J. Agric. Res. Technol., 47 (2) : 239-242 (2022) https://doi.org/10.56228/JART.2022.47221

Hypsometric Analysis of Watershed using Geographical Information System

R. B. Kadlag[1], P. P. Pawase[2], N. R. Gatkal[3], J. K. Khurdal[4] and S. M. Nalawade[5]
Department of Soil and Water Conservation Engineering, Dr. ASCAET,
Mahatma Phule Krishi Vidyapeeth, Rahuri - 413 722 (India)
Corresponding Author Email : pawasepranav@gmail.com

Abstract

Hypsometry of drainage basins (area-elevation analysis) has generally been used to reveal the stages of geomorphic development (stabilized, mature and young). In the present study, Kanoli river watershed located in Nashik district of Maharashtra was considered as the study area. The watershed was delineated into seven sub-watersheds and hypsometric analysis was carried out for all of them using the digital contour map, which was generated using Arc/Info GIS. In analysis, a curve is derived by plotting the relative heights (h/H) and relative areas (a/A); the obtained curve is called as hypsometric curve. The area under the Hypsometric curve is the Hypsometric Integral (HI). The hypsometric integral values for all of the sub-watersheds of Kanoli river ranges between 0.45 and 0.88. It was observed from HI that the sub-watersheds WS2, WS4, WS6 are in the mature stage and moving toward the deteriorating stage. The sub-watershed WS3 yielded higher hypsometric integral value, explaining its late youthful stage which calls for suitable measures of soil and water conservation. Further, sub-watersheds WS1, WS5 and WS7 have got very high value of hypsometric integral which takes them to young stage i.e. very susceptible to erosion. Therefore, these sub-watersheds are more prone to subsequent erosion activities and needs immediately appropriate soil and water conservation measures.

Key words : GIS, Geologic Stage, Hypsometric Analysis, Watershed.

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 condi-\tions. 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 *et al*., 1999). It is a continuous function of non-dimensional distribution of relative basin elevations with the relative area of the drainage basin (Strahler, 1957).

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 analyzing 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

1. M.Tech. Student, 2, 3. and 4. Ph.D. Student and 5. Professor and Head.

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 (HI) 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 of the cycle can be divided into three stages *viz*. manadnock (old) (HI=0.3), in which the watershed is fully stabilized; equilibrium or mature stage (HI= 0.3 to 0.6) and inequilibrium or young stage (HI> 0.6), in which 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 reserchers in India dealing with erosional topography (Pandey *et al*., 2004; Singh *et al*., 2008a and Singh *et al*., 2008b). 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 Geomorphological Information System (GIS) technique 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-watershed of Kanoli river in the Malegaon Tahsil, Nashik district of Maharashtra.

Materials and Methods

Description of study area : The study area, named Kanoli watershed located at Malegaon Tahsil, Nasik District of Maharashtra. Girna is the tributary of the Tapi basin, which originates from the Western Ghat. Malegaon is situated in the eastern frontier of the Upper Girna basin. Kanoli river is the left bank tributary of Girna River. The area of study watershed is 189.41 km^2. It lies between North latitude 20° 37' and 20° 39' and East longitude 74° 31' and 74° 44'. The elevation ranges from 680 to 398 m above MSL.

The study area has subtropical, semi-arid monsoon climate with average annual rainfall of 1100 mm. The climate of study area is hot in summer and cold in the winter and slightly humid in the rainy season. Study area has three distinct seasons *viz*. Monsoon starting from mid-June to September, winter from November to February, summer from March to mid-June. 90% of the rainfall occurs in monsoon season.

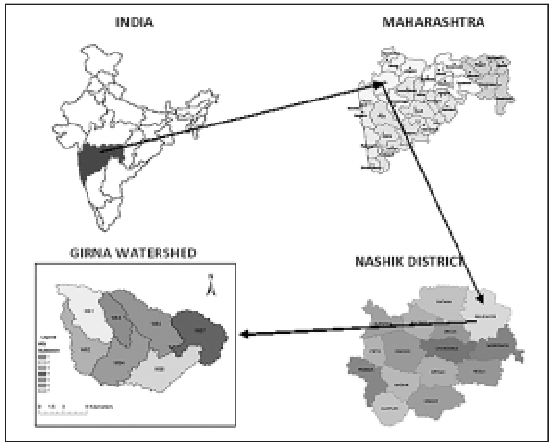


Fig. 1. Location Map of study area

Watershed Delineation and generation of contour map : Base map of study area was prepared using Survey of India (SOI) toposheet 46L/10. The topographical information of the watershed in 1:50000 scale with contour interval 20 m acquired from SOI toposheet were digitized using capability if ArcInfo and ArcGIS tools (Fig. 2). Drainage network was also digitized. Then the watershed boundary and sub-watersheds boundary were digitized. Contour map can be further used for delineation of sub-watersheds within watershed and identify the natural drainage network. Then contour map was polygonized to determine the area enclosed by each contour.

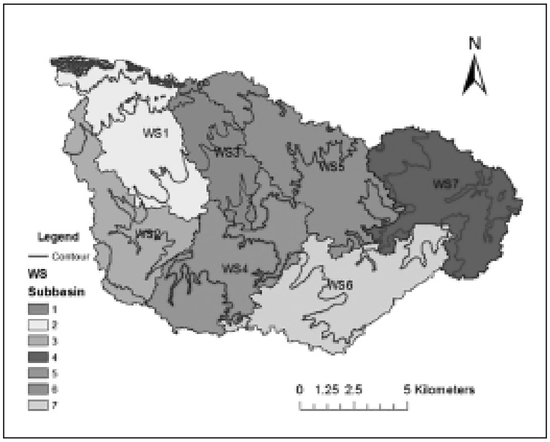


Fig. 2. Contour map of study area

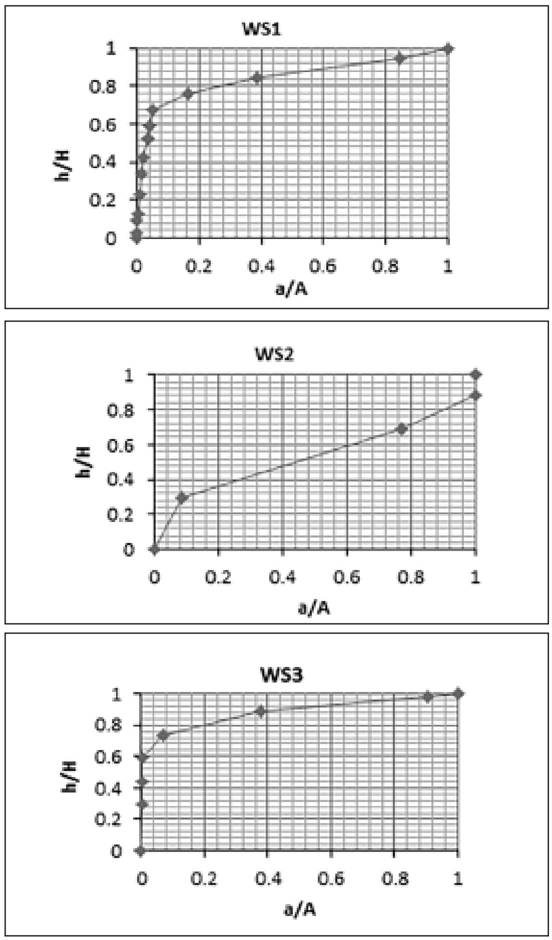
Plotting of hypsometric curves (HC) : Hypsometric curve was obtained by plotting the relative area along the abscissa and relative elevation along the ordinate. The relative area is obtained as a ratio of the area above a particular contour to the total area of the watershed encompassing the outlet. 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). The hypsometric integral (Hsi) was estimated using the of hypsometric curves (HC).

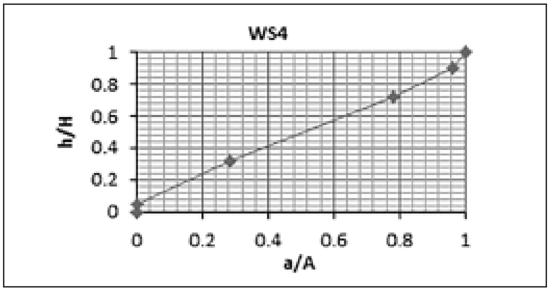
Table 1. Hypsometric Integral of sub-watershed of study area

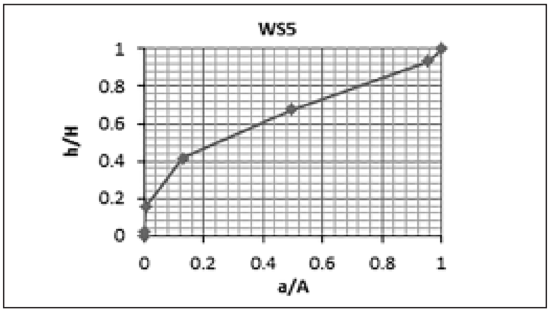
Sub-watershed	Area (m^2)	Hypso-metric integral	Geological stage
WS1	29181849	0.83	Young
WS2	22160754	0.53	Mature
WS3	14879850	0.88	Young
WS4	29569680	0.45	Mature
WS5	32575485	0.64	Young
WS6	30047281	0.55	Mature
WS7	30993343	0.73	Young
Total	189408242		

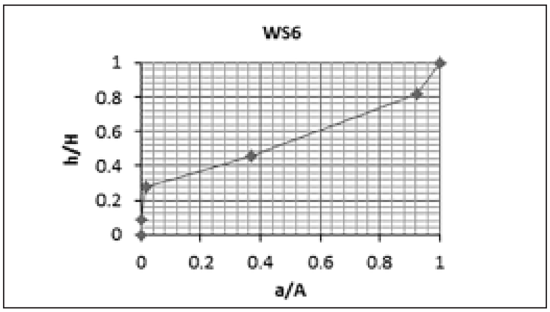
Results and Discussion

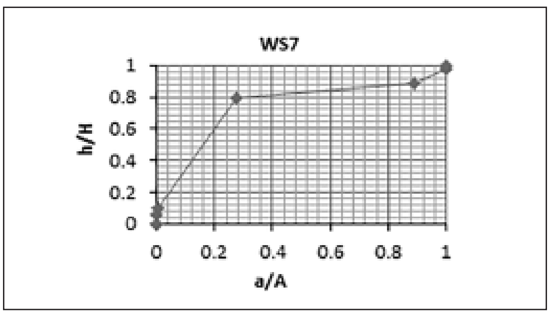
The co-ordinates of the hypsometric curves of the seven sub-watersheds of Kanoli river watersheds as obtained were plotted and presented in Fig 3. It was observed from the hypsometric curves of these sub-watersheds that the drainage system is attaining the mature stage from the youth stage. The comparison between these curves shown in the Fig. 3 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 theses 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.

The hypsometric integral (HI) values obtained for 7 micro-watersheds of study area are presented in Table 1. The HI values of these sub-watersheds ranged between 0.45 to 0.88. It was observed from HI that the sub-watersheds WS2, WS4, WS6 are in the mature stage and moving toward the deteriorating stage. Further, sub-watersheds WS1, WS3, WS5 and WS7 have got very high value of hypsometric integral which takes them to young stage i.e. very susceptible to erosion. Therefore, these sub-watersheds are more prone to subsequent erosion activities and needs immediately appropriate soil and water conservation measures.

Conclusion

Hypsometric analysis of watershed expresses the complexity of denudation 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 due to its complex nature of computation. The results of hypsometric integrals revealed that the sub-watersheds WS1, WS3, WS5 and WS7 are 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 and conserve water. Further, the sub-watersheds, which are having HI values more than 0.5 (i.e. approaching youthful stage) need construction of both vegetative and mechanical soil and water conservation structures to arrest sediment load and conserve water for integrated watershed management. However, the HI values less than 0.5 (i.e. approaching monadnock stage) needs minimum mechanical and vegetative 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.

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