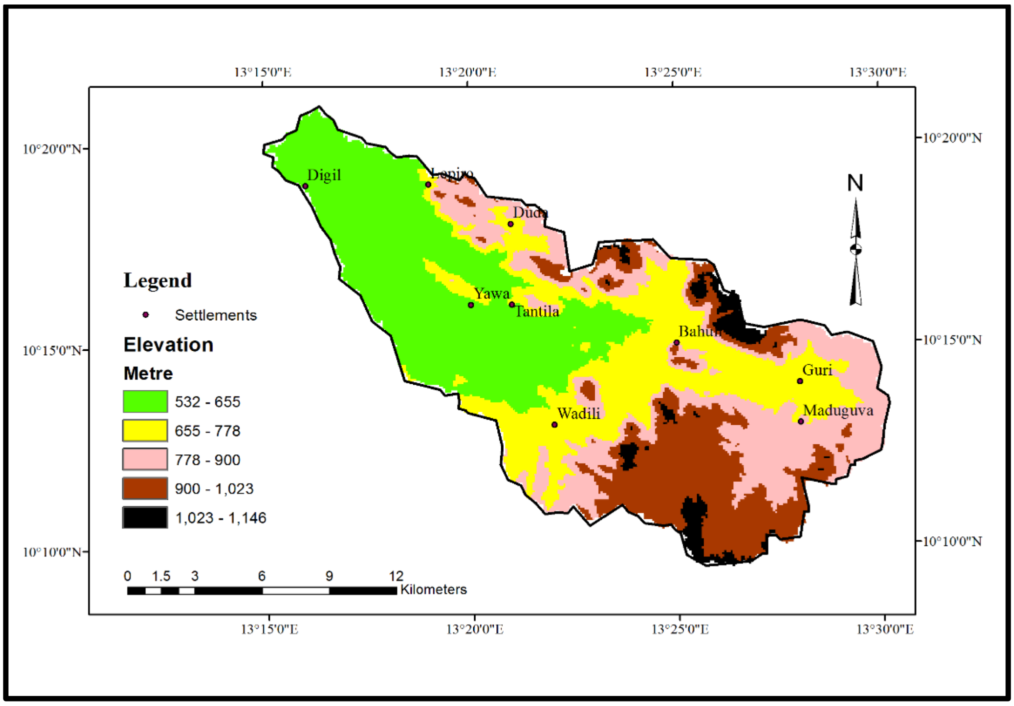

Figure 2; Relief of the River Digil Catchment

Soils in the River Digil catchment are chromic luvisols, cambic arenosols and eutric regosols dominating the upper, middle and lower segments of the river catchment respectively as shown in Figure 3.

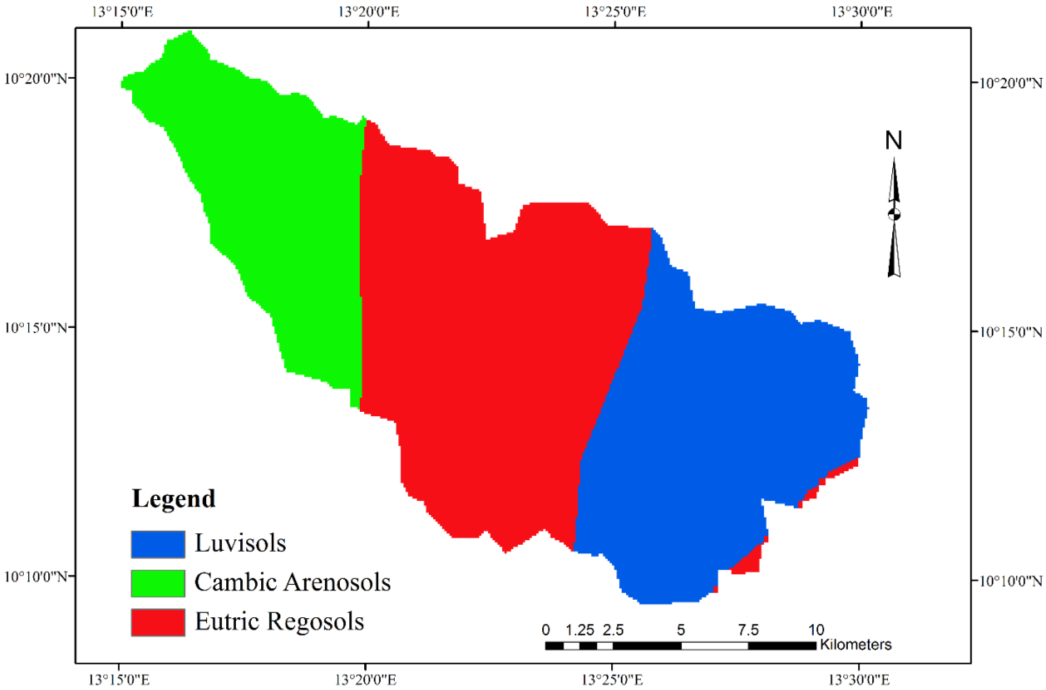

Figure 3: Soil Units in the Study Area

Luvisols are characteristically coarse-textured and fertile soils, which makes them suitable for farming. The widespread human interference with the luvisols predispose them to soil erosion. This class of soil dominates the upper section of the study area. Here, hill slopes are relatively steeper than the adjoining middle and lower sections of the river catchment. That notwithstanding, this section of the study area is less vulnerable to soil erosion due to the dominance of crystalline basement complex rocks.

In the middle section of the study area, Eutric Regosols constitute the dominant soil class. This category of soil develop on the foot of volcanic cones or steep hills in the Precambrian formation. Due to their poor fertility and proximity to hill slopes, the soils are rarely cultivated, but constitute suitable site for grazing of animals..

Cambic Arenosols are the dominant soil class in the lower section of the River Digil Catchment. Arenosols are sub-surface soils without a well-defined profile development due to lack of appreciable accumulation of alluvial materials such as clay, aluminium and humus. They are sandy textured soil emanating from recent weathered rock materials deposited mainly in form of colluvium. Due to their loose texture, cambic arenosols are susceptible to soil erosion. Most of the riparian corridors affected by channel migration in the River Digil catchment are made up of this category of soil

Climate of the study area is the dry and wet tropical type with rainfall starting from the month of May and ceases in the month of October. Annual rainfall totals in the area range from 850mm to 1100mm (Adebayo, 2004). Movement of the Inter-Tropical Discontinuity (ITD) dominantly influence the time of commencement and cessation of rainfall in the study area. Some spatial variation in the distribution of rainfall resulting from orographic effects in response to the south-westerly winds can be observed in the study area. The highland areas therefore, experience relief rainfall and receive rainfall amounts that are slightly higher than the lowland areas even though on the same latitude. Adebayo (1999) reported mean annual rainfall of 1050mm for Mubi which comprises of the study area.

There is little diurnal, monthly and seasonal temperature variations in the study area. Except for cloudy days in the rainy season and the dusty

Harmattan period between November and February, daytime temperatures are generally high. The month of April, is the hottest period in the year with temperatures rising to 37^o C, while the months of December and January constitute the coldest months when temperatures drop to 15.3^o C (Adebayo, 2004).

Estimation of Hypsometric Integrals and Plotting of Hypsometric Curves

Hypsometric integrals and hypsometric curves are widely used to illustrate the topography of drainage basins. The geological stages of development and erosion status of the watersheds can be quantified by hypsometric integral (Sharma, *et al.,* 2018). A hypsometric integral (HI) is a macroscopic indicator that can be used to study the quantitative relationship between the area of a regional horizontal section and its elevation, which can reflect the state of watershed development (Duan and Zhang, 2022; Ashwini, *et al*., 2021)

A hypsometric curve is a plot between percentage elevation and percentage area in a river basin (Mehar, *et al*., 2018). Based on the values obtained from hypsometric integral, cycle of erosion can be divided into the three stages. These are; monadnock (old) (HI <0.3), in which the watershed is fully stabilized, equilibrium or mature stage (HI 0.3 to 0.6) and young stage (HI > 0.6), in which the watershed is highly susceptible to erosion (Strahler, 1952).

This study employed the Geographic Information System-GIS method to assess the evolutionary stage of the River Digil catchment through hypsometric analysis. Shuttle Radar Topography Mission-Digital Elevation Model (SRTM-DEM) was downloaded from the USGS Earth explorer portal (https://earthexplorer.usgs. The DEM was used to delineate the River Digil catchment, which was subsequently divided into five sub-basins through automatic procedure in the ARC GIS environment. The River Digil catchment and its sub-basins on which the hypsometric analyses were based are shown in Figure 4. In each of the five sub-basins, elevations were classified into equal intervals and reclassified using the spatial analyst tool in the ARC GIS 10.0 Software.

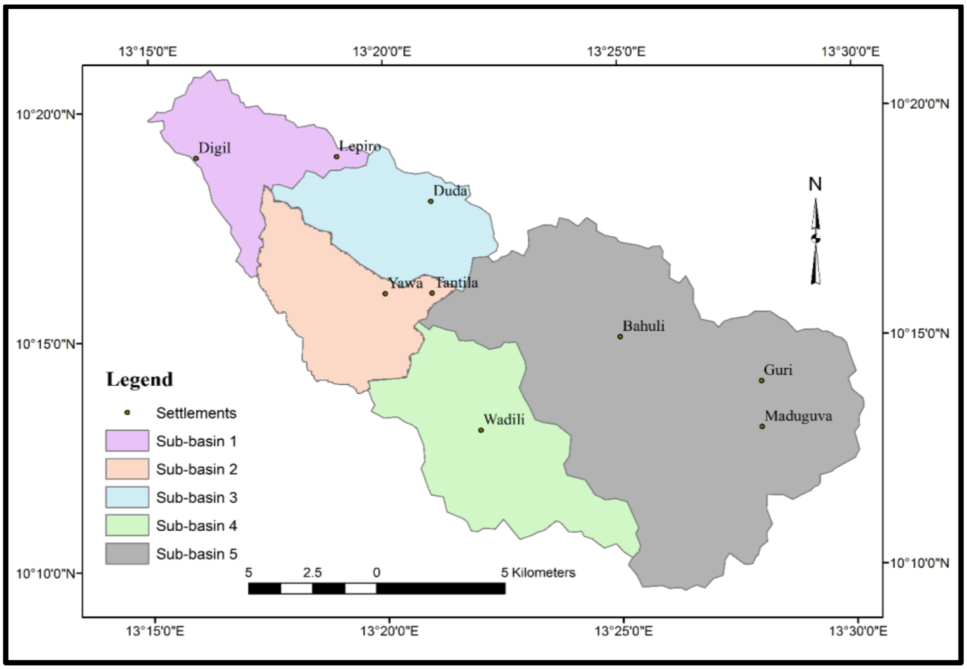

Figure 4: River Digil Sub-basins

The elevation-relief ratio method advanced by Pike and Wilson (1971) as shown Equation 1 was used for hypsometric analysis.

$$E \approx HI = \frac{Elevmean - Elevmin}{Elevmax - Elevmin} \text{……Eq.1}$$

Elevation and Area data required for the hypsometric analysis were generated by processing the values contained in attribute tables of DEM and Reclassified maps of River Digil sub-basin using the Zonal statistics tool in Arc GIS. The data obtained as table were exported to excel spreadsheet and used to estimate the hypsometric integral (HI) of the five sub-basins.

The procedure involves computing relative elevation as the ratio of the height of a given contour (h) from the base plane to the maximum basin elevation (H). The relative area is obtained as a ratio of the area of polygon enclosed by two successive contours (a) to the total area of the entire basin (A). The value of relative area (a/A) is in a range from one to zero although this can be converted to percentages for easy interpretation. The lowest point in the drainage basin (h/H = 0) has the largest area and the highest point in the basin (h/H = 1) has the smallest area (Pathak *et al*., 2019). In other words the cumulative percentage of the area ratio (a/A) is arranged in descending order of size, while the values of the height or elevation ratios are arranged in ascending order.

Where E is the elevation-relief ratio equivalent to the hypsometric integral HI; $Elev_{mean}$ is the weighted mean elevation of the watershed estimated from the identifiable contours of the delineated watershed; $Elev_{max}$ and $Elev_{min}$ are the maximum and minimum elevations within the watershed.

To produce the hypsometric curve, two ratios are involved and plotted against each other on a graph. The ratio of relative elevation (h/H) is represented on the Y-axis (ordinate) and the ratio of relative area (a/A) is represented on the X-axis (abscissa).

Results and Discussions

The estimated hypsometric integral value for the River Digil catchment is 0.48. The values for sub-basins range from 0.47 to 0.49 as shown in Table 1.

Table 1: Hypsometric integral values by Sub-basins in the River Digil Catchment

Sub-basin	Area km^2	Elevations in metre			Computation parameters		HI	Stage
		Mean	Min	Max	E_{mean}- E_{min} (m)	E_{max}-E_{min} (m)		
1	25	740	532	951	178	378	0.47	Equilibrium
2	31	686	553	820	119	256	0.47	Equilibrium
3	28	780	554	1007	213	443	0.48	Equilibrium
4	46	859	599	1121	250	513	0.49	Equilibrium
5	131	873	600	1149	257	540	0.48	Equilibrium
Digil Catchment	261	789	532	1149	1025	2122	0.48	Equilibrium

Source: Researcher’s Analysis, 2022

All five sub-basins fall under the category of equilibrium or mature stage of landscape evolution. This indicates that erosion process in the study area has stabilised. Singh *et al*. (2008) reports that soil erosion in river catchments that have attained matured stage of landscape evolution occur primarily in form of the incision of channel beds, down slope movement of topsoil and bedrock material, washout of the soil mass and cutting of stream banks. This assertion was partly corroborated by Yonnana (2021), who averred that significant proportion of the riparian corridors of the River Digil are being continuously affected by erosion leading to river bank failures and stream channel migration.

The hypsometric integral values of the Digil River catchment (0.48) indicated that 48% of the original rock masses still exist in the river catchment. The Hypsometric integral values of sub-basins 1 and 2 (0.47) are relatively lower than the values for sub-basins 3, 4 and 5; which are 0.48, 0.49 and 0.48 respectively. These variations in hypsometric integral values among the sub-basin are primarily attributed to the lithological differences across the sub-basins. The sub-basins 3, 4 and 5 have higher hypsometric integral values mainly, because they are located in the upper section of the study catchment where relatively more resistant crystalline basement complex rock materials predominate. Conversely, sub-basins 1 and 2 are located towards the catchment outlet where the area is dominated by unconsolidated sub-surface rock materials that are more susceptible to erosion. Moreover, the sub-basins located at lower elevations (sub-basins 1and 2) experience human interventions in the form of road construction, intensive agricultural practices and deforestation activities which accelerate denudation processes.

The shape of hypsometric curves can serve as indicators of the history of landscape process. Generally, hypsometric curves in river catchments that have attained the old stage of landscape evolution are concave in shape. Conversely, hypsometric curves in river catchments that are still at the early or young stage of landscape evolution are characterised by convex shape (Farhan *et al.*, 2016).

Sub-basins of the River Digil catchment are characterized by hypsometric curves with straight or flat shapes as shown in Figure 5. These shapes are in consonance with the Hypsometric Integral of mature or equilibrium stage of landscape development in all the sub-basins earlier indicated in Table 1.

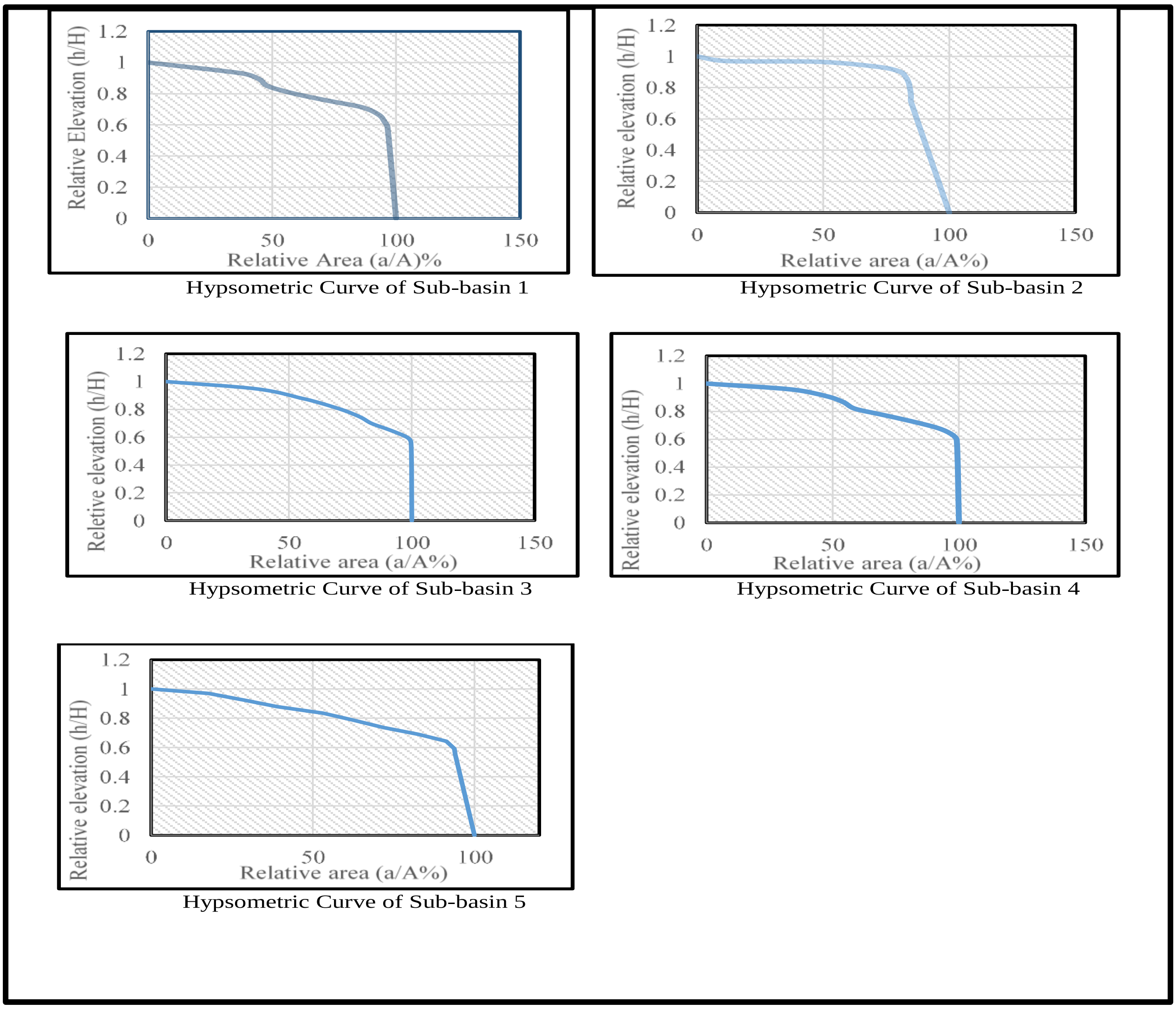

Figure 5: Hypsometric Curve of River Digil Sub-basins

Conclusion

Hypsometric analysis is a method used to investigate the complex factors influencing denudation process in a river catchment. Hypsometric analysis is particularly important for the study of runoff and erosion in hilly terrains where most areas are inaccessible. This study generated information on the stage of geological evolution and erosion proneness in the River Digil catchment. The study catchment falls under the category of equilibrium or mature stage of landscape evolution. This indicates that the erosion process in the study area has stabilised. It is, however, pertinent to point out that soil erosion will persist in the downstream section of the study catchment due to runoff generated in the rocky terrain upstream. This study recommends the construction of reservoir upstream of the River Digil catchment to impound water generated through surface runoff. The reservoir can help in checking erosion and flooding in the downstream sector, while the impound water serves as source of urban water supply.

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