GIS and Hypsometry based Analysis on the Evolution of Sub Basins of Ponnaiyar River, Krishnagiri District, Tamil Nadu

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Abstract

GIS aided hypsometric analysis of a river basin is generally used to understand the stage of geomorphic evolution (youth, mature and old). The present study focuses on identifying the growth stage of Ponniyar river sub basins based on the shape of the hypsometric curve and hypsometric integral value. The study area geographically lies between the latitudes 12˚.15′N & 12˚55′N and longitudes 77˚ 15′ E & 78˚ 45′ E. The six sub basins of Ponaiyar River are analysed in the present study which include Chinnar basin-A, Chinnar basin-B1, Chinnar basin-B2, Ponnaiyar basin, Marakandanadhi basin and Veppanapalli basin. The drainage network for all the above six sub basins were extracted from Survey of India Topographical Maps of 1:50,000 scale. ASTER DEM product was used to prepare elevation contours with 20 m interval. The Hypsometric Curves for the sub basins were prepared using Strahler's Percentage Method (1952), from which the ratios a/A and h/H were plotted. Hypsometric integrals were estimated using Elevation relief ratio method. The results show that the hypsometric integral values range between 0.45 and 0.56 indicating mature stage development for all the river basins. However, the values of 0.55 and 0.56 obtained for Veppanapalli basin and Marakandanadhi basin are close to the lower limit of the youthful stage value range which reveals that these two basins are in the early mature stage. The hypsometric shapes for Chinnar basin–B2 and Marakandanadhi basins are slightly convex indicating that they have just completed the youth stage and presently at the early mature stage.
Keywords: Equilibrium stage, GIS, Hypsometric curve, Hypsometric integral, Sub basins

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I. INTRODUCTION

Hypsometry is a term that pertains to measurement of Earth's terrestrial surface. Langebein (1947) was the first person to introduce hypsometric analysis to express the overall slope and the forms of a drainage basin. Experts often evaluate different hypsometric measurements for different natural drainage basins, or other well defined areas, to determine the types and rates of different processes that shape the Earth's surface over time. It aims at developing a relationship between horizontal cross section area of a watershed and its elevation in a dimensionless form that permits comparison of watersheds irrespective of scale issues. Hypsometry analysis of drainage basins (area-elevation analysis) has been evaluated by the researchers to simulate the geological stages of development and to study the influence of varying forcing factors on watershed topology. This analysis of watershed (area-elevation analysis) has mainly been used to reveal the stages of geomorphic development

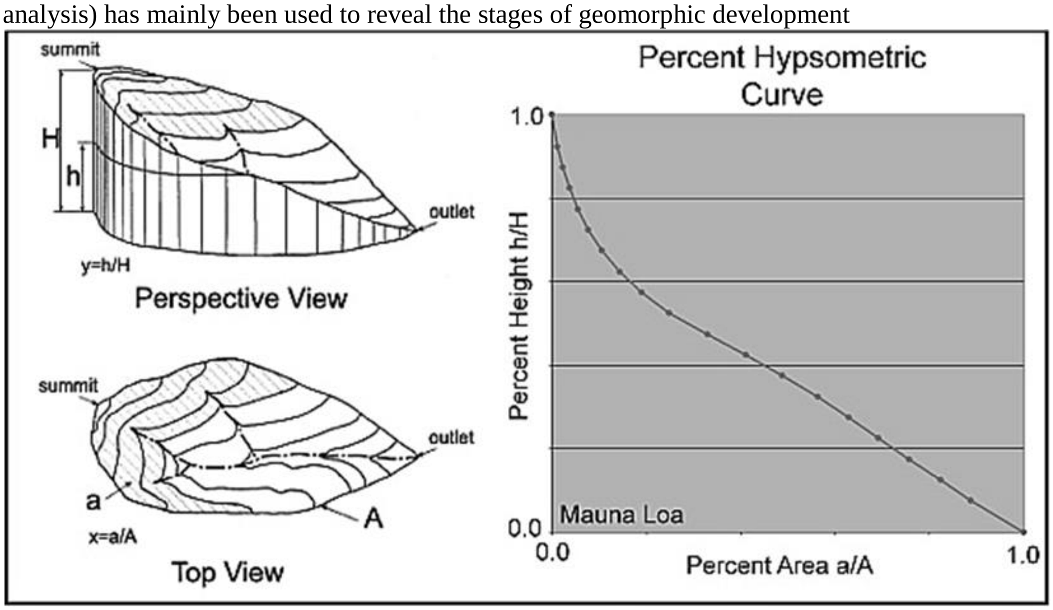

Fig. 1: The Concept of Hypsometric Analysis and the Model Hypsometric Curves (Ritter et al. 2002).

(Stabilized, mature and young). Two simple and common approaches used to measure the landscape in this context are the hypsometric curve and hypsometric integral. Hypsometric curves and hypsometric integrals are major indicators of watershed conditions. Hypsometric curve is obtained by plotting the relative area (a/A) along the abscissa and relative elevation (h/H) along the ordinate. The relative area is obtained as a ratio of the area above a particular contour (a) to the total area of the sub watershed above the outlet (A). Similarly, considering the watershed area to be bounded by vertical sides and a horizontal base plane passing through the outlet, the relative elevation is calculated as the ratio of the height of a given contour (h) from the base plane to the maximum basin elevation (H), (Sarangi et al. 2001 and Ritter et al. 2002). To perform a hypsometric analysis on any given basin, elevation (often normalized elevation) is plotted against percent area. The percent area will be the proportion of total basin area at each elevation. Strahler (1952) interpreted the 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 low elevations) and peneplain (concave upward curves). Hypsometric integral helps in explaining the erosion that had taken place in the watershed. This paper focuses on delineating the landform development stages for Ponnaiyar river basin covering Krishnagiri district of Tamilnadu. The study couples hypsometry analysis with the GIS technology.

II. Study area

The study area of the watershed is the South Pennar basin, a east flowing river also known as Ponnaiyar basin covers an area of 1013.13 km^2. It geographically lies between the latitudes 12˚.15′N & 12˚55′N and longitudes 77˚ 15′E & 78˚ 45′E.

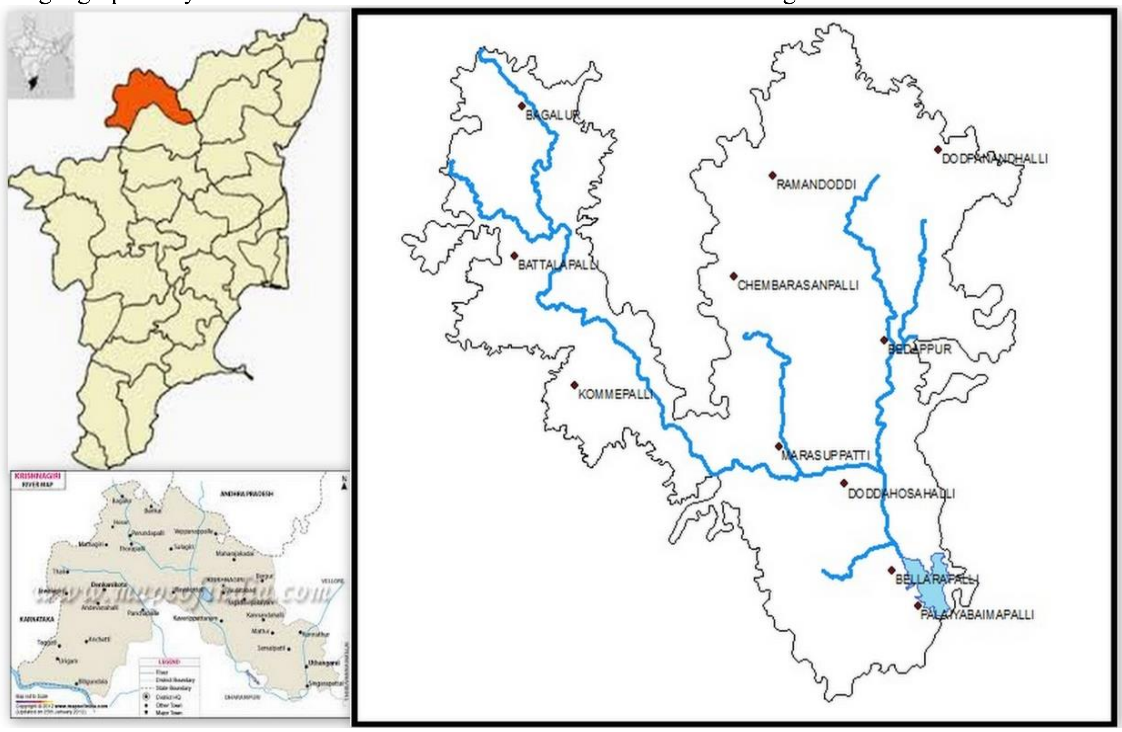

Fig. 2: Location map of study area

The climate of study area is comparatively more pleasant. The climate becomes cool in December and continues to be the same till February. The study area receives the rain under the influence of both South-West and North-East monsoons. Elevation varies from 550m to 900m approximately. The yearly average rainfall received ~850 mm in the basin. Geologically, the area broadly consists of Charnockite and Gneissic rock. The important soil types present in the area can be broadly categorized into black red loamy and sandy soil.

III. Materials and methods

The drainage basin of the study area extends from Sokkarasanapalli to Palaiyabaiyamballi Lake in Krishnagiri district in Tamilnadu. The topographical information of the study area were extracted from Survey of India (SOI) Topographical maps (57H/13, 57H/14, 57L/1, 57L/2, 57L/3) of 1:50,000 scale. The main stream and drainage lines were digitized along the basin area using GIS tools. Totally six sub basins were delineated namely (Chinnar basin-A, Chinnar basin-B1, Chinnar basin-B2, Ponnaiyar basin, Marakandanadhi basin and Veppanapalli basin) by overlaying the drainage map and study area boundary. ASTER DEM was utilized for generating elevation contours (20 m interval). These elevation details have been transferred to GIS platform and were converted to vector format to enable further analysis. The maximum, minimum and mean elevations of each basin extracted. The attribute feature classes containing elevation values, sub basins area and area enclosed between contours were used to plot the hypsometric curve of the sub-watersheds from which the hypsometric integrals were calculated.

IV. Plotting Hypsometric Curve

The Hypsometric Curve of the study area was prepared using Strahler's Percentage Method (1952), from which the ratios a/A and h/H were plotted. The digital contour map was used to generate the data required for relative area and elevation analysis. Hypsometric curve is obtained by plotting the relative area (a/A) along the abscissa and relative elevation (h/H) along the ordinate.

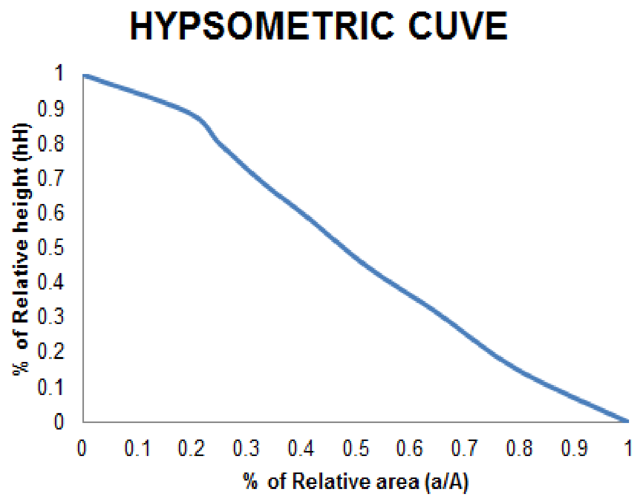

Fig. 3: Hypsometric curve

A-Sum of the area between each pair of adjacent contour lines.
A-The surface area within the basin above the given line of elevation (h).

V. Hypsometric Integral (HI)

Hypsometric integral, a dimensionless parameter, was proposed by Strahler in 1952. Hypsometric analysis has been used to differentiate between erosional landforms at different stages during their evolution. The hypsometric integral (HI) is the area beneath the hypsometric curve which relates the percentage of total relief to its cumulative percentage. This provides a measure of the distribution of landmass volume remaining beneath or above a reference plane. HI thus helps in explaining the erosion that had taken place in the watershed during the geological time period due to hydrological processes and land degradation factors. The advantage of hypsometric integral is that we can calculate and compare different basins of different regions irrespective of scale.

Integration of the hypsometric curve gives the hypsometric integral. Pike and Wilson (1971) mathematically defined the elevation-relief ratio E as

$$E \approx HI = \frac{\text{Elev (mean)} - \text{Elev (min)}}{\text{Elev (max)} - \text{Elev (min)}}$$

Where,
E is the elevation-relief ratio equivalent to the hypsometric integral HI;
Elev (mean) is the weighted mean elevation of the basin estimated from the identifiable contours of the delineated basin;
Elev (min) and Elev (max) are the minimum and maximum elevations within the basin.

The hypsometric curves and HI values give valuable information about the geological stages of the development of a river basin. According to Strahler (1952) and Kusre (2013), it can be categorised as

1) $HI \geq 0.6$ = the basin is at in-equilibrium (youthful) stage.
2) $0.35 \leq HI < 0.6$ = the basin is at equilibrium (mature) stage.
3) $HI < 0.35$ = the basin is at monadnock (old) stage.

In the in-equilibrium (youthful) stage, the basin is still under developed. The equilibrium stage is the mature phase of basin development, and the monadnock phase occurs, particularly when isolated bodies of resistant rock from major hills (monadnock) are found above the subdued surface. It is a rejuvenation stage controlled by structural features (Kusre, 2013).

Vivoni et al. (2008) stated that the watershed with higher HI values indicated higher soil moisture, whereas watersheds with lower HI values were characterized by soil moisture being concentrated at the shallow depth. Whereas, watershed with higher HI values shows subsurface runoff is major process contributing the total runoff.

VI. Results and discussion

The entire drainage network and sub basins of the river have been digitized from SOI topographic map are presented in fig 4 and 5. Slope map for the entire study area basin have been generated from ASTER DEM in Arc GIS and contours of 20m interval were extracted. The ASTER DEM data was further processed in Arc GIS to generate Triangulated irregular network (TIN) representing the terrain topology as presented in Fig 7.

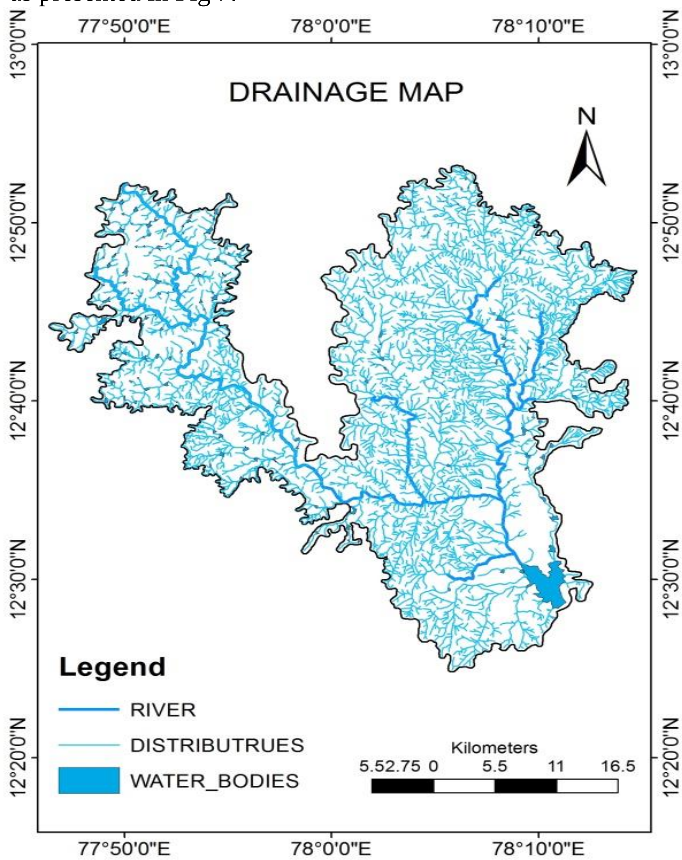

Fig. 4: Drainage network for study area

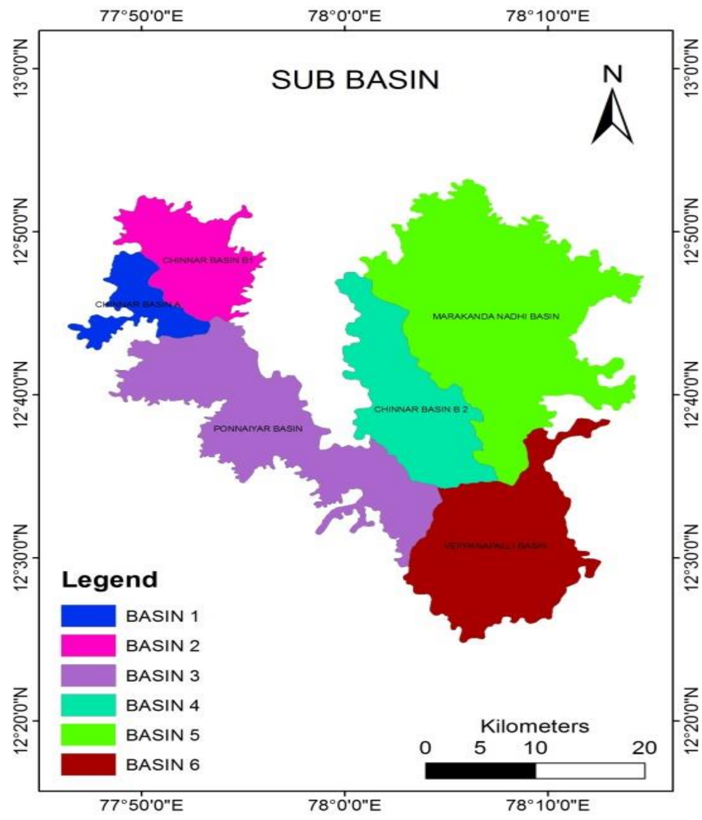

Fig. 5: Sub basins for study area

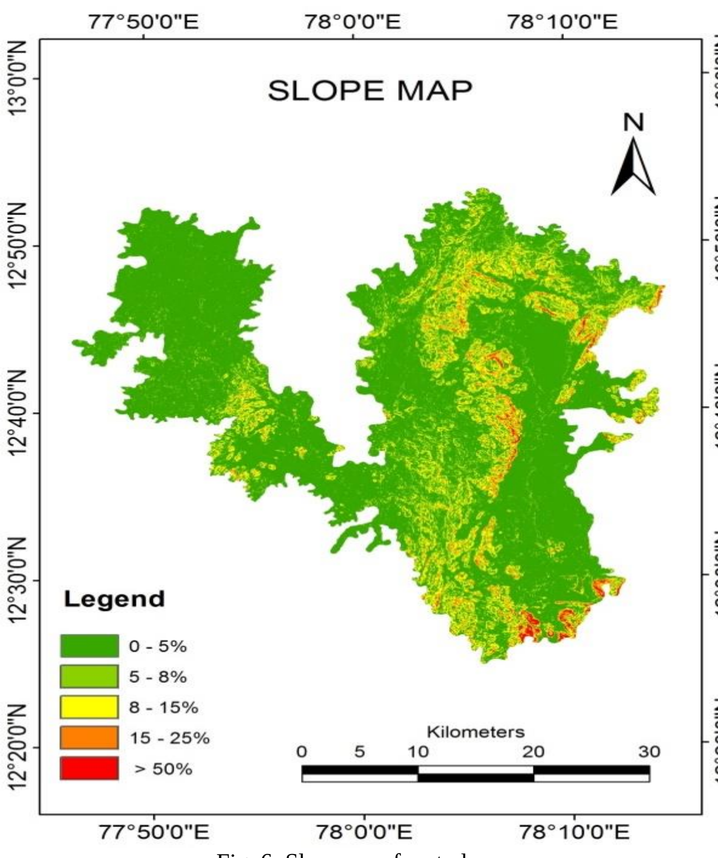

Fig. 6: Slope map for study area

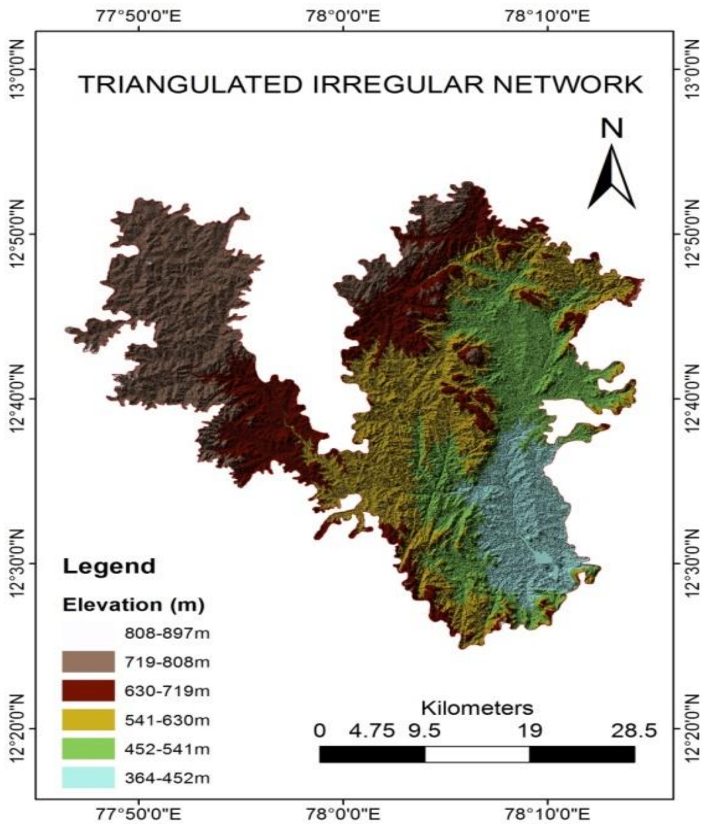

Fig. 7: Triangulated irregular network for study area

A. Hypsometric integral value

The hypsometric integral (Hi) values obtained for the 6 sub basins based on Elevation relief ratio method are presented in table. The hypsometric integral values range between 0.45 to 0.56. The values indicate that all the six sub basins are under mature stage. However the values of 0.55 and 0.56 obtained for Veppanapalli basin and Marakandanadhi basin are close to the lower limit of the youthful stage value range.

Table - 1
Sub Basin wise Hypsometric Integral values for the study area

Basin name	*Basin area (Km^2)*	*Maximum Elevation (m)*	*Minimum Elevation (m)*	*Mean Elevation (m)*	*Hypsometric integral value*
Chinnar basin-A	*43.2*	*830*	*640*	*725.5*	*0.45*
Chinnar basin-B1	*89.23*	*800*	*640*	*723.34*	*0.52*
Chinnar basin-B2	*133.05*	*720*	*530*	*622.78*	*0.49*
Ponnaiyar	*212.57*	*760*	*560*	*653*	*0.46*
Marakandhanadhi	*346.08*	*740*	*480*	*627.66*	*0.56*
Veppanapalli	*189.18*	*680*	*360*	*536.43*	*0.55*

B. Hypsometric curve shape

By plotting percentage of relative height against percentage of relative area hypsometric graphs are obtained. The hypsometric curve originates in in the upper left-hand corner (x = 0, y = 1) and reach the lower right hand corner (x = 1, y = 0). The hypsometric curves plotted for the six sub basins of the study area are presented in figure. Based on the shapes of these curves the above basins are grouped under two category. The two basins Chinnar basin- B2 and Veppanapalli basin are considered that they are in the early stage of maturity. The remaining four sub basins are in the mature stage of development. From the curves it is clear that the above four basins gradual unloading of sediments is taking place.

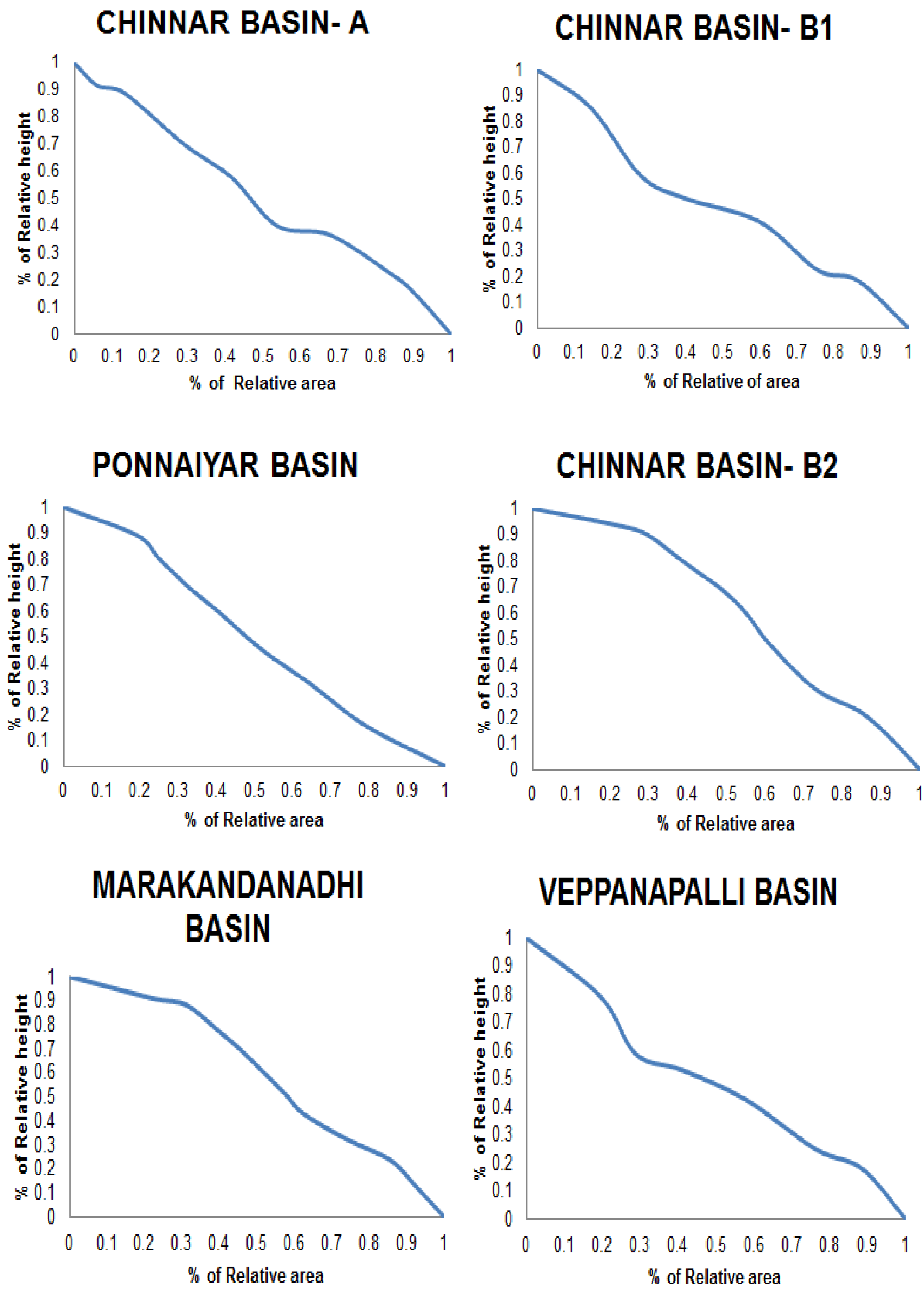

Fig. 7: Hypsometric curves for six sub basins

VII. Conclusion

Hypsometric study quantifies the geologic stages of development and erosional proneness of a river basin. Therefore, it is useful to comprehend the erosion status of drainage basins and prioritize them for undertaking soil and water conservation measures if necessary. But, great care must be exercised in interpreting and comparing hypsometric curves due to its complex nature of computation. It was observed from the hypsometric curves and integral value of these sub basins that the drainage system has transformed into mature stage as compared with Strahler's (1952) classification of various drainage basins. The hypsometric curve of study area basins suggests that a larger part of the area is moderate to gently sloping. The curve can be characterized as mature/ equilibrium stage of landscape development. Among the six sub basins Marakandanadhi basin shows a high hypsometric integral value (0.56). Hence these values show that the study area is passing through mature stage of development. The hydrologic response of the sub basins attaining the mature stages will have slow rate of erosion unless there is very high rainfall leading to high runoff.

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