Hypsometric Analysis of the Morna River basin, Akola District, Maharashtra, India

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Abstract: :The ground water salinity forms a crucial problem in the Akola district which needs a proper integrated study and management to cater the drinking water and agricultural needs. Hypsometric analysis is the relationship of horizontal cross-sectional drainage basin area to elevation. The hypsometric curve has been termed as the drainage basin relief graph. Hypsometric curves and hypsometric integrals are important indicators of watershed conditions Differences in the shape of the curve and hypsometric integral values are related to the degree of disequilibria in the balance of erosive and tectonic forces. In this study it is being used to express the overall slope and the forms of drainage basin. The hypsometric curve is related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass. Comparisons of the shape of the hypsometric curve for different drainage basins under similar hydrologic conditions provides a relative insight into the past soil movement of basins. Thus, the shape of the hypsometric curves explains the temporal changes in the slope of the original basin. Hypsometric curves and hypsometric integral is important watershed health indicator. Hypsometric analysis using GIS has been used in this study to understand the erosional topography. Further, there is lack of hypsometric based studies to watershed health, which is attributable to the tedious nature of data acquisition and analysis involved in estimation of hypsometric analysis. Employing Geographical Information System (GIS) techniques in hypsometric analysis of digitized contour maps helps in improving the accuracy of results and save time. Hypsometric analysis of watershed expresses the complexity of denudetional processes and the rate of morphological changes. Therefore, it is useful to comprehend the erosion status of watersheds and prioritize them for undertaking soil and water conservation measures. But, great care must be exercised in interpreting and comparing hypsometric curves which is more prone to erosion in comparison to other sub-watersheds which would necessitate construction of soil and water conservation structures at appropriate locations of sub-watersheds to arrest sediment outflow andconserve water. The hypsometric integral values less than 0.5 (i.e. monadnock stage) needs minimum mechanical and relative measures to arrest sediment loss but may require more water harvesting type structures to conserve water at appropriate locations in the watershed for conjunctive use of water.

Hypsometric analysis is carried out in the Morna River basin to ascertain the susceptibility of watershed to erosion and prioritize them for treatment. The slope of the hypsometric curve changes with the stage of watershed development, which controls the erosion characteristics of watershed and it, is indicative of cycle of erosion. The hypsometric integral (Hsi) is found to be an indication of the cycle of erosion in the study area The cycle of erosion is the total time required for reduction of land area to the base level i.e. lowest level. This entire period or the cycle of erosion can be divided into the three stages viz. monadnock (old) (Hsi 0.3), in which the watershed is fully stabilized; equilibrium or mature stage (Hsi 0.3 to 0.6); and in equilibrium or young stage (Hsi> 0.6), in which the watershed is highly susceptible to erosion. Land use and land pattern maps, SRTM, 3D model maps have been prepare by using GIS techniques to understand hydro geomorphological nature of the basin.

***KeyWords**: Hypsometric curves, watershed health, drainage basin, cycle of erosion, GIS*

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I. INTRODUCTION

The hypsometric analysis can be used as a morphometric parameter, i.e. hypsometric integral, to deduce its relationship with the area of watersheds. Statistical analysis of these parameters has been carried out by classifying them into different classes based on the natural breaks method. This brings out strong relationships for hypsometric integral classes and area classes with the number of watersheds in respective classes and the total area occupied by respective hypsometric and area classes. It has also been found that stronger relationships exist for watersheds The anomalous watershed has been directly attributed to the difference in geologic structure The results are inspiring and very promising as they indicate some statistically strong relationships among the hypsometric integral and area of watersheds that are not apparent in the Hypsometric analysis is the relationship of horizontal cross-sectional drainage basin area to elevation. The hypsometric curve has been termed the drainage basin relief graph. Hypsometric curves and hypsometric integrals are important indicators of watershed conditions, Ritter, (2002). Differences in the shape of the curve and hypsometric integral values are related to the degree of disequilibria in the balance of erosive and tectonic forces Weissel, (1994).

Hypsometric analysis was first time introduced by Langbein, (1947) to express the overall slope and the forms of drainage basin. The hypsometric curve is related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass Hurtrez, (1999). It is a continuous function of non-dimensional distribution of relative basin elevations with the relative area of the drainage basin Strahler, (1952). This surface elevation has been extensively used for topographic comparisons because of its revelation of three-dimensional information through two-dimensional approach Harrison, (1983); Rosenblatt and Pinet, (1994). Comparisons of the shape of the hypsometric curve for different drainage basins under similar hydrologic conditions provides a relative insight into the past soil movement of basins. Thus, the shape of the hypsometric curves explains the temporal changes in the slope of the original basin. Strahler, (1952) interpreted the shape of the hypsometric curves by analysing numerous basins and classified the basins as young (convex upward curves), mature (S-shaped hypsometric curves which is concave upwards at high elevations and convex downward at low elevations) and peneplain or distorted (concave upward curves). 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. Hypsometric analysis is carried out to ascertain the susceptibility of watershed to erosion and prioritize them for treatment. The slope of the hypsometric curve changes with the stage of watershed development, which has a greater bearing on the erosion characteristics of watershed and it, is indicative of cycle of erosion. The hypsometric integral (Hsi) is also an indication of the 'cycle of erosion' Strahler, (1952); Garg, (1983). The cycle of erosion is the total time required for reduction of land area to the base level i.e. lowest level. This entire period or the cycle of erosion can be divided into the three stages viz. monadnock (old) (Hsi 0.3), in which the watershed is fully stabilized; equilibrium or mature stage (Hsi 0.3 to 0.6); and in equilibrium or young stage (Hsi> 0.6), in which the watershed is highly susceptible to erosion Strahler, (1952).Hypsometric curves and hypsometric integral is important watershed health indicator. Hypsometric analysis using GIS has been used by several researchers in India dealing with erosional topography Pandey, (2004); Singh, (2008). Further, there is lack of hypsometric based studies to watershed health, which is attributable to the tedious nature of data acquisition and analysis is involved in estimation of hypsometric analysis. Employing Geographical Information System (GIS) techniques in hypsometric analysis of digitized contour maps helps in improving the accuracy of results and save time. Considering the above facts, this study was undertaken to determine geological stage of development of sub-watersheds of Morna river basin Akola district Maharashtra.

II. STUDY AREA

The Morna River basin which is a tributary of Purna River lies towards the northern and southern part of Akola district, and parts of Washim district, forming near about 190 to 200 meters thick lava flows covering an area of 941.39 sq. km. and lies between 76°45’38” to 77° 5’ 26” E longitude and 20° 25’ 7” to 20° 29’ 34” N Latitude and Survey of India Toposheet No. 55H/1,H/2, H/15, D/3, and 55D/15(Fig 1).

III. HYDRO-GEOMORPHOLOGICAL ANALYSIS

Physiographically, the study area can be broadly divided into low lying plain towards the banks of the Morna River in the northeast and horizontal Deccan Trap flows with multiple scarps and abrupt cliffs towards the southern parts. The study area consists of various erosional surfaces in step-like terraces. The horizontal dispositions of the lava flows with a fair degree of uniformity in lithology have considerably simplified the changes brought by the secondary processes like weathering and denudation. Differential weathering forces has resulted in wiping out of thick.

IV. WATERSHED DELINEATION AND GENERATION OF DEM

Base map of the study area was prepared using Survey of India (SOI) toposheets 55H/1, H/2, H/15, D/3, and 55D/15. The topographical information of the watershed in 1:50000 scale with contour interval 25m acquired from SOI toposheets were digitized using capability of Arc-lnfo and Arc-GIS tools. Subsequently drainage network was also digitized. Then the watershed boundary and sub-watersheds boundaries were delineated (Fig. 2). The contours were generating the line feature class in Arc-GIS, and then it was polygonized to determine the area enclosed by each contour.

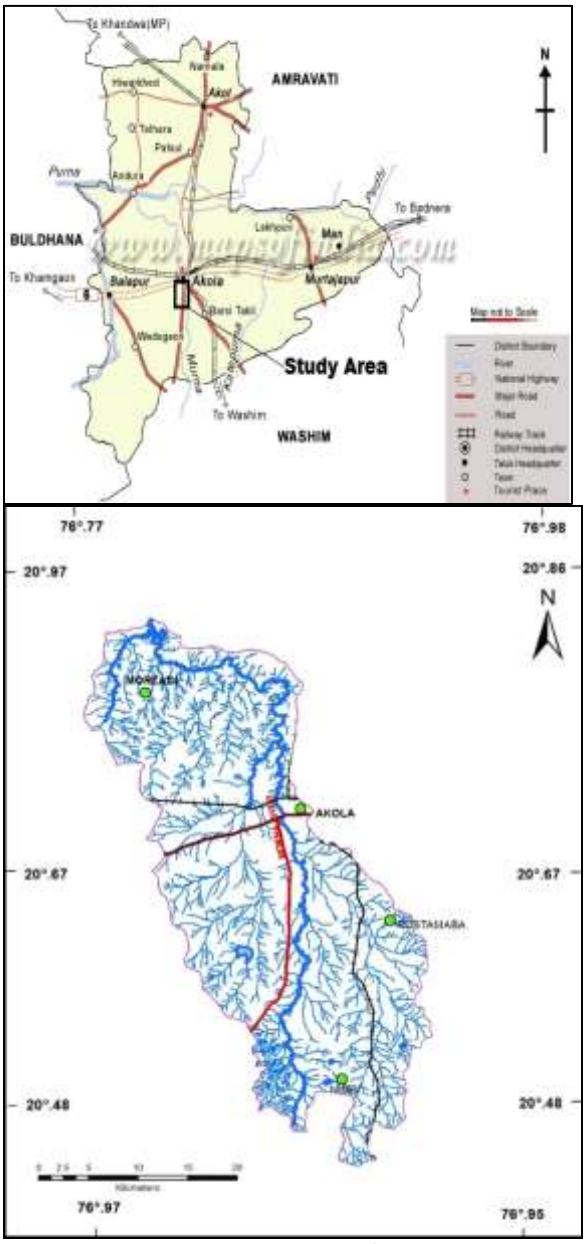

Figure 1. Location map of the study area

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IV. PLOTTING OF HYPSOMETRIC CURVES (HC)

Hypsometric curve was 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 watershed encompassing the outlet. 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) (up to the most remote point of the watershed from the outlet) Sarangi, (2001); Reitter , (2002). This provides a measure of the distribution of landmass volume remaining beneath or above a basal reference plane.

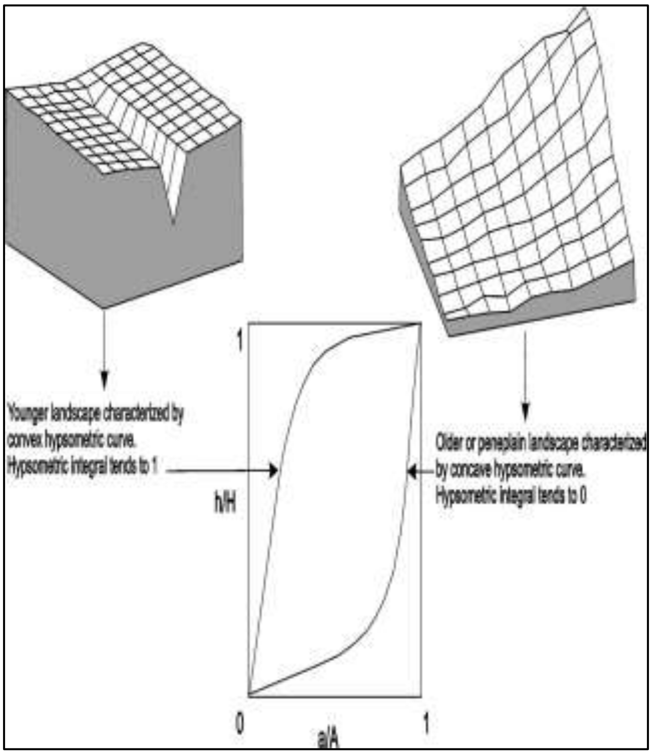

Figure 2.Hypothetical diagram showing how watershed morphology is related to hypsometriccurve and hypsometric integral. 'a' is the area of the watershed above a particular elevation 'h', 'A' is the total area and 'H' is the maximum elevation of the watershed (Source: Tejpal Singh,2008)

V. ESTIMATION OF HYPSOMETRIC INTEGRALS (HSI)

The hypsometric integral (Hsi) was estimated using the elevation relief -ratio method as proposed by Pike and Wilson (1971). The relationship is expressed as

$$E \approx His = \frac{\text{ELEVATION (mean.)} - \text{ELEVATION (min.)}}{\text{ELEVATION (max.)} - \text{ELEVATION (min.)}}$$

Where, E is the elevation-relief ratio equivalent to the hypsometric integral Hsi ; Elevation mean is the weighted mean elevation of the watershed estimated from the identifiable contours of the delineated watershed ; Elevation maximum and Elevation minimum are the maximum and minimum elevations within the watershed. The hypsometric integral is expressed in percentage units. However, this method was observed to be less cumbersome and faster than the other methods in practice for HsiSingh, (2008).

VI. Soil Texture analysis

Soil in the major part of the Morna basin is deep, clayey and sticky. The dominant clay minerals are Montmorillonite, Bentonite and Smectite type. The soils have good water retentivity with 36.5% to 45% surface layer and also have about 12.21% water holding capacity, Nimkar , (1992). Higher ranges of cation exchange capacity make the soil a good source and supplier of plant nutrients. The soil have poor hydraulic conductivity, high degree of shrink, swell potential leading upto 1 to 4 cm, wide cracks upto 70 cm depth and very compact and dense soil fabric having high value of bulk density (Fig. 6,7,8,9). The soils in the uplands with down gradient direction are relatively free from salinity and sodicity. The soils in the basin located along the sides of river Morna in the absence of adequate down gradient direction are subjected to salinization of soil and ground water. Surface soils are sandy loam in texture having about 65% fine sand and soil texture become gradually finer with depth. The soil layer below 1 m and upto a depth of 5.2 m are loamy in texture and below 5.2 m depth soil is silty clay(Fig. 6,7,8,9). Broadly, the soil of the area can be classified into three categories viz. Coarse shallow, found in the south at higher level. Medium black soil found in the plain and deep black soil found in the river valley.The thickness of soil is vary from place, in the northern part of the basin in Andura, Antri, Morjhadi, KaranjaRamzanpur,Morgaon area the thickness is maximum, in the central part of the basin it is minimum such as Patkhed , Mahagaon Akola, HinganaWaghjali area. From sindhkhed, Rajanda, Chincholi, Rudrayani i.e. in the southern part of the basin there shows again rise in thickness of the soil, and the slope in the area shows good layering characteristic in the northern part as compared to the southern part of the basin. The soil depth map of the area is prepared with help of Arc-GIS and different depth zones are shown, the deep soil zone is found in south eastern part of the basin, very deep soil zone lies in the most of the part of the basin while moderately deep soil zone is occurred in central-western part as well as at some places in southern part. The shallow soil zones occurs in the central and marginal or peripheral part of the basin. (Fig. 4, 5, 6).

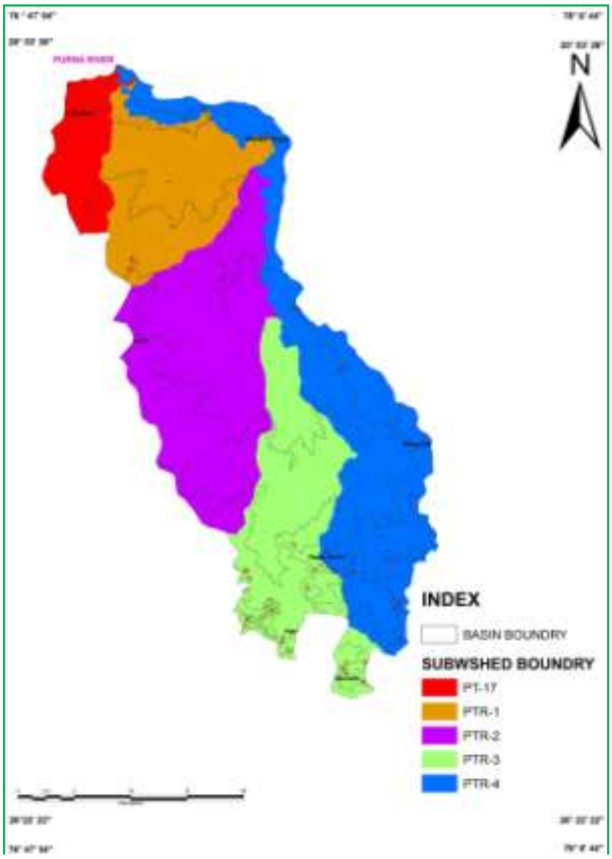

Figure 3. Sub-watershed map of Morna River basin.

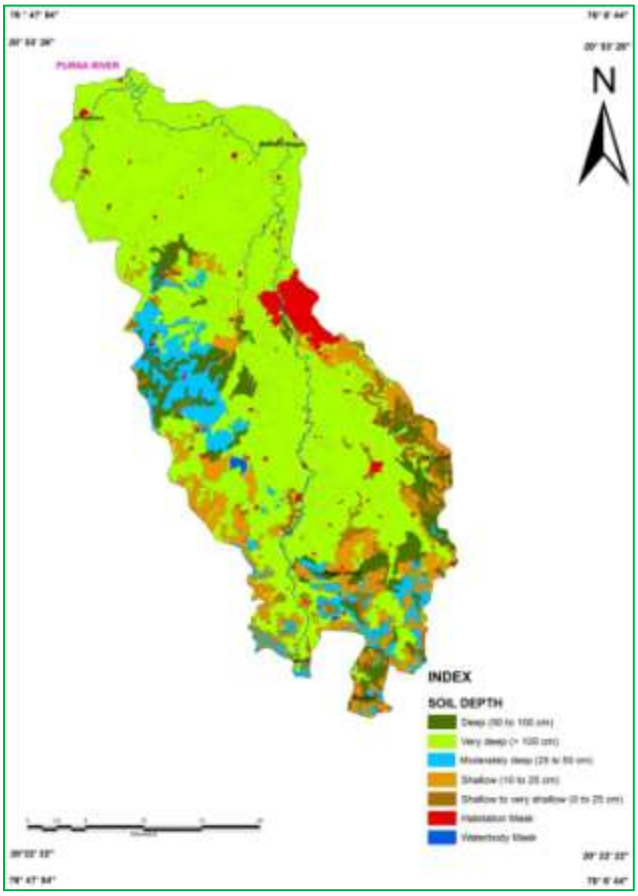

Figure 4. Soil Depth of Morna River basin.

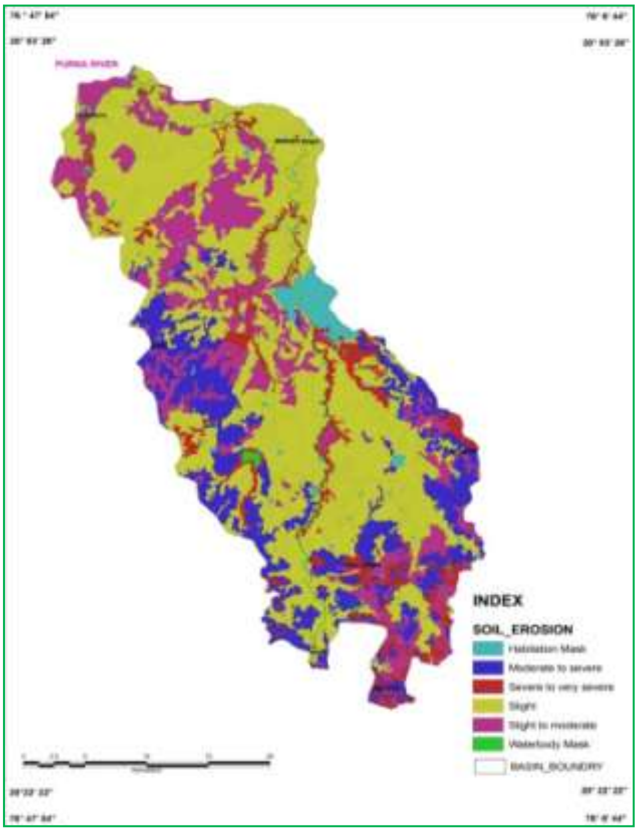

Figure 5. Soil Erosion of Morna River basin.

VII. RESULTS AND DISCUSSION

The co-ordinates of the hypsometric curves of the five sub-watersheds of Morna river watersheds as obtained were plotted and presented in (Table 1 and 2). It was observed from the hypsometric curves of these sub-watersheds that the drainage system is attaining the monadnock stage from the youth stage. The comparison between these curves shown in the (Fig.2.16) indicated a marginal difference in mass removal from the sub-watersheds of study area. It was also observed that there was a combination of convex-concavo and S-shape of the hypsometric curves for the sub-watersheds under study. This could be due to the soil erosion from these sub-watersheds resulting from the incision of channel beds, down slope movement of topsoil and bedrock materials, washout of the soil mass and cutting of streams banks.(Fig.7.8.9.10.11).

Table I. Sub-watershed wise hypsometric integral values of Morna River basin

Sub-watershed No.	Area (km^2)	Maximum elevation (m)	Minimum elevation (m)	Mean elevation (-)	Hypsometric integral	Geological stage
PTR-1	140	330.00	230.00	271	0.41	Mature Stage
PTR-2	300	355.00	245.00	303.75	0.53	Mature Stage
PTR-3	150	380.00	270.00	319.00	0.44	Mature
PTR-4	300	380.00	220.00	271.53	0.31	Late Mature or Monadnock

						Stage
PTR-7	60	305.00	220.00	330.00	0.49	Mature

Table II. Relative area and relative height of the sub-watershed.

PTR-1		**PTR-2**		**PTR-3**		**PTR-4**		**PTR-7**	
a/A	h/H	a/A	h/H	a/A	h/H	a/A	h/H	a/A	h/H
0.5	0.7	0.8	0.71	0.24	0.73	0.3	0.6	0.17	0.75
0.56	0.8	0.43	0.78	0.4	0.8	0.8	0.7	0.7	0.8
0.36	0.9	0.27	0.85	0.21	0.86	0.1	0.9	0.13	0.9
0.3	0.95	0.23	0.92	0.14	0.93	0.15	0.8	-	-
-	-	-	-	-	-	0.21	0.86	-	-
-	-	-	-	-	-	0.42	0.9	-	-

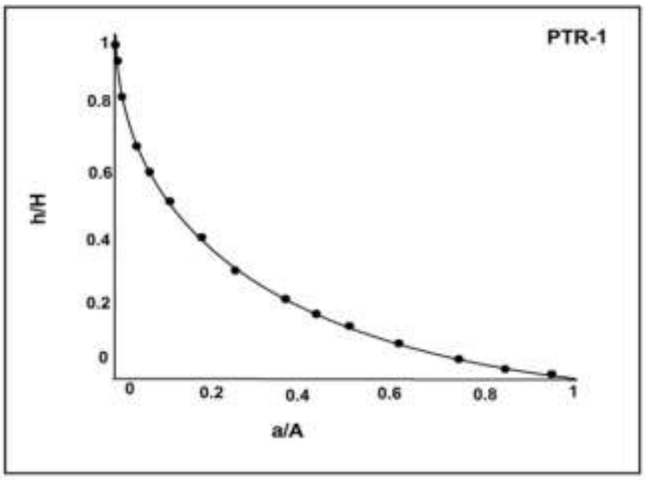

Figure 6. Hypsometric curve of PTR-1 sub-watershed

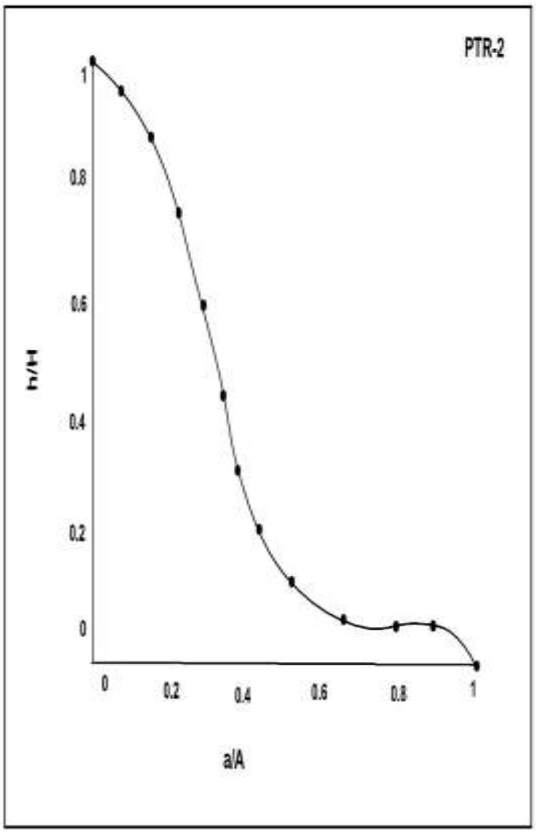

Figure 7. Hypsometric curve of PTR-2 sub-watershed

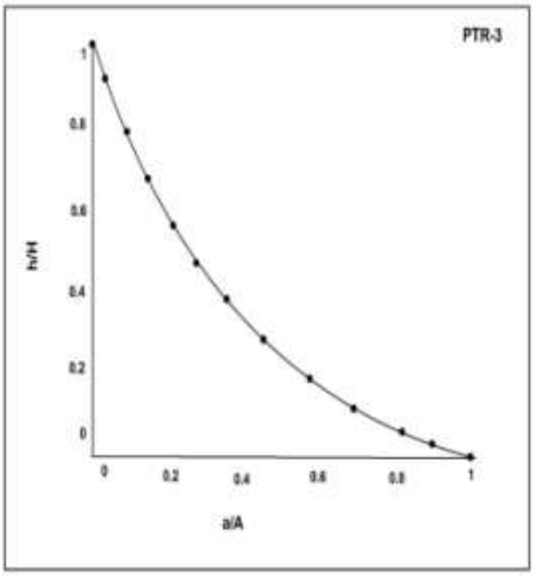

Figure 8. Hypsometric curve of PTR-3 sub-watershed

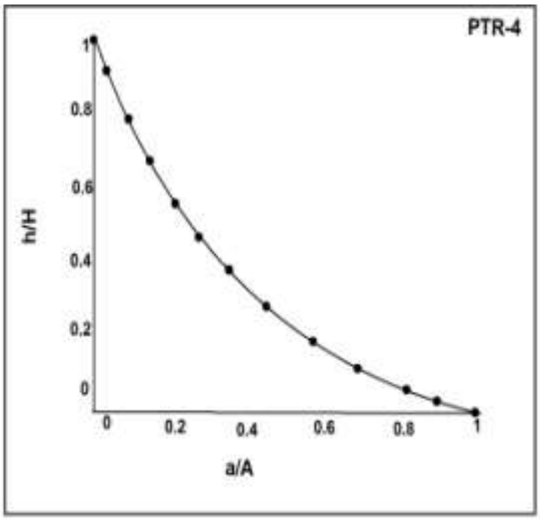

Figure 9. Hypsometric curve of PTR-4 sub-watershed

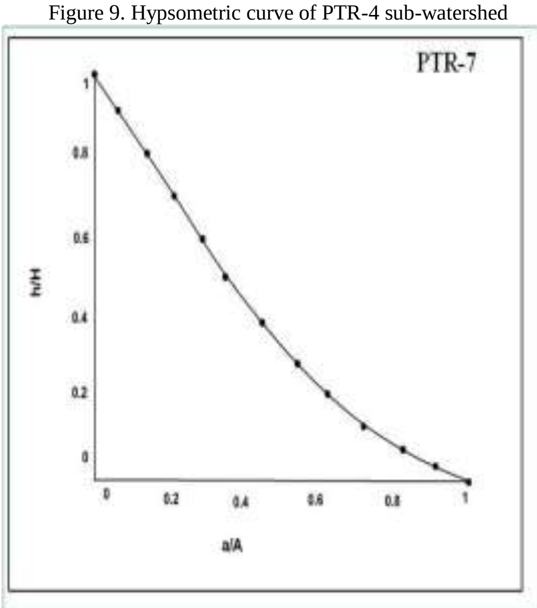

Figure 10. Hypsometric curve of PTR-4 sub-watershed

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VIII. SUMMARY AND CONCLUSIONS

Hypsometric analysis of watershed expresses the complexity of denudetional processes and the rate of morphological changes. Therefore, it is useful to comprehend the erosion status of watersheds and prioritize them for undertaking soil and water conservation measures. But, great care must be exercised in interpreting and comparing hypsometric PTR -4, is more prone to erosion in comparison to other sub-watersheds which would necessitate construction of soil and water conservation structures at appropriate locations of the sub-watersheds to arrest sediment outflow andconserve water. Further, the hypsometric integral values less than 0.5 (i.e. approaching monadnock stage) needs minimum mechanical and relative measures to arrest sediment loss but may require more water harvesting type structures to conserve water at appropriate locations in the watershed for conjunctive use of water. The hypsometric integral provides a very good idea about the distribution of land surface at various elevations. It is also a strong indicator of tectonic control, i.e. active tectonics, irrespective of area, lithology and climate. However, the relationships of the hypsometric integral to other morphometric parameters related to watershed shape have always been debatable. This study has brought to light some important relationships that exist between the hypsometric integral and the area of watersheds in an active tectonic setting where the other factors like lithology, climate and geologic structure are the same. Hypsometric integral is a useful parameter for assessing the nature of active tectonic deformation. It also helps in ascertaining the dominance of either tectonic or erosional processes in shaping the watersheds.

It is of utmost importance as it helps to ascertain the activity of the known structures, The study also confirms that the parameter of the hypsometric integral is not fully independent of the area of the watersheds; rather the relationship has to be sorted out in relation to the variation in the controlling factors.

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