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Hypsometric Integral Estimation Methods and its Relevance on Erosion Status of North-Western Lesser Himalayan Watersheds

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Abstract Assessment of erosion status of a watershed is an essential prerequisite of integrated watershed management. This not only assists in chalking out suitable soil and water conservation measures to arrest erosion and conserve water but also helps in devising best management practices to enhance biomass production in watersheds. The geologic stages of development and erosion proneness of the watersheds are quantified by hypsometric integral. The estimation of hypsometric integral is carried out from the graphical plot of the measured contour elevation and encompassed area and by using empirical formulae. In this study, efforts were made to estimate the hypsometric integral values of the Sainj and Tirthan watersheds and their sub watersheds in the Lesser Himalayas using four different techniques, and to compare the procedural techniques of its estimation and relevance on erosion status. It was revealed that the hypsometric integral calculated by elevation–relief ratio method was accurate, less cumbersome and easy to calculate within GIS environment. Also comparison of these hypsometric integral values revealed that the Sainj watershed (0.51) was more prone to erosion than the Tirthan watershed (0.41). Further, the validation of these results with the recorded sediment yield data of 24 years (1981–2004) corroborated that the average annual sediment yield during this period for Sainj watershed (0.53 Mt) was more than that of the Tirthan watershed (0.3 Mt). Thus, the hypsometric integral value can be used as an estimator of erosion status of watersheds leading to watershed prioritization for taking up soil and water conservation measures in watershed systems.

Keywords GIS · Hypsometry · Drainage basin · Watershed degradation · Geologic stage · Erosion status

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1 Introduction

1.1 General Overview

Land degradation and topological changes within watersheds are accomplished by weathering processes, stream erosion patterns and sediment transportation by surface runoff. Moreover, the quantification and interpretation of the topological changes becomes very difficult due to the complex nature of these hydrological and landform processes acting on watershed systems. In an attempt to simulate the geologic stages of development and to study the influence of varying forcing factors (i.e. tectonics, climate, lithology) on watershed topology, the hypsometry of drainage basins (area-elevation analysis) (Strahler 1952) have been evaluated by the researchers (Bishop et al. 2002; Ritter et al. 2002). Classically, it has been used to differentiate between erosional landforms at different stages during their evolution (Strahler 1952; Schumm 1956). Hypsometric analysis is appealing because of its dimensionless parameter that permits comparison of watersheds irrespective of scale issues (Dowling et al. 1998). Hypsometric curves (HC) and hypsometric integrals are important indicators of watershed conditions (Ritter et al. 2002). Differences in the shape of the curve and the hypsometric integral value are related to the degree of disequilibria in the balance of erosive and tectonic forces (Weissel et al. 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 et al. 1999a). 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 distribution have been extensively used for topographic comparisons because of its revelation of three-dimensional information through two-dimensional approach (Harrison et al. 1983; Rosenblatt and Pinet 1994). Comparison of the shape of the hypsometric curve for different drainage basins under similar hydro geologic condition provides a relative insight into the past soil movement of basins. Thus, the shape of the hypsometric curve explains the temporal changes in the slope of the original basin. Strahler (1952) interpreted the shapes of the hypsometric curves by analyzing numerous drainage basins and classified the basins as youth (convex upward curves), mature (S-shaped hypsometric curves which is concave upwards at high elevations and convex downwards at low elevations) and peneplain or distorted (concave upward curves). These hypsometric curve shapes described the stages of the landscape evolution, which also provides an indication of erosion status of watershed. 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. Convex shaped hypsometric curves indicate that the watershed is stabilized and the concave hypsometric curves indicate more proneness of watershed to the erosion processes (Hurtrez et al. 1999b). Hypsometric curves plotted for homogenous landforms in hundreds of small basins of different regions generally show stable hypsometric curve properties and the erosion stage is described as mature. However, there is existence of marginal but distinct differences in the shapes of HC for different watershed regions.

The hypsometric integral (HI) is a geomorphological parameter classified under the geologic stages of watershed development. It assumes importance in estimation of erosion status of watershed and subsequent prioritization for taking up soil and water conservation activities. The hypsometric integral is also an indication of the 'cycle of erosion' (Strahler 1952; Garg 1983). The cycle of erosion is defined as the total time required for reduction of a land topological unit to the base level i.e. the lowest level (Fig. 1). This entire period or the cycle of erosion can be divided into three stages viz. monadnock (old) ($H_{si}\leq 0.3$), in which the watershed is fully stabilized; equilibrium or mature stage ($0.3\leq H_{si}\leq 0.6$); and inequilibrium or young stage ($H_{si}\geq 0.6$), in which the watershed is highly susceptible to erosion (Strahler 1952; Sarangi et al. 2001). Strahler (1952) found that the hypsometric integral (HI) was inversely correlated with total relief, slope steepness, drainage density and channel gradients. The HI is expressed as a percentage, and is an indicator of the remnant of the present volume as compared to the original volume of the basin (Ritter et al. 2002). The hypsometric integral thus helps in explaining the erosion that had taken place in the watershed during the geological time scale due to hydrologic processes and land degradation factors (Bishop et al. 2002). Besides this, it also provides a simple morphological index with respect to relative height of the elevation distribution within the area considered, which can be used in surface runoff and sediment yield prediction from watersheds (Sarangi and Bhattacharya 2000; Jain et al. 2001). On the other hand, this parameter also reflects ambiguity in estimation due to the fact that the hypsometric curves of different shapes can yield the same hypsometric integral value (Ohmori 1993). Hurtrez et al. (1999b) investigated the sensitivity of hypsometry to digital elevation models (DEMs) of different resolutions and afterwards assessed the influence of varying drainage area on hypsometry in Siwalik Hills of Central Nepal. Awasthi et al. (2002) studied hypsometric curves and integrals to explain the watershed health of two Nepalese watersheds and revealed that the watersheds had undergone severe erosion during the past and are susceptible to surface erosion and soil degradation.

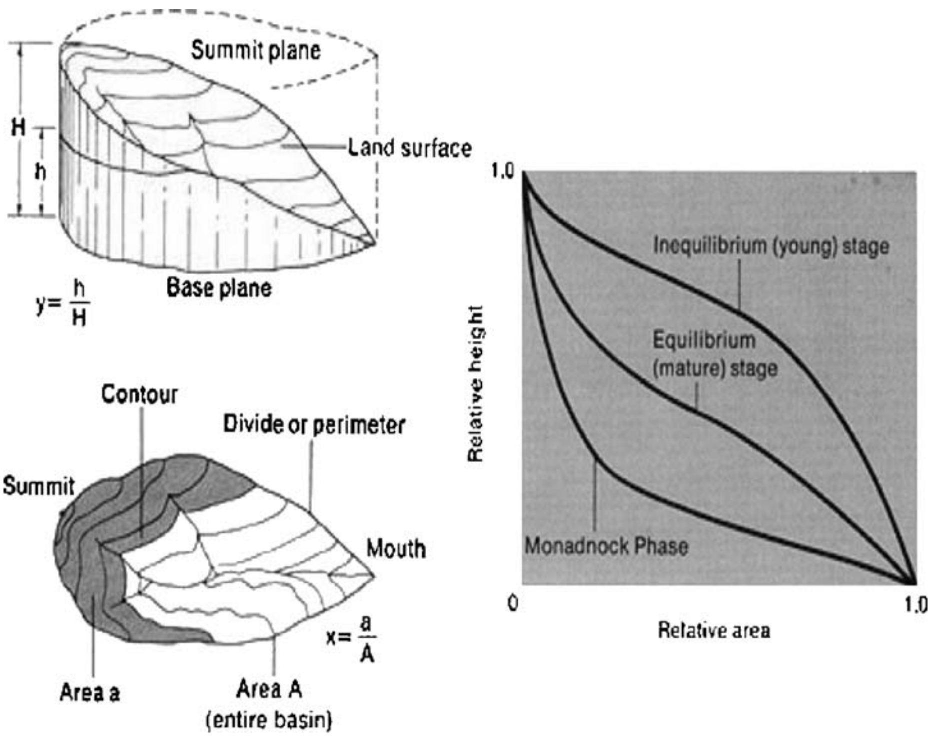


Fig. 1 The concept of hypsometric analysis and the model hypsometric curves (Ritter et al. 2002)

Moreover, the hypsometric technique has been used by several researchers in India dealing with erosional topography and its subsequent application in prediction of sediment yield from watersheds (Rao et al. 1994; Mishra 1988; Pradhan and Senapati 2002; Dabral 2003; Jain et al. 2003; Pandey et al. 2004; Sarangi et al. 2001; Goel and Singh 2000). It was revealed from these research findings that the hypsometric integral was estimated from the hypsometric curves generated using the standard graph based area estimation procedures. However, they have not discussed in detail the effect of HI values on the erosion status and sediment yield transport behavior from watersheds.

This review revealed that the hypsometric curve and hypsometric integral are important watershed health indicators and need to be estimated for the watersheds of fragile Himalayan ecosystem regions. The watersheds of the Himalayan mountainous regions are vulnerable to erosion due to high monsoon rainfall and intense pre-monsoon storms. Further, it was also observed that there is lack of hypsometric curve based studies to assess the watershed health in this region. This may be attributed to the tedious nature of data acquisition and analysis involved in estimation of hypsometric integral. However, due to the advent of GIS and remote sensing image interpretation techniques, the estimation process becomes less cumbersome and more accurate. Based on literature review, to fill the research gap, an effort was made in this paper to compare different hypsometric integral estimation techniques and to study its effect on sediment yield behaviour of two watersheds in the North-Western Lesser Himalayan region.

2 Materials and Methods

2.1 Description of Study Area

The study area is delineated into two distinct watersheds named as Sainj (741 km^2) and Tirthan (687 km^2). Both watersheds fall under the left bank of Upper Beas river system in the Lesser Himalayas. The area extends between latitudes 31°30′28″ and 31°55′02″ north and longitudes 77°13′02″ and 77°45′57″ east as shown in Fig. 2. The watersheds present a typical mosaic of moderate to high rugged topography with numerous mountain peaks over 4,000 m. The average slope of Sainj and Tirthan watersheds are 38.12° and 40.04° along with the mean elevation of 3,510 and 2,826 m, respectively. The rock types were mainly of colluvium, alluvium, glacial deposits, phyllite, slate, quartzites, dolomites, sandstone, schist and granites. The soil texture varies from sandy loam to loam with average organic matter content of around 70%.

The climate of the watersheds is mostly warm temperate and receive an average annual rainfall of 1,000 mm and more than 50% of which is received during the south-west monsoon (June–September). Average annual snowfall in the region is about 345 mm confined to upper reaches and during winter season only. The mean monthly temperatures at Larji (the outlet of watersheds) ranged from a minimum of 8.7°C during January to the maximum of 26.3°C during June. The minimum and maximum relative humidity is recorded in the months of May (63.3%) and August (78.7%) respectively. Evaporation was observed to be minimum in the months of December (36.1 mm) and January (38.7 mm), the coldest months of the year and maximum during June (165.0 mm), the warmest month of the year.

2.2 Watershed Delineation and Generation of DEM from the Topological Data

The topological information of the study watersheds was digitized and geo referenced using the capabilities of ArcInfo and ArcGIS tools. The contours were digitized to generate the

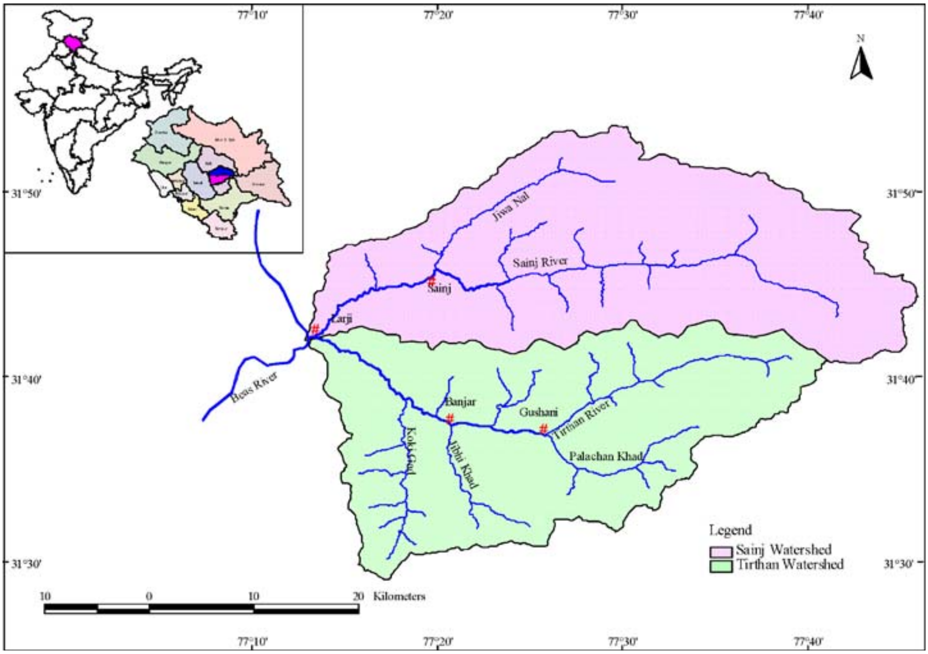


Fig. 2 Location map of study watersheds

line feature class in ArcGIS which was further processed using the spatial analyst module to generate the digital elevation model (DEM) representing the watershed terrain topology. Further, the developed DEM was processed to generate the delineated watershed and sub watershed regions and the natural drainage pattern of the watershed using the Watershed Morphology Estimation Tool (WMET) interface (Sarangi et al. 2004). The digitized contour and drainage map of the Sainj and Tirthan watersheds are shown in Figs. 3 and 4 respectively. The delineated 23 sub basins of the watershed marked from 1 to 23 are also shown in Fig. 4. The drainage network ordering was done using the Strahler's stream ordering scheme (Strahler 1964). The attribute tables of the geo referenced feature classes representing the contours and their enclosed area with the watershed boundaries contained the elevation and length of the contours and their respective area and perimeter values. The attribute feature classes containing these values were used to plot the hypsometric curve of the study watersheds from which the hypsometric integral was estimated (Fig. 5).

2.3 Sediment Yield Information of Major Watersheds

The daily stream runoff and suspended sediment data measured at the Larji hydrologic monitoring station over the past 24 years (1981–2004) maintained by the Bhakra Beas Management Board were compiled, analyzed and interpreted. The shape of the cross section at the site of measurements varied from trapezoidal at the bottom to rectangular at the top. The mean velocity of water was measured by using the float method (Todd et al. 1997). The mean average velocity was determined by taking average of a number of replicative float measurements. The cross sectional area was then multiplied with the mean velocity to obtain discharge in the streams. It was recorded in cubic feet per second (ft.^{3}/s) unit.

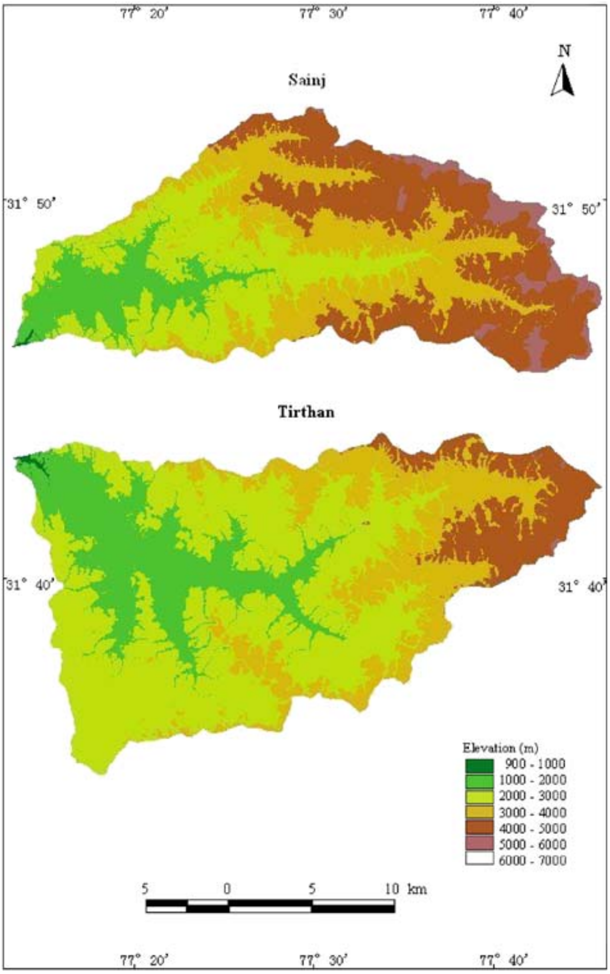


Fig. 3 The DEM of the Sainj and Tirthan watersheds

For determining the suspended sediment concentration, the samples were taken from three transects across the stream with the help of depth integrating samplers. The samples were then passed separately through a 100-mesh sieve and the fraction retained was dried and weighed. It represented the coarse fraction (>0.20 mm). The sieved samples were again stirred and allowed to stand for the time required for settling of the medium fraction (0.075–0.20 mm) depending upon the temperature of water. A 25 ml sample of the remaining material was dried and weighed to represent the fine fraction (<0.075 mm) and dissolved salts. Another 25 ml was filtered out, dried and weighed to represent dissolved salts. The weight of the fine fraction was determined by subtracting the weight of the dissolved salts from the mixture of fine fraction and dissolved salts. Further, the average sediment concentration in 1 l of water was calculated. The sediment load in the watersheds was calculated by multiplying the average sediment concentration with the corresponding discharge. This was converted to cubic meter unit by dividing the load in tonnes by 1.4, assuming that the sediment density was 1.4 t m^{-3} (BBMB 1997).

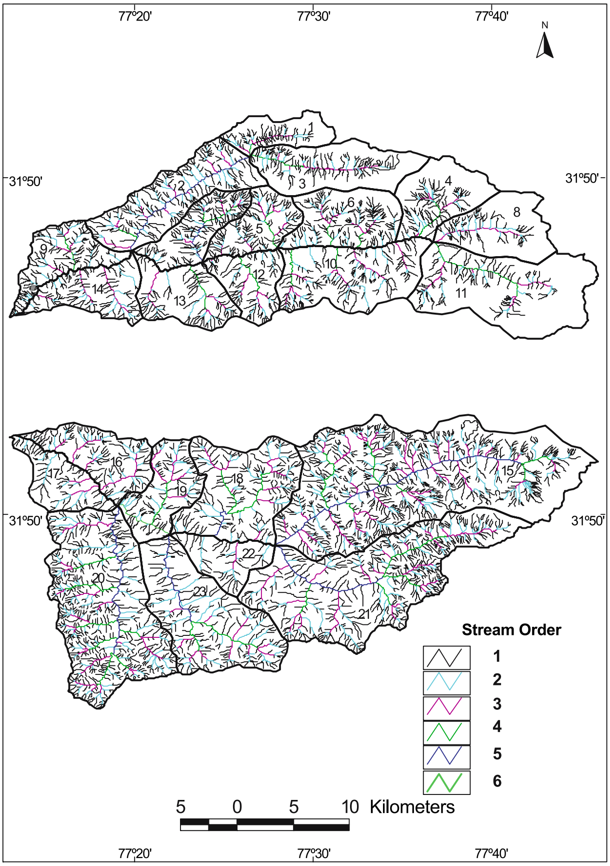


Fig. 4 Delineated sub basins and natural drainage network of the Sainj and Tirthan watersheds

2.4 Plotting of Hypsometric Curves (HC) and Estimation of Hypsometric Integrals (HI)

Hypsometric analysis aims at developing a relationship between horizontal cross-sectional area of the watershed and its elevation in a dimensionless form. 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 watershed encompassing the outlet. Similarly, referring to Fig. 1, 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 remote point of the watershed from the outlet) (Sarangi et al. 2001; Ritter et al. 2002). 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 is obtained from the percentage hypsometric curve by measuring the area under the curve. This provided a measure of the distribution of landmass volume remaining beneath or above a basal reference plane.

In the present study, the hypsometric integral or the area under the curve was estimated using four different methods. Besides these estimation, a comparative evaluation was also attempted based on the accuracy of estimation, calculation time and the complexity of

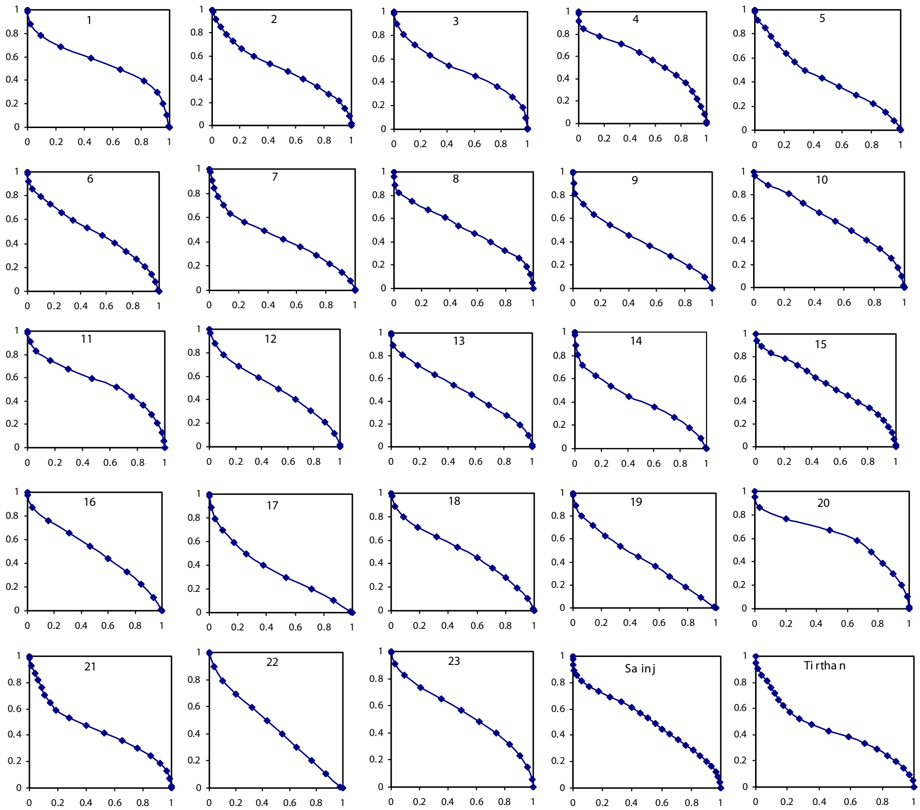
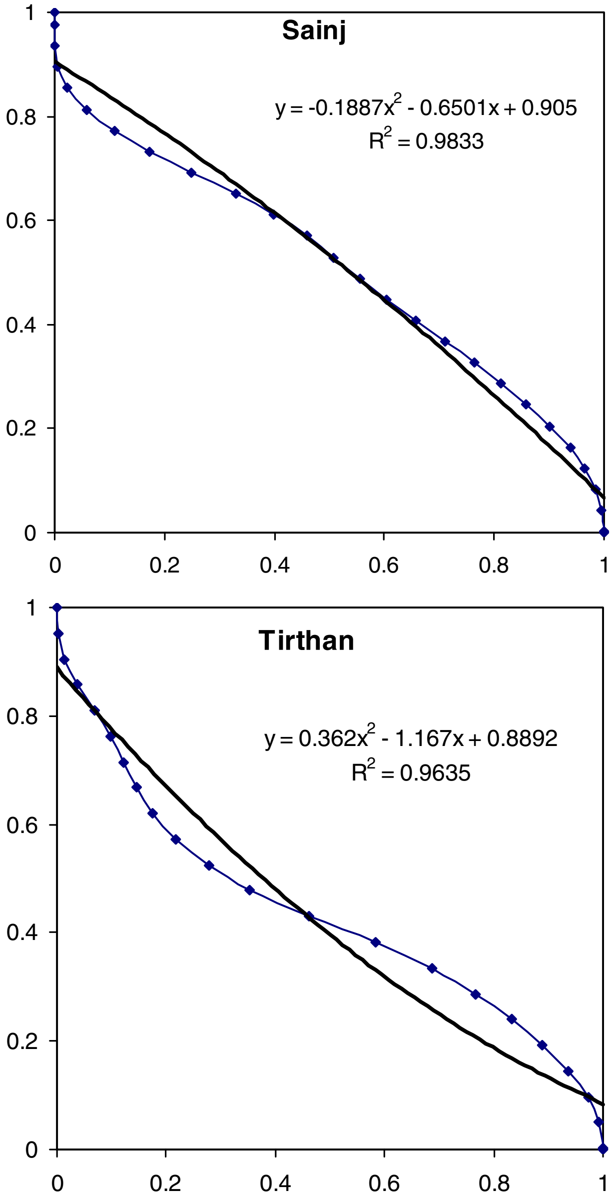


Fig. 5 Hypsometric curves of Sainj and Tirthan watersheds along with their 23 sub basins

methods and tools required to accomplish the task. The methods adopted to calculate the area under the curve are:

1. *Integration of Hypsometric Curve* The plotted hypsometric curves were fitted with a trend line to represent an equation of the curve and the best fitting equation was obtained for highest coefficient of determination (R^2) value. The equation was further integrated within the limits of 0 to 1 (due to the non-dimensional nature of the graph) for estimating the area under the curve. Thus the estimated area gives the hypsometric integral value of the hypsometric curve. The developed polynomial equation by fitting the hypsometric curve of the Sainj and Tirthan watersheds are shown in Fig. 6. The fitted equation was integrated within the desired limits to estimate the area under the HC. Similar procedure was adopted for all the 23 sub basins of these two watersheds. However, this method was time consuming and necessitated mathematical integration procedures and subsequent calculation within the desired limits of HC.
2. *Use of the Leaf Area Meter (LAM) Equipment* Leaf area meter (LAM) equipment measures the area of plant leaves passed through the roller surface of the equipment. In this study, the LI-COR-Model 3100 LAM was used. In this case the hard copy of the graphs of hypsometric curves were taken using a standard printer. Further, the graph area was cut using a paper-cutting device and passed through leaf area meter and readings were noted. Then the graph was cut into two halves following the shape of the

Fig. 6 The fitted equation of the hypsometric curves for the Sainj and Tirthan watersheds



hypsometric curve and again passed through the leaf area meter and readings were again noted and the hypsometric integral was calculated. However, this method was more rigorous, cumbersome and time consuming due to cutting of the printed graphs as per curve shapes followed by subsequent equipment operation and calculations. Also, the accuracy of this method depends on the accuracy of the LAM equipment and in this study there was instrument error of about 1%.

3. *Use of the Planimeter Equipment* Planimeters are widely used by the engineers, geographers, surveyors and planners to estimate the area. In this study, the R-type computer co-ordinated area-planimeter was used. Initially the nose of the planimeter was rotated on the entire graph area and readings were recorded. Further the planimeter was rotated on the curved area beneath the hypsometric curve and the readings were noted. Finally, the entire graph area readings were divided by the area readings below the hypsometric curve to estimate the hypsometric integral. This method was also cumbersome and time consuming, as observed with LAM equipment, in which the estimation error was also due to precision and accuracy of the equipment besides human error.
4. *Use of Elevation–Relief Ratio (E) Relationship* In order to overcome the difficulty faced by above three methods, the elevation–relief ratio method proposed by Pike and Wilson (1971) was used. The relationship is expressed as

$$E \approx H_{si} = \frac{\mathrm{Elev}_{\mathrm{mean}} - \mathrm{Elev}_{\mathrm{min}}}{\mathrm{Elev}_{\mathrm{max}} - \mathrm{Elev}_{\mathrm{min}}} \tag{1}$$

Where, E is the elevation–relief ratio equivalent to the hypsometric integral H_{si}; $\mathrm{Elev}_{\mathrm{mean}}$ is the weighted mean elevation of the watershed estimated from the identifiable contours of the delineated watershed; $\mathrm{Elev}_{\mathrm{min}}$ and $\mathrm{Elev}_{\mathrm{max}}$ are the minimum and maximum elevations within the watershed.

3 Results and Discussion

The co-ordinates of the hypsometric curves of the Sainj and Tirthan watersheds and their sub basins obtained using the WMET interface in ArcGIS were plotted (Fig. 5). It was observed from the hypsometric curves of these two watersheds along with their 23 sub basins that the drainage system is attaining a mature stage from the youth stage, which is true for most of the Himalayan watershed systems. The comparison between these curves shown in Fig. 5 indicated a marginal difference in mass removal from the two main watersheds and their sub basins. It was also observed that there was a combination of convex–concavo and S shape of the hypsometric curves for the Sainj and Tirthan watersheds and the sub basins.

3.1 Estimation of Hypsometric Integral (H_{si}) Values

The hypsometric integral values obtained using the four different methods for the 23 sub basins and the two main watersheds are presented in Table 1. It was observed from the table that there was not much difference in the estimated values of the hypsometric integral for all the methods except for a minor difference of 0.01 in a couple of cases. However, the elevation–relief method was observed to be less cumbersome and faster than the other three methods. Moreover, the comparison of the estimated H_{si} values from the elevation–relief method and the rest three hypsometric curve based methods revealed that there is no significant difference between the estimated hypsometric integral values. This indicated that, the estimation of H_{si} from hypsometric curve using the ratio of areas is not always a better estimator of hypsometric integral. Therefore, the elevation–relief method can be adjudged as the most efficient method for estimation of hypsometric integral.

Table 1 Estimated hypsometric integral values of the Sainj and Tirthan watershed and their sub basins using 4 different methods

Sub watershed number	Sub watershed name	Elevation-relief ratio method	Integration method	Leaf area meter method	Planimeter method	Geologic stages
1	Upper Jiwa Nal	0.55	0.55	0.55	0.56	Late youthful
2	Jiwa Nal	0.49	0.49	0.50	0.49	Mature
3	Lower Jiwa Nal	0.51	0.51	0.51	0.51	Mature
4	Chyos Nal	0.58	0.58	0.57	0.58	Late youthful
5	Nilathotha Khad	0.43	0.44	0.44	0.44	Mature
6	Maurar Khad	0.50	0.50	0.50	0.50	Mature
7	Kartaul Gad	0.43	0.43	0.43	0.44	Mature
8	Rakti Nal	0.51	0.51	0.51	0.51	Mature
9	Bagla Khad	0.41	0.40	0.40	0.42	Mature
10	Gahru Nal	0.59	0.59	0.59	0.58	Late youthful
11	Sainj Nal	0.56	0.56	0.56	0.56	Late youthful
12	Niharni Khad	0.50	0.50	0.50	0.50	Mature
13	Kotlu Gad	0.50	0.50	0.50	0.50	Mature
14	Dhaugi Khad	0.41	0.41	0.41	0.42	Mature
	Entire Sainj watershed	**0.51**	**0.51**	**0.51**	**0.52**	**Mature**
15	Tirthan Khad	0.56	0.56	0.56	0.56	Late youthful
16	Paldi Nala	0.50	0.50	0.50	0.51	Mature
17	Bali Khad	0.36	0.35	0.36	0.34	Late mature or near monadnock
18	Kalwari Nala	0.50	0.50	0.49	0.48	Mature
19	Gharat Gad	0.42	0.42	0.41	0.43	Mature
20	Koki Gad	0.60	0.61	0.60	0.62	Inequilibrium or youthful
21	Palachan Khad	0.44	0.44	0.45	0.44	Mature
22	Nagni Khad	0.44	0.44	0.43	0.45	Mature
23	Jibhi Khad	0.54	0.55	0.54	0.54	Late youthful
	Entire Tirthan watershed	**0.44**	**0.44**	**0.43**	**0.43**	**Mature**

3.2 Relevance of Hypsometric Integral (H_{si}) on Watershed Hydrologic Responses

Surface runoff and sediment losses are the two important hydrologic responses from the rainfall events occurring over the watershed systems. The hypsometric integral value can be an indirect estimator of the erosion from the watershed systems. It was observed from the H_{si} values (Table 1) that the watersheds and their sub basins are in the mature stage and moving towards the peneplanation or the deteriorating stage. This revealed that the soil erosion from these watersheds and their sub basins were derived primarily from the incision of channel beds, down slope movement of topsoil and bedrock material, washout of the soil mass and cutting of stream banks. These landform changes were also reflected in different sub basins of the study watersheds. Topographic evidence of the study region indicated the landscape concavity due to river incision. The H_{si} values of Sainj watershed (0.51) and Tirthan watershed (0.44) indicated that 51% and 44% of the original rock masses still exist in these watersheds respectively. Hypsometric integral values were ranged between 0.41 to 0.59 for sub basins of Sainj watershed and between 0.36 to 0.60 in the sub basins of Tirthan watershed. While comparing the standard H_{si} values of different stages, the *Koki gad* sub basin (No. 20) of Tirthan and *Gahru Nal* (No. 10) of Sainj watersheds were observed to be in youthful stage. However, Bali Khad (No. 17) of Tirthan and *Bagla* and *Dhaugi* Khad (No. 9 and 14) in Sainj watersheds were approaching monadnock stage. These sub basins with mature stages were located at lower elevations (Fig. 7), the reason of which can be mainly attributed to the human interventions in the form of construction of roads, intensive agricultural practices (Fig. 8) and deforestation activities. Further, the sub basin numbers 1 and 11 under permanent snow cover and glaciers and sub basins 4 and 10 in high slope terrains yielded higher values of hypsometric integrals, explaining their late youthful stages. It is understood that the hydrologic response of the sub basins attaining the mature stages will have slow rate of erosion (Ritter et al. 2002) unless there is very high intense storms leading to high runoff peaks. In contradiction to this statement, the outlet of the Tirthan watershed was observed to be of broader valleys and wider flood plain indicating higher erosion rates (Fig. 9). This can be attributed to the higher average slope of the study watersheds leading to quicker translation of surface runoff with higher velocity through the watershed outlet and thus widening the flood plains.

The comparison of the hypsometric integral values revealed that the Sainj watershed was more susceptible to erosion than the Tirthan watershed. Moreover, hypsometric value based indirect assessment on the erosion status was validated using the recorded sediment yield information of the two watersheds during the years from 1981 to 2004. The recorded annual sediment yields were presented in Table 2. From the tabulated data, the sediment yield varied from a minimum of 0.09 Mt to a maximum of 1.73 Mt from the Sainj watershed and from 0.03 Mt to 1.3 Mt for Tirthan watershed. It was also observed that the sediment yield from the Sainj watersheds for all the years from 1981 to 2004 were more than that of the Tirthan watershed. These recorded sediment yield data were in conformity with the higher hypsometric integral value, which indicated the youthful nature of the Sainj watershed (0.51) in comparison to the Tirthan watershed (0.44). Also, the 24 years average of annual

Fig. 7 Degraded land with matured landscape in Tirthan watershed

Fig. 8 Intensive agricultural practices on the terraced lands of Tirthan watershed

sediment yield for the Sainj watershed (0.53 Mt) was more than the Tirthan watershed (0.3 Mt) corroborated that the youthful or young stage watersheds could release more sediments than the watersheds which have attained the mature stage.

Moreover, the information of erosion status based on the hypsometric integral values as discussed above can be used for watershed prioritization. The results of this study

Fig. 9 Widened flood plain and eroded stream bank in the drainage channel of Tirthan watershed

Table 2 Annual sediment yield of Sainj and Tirthan watersheds for the period from 1981 to 2004

Year	Annual sediment yield (Mt)	
	Sainj watershed	Tirthan watershed
1981	0.19	0.03
1982	0.12	0.09
1983	0.23	0.11
1984	0.09	0.08
1985	0.31	0.23
1986	1.00	0.09
1987	0.15	0.07
1988	0.98	0.95
1989	0.34	0.12
1990	0.29	0.13
1991	0.19	0.05
1992	0.32	0.15
1993	1.73	1.30
1994	0.69	0.15
1995	1.57	0.96
1996	0.39	0.11
1997	0.63	0.42
1998	0.38	0.31
1999	0.55	0.44
2000	0.55	0.43
2001	0.34	0.33
2002	0.59	0.18
2003	0.42	0.19
2004	0.68	0.22
Average of 24 years	0.53	0.30

revealed that the Sainj watershed and most of its sub basins are more prone to erosion in comparison to Tirthan and its sub basins, which necessitate construction of soil and water conservation structures at appropriate locations of the watershed to arrest the sediment outflows and conserve water. Further, the sub basins of both watersheds, which are having hypsometric integral 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 H_{si} 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 water use.

4 Summary and Conclusions

Hypsometric analysis is useful to comprehend the erosion status of a watershed 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. Out of the four methods used to compute the hypsometric integral, the elevation–relief ratio method was the best because of its easiest estimation procedure in minimal time without any equipment. Moreover, the results obtained from the equation were in line with other methods. This method has an added advantage over other methods, in which the H_{si} values can be estimated without plotting the hypsometric curve. But in other three methods, drawing of the hypsometric curve was the foremost exercise followed by other computational procedures. While, in curve fitting method, the polynomial equation was used to obtain a better R^2 value that leads to complex mathematical calculations. In rest of the methods, there was need of the planimeter and leaf area meter, which need to be procured. Besides the equipment cost, the human and equipment errors along with the cumbersome nature and extended estimation time required for these methods are not always an encouraging proposition. In this context, as revealed from this study, the elevation–relief ratio method can be the best alternative for hypsometric integral estimation. The recorded annual average sediment yield data from the study watersheds also ascertained the concept that higher hypsometric value indicating the youthful nature of the landmass leads to higher sediment outflow. Also, the estimated integral values have a strong relevance on watershed erosion status leading to watershed prioritization and subsequent decision for taking up soil and water conservation measures, which is the prerequisite of integrated watershed management.

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