

# Hypsometry and Geomorphic Development of a Watershed: A Case Study from South India

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**Abstract:** *Hypsometric analysis is useful for understanding the stages of geomorphic development of a river basin. Hypsometric integral quantifies the geologic stages of development and erosional proneness of the watershed. In this study, efforts were made to estimate the hypsometric integral values of the Chalakudy river basin located in Kerala state of south India. River basin was delineated into five sub watersheds and hypsometric analysis was carried out for all of them by using the 30 m ASTER DEM. Elevation, relief ratio method was also used for calculation of hypsometric integral values. The hypsometric integral values of all the sub watersheds of Chalakudy watershed ranges between 44 to 62 %. In the study area, two stages of erosional cycle development namely youthful to mature stage are identified. The development of stream segment is effected by slope and local relief. These factors produce differences in values of drainage density among the sub basins. The morphometric parameters such as drainage density and constant channel maintenance were also computed and relative extent of erosion in different subbasins is estimated. The values of geomorphic aspects were in agreement with hypsometric integral values. An attempt is also made to examine the effect of lithological characteristics on the denudation process in different subbasins. The estimation of erosion status of sub basins helps in the water shed prioritization for taking up soil and water conservation measures in watershed systems.*

**Keywords:** GIS, Hypsometry, Drainage Density, Constant Channel Maintenance, Lithology

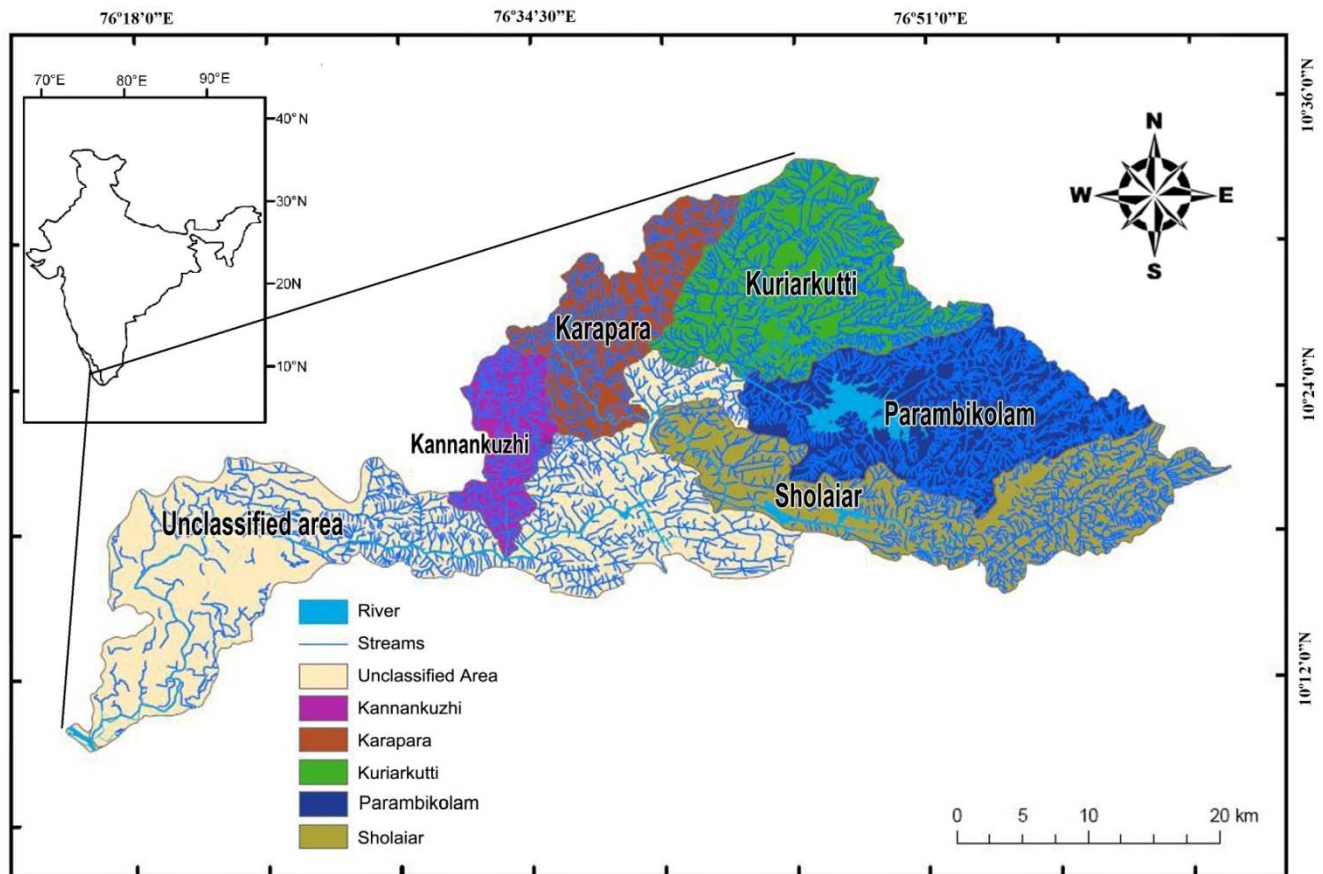
## 1. Introduction

Land degradation and topological changes within the watershed are accomplished by weathering process, stream erosion pattern and sediment transportation by surface run off. Hypsometric analysis aims at developing a relationship between horizontal cross section area of watershed and its elevation in a dimensionless form that permits comparison of watersheds irrespective of scale issues [2], [10]. Naturally hypsometric analysis has been used to differentiate between erosional landforms at different stages during their evolution [12], [11]. According to [12] a convex shape hypsometric curve is characteristic of youth stage of watersheds. On the other hand S-shaped curve ie, concave upwards at higher elevation and concave downwards at lower elevations characterises mature watersheds, where as concave hypsometric curve characterises old or peneplain watersheds. The Hypsometric integral (HI) is an indication of cycle of erosion [12], [3]. The cycle of erosion is the total time required for reduction of land area to the base level. The entire period can be divided into three stages namely monadnock (old) (HI less than 30%), in which the water shed is fully stabilised; equilibrium or mature stage (HI 30 to 60 %); and inequilibrium and young stage (HI greater than 60 %) in which the water shed is highly susceptible to erosion. Hypsometric integrals and hypsometric curve are the important indicators of watershed conditions [8], [5]. Differences of the shape of the curve and hypsometric integral values are related to the degree of disequilibria in

the balance of erosive and tectonic forces [16]. Basin characters such as drainage density (Dd), constant channel maintenance (C) are also good indicators of erosion status. Low drainage density generally results in the areas of the highly resistant or permeable strata under dense vegetation and low relief [14]. High drainage density is the result of weak or impermeable subsurface material, sparse vegetation and mountaneous relief. Generally, the higher the constant of channel maintenance of the basin, the greater permeability of rocks of that basin [7]. Relatively higher C value indicating more resistance to erosion [9]. Influence of the lithology over the erosion proneness of the area was established by [15].

## 2. Description of the Study Area

The Chalakudy river is one among the 41 rivers flowing from Kerala Western Ghats to Arabian Sea on the western part of India. The Chalakudy River Basin (CRB) lies between 10 05' to 10 35' North Latitude and 76 15' to 76 55' East Longitude. The 130 km long Chalakudy River, the 5<sup>th</sup> largest river in Kerala drains the runoff from a 1448.73 km<sup>2</sup> catchment area (figure 1). It originates at an altitude of 1250 m in Western Ghats. The CRB is composed of well developed drainage network ranging from first to seventh order stream. The CRB has been delineated into 5 sub basins, Kuriarkutti, Parambikolam, Sholaiar, Karapara and Kannankuzhi.



**Figure 1:** Chalakudy River Basin and sub watersheds

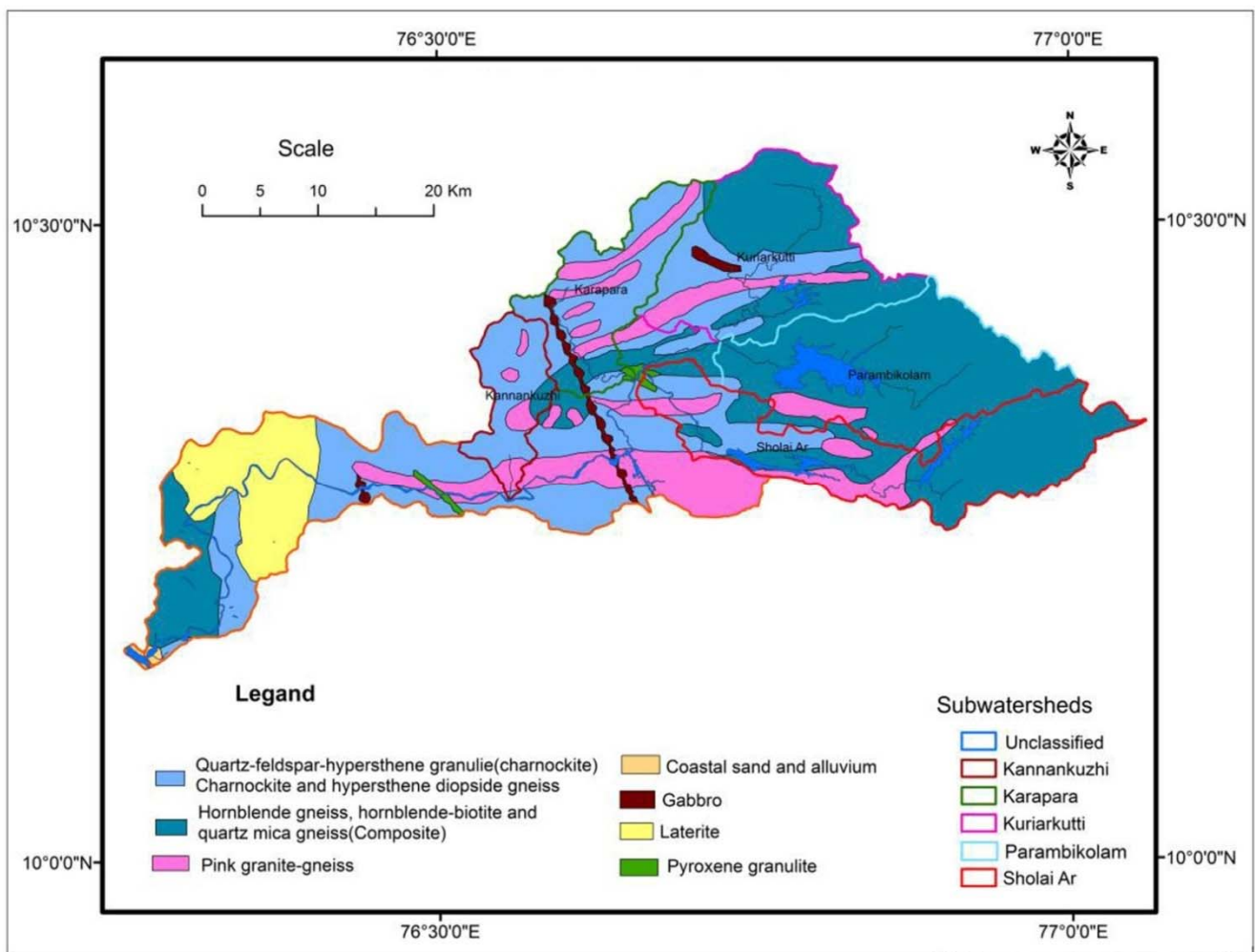
### 3. Lithology of the Chalakudy River Basin

Three main spatial lithological variations are evident in the study area. The entire basin mainly consists of Charnockite, Hornblende gneiss and Pink granite. We computed area of

main lithology ie, lithology that appears most often in each subbasin and calculated its areal extent in percentage (table 1 and figure 2). Karapara sub basin is relatively dominant in Charnockite. However, in other sub basins hornblende gneiss and pink granite dominate over Charnockite.

**Table 1:** Areal extent (percentage) of litho units in each subbasin.

Sub basins	Charnockite	Hornblende gneiss	Pink granite	Gabbro	Pyroxene granulite	Coastal and sand alluvium
Kuriarkutti	26.64	62.70	9.44	1.22	0.00	0.00
Parambikolam	1.78	91.58	6.64	0.00	0.00	0.00
Sholaiar	16.20	68.10	15.11	0.00	0.59	0.00
Karapara	62.88	9.76	22.95	4.41	0.00	0.00
Kannankuzhi	0.00	77.21	7.05	0.00	0.00	15.74



**Figure 2:** Lithological map of Chalakudy River Basin

#### 4. Methodology

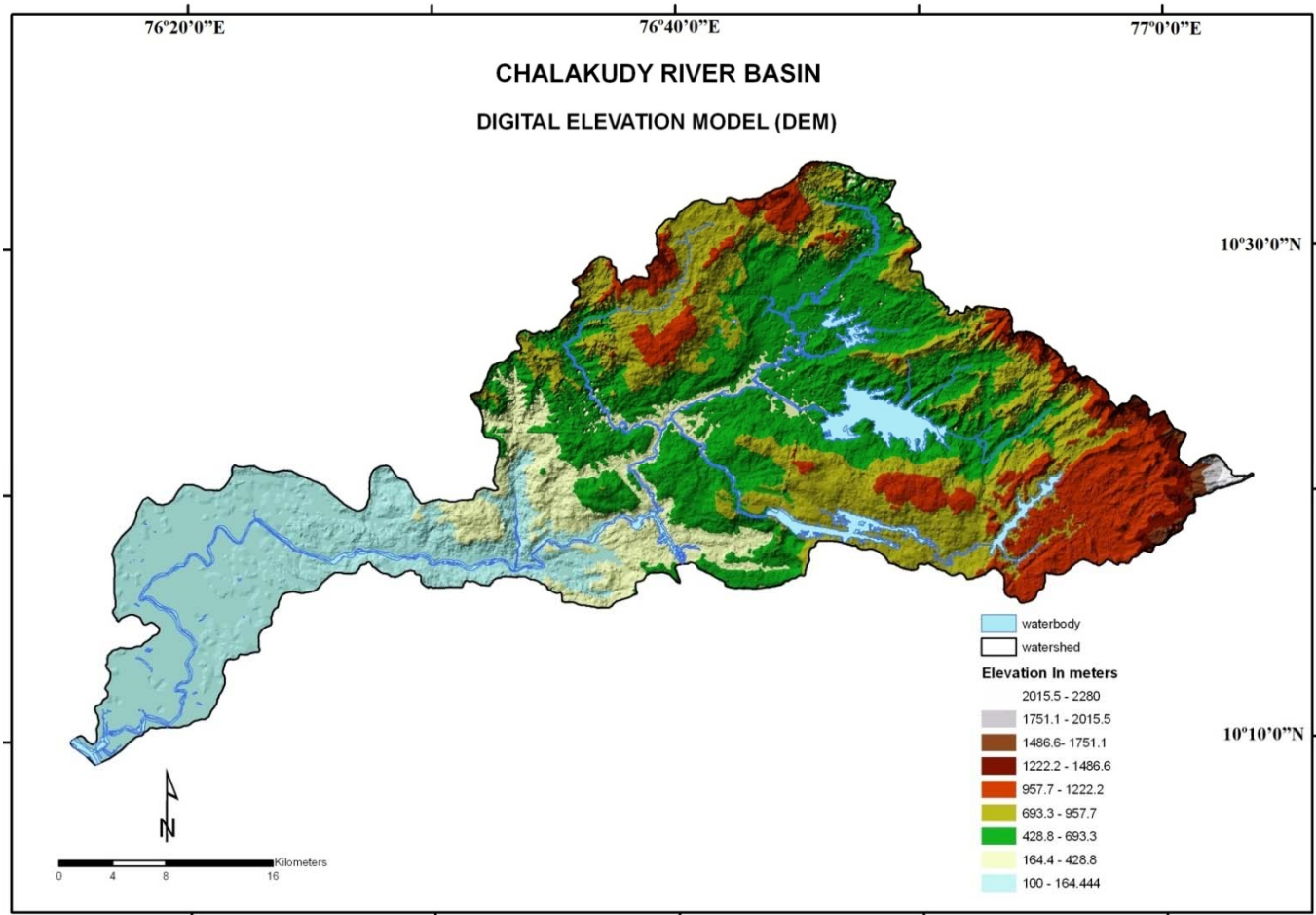
The topological information of the study area was geo referenced and digitized from Survey of India toposheets using Arc GIS 9.3 Software. The drainage lines were digitized and stream ordering was done in accordance with [13]. The CRB has been delineated into 5 subbasins (Kuriarkutti, Parambikolam, Sholaiar, Karapara and Kannankuzhi) and their boundaries were digitized using Arc GIS tools (figure 1). The contours were digitized to generate the line feature class in Arc GIS which was further processed using spatial analyst module to generate the digital elevation model (DEM) representing the watershed terrain topology (figure 3).

Hypsometric analysis was carried out for all the sub basins using 30 m ASTER DEM. Hypsometric curve is obtained by plotting the relative area along the abscissa and relative elevation along the ordinate. The relative area is obtained as a ratio of the area above a particular contour to the total area of the sub watershed encompassing the outlet. The relative elevation is calculated as the ratio of the height of a given contour from the base plane to the maximum basin elevation

[8]. The hypsometric integral is obtained from the hypsometric curve and is equivalent to the ratio of the area under the curve to the area of the entire square formed by covering it. It is expressed in percentage units and it is obtained from percentage hypsometric curve by measuring the area under the curve [6].

Hypsometric analysis is an important tool to assess and compare the geomorphic evolution of various landforms irrespective of the factor that may be responsible for it. The major factors governing the evolution of landscape are tectonics and/or climate and the variation in lithology. The hypsometric curve is related to the volume of the rock in the basin and the amount of erosion that has occurred in a basin compared to what still remains [4]. The hypsometric integral helps to define the erosion that has taken place over geological time. For different basins under the same climatic condition and approximately equal areas, the shape of the hypsometric curves provide relative insights into the past erosional environment of the basins [1]. The hypsometric integral (HI) can be calculated from the area under the curve, and it expresses, in percentage, the volume of the original basin that remains unweathered.





**Figure 3:** Digital Elevation Model of Chalakudy River Basin

Hypsometric curves are usually interpreted as youthful (convex upward curves), mature (S shaped curves) and peneplain or old age (concave upwards curves) stages of landscape evolution. Convex hypsometric curves are more likely typical of a plateau with little erosion, which can evolve into an S shape, while concave hypsometric curves indicate greater erosion [4]. The hypsometric curve represents the relative proportions of a watershed area that lies below a given height. For each basin, the range of basin was divided into equal intervals and for each interval the basin area proportion was calculated. For all the five sub basins of CRB, hypsometric curve have been prepared and hypsometric integral are calculated. The shape of hypsometric curves represents different stages of land degradation.

Quantitative analysis of basin characteristics such as drainage density (Dd), constant channel maintenance (C) have been computed from linear, areal and relief morphometric parameters using the established mathematical equations. According to [11] constant channel maintenance is inverse of drainage density. The constant C tells the number of km<sup>2</sup> of watershed surface that is required to maintain one linear km of stream channel. Generally, the

higher the constant C of a basin, the greater the permeability of rocks of that basin.

## 5. Results and discussions

The coordinates of the hypometric curve of five subbasins of CRB obtained were plotted and presented in the Figure 3. It is evident from the hypsometric curves of CRB and its basins that the drainage system is attaining mature stage from the youth stage. The comparison between the curves of sub basins, Karapara subbasin is interpreted as youthful as the curve is convex upward (figure 4). All the other curves evolve into an S shaped indicating matured stage.

The HI value can be an indirect estimator of the erosion from the watershed system. The HI value for the entire Chalakudy River Basin is 48.24 %. The HI values of the sub basins were ranged from 43.77% (Kannankuzhi) to 61.60 % (Karapara). It is indicated that 43.77 % and 61.60 % of the original rock mass still exist in the respective basins. The HI value of the different sub basins are presented in Table 2. It was observed from the HI values that all the sub basins except Karapara falls under mature stage. The values suggests that Karapara basin is relatively youthful compared to other basins.

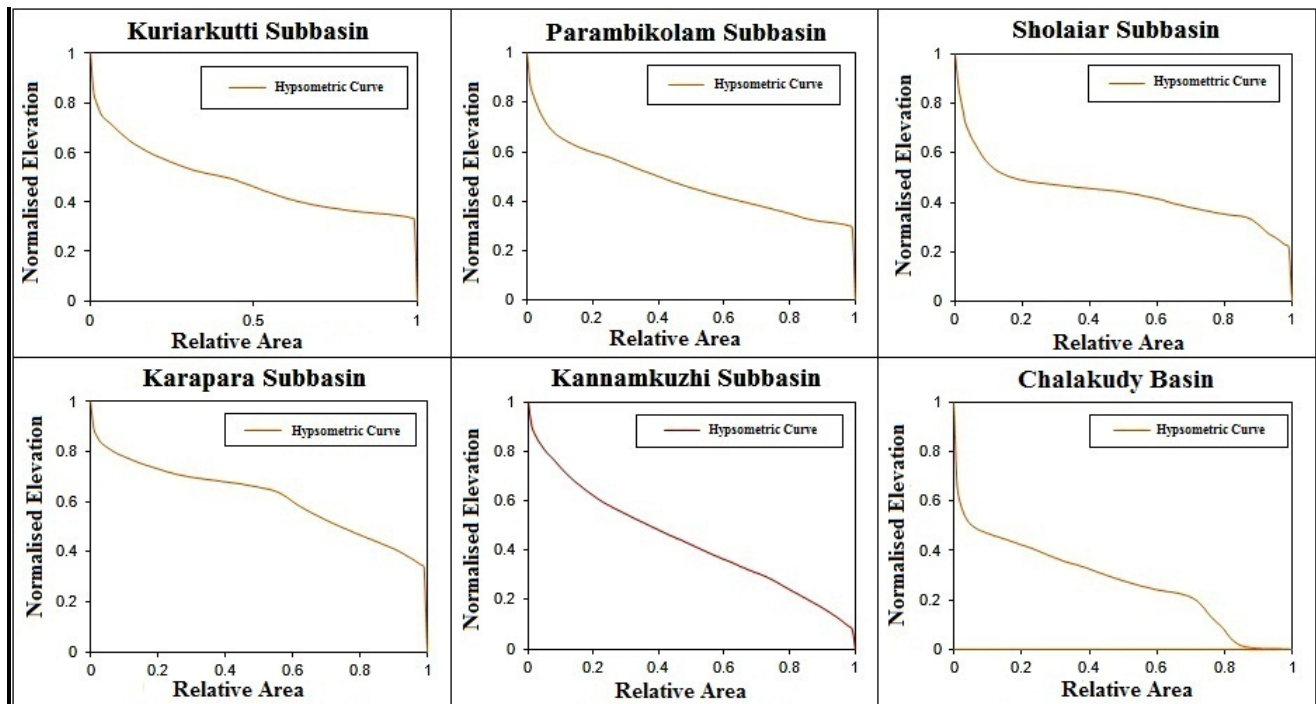


Figure 4: Hypsometric Curves of CRB and different subbasins

Comparing HI value and lithological characteristics of each sub basins (Table 1 and 2) it is revealed that the Karapara sub basin with greater extent of charnockite is more resistant to erosion with respect to other sub basins which are dominated by Pink granite and Hornblende Gneiss. It is understood from the analysis that other four sub basins have already attained mature stage. This indicate that lithology have played a very important role in the erosional cycle of the Chalakudy River Basin.

Table 2: Estimated basin parameters and hypsometric integral values of sub basins of CRB

S No	Sub basin Name	Constant Channel Maintenance (C)	Drainage Density (Dd)	HI (%)	Erosional stage
1	Kuriarkutti	0.39	2.54	48.24	Mature
2	Parambikolam	0.35	2.88	47.96	Mature
3	Sholaiar	0.39	2.56	43.88	Mature
4	Karapara	0.44	2.28	61.60	Youthful
5	Kannankuzhi	0.37	2.69	43.77	Mature
6	CRB	0.40	2.51	48.24	Mature

The basin characteristics such as Dd and C for the entire basin and each sub basin is calculated and presented in table 2. The drainage density (Dd) expresses closeness of the spacing of the streams and indirectly reflects the structural framework of underlying rocks of the watershed. According to [14] a low Dd is favoured in regions of highly resistant or highly permeable strata under dense vegetation and low relief. The Dd for the entire basin is 2.51 and for the sub basins it ranges from 2.28 (Karapara) to 2.88 (Parambikolam). From the tabulated data it was observed that Karapara subbasin has the lowest drainage density among the sub basins of CRB. This observation is inconformity with the underlying lithology.

Constant channel maintenance (C) is the number of square kilometer watershed surface that required to maintain one linear kilometer of stream channel. Constant channel

maintenance for the entire basin is 0.40 and among the sub basins it ranged from 0.37 (Kannankuzhi) to 0.44 (Karapara). High value of C reveals the low magnitude of erodability of surface topography due to hard geological structure and thick forest cover. This revealed that Karapara sub basin is underlied by lithological units which are more resistant to erosion.

These basin characteristics and HI value would have maintained the youthful characteristic of Karapara sub basin. Moreover, hypsometric integral based assessment on the erosion status was validated using the basin characteristics. It is evident that presently the Karapara sub basin is more prone to erosion and contribute significantly in the sediment yield.

The information of erosion status based on the HI values as discussed above can be used for watershed prioritization. The results of the study reveals that all the sub basins except Karapara subbasin are in mature stage and current erosion rate is low. However the Karapara sub basin which is in the youthful stage is more prone to erosion, which necessitate conservation of soil and water. Artificial recharge structures at appropriate location in the sub basin is required to arrest the sediment outflow and increasing ground water potential. However other sub basins needs minimum mechanical and vegetative measure to arrest sediment loss but may require more water harvesting type structures to conserve water at appropriate location in the watershed for its conjunctive water use.

## 6. Conclusion

Hypsometric analysis of the river basin expresses the degree of denudation and rate of morphological changes therefore it is useful to comprehend the erosion status of a river basin and prioritize them for undertaking soil and water conservation measures. The study of hypsometric properties

of drainage basin using hypsometric integral and hypsometric curve has been retrieved in that the HI values of sub basins ranges from 43.77 to 61.60 %. Among the five sub basins, four sub basins are in mature stage. Karapara sub basin is still in youthful stage and is highly prone to erosion and sediment yield. The underlying lithology of Karapara basin is dominantly Charnockite and it might have resisted degradation compared to other sub basins which are in mature stage. The geoprocessing techniques employed in this study will assist the planners and administrators in watershed development and natural resource management. The watershed development for each river basins in the State is to be carried out for sustainable management of natural resources especially soil, water and forest cover under extreme drought and salinity condition in the downstream side of the rivers. The study shows that a river authority must be constituted in the state to assess and to take up necessary remedial measures to maintain the health of the river basins.

## 7. Acknowledgement

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