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IDENTIFICATION OF EROSION PRONE AREAS IN SUKETI WATERSHED, HIMACHAL HIMALAYAS, INDIA

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Abstract

Identification of erosion prone areas is an essential requirement for management of watersheds. The geologic stages of development of erosional landscapes in the watershed systems can be quantified by hypsometric analysis, which is considered as an important indicator for watershed health assessment. In addition, the hypsometric analysis helps in identifying the erosion that had taken place in the watershed systems during the geologic time scale on account of hydrological processes and land degradation factors. The present study therefore has been undertaken to identify the erosion prone areas of Suketi watershed in Beas catchment of Himachal Pradesh. The hypsometric analysis performed on the watershed reveals that Suketi watershed as a whole (422 km^2*) along with four of its sub-watersheds are in monadnock stage, whereas three other sub-watersheds are in equilibrium or mature stage. The hypsometric value obtained for Suketi watershed indicates that only 19 per cent of the original land mass is available and remaining has been eroded away from the watershed. This study highlights that hypsometric analysis can be used as an estimator of erosion proneness leading to prioritization for taking up soil and water conservation measures in watershed systems.*

Introduction

Soil erosion is a major environmental problem worldwide and affects millions of people's livelihoods. Quantitatively, it affects about1964 Mha of the terrestrial land (Valentin et al., 2005; Pimentel, 2006). In a developing country like India about 167 Mha (53 per cent) land is affected seriously by water and wind erosion out of the total geographical area of 329 Mha (Goyal, 2014). It has been estimated that about 5334 million tons of soil is being detached annually in the country corresponding to 16.75 t/ha/year against the permissible range of 7.5-12.5 t/ha/year. Estimates also indicate that the loss of nutrients due to soil erosion ranges from 5.4 to 8.4 million tons, resulting a production loss of 30-40 million tons of food grains per year (Pimentel and Burgess, 2013). This problem is serious enough because India supports about 17 per cent of world population on 2 per cent of the global land area.

Currently, studies on soil erosion in India are mainly focused on Western Ghats (Sujatha et al., 2014), Vindhyachal and Satpura ranges (Patil et al., 2015), arid region (Javed et al., 2011), Chhota Nagpur Plateau (Das, 2014) and north-eastern region (Sarma and Saikia, 2012). However, in recent years the seriousness of soil erosion has been felt in mountainous areas where erosion occurs as sheet, rill and gully erosion, causing declines of crop yields and income levels (Kumar et al., 2014). Therefore, more attention is needed to the Himalayan region, most parts of which are composed of sandstone, grits, shale and conglomerates. These formations are geologically weak and unstable and hence highly prone to soil erosion. In addition, this area is characterized by young mountain ranges with steep slopes, high seismicity, depleted forest cover, large-scale road construction, mining, cultivation on steep slopes, erratic monsoon pattern of rainfall, low water retention and high soil loss associated with runoff (Jain et al., 2003).

For identification of erosion prone areas and subsequent prioritization for the watershed systems several methods have been designed in the past ranging from simple empirical models to process oriented physical based models. These empirical and process oriented models are cumbersome, data hungry and complex for watershed prioritization, which can be reinstated with less data requirement and effective technique such as hypsometry. Hypsometry which encompasses hypsometric curves and integrals has been found to be an efficient tool to assess erosion vulnerability in watershed systems even without considering the soil type, rainfall and vegetation characteristics of the watersheds. Therefore, hypsometry has been extensively used in study of eroded topography for watershed management, resource conservation and sustainable development (Dabral, 2003; Pandey et al. 2004; Singh et al., 2008).

Hypsometry is the relationship of horizontal cross-sectional drainage basin area to elevation. Classically, it has been used to differentiate between eroded landforms at different stages during their evolution (Strahler, 1952; Schumm, 1956). This indicator is appealing because it is a dimensionless parameter and, therefore, allows different catchments to be compared irrespective of scale. The hypsometric integral (HI) is the area beneath the curve which relates the percentage of total relief to cumulative percentage of area. This provides a measure of the distribution of landmass volume remaining beneath or above a basal reference plane. In theory, HI values range from 0 to 1. Hypsometric curves and integrals can be interpreted in terms of degree of basin dissection and relative age of the landform. Convex-up curves with high integrals are typical for youth, undisseceted (disequilibrium stage) landscapes; smooth, s-shaped curves crossing the centre of the diagram characterize mature (equilibrium stage) landscapes, and concave up with low integrals typify old and deeply dissected landscapes (Strahler, 1952).

The above review reveals that hypsometry is an important geological indicator to assess the soil erosion susceptibility of watershed systems and therefore, need to be estimated for the watersheds of fragile Himalayan ecosystem regions. It has been also observed that there is a lack of hypsometry based studies to assess the soil erosion susceptibility in this region. Therefore, to fill the research gap, the present study on hypsometric analysis has been undertaken for Suketi watershed, falling in Beas basin of Mandi district in Himachal Pradesh, India so that the critical erosion prone areas could be identified for soil and water conservation measures. The findings from this study could provide a scientific basis for soil and water conservation planning and management in Suketi watershed.

Objectives

Major objectives of the present study are:

- to determine the geological stages of landform development in the study area;
- to identify erosion proneness of Suketi watershed and its sub-watersheds; and
- to prioritize watershed systems for conservation of soil and water resources.

Study Area

Suketi is a seventh order watershed which falls under the left bank of the river Beas. The watershed has a peculiar physiographic character, because it encompasses a central inter-montane valley and surrounding mountainous terrain in the Lower Himachal Himalaya in the Mandi district of Himachal Pradesh, India, between two major towns, i.e., Mandi towards the north and Sundernagar towards the south. Suketi watershed is socio-economically very significant in the entire Beas basin, because it is known as the granary of Himachal Pradesh. The area of the watershed is about 422 km^2 extending between latitudes 31°27′08′′and 31°45′00′′ north and longitudes 76°48′20′′ and 77° 03′09′′east (Fig. 1). The Suketi originates from an altitude of about 2900 m above mean sea level (amsl) in the south-eastern part of the basin, and discharges water at an altitude of 750 m amsl in its northernmost part, where it joins the river Beas. The overall drainage pattern of the watershed is dendritic to sub-dendritic which is dominated by lower order streams with perennial flow due to rainfall, snowfall and effluent seepage from groundwater. The major rock types in eastern sector of the watershed are composed of granite, gneisses, quartzites and phyllites, whereas the western part is comprised by sandstone, phyllite, schists, dolomites, limestones, quartzites, etc. The surface soil texture of the area is mainly of loamy type with light grey to brown in colour. Depth of soil varies from shallow to very deep.

The climate of the watershed under study is of sub-tropical highland type in the scheme of Koppen's classification. The mean monthly temperature ranges from a minimum of 10.5°C during January to the maximum of 21.5°C during June. The weather in the area remains pleasant from April to October. The watershed receives precipitation both in the form of rain and snow. The average annual rainfall is about 1100 mm with average 55-75 rainy days. The area receives highest rainfall in the month of July and lowest in the month of November and December. Average seasonal percentage of annual rainfall for January to February is 7.2 per cent, March to May is 6.3 per cent, June to September is 81 per cent and October to December is 5.4 per cent. The mountain peaks of the study area experience snowfall during winter, which often comes down to 1300 m for a short period. The predominant land use in the watershed is rocky outcrops (38 per cent) followed by agricultural land (26 per cent) and forest land (22 per cent).

Database and Methodology

In the present study, different datasets have been used which includes (i) Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data, with 30 m spatial resolution, (ii) Survey of India (SOI) topographical maps on the scale 1: 50000 and (iii) High resolution digital globe image data from Google Earth through the software Map Graber 1.0.7 on a resolution of 7 m. Additional information of the Suketi watershed has been collected through field survey, reports and research studies.

Generation of Digital Input Maps

In the present study, Arc GIS (9.3) has been used in geo-registration and digitization of topological information at 1:50000 scale. Arc GIS is designed for basic visualization, generation of integrated database, computation of attribute data, spatial query and modeling. Thematic maps such as Digital Elevation Model (DEM) derived by digitizing the contours of Survey of India (SOI) topographic maps and ASTER 30 m resolution data with spatial analysis tools (Arc GIS 9.3) have been created, representing the watershed terrain (Fig.1). Spatial analysis tools uses logical, efficient and consistent algorithm compared to the manual approach of drainage extraction. Further, drainage on the topographic maps has been digitized and updated using the high resolution digital globe image data (derived from Map Graber 1.0.7 version software on a resolution of 7.0 m) from Google Earth for DEM manipulation. For proper determination of flow direction and flow accumulation, DEM sinks have been also identified and filled. The manipulated DEM is then used to generate the drainage network using the concept of channel

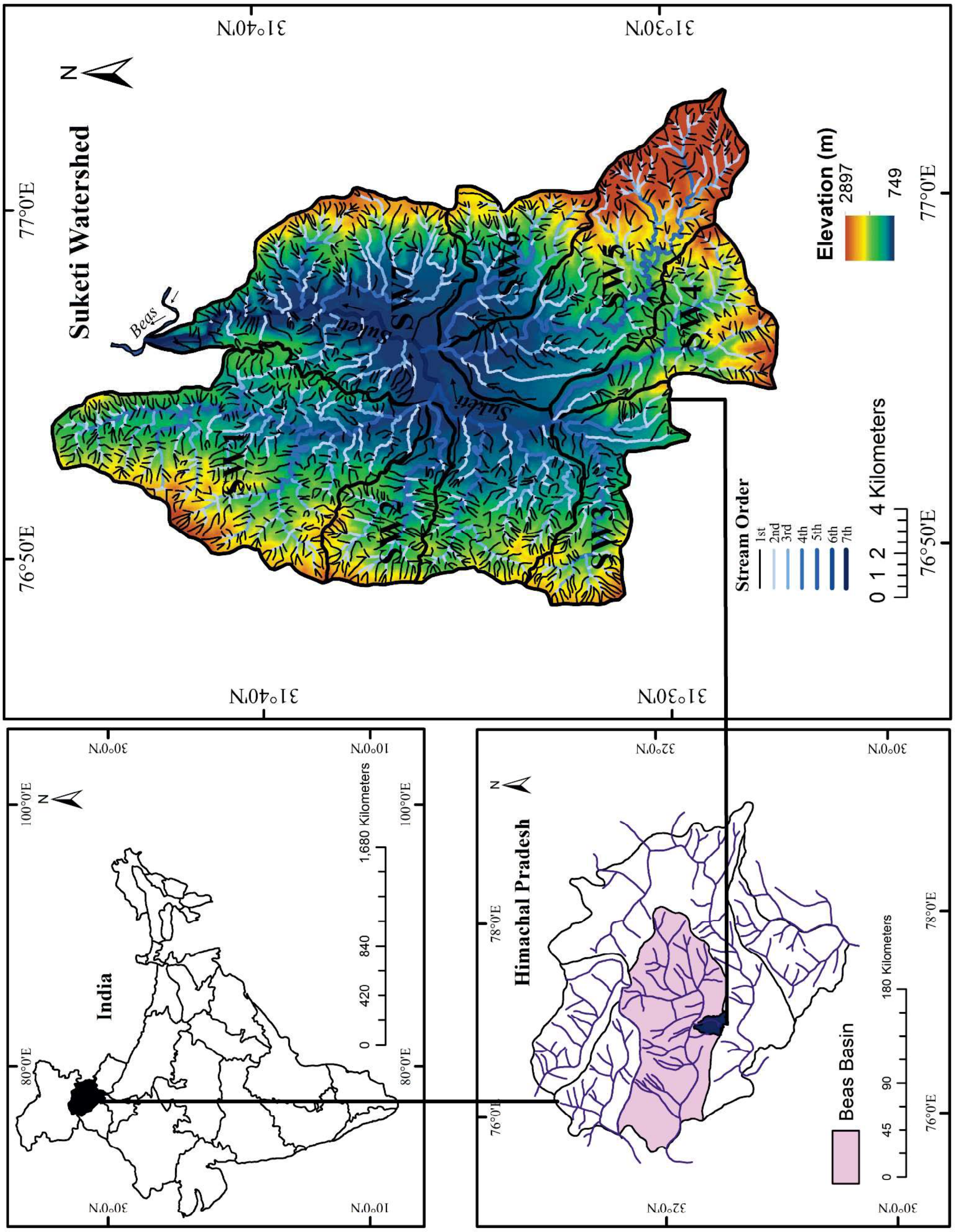
Suketi Watershed
N
Beas
Suketi
SW1
SW2
SW3
SW4
SW5
SW6
SW7
Elevation (m)
2897
749
Stream Order
1st
2nd
3rd
4th
5th
6th
7th
0 1 2 4 Kilometers
76°50'E
77°0'E
31°40'N
31°30'N
India
0 420 840 1,680 Kilometers
80°0'E
100°0'E
10°0'N
30°0'N
Himachal Pradesh
Beas Basin
0 45 90 180 Kilometers
76°0'E
78°0'E
32°0'N
30°0'N

Fig. 1

initiation threshold. The drainage networks thus generated have been ordered on the basis of Strahler's stream ordering method. The drainage and DEM generated in this manner have been further used to delineate the boundaries of Suketi watershed and its seven sub-watersheds (numbered as SW1 to SW7) by defining different pour points, the site where water drains out into the main river from entire watershed (Fig.1). From the delineated sub-watersheds the geomorphic parameters viz, area, slope and maximum, minimum and mean elevation levels have been derived. The delineation process generated the data required for relative area and elevation analysis.

Plotting of Hypsometric Curve (HC)

Hypsometric curve has been obtained by plotting the relative area (a/A) along the abscissa and relative elevation (h/H) along the ordinate of Suketi and its sub-watersheds (Fig. 2). 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) and expressed as (a/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) (up to the remote point of the sub-watershed from the outlet and expressed as h/H) (Ritter et al. 2002). This provides a measure of the distribution of landmass volume remaining beneath or above a basal reference plane.

Estimation of Hypsometric Integral (HI)

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. Hypsometric integral of each sub-watershed has been estimated through the elevation-relief ratio method as proposed by Pike and Wilson (1971). The relationship is expressed as:

$$\mathbf{E} \approx \mathbf{HI} = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{\min}}$$

where, E is the elevation-relief ratio equivalent to the hypsometric integral HI; $Elev_{mean}$ is the weighted mean elevation of the watershed estimated from the identifiable contours of the delineated watershed; $Elev_{\min}$ and $Elev_{\max}$ are the minimum and maximum elevations within the watershed.

The HC and HI values provide valuable information in deciding the geological stage of the development of the watershed systems. The threshold limits such as monadnock (old) (HI≤0.3), in which the watershed is fully stabilized; equilibrium or mature stage (HI 0.3-0.6); and inequilibrium or young stage (HI≥0.6), in which the watershed is highly susceptible to erosion as recommended by Strahler (1952) have been adopted for deciding the stage of the watershed development. Finally, based on the runoff generation characteristics of the sub-watersheds ranking have been done. The sub-watershed with highest HI values has been assigned rank 1 (lower ranking) and sub-watershed with lowest value was given higher ranking (Table 1). This ranking scheme has been taken up in prioritizing the sub-watersheds for suggesting suitable treatment measures.

Results and Discussion

Hypsometric Curve and its Relevance to Erosion

The HC for Suketi watershed and its sub-watersheds have been plotted and subsequently the shoulders of these curves have been studied (Fig. 2). The shoulders of any HC are a result of erosional processes in the watershed systems (Strahler, 1952, 1957). The shoulders of most of HC for Suketi and its sub-watersheds are concave in shape thereby indicating towards steep fall in the initial portion, lesser land mass above average elevation and high degree of dissection (Ritter,

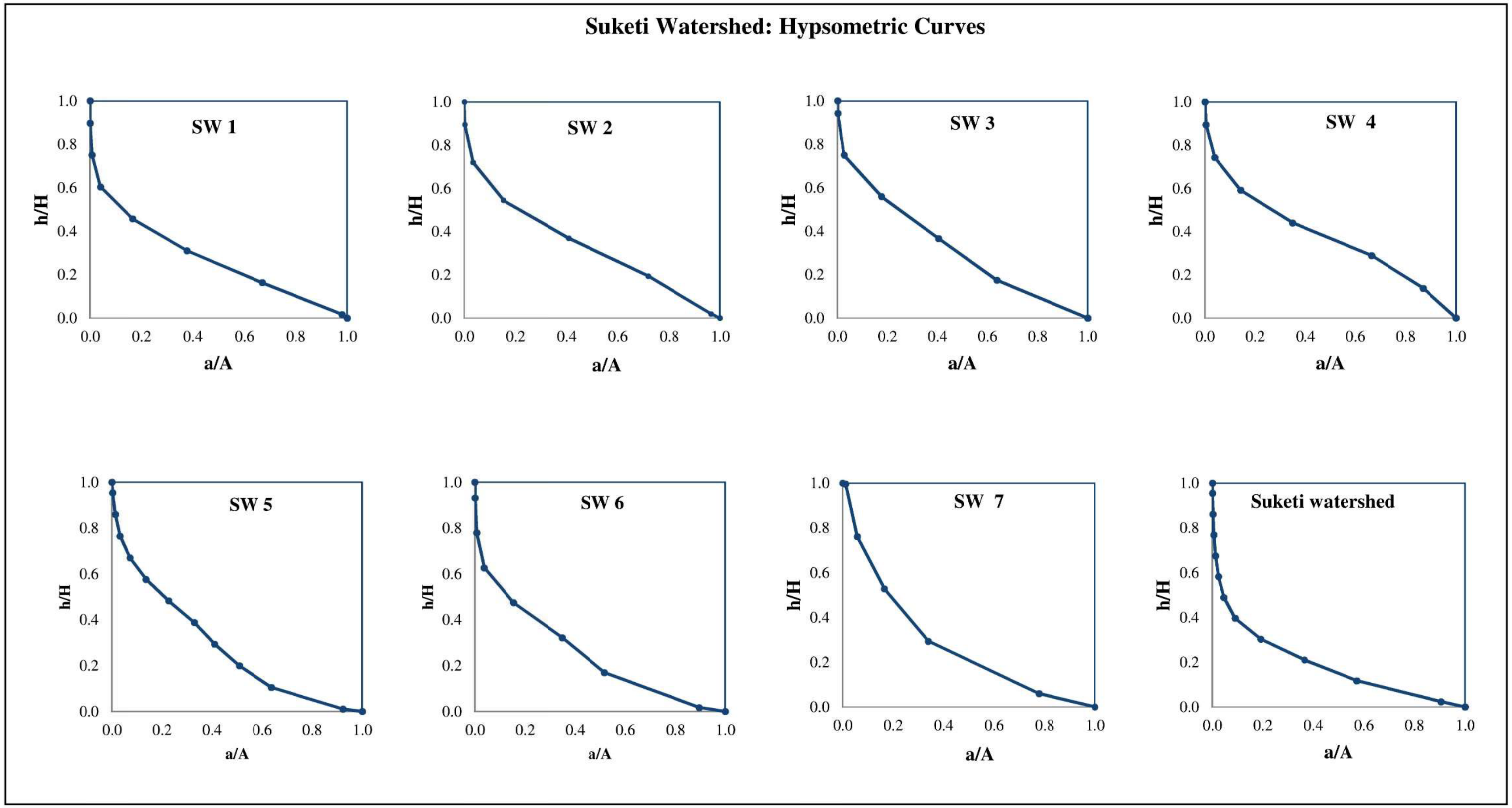
Suketi Watershed: Hypsometric Curves

Fig. 2

Table 1
Suketi Watershed: Estimated Hypsometric Values

Sub-watershed Code	Area (km^2)	Maximum Elevation (m)	Minimum Elevation (m)	Mean Elevation (m)	Slope (°)	Hypsometric Integral (HI)	Geological Stage	Prioritization Ranking
SW1	95.98	2040	778	1151	17.49	0.30	Monadnock	4
SW2	25.87	1920	778	1159	18.64	0.33	Mature	2
SW3	32.43	1860	818	1153	16.67	0.32	Mature	3
SW4	37.17	2140	818	1315	24.02	0.38	Mature	1
SW5	74.77	2897	778	1365	18.09	0.28	Monadnock	5
SW6	29.2	2090	778	1102	15.45	0.25	Monadnock	6
SW7	126.26	1604	749	984	13.49	0.28	Monadnock	5
Suketi	**421.69**	**2897**	**749**	**1151**	**16.95**	**0.19**	**Monadnock**	**-**

Source: Computed by Authors

2002). The comparisons between these curves indicate a marginal difference in mass removal from the Suketi and its sub-watersheds. These curves also reveal that the drainage system of Suketi and its sub-watersheds are attaining a monadnock (peneplanation) stage from the mature stage. However, these results are not in correspondence with other western Himalayan watershed systems because most of the studies have witnessed a mature stage from the youth stage (Singh et al., 2008). In addition, the high degree of dissection (soil erosion) or peneplanation stage in Suketi and its sub-watersheds may be the result of various factors such as incision from channel bed, downslope movement of bedrock material and top soil, slope wash, bank erosion and wash out of the soil mass etc.

Hypsometric Integral and Erosion

The HI value of entire Suketi watershed is 0.19 which suggests that only 19 per cent of the original landmass is available in the watershed, thereby it is less susceptible to erosion unless there are very high intense storms leading to high runoff peaks and sediment generation. Whereas, HI for sub-watersheds ranges from 0.25 to 0.38 (Table 1). These values of HI indicate that all the sub-watersheds are either in equilibrium or monadnock stage. Out of the 7 sub-watersheds, 3 sub-watersheds fall under equilibrium or mature stage and are moving towards stabilization, while 4 sub-watersheds fall under monadnock stage (less susceptible to erosion). Apart from this, SW4 may result in higher runoff and sediment loss on account of steep slope in comparison to other sub-watersheds (Table 1). The spatial distribution of HI reveals that most of the sub-watersheds in northern, central and south-eastern parts fall under monadnock stage whereas sub-watersheds on western and south-western parts comes under equilibrium or mature stage (Fig. 3). The spatial variations in HI values of sub-watersheds can be attributed to the kind of heterogeneity encountered by flowing water. Strahler (1957) stated that the hypsometric distribution is a function of basin age. However, Moglen and Bras (1995) demonstrated that stratification of underlying formation also controls the hypsometric distribution. In addition, Vivoni et al. (2008) stated that sub-watersheds with higher HI values indicate higher soil moisture in channel network, whereas sub-watersheds with lower HI values reveal soil moisture concentration at shallow depths. This means that sub-watersheds with lower HI values has less total runoff with major contribution from surface runoff, whereas, for sub-watersheds with higher HI values the total runoff is higher with sub-surface runoff as the major process.

Geological Characteristics and Hypsometric Integral

The geological characteristics of Suketi and its sub-watersheds have been analysed in association with HI values. It has been observed that most of Suketi watershed is composed of consolidated (43.4 per cent), semi-consolidated (36.5 per cent) and unconsolidated formations (20.1 per cent) (Fig. 4). Lithologically, consolidated formations consist of metamorphics and crystallines. These formations are older in age and as expected are reflected in lower HI values of SW5 and SW6. These sub-watersheds are less susceptible to erosion as compared to others. SW7 has low value of HI but it is located in lower altitudes and composed of Quaternary alluvium and valley fills. SW1, SW2 and SW3 have high values of HI on account of their location in semi-consolidated formations of Siwalik group which are relatively younger than consolidated formations. The high value of HI for SW4, a part of consolidated formations, is basically covered with resistant granite intrusions (Pophare and Balpande, 2014).

Watershed Prioritization and Management

The higher runoff generation characteristics of Suketi watershed is reflected in southern and western parts. It is therefore,

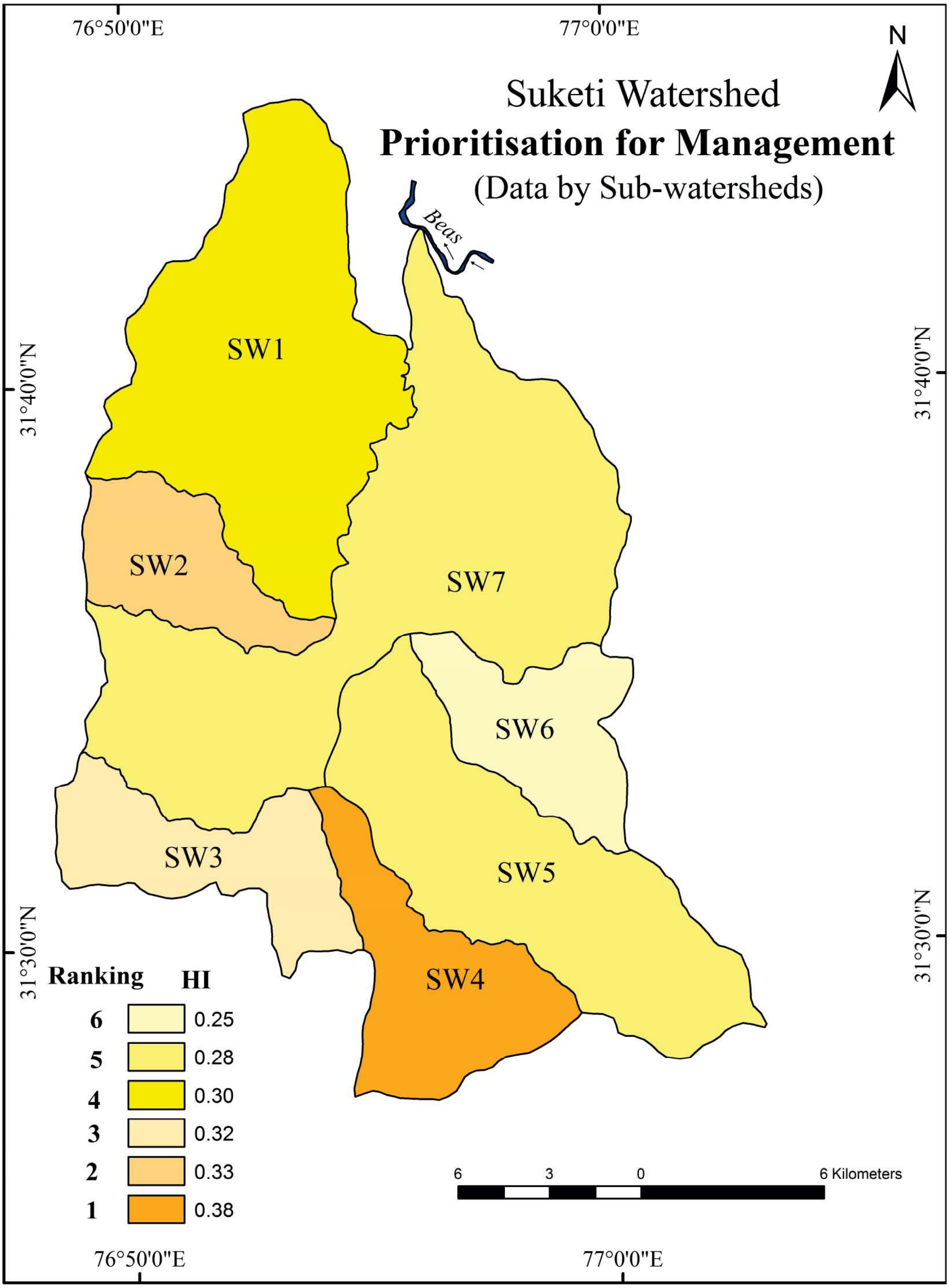
76°50'0"E
77°0'0"E
N
Suketi Watershed
Prioritisation for Management
(Data by Sub-watersheds)
Beas
31°40'0"N
31°30'0"N
SW1
SW2
SW3
SW4
SW5
SW6
SW7
Ranking HI
6 0.25
5 0.28
4 0.30
3 0.32
2 0.33
1 0.38
6 3 0 6 Kilometers

Fig. 3

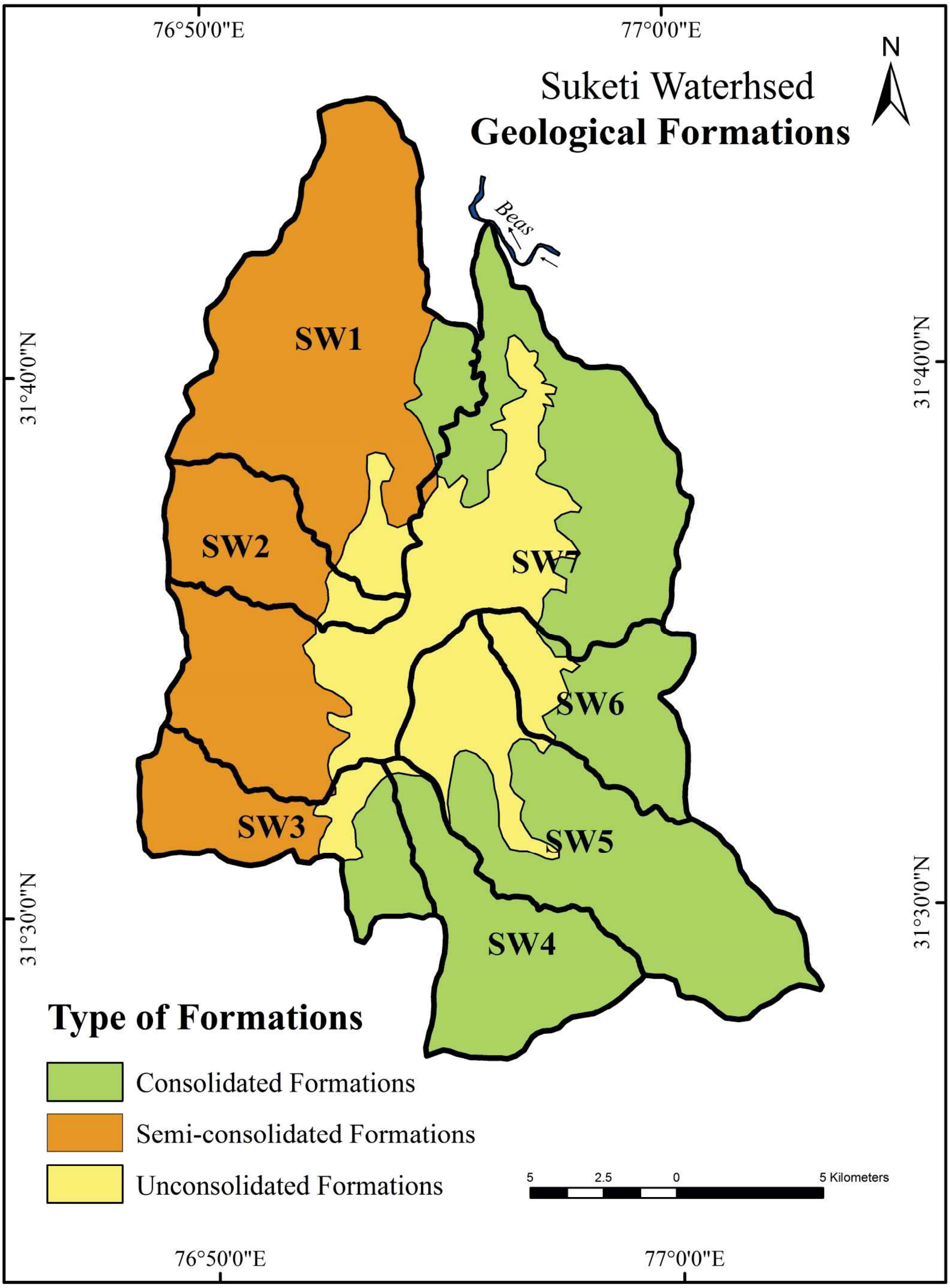
76°50'0"E
77°0'0"E
N
Suketi Waterhsed
Geological Formations
Beas
SW1
SW2
SW3
SW4
SW5
SW6
SW7
31°40'0"N
31°30'0"N
Type of Formations
Consolidated Formations
Semi-consolidated Formations
Unconsolidated Formations
5
2.5
0
5 Kilometers

Fig. 4

necessary to take up immediate steps to control the surface runoff in these parts of the watersheds. The HI value indicates that 3 sub-watersheds (SW2, SW3 and SW4) are contributing for maximum total runoff (Table 1). Therefore, HI values can be taken as an indicator for priority consideration of sub-watersheds. Once the sub-watersheds are identified, suitable measures of watershed management can be identified on the basis of finances available. For moderating and checking the surface runoff and subsequent sediment loss (erosion) in SW2, SW3 and SW4 both structural and non-structural measures are suggested in these sub-watersheds. The structural measures may include construction of water retention structures such as small reservoirs, berms, on farm retention basins, check dams and vegetative measures. Construction of these structures in SW2, SW3 and SW4 can store water for agriculture use (agronomic and livestock use), flood and drought mitigation, and improvement in water quality by capturing sediments, nutrients and pesticides. Apart from this, to identify the location for suitable measures, integrated maps of slope, drainage and land use need to be prepared so that the exact location of these structures installation could be identified. The non-structural measures for these sub-watersheds may include runoff (flood) forecasting and modification in traditional farming system.

Summary and Conclusions

Hypsometric analysis is useful to comprehend the erosion and runoff status of watershed systems and subsequently prioritize them for undertaking soil and water conservation measures. However, great care must be exercised in interpreting and comparing HC and HI on account of its complex nature of computation. Apart from this, in watersheds with scarce data on observed runoff and sediment yield these indicators (HC and HI) provide valuable insights into the dominant operational processes. Therefore, the use of hypsometry is a useful technique for planning soil and water conservation measures in watershed systems with scanty information. The specific conclusions drawn from the present study are:

- The analysis reveals that Suketi watershed as a whole is in monadnock stage of geologic development and therefore, erosive processes have stabilized.
- The shoulders of most of HC for Suketi and its sub-watersheds are concave in shape thereby indicating towards high degree of dissection.
- Lower values of HI have been observed in sub-watersheds having older geological formations, whereas high values of HI have been witnessed in sub-watersheds having younger formations.
- The study reveals that sub-watersheds SW2, SW3 and SW4 require attention for arresting the runoff and sediment loss on priority.
- For moderating and checking the surface runoff and erosion in SW2, SW3 and SW4 both structural and non-structural measures are suggested.

References

Dabral, P. P. 2003. Hypsometric analysis of Dikrong River basin of Arunachal Pradesh. *Journal of Soil and Water Conservation*, India, 2: 97-100.

Das, D. 2014. Identification of erosion prone areas by morphometric analysis using GIS. *Journal of Institutional Engineering India*, Series A, 95:61-74.

Goyal, M. K. 2014. Modelling of sediment yield prediction using M-5 model tree algorithm and wavelet regression. *Water Resources Management*, 28:1991-2003.

Jain, S.K., Singh, P., Saraf, A.K. and Seth, S.M. 2003. Estimation of sediment yield for a rain, snow and glacier fed river in the western Himalayan region. *Water Resources Management*, 17: 377-393.

Javed, A., Khanday, M.Y. and Rais, S. 2011.

Watershed prioritization using morphometric and land use/land cover parameters: a remote sensing and GIS based approach. *Journal of the Geological Society of India*, 78: 63-75.

Kumar, A., Devi, M. and Deshmukh, B. 2014. Integrated remote sensing and geographic information system Based RUSLE modeling for estimation of soil loss in western Himalaya, India. *Water Resources Management*, 28: 3307-3317.

Moglen, G.E. and Bras, R.L. 1995. The effect of spatial heterogeneities on geomorphic expression in a model of basin evolution. *Water Resources Research*, 31(10): 2613-2623.

Pandey, A., Chowdary, V.M. and Mal, B.C. 2004. Hypsometric analysis of watershed using geographic information system. *Journal of Soil and Water Conservation*, India, 3:123–127.

Patil, R.J., Sharma, S.K. and Tignath, S. 2015. Remote sensing and GIS based soil erosion assessment from an agricultural watershed. *Arabian Journal of Geosciences*, 8: 6967-6984.

Pike, R.J. and Wilson, S.E. 1971. Elevation-relief ratio, hypsometric integral and geomorphic area-altitude analysis. *Geological Society of American Bulletin London*, 82: 1079-1084.

Pimentel, D. 2006. Soil erosion: a food and environmental threat. *Environment Development and Sustainability*, 28:119-137.

Pimentel, D. and Burgess, M. 2013. Soil erosion threatens food production. *Agriculture*, 3(3):443-463.

Pophare, A.M. and Balpande, U.S. 2014. Morphometric analysis of Suketi river basin, Himachal Himalaya, India. *Journal of Earth System Science*, 123:1501-1515.

Ritter, D.F., Kochel, R.C. and Miller, J. R. 2002. *Process Geomorphology*. McGraw Hill, Boston: 652.

Sarma, S. and Saikia, T. 2012. Prioritization of sub-watersheds in Khanapura-Bornihat area of Assam-Meghalaya (India) based on land use and slope analysis using remote sensing and GIS. *Journals of the Indian Society of Remote Sensing*, 40: 435-446.

Schumm, S.A. 1956. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological Society of American Bulletin*, 67: 597-646.

Singh, O., Sarangi, A. and Sharma, M.C. 2008. Hypsometric integral estimation methods and its relevance on erosion status of north-western Lesser Himalayan watersheds. *Water Resources Management*, 22: 1545-1560.

Strahler, A.N. 1952. Hypsometric (Area-altitude) analysis of erosional topography. *Geological Society of American Bulletin*, 63:1117-1142.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. *Transactions of American Geophysical Union*, 38 (6): 913-920.

Sujatha, E.R., Selvakumar, R. and Rajasimman, B. 2014. Watershed prioritization of Palar sub-watershed based on morphometric and land use analysis. *Journal of Mountain Science*, 11: 906-916.

Valentin, C., Poesen, J. and Li, Y. 2005. Gully erosion: impacts, factors and control. *Catena* 63:132-153.

Vivoni, E.R., Di Benedetto, F., Grimaldi, S. and Eltahir, E.A.B. 2008. Hypsometric control on surface and subsurface runoff. *Water Resources Research*, 44: W12502.

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