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Integrated watershed modeling and characterization using GIS and remote sensing techniques

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ABSTRACT

The digital revolution in the last few decades made possible the modeling of watershed by integration of different hydrologic processes occurring on the watershed. The recent advances in watershed modeling are the integrated use of numerical methods, remote sensing and GIS technologies. Numerical methods are used in the solution of the prevailing equations for the soil erosion modelling, landslide hazard zonation, sediment yield estimation, and rainfall runoff simulation. Remote sensing technology solved the problem of data needs of watershed modeling. ArcGIS made its utility in the processing of large quantities of data, which is essential in watershed modeling. In the present paper, characterization of watershed for the key parameters such as morphometric analysis, slope analysis, LULC change pattern analysis by using GIS / RS data has been discussed. Morphometric and slope analysis have carried out by DEM based model, soil erosion modelling based on USLE model, surface runoff modelling based on SCS model, landslide hazard zonation based on multicriteria model, and sediment yield estimation based on InVEST model have been presented in this paper, and has prepared the watershed characteristic maps. LULC of the watershed has been derived from remotely sensed data, which has used as an input of all analysis/modelling. The methodology can be used in various watershed development schemes.

Key Words: Watershed characterization, GIS based modelling, remote sensing.

1. INTRODUCTION

Land and water are the most vital natural resource of the country and these are under tremendous stress due to ever increasing biotic pressure (Gawande, 2002). The optimal management of these resources with minimum adverse environmental impact is essential not only for sustainable development but also for human survival. Watershed is an ideal unit calling for multidisciplinary approach to the resources management for ensuring continuous benefit on sustainable basis. Integrated watershed management is a prerequisite not only for land, water and bio-mass management of degraded areas but also for conservation of protection areas so that bio-diversity and genetic riches are protected for future generations. The purpose of this paper is to provide a general description of the Siul river watershed with the intent of identifying opportunities for implementation to improve the condition of the Watershed. A review of the physical, biological and chemical condition of the Watershed, as well as the social components will serve to identify areas that may be in need of some type of watershed project, or may respond well to project implementation. This paper specifically addresses the following aspects of the Watershed i.e. landuse, geology, geomorphology, river morphometry, soil, soil erosion, climate, hydrology, surface runoff,

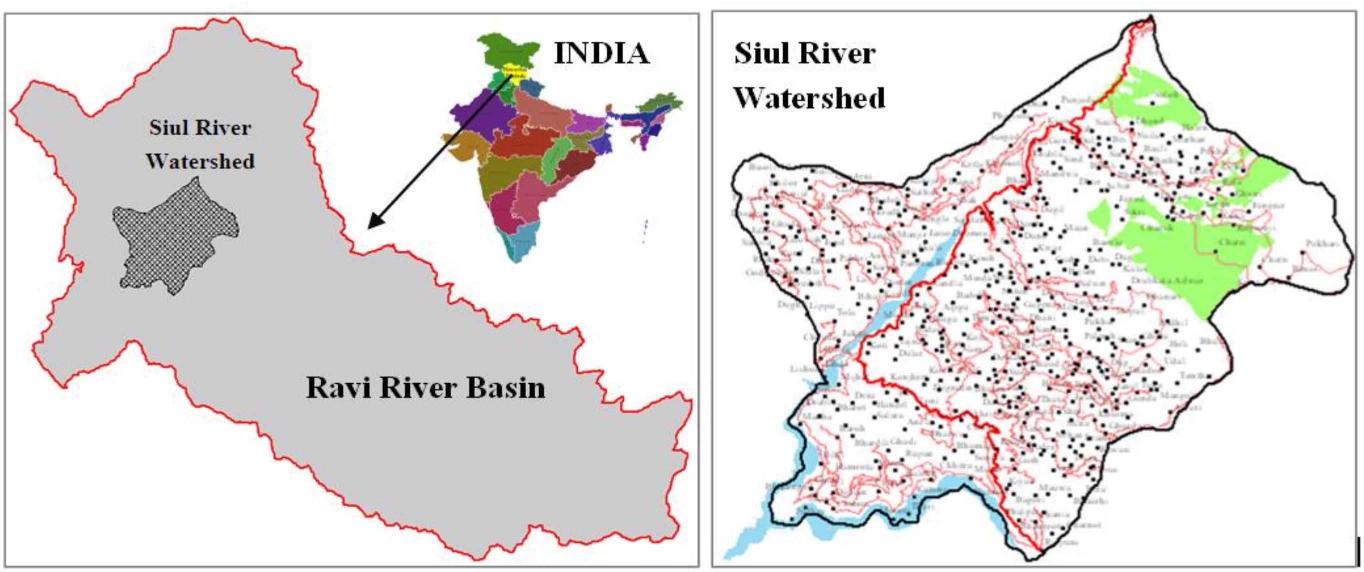

Figure 1
Location map of the study area

sedimentation, demography, socio-economic, habitat, and landslide.

2. DESCRIPTION OF THE STUDY AREA

Siul River is a moderate size northern sub-tributary of the river Ravi, and originating at the North-east part of Gamgul Siva Behi Wildlife Sanctuary (Biddi Village) about 3029m of Chamba district (32°55'52.13" N Latitude, and 75°49'24.78" E Longitude), it is flow essentially SE, then SW and over 71.83 km to join the Ravi River near the Ranjit Sagar Dam (Thein Dam) of Chamba district of Himachal Pradesh (Fig. 1). The watershed area of Siul River is 238.18 Sq. Kms. & situated between 32.59 to 32.77 N latitude and 75.99 to 76.22 E longitudes. Though there is no main tributaries of the Siul River, there are some small tributaries pouring into the river, notable amongst there are Sunri Nala, Suledh Nala, Kupdeni Nala, Kuleoh Nala, Koln Nala, Khared Nala, Bhstlun Nala, & Bhattu Nala on the right bank, and Patned Nala, & Ghrat Nala on the left bank. The study area falls in Survey of India (1:50,000) toposheets No I-43-V-14, I-43-W-01, and I-43-W-02.

3. DATA USED AND METHODOLOGY

The methodology for this study involves the following steps.

Table 1 Different data layers / maps and sources

S. No.	Data Layer / Maps	Source
1.	Topographical Map	- Topographical Map, Survey of India (1:50,000) - No. I-43-V-14, I-43-W-01, and I-43-W-02
2.	Remote Sensing Data	- IRS-P6 (ResourceSAT-1) LISS-IV Mx Satellite Imagery with 5.8 m Spatial Resolution - IRS-P6 (ResourceSAT-1) LISS-III Satellite Imagery with 23.5 m Spatial Resolution - LANDSAT-7 ETM+ Satellite Imagery with 30.0 m Spatial Resolution
3.	Geological Map	- Chamba District Geological Map has been collected from GSI and updated through IRS-P6 LISS-IV Satellite Remote Sensing Data with Limited Field Check
4.	Geomorphological Map	- Landforms & geomorphological map have been prepared by using satellite remote sensing techniques with limited field check
5.	Morphometric Analysis	- Quantitative analysis has been done based on SOI toposheets @ 1:50,000 Scale / ASTER (DEM) @ 30m Spatial Resolution / CartoSAT-1 (DEM) @ 30m Spatial Resolution & different morphometric parameters have been generated in GIS environment
6.	Slope Map	- Slope map has been created using Spatial Analyst Extension in ArcGIS-10 software, and ASTER (DEM) @ 30m Spatial Resolution / CartoSAT-1 (DEM) @ 30m Spatial Resolution
7.	Drainage Map	- Drainage network has been generated in GIS environment using ASTER (DEM) data, CartoSAT-1 (DEM) Data and ArcHydro Tool in ESRI ArcGIS-10 software
8.	Land Use / Land Cover Map	- Land use and land cover map have been prepared by using IRS-P6 (ResourceSAT-1) LISS-IV Mx Satellite Imagery, and it was verified through limited field check
9.	Soil Map	- Soil map of Chamba district has been collected from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) and updated through Satellite Data
10.	Climatic Data	- Climatic Data i.e. Rainfall, Temperature, Relative humidity & Wind Speed have been collected from Indian Meteorological Department (IMD)
11.	Demographic Map	- Census of India, 2011

4. REGIONAL SETTING

4.1. General geology

In order to understand the geological aspect of the study area, a general lithological map has been prepared with the help of IRS-P6 (ResourceSAT-1) LISS-IV Mx (5.8m), LISS-IIII (23.5m), and Landsat-7 ETM+ (30m) satellite imageries (Fig. 2). Through the general geology of the area has been mapped by the GSI in the usually way, various their similar have contributed to diverse geological aspects of the study area. Notable among these are [19], [12], [56], [13], [28], [58], [4], [63], [8], and [7] etc. They recorded the principal rock formations namely Alluvial Plain, Bhulai Formation, Chamba Formation, Dalhousie Granite, Kalhel Limestone, Manjir Conglomerate, Pukhri Slates, and Salooni Formation.

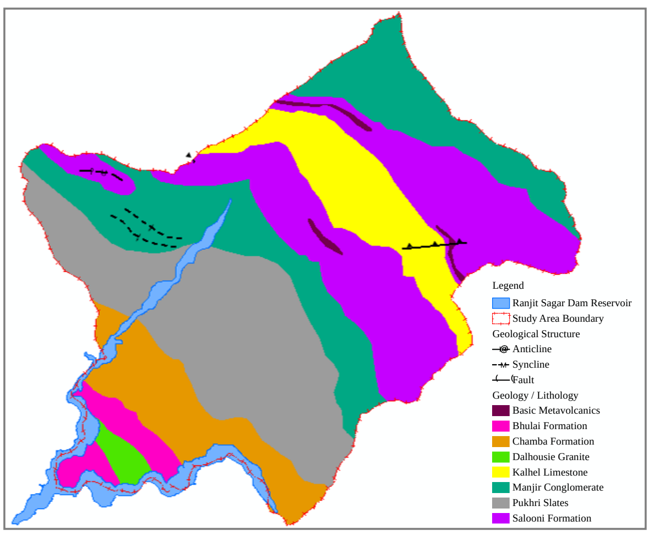

Figure 2
Geological map

4.2 Geomorphology

The use of remote sensing technology for geomorphological studies has definitely increased its importance due to the establishment of its direct relationship with allied disciplines, such as, geology, soils, vegetation / landuse & hydrology [44]. The remote sensing and GIS technology is ideal for morphometric analysis and geomorphological studies since terrain does control movement and accumulation of surface and groundwater [47]. The authors have prepared a geomorphological map by using IRS-P6 (ResourceSAT-1) LISS-IV Mx (5.8m), LISS-IIII (23.5m), and Landsat-7 ETM+ (30m), SoI maps of 1:50,000 scale, and field observations. Geological map (structural and lithological) has also referred. The geomorphology of the study area is intimately related with the geological and tectonic history of the Himalaya. The Siul watershed presents an intricate mosaic of mountain ranges, hills and valleys. It is primarily a hilly watershed with altitudes ranging from 1513 m amsl to 5563 m amsl. Physiographically the area forms part of middle Himalayas with high peaks ranging in height from 756 m to 3098 m amsl. It is a region of complex folding, which has under gone many orogeneses. The topography of the area is rugged with high mountains and deep dissected by river Tundah and its tributaries. Physiographically the watershed can be divided in to two units-viz. (i) high hills, which cover almost entire watershed, (ii) few valley fills.

4.3. Soil type

The soil map was generated in GIS environment using soil map collected from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) - Nagpur and were updated using IRS-P6 (ResourceSAT-1) LISS-IV Mx (5.8m), LISS-IIII (23.5m), and Landsat-7 ETM+ (30m) multi-spectral satellite imageries. The soil map obtained from the NBSS&LUP was geo-metrically registered to the base data to match Landsat & IRS satellite imageries. The geo-referenced soil map was used to assist in visual classification of satellite imagery for obtaining soil categories. The final vector map was stored in a geo-database which is amenable to spatial analyze (Fig. 3). Major soil type of the study area is coarse loamy soils, fine loamy soils, loamy skeletal soils, sandy soils, and rock outcrops.

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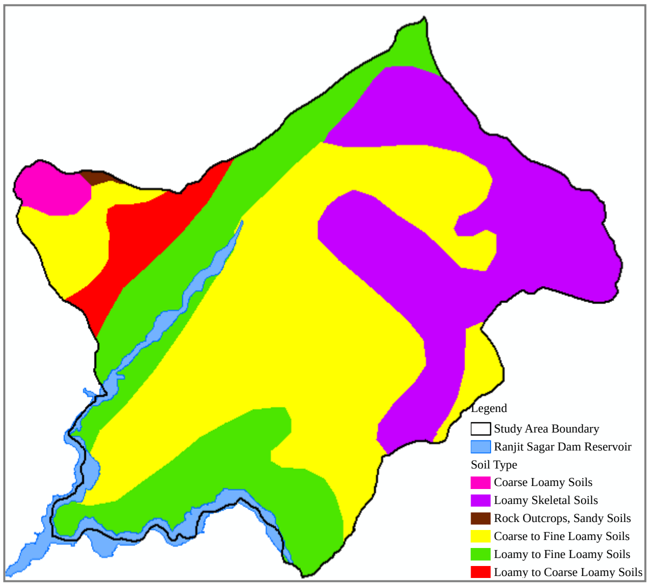

Figure 3
Soil map

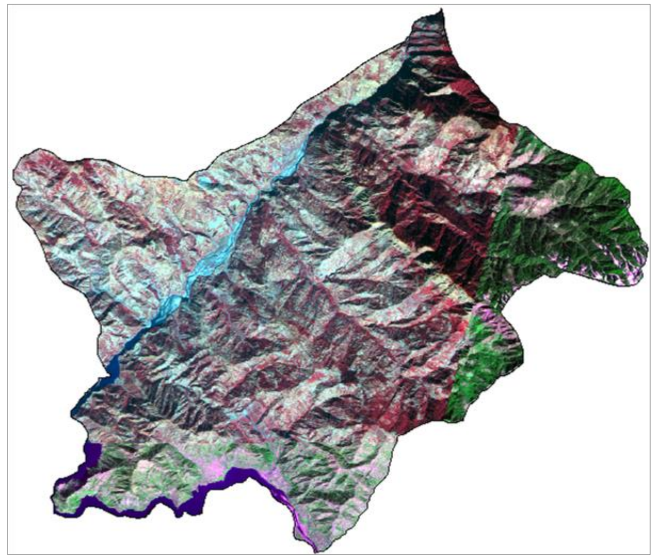

Figure 4
IRS-P6 (ResourceSAT-1) LISS-IV Mx satellite imagery with 5.8m spatial resolution

4.4. Land use and land cover

Land is the most important natural resource, which embodies soil, water and associated flora and fauna involving the total ecosystem. Comprehensive information on the spatial distribution of land use / land cover categories and the pattern of their change is a prerequisite for management and utilization of the land resources of the study area. The land use pattern of any terrain is a reflection of the complex physical processes acting upon the surface of the earth. These processes include impact of climate, geologic and topographic conditions on the distribution of soils, vegetation and occurrence of water. For better development and management of the catchment areas of reservoirs, it is necessary to have timely and reliable information on environmental status.

Land use and land cover are play important role in instability of slope [3]. Extensive investigations have shown that land-use cover or vegetation cover, especially of a woody type with strong and large root systems, helps to improve stability of slopes [21]; [22]. Vegetation provides both hydrological and mechanical effects that generally are beneficial to the stability of slopes. The land use pattern of any terrain is a reflection of the complex physical processes acting upon the surface of the earth [11]. These processes include impact of climate, geologic and topographic conditions on the distribution of soils, vegetation and occurrence of water.

Keeping the above views in mind, the authors have prepared a land use / land cover map (Fig. 5) using IRS-P6 (ResourceSAT-1) LISS-IV Mx (5.8m) (Fig. 4) multi-spectral satellite imagery.

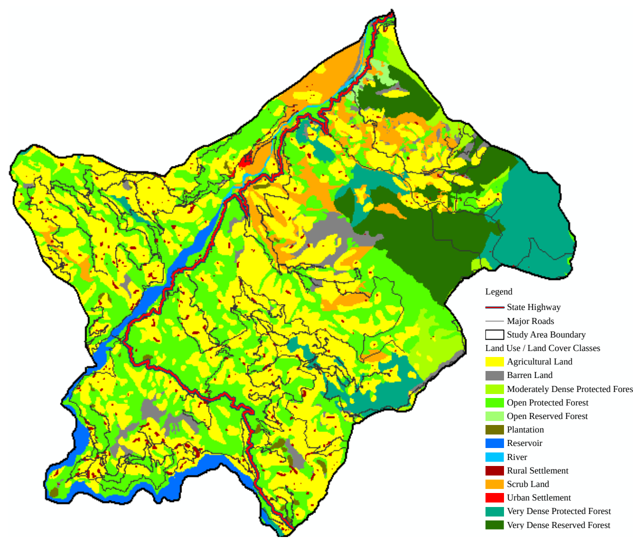

Figure 5
Land use / land cover map - 2012

4.5. Climate data

Climate data used in the USLE model, SCS model, SYI model, and landslide hazard zone model consists of daily rainfall, temperature, wind speed, humidity and evapotranspiration data. These data have been collected for the period of 2007 to 2011 by Directorate of Land Records, H.P., Indian Meteorological Department (IMD) Station, and using LocClim v1.10 software. The climate data was able to provide continuous and complete data ranging from the years 2008 to 2011, which was used in the model simulations.

5. MORPHOMETRIC ANALYSIS

The measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landform provides the basis of the investigation of maps for a geomorphological survey. This approach has recently been termed as Morphometry. The area, altitude, volume, slope, profile and texture of landforms comprise principal parameters of investigation. [14], [10] applied various methods for landform analysis, which could be classified in different ways and their results presented in the form of graphs, maps or statistical indices.

The morphometric analysis of the Siul watershed was carried out on the Survey of India topographical maps No I43V14, I43W01, and I43W02 on the scale 1:50,000 and CartoSAT-1 DEM with 30m spatial resolution. The lengths of the streams, areas of the watershed were measured by using ArcGIS-10 software, and stream ordering has been generated using [53], [54] system, and ArcHydro tool in ArcGIS-10 software. We have used several method for linear, areal and relief aspects studies i.e. [24], [25] for stream ordering, stream number, stream length, stream length ratio, bifurcation ratio, length of overland flow, rho coefficient, form factor, & stream frequency; [53], [54], [55] for weighted mean bifurcation ratio, mean stream length, ruggedness number, & hypsometric analysis; [62] for sinuosity index analysis; [32] for channel & valley index. [46] for basin area, length of the basin, elongation ratio, texture ratio, relief ratio & constant of channel maintenance; [23] for length area relation; [10] for lemniscate's; [31] for circularity ratio; [50] for drainage texture; [20] for compactness coefficient; [29], [30] for fitness ratio, & drainage density; [49] for wandering ratio; [6] for watershed eccentricity; [15] for drainage intensity; [59] for slope analysis, and [37] for erosion analysis.

5.1. Linear aspects

5.1.1. Stream order (Su)

Stream ordering is the first step of quantitative analysis of the watershed. The stream ordering systems has first advocated by [25] but [53], [54] has proposed this ordering system with some modifications. Authors have been carried out the stream ordering based on the method proposed by Strahler (Table 2). It has observed that the maximum frequency is in the case of first order streams. It has also noticed that there is a decrease in stream frequency as the stream order increases (Fig. 6).

5.1.2. Stream number (Nu)
The total order wise stream segments are known as stream number. [25] states that the numbers of stream segments of each order form an inverse geometric sequence with order number (Table 2).

5.1.3. Stream length (Lu)
The total stream lengths of the Siul watershed have various orders, which have computed with the help of SOI topographical sheets, CartoSAT-1 DEM, and ArcGIS software. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in watershed of increasing order [55]. Authors have been computed the stream length based on the law proposed by [25] as shown in Table 2.

5.1.4. Bifurcation ratio (Rb)
The bifurcation ratio is the ratio of the number of the stream segments of given order 'Nu' to the number of streams in the next higher order (Nu+1) (Table 2), [25] considered the bifurcation ratio as index of relief and dissertation [54], demonstrated that bifurcation shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. It is observed from the Rb is not same from one order to its next order these irregularities are dependent upon the geological and lithological development of the drainage basin [55]. The bifurcation ratio is dimensionless property and generally ranges from 3.0 to 5.0. The lower values of Rb are characteristics of the watersheds, which have suffered less structural disturbances [55] and the drainage pattern has not been distorted because of the structural disturbances [33]. In the present study, the higher values of Rb indicates strong structural control on the drainage pattern, while the lower values indicative of watershed that are not affect by structural disturbances.

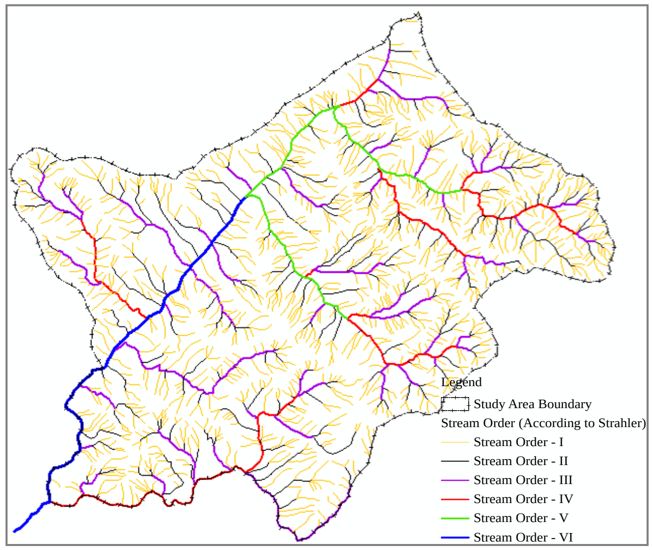

Figure 6
Stream order map

5.1.5. Mean stream length (Lum)
Mean Stream length is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces [55]. It is obtained by dividing the total length of stream of an order by total number of segments in the order (Table 2).

5.1.6. Length of overland flow (Lg)
Use this term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels [25]. Since this length of overland flow, at an average, is about half the distance between the stream channels, Horton, for the sake of convenience, had taken it to be roughly equal to half the reciprocal of the drainage density. In this study, the length of overland flow of the Siul river watershed is 0.13 Kms (Table 2), which shows low surface runoff of the study area.

Table 2 Linear aspects of Siul river watershed

S. No.	Stream Order (Su)	Stream Number (Nu)	Bifurcation Ratio (Rb)	Stream Length (Lu)	Mean Stream Length (Lum)	Length of Overland Flow (Lg)
1	I	1148		564.81		0.13
2	II	220	5.22	149.39	3.78	
3	III	50	4.40	78.11	1.91	
4	IV	10	5.00	38.93	2.01	
5	V	3	3.33	18.31	2.13	
6	VI	1	3.00	17.27	1.06	
	Total	1432	866.83	20.95	10.89	
			Average	4.19	2.18	

5.2. Areal aspects
5.2.1. Form factor (Ff)
According to [25] form factor may be defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.754 (for a perfectly circular watershed). Smaller the value of form factor, more elongated will be the watershed. The watershed with high form factors have high peak flows of shorter duration, whereas elongated watershed with low form factor ranges from 0.44 indicating them to be elongated in shape and flow for longer duration (Table 3).

5.2.2. Elongation ratio (Re)
According to [46] elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (less than 0.5). The elongation ration of Siul watershed is 0.75, which is represented the watershed is less elongated to oval (Table 3).

5.2.3. Texture Ratio (Rt)
According to [46] texture ratio is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. The texture ratio is expressed as the ratio between the first order streams and perimeter of the basin ($Rt = N_l / P$) and it depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. In the present study, the texture ratio of the watershed is 14.44 and categorized as high in nature (Table 3).

5.2.4. Circularity ratio (Rc)
For the out-line form of watershed [55], [31] used a dimensionless circularity ratio as a quantitative method. Circularity ratio is defined as the ratio of watershed area to the area of a circle having the same perimeter as the watershed and it is pretentious by the lithological character of the watershed. Miller et al. (1960) has described the basin of the circularity ratios range 0.4 to 0.7, which indicates strongly elongated and highly permeable homogenous geologic materials. The circularity ratio value (0.47) of the watershed corroborates the Miller's range, which indicating that the watershed is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition (Table 3).

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Table 3 Areal aspects of Siul river watershed			
S. No.	Morphometric Parameter	Formula	Result
1	Basin Area (A) Sq Kms	-	238.18
2	Basin Length (Lb) Kms	-	23.36
3	Basin Perimeter (P) Kms	-	79.49
4	Length Area Relation (Lar)	$Lar = 1.4 * A^{0.6}$	37.35
5	Form Factor Ratio (Rf)	$Ff = A / Lb^2$	0.44
6	Shape Factor Ratio (Rs)	$Sf = Lb^2 / A$	2.29
7	Elongation Ratio (Re)	$Re = 2 / Lb * (A / \pi)^{0.5}$	0.75
8	Texture Ratio (Rt)	Rt = N1 / P	14.44
9	Circularity Ratio (Rc)	$Rc = 12.57 * (A / P^2)$	0.47
10	Circularity Ration (Rcn)	Rcn = A / P	3.00
11	Drainage Texture (Dt)	Dt = Nu / P	18.01
12	Compactness Coefficient (Cc)	$Cc = 0.2841 * P / A^{0.5}$	1.46
13	Drainage Density (Dd) Km / Kms2	Dd = Lu / A	3.64

5.2.5. Drainage texture (Dt)

Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines. Drainage texture is on the underlying lithology, infiltration capacity and relief aspect of the terrain. Dt is total number of stream segments of all orders per perimeter of that area [25]. [50] has classified drainage texture into five different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). In the present study, the drainage texture of the watershed is 18.01 (Table 3). It indicates that category is very fine drainage texture.

5.2.6. Compactness coefficient (Cc)

According to [20] compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. The Cc is independent of size of watershed and dependent only on the slope. The authors have computed the compactness coefficient of Siul river watershed, which is 1.46 (Table 3).

5.2.7. Drainage density (Dd)

Drainage density is the stream length per unit area in region of watershed [25], [30], [53], and [54] are another element of drainage analysis. Drainage density is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology and structures and relief history of the region can finally use as an indirect indicator to explain, those variables as well as the morphogenesis of landform. Authors have calculated the drainage density by using Spatial Analyst Tool in ArcGIS-10, which are 3.64 Km/Km^2 indicating moderate drainage densities (Table 3). It is suggested that the moderate drainage density indicates the basin is moderate permeable sub-soil and thick vegetative cover [33].

5.3. Relief aspects

5.3.1. Relief ratio (Rhl)

Difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line [46]. The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin suggested by Schumm who found that sediments loose per unit area is closely correlated with relief ratios. In the study area, the value of relief ratio is 110.00 (Table 4). It has been observed that areas with low to moderate relief and slope are characterized by moderate value of relief ratios. Low value of relief ratios are mainly due to the resistant basement rocks of the basin and low degree of slope.

Table 4 Relief aspects of Siul river watershed			
S. No.	Morphometric Parameter	Formula	Result
1	Height of Basin Mouth (z) m	-	756.00
2	Maximum Height of the Basin (Z) m	-	3327.00
3	Total Basin Relief (H) m	H = Z - z	2571.00
4	Relief Ratio (Rhl)	Rhl = H / Lb	110.00
5	Dissection Index (Dis)	Dis = H / Ra	0.77
6	Ruggedness Number (Rn)	Rn = Dd * (H / 1000)	9.36

5.3.2. Dissection index (Dis)

Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed [48]. On average, the values of Dis vary between‘0’ (complete absence of vertical dissection/erosion and hence dominance of flat surface) and‘1’ (in exceptional cases, vertical cliffs, it may be at vertical escarpment of hill slope or at seashore). Dis value of Siul river watershed is 0.77 (Table 4), which indicate the watershed is a moderate dissected.

5.3.3. Ruggedness number (Rn)

Ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length [55]. Calculated accordingly, the Siul river watershed has a ruggedness number of 9.36 (Table 4). The low ruggedness value of watershed implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density.

5.3.4. Slope analysis

Slope is the most important and specific feature of the earth's surface form. Maximum slope line is well marked in the direction of a channel reaching downwards on the ground surface. In any region valley slopes, occupy most of the area of erosional relief in greater extent in comparison to flood plains, river terraces and other local depositional landforms. In geomorphology, the slope is combined effect of 'form' (Environmental conditions of slopes such as the geology, climate and vegetal cover) and 'process' (agents, such as soil creep, surface wash and the process of weathering). 'Form' and 'Processes' - both have existed right from the remote past. The sequence of the past forms prepares the way for the present ones, and this constitutes the evolution of a slope. The average level over much of the Siul watershed varies between 756 m to 3327 m above mean sea level though extreme values ranges from 756 m in the south-west (Ranjit Sagar ‘Thein’ Dam) to 3327 m in the north-east (Pukhari Dhar).

Recently a major source of elevation information for the whole world was SRTM / ASTER providing digital elevation model of the world at a spatial resolution of 90 m. While fortunately by the time this study was conducted Indian coverage of CartoSAT-1 based digital elevation model (DEM) is released. This DEM (Fig. 7) has a spatial resolution of 30m which makes it captures more detailed information then SRTM / ASTER base DEM. A slope map (Fig. 8) and slope aspect map (Fig. 9) of the study area were generated using 3D analyst and spatial analyst extension in ArcGIS by using IRS-P5 CartoSAT-1 based DEM.

6. SOIL EROSION MODELLING

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water [17], [61], and [27]. The major forces originate from raindrop impact and flowing water.

6.1. The Universal Soil Loss Equation (USLE)

Soil loss is defined as the amount of soil lost in a specified time period over an area of land which has experienced net soil loss. The Universal Soil Loss Equation was developed by [61] to estimate the average annual soil loss occurring over an area. Soil conservationists around the world use the Universal Soil Loss Equation to estimate soil erosion rates by water. The equation provides an estimate of the Soil Loss Rate in Ton ha^{-1} y^{-1}. The USLE computes soil erosion as the product of six factors representing rainfall erosivity, soil erodibility, slope length, slope steepness, cover management practices, and support conservation practices [45]. This paper uses the USLE (Universal Soil Loss Equation) to predict annual soil loss from agricultural lands. The USLE equation is summarized as [61]:

$A = R * K * LS * C * P$ ……………………... (1)

Where:

A = Estimated average annual soil loss; computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in ton × $acre^{-1}$ × yr^{-1}, but other units can be selected (that is, ton × ha^{-1} × yr^{-1}).

R = Rain erosivity factor; the erosive power of rainfall which is calculated as the product of the kinetic energy of the storm event and the 30 minute intensity.

K = Soil erodibility factor; the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6 feet (22.1 m) length of uniform 9% slope in continuous clean-tilled fallow.

L = Slope length factor; the ratio of soil loss from the field slope length to soil loss from a 72.6 feet length under identical conditions.

S = Slope steepness factor; the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C = Cover management factor; the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P = Support practice factor; the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight-row farming up and down the slope.

6.2. Soil erosion calculation

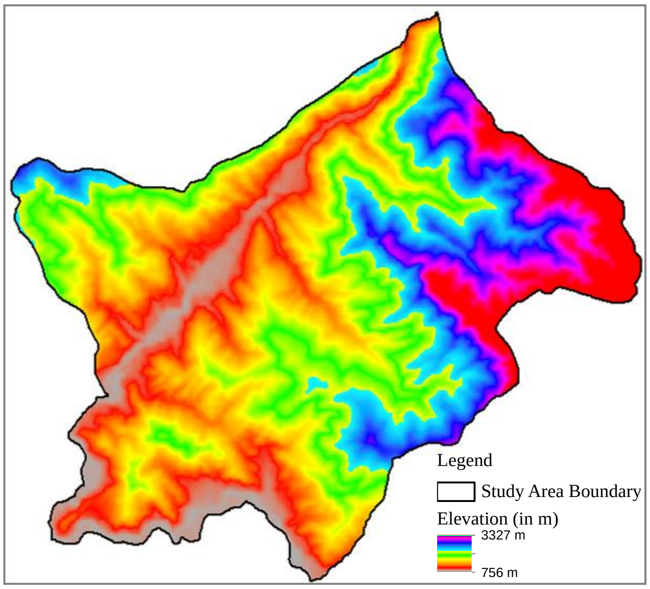

Figure 7

IRS-P5 CartpSAT-1 DEM with 30m spatial resolution

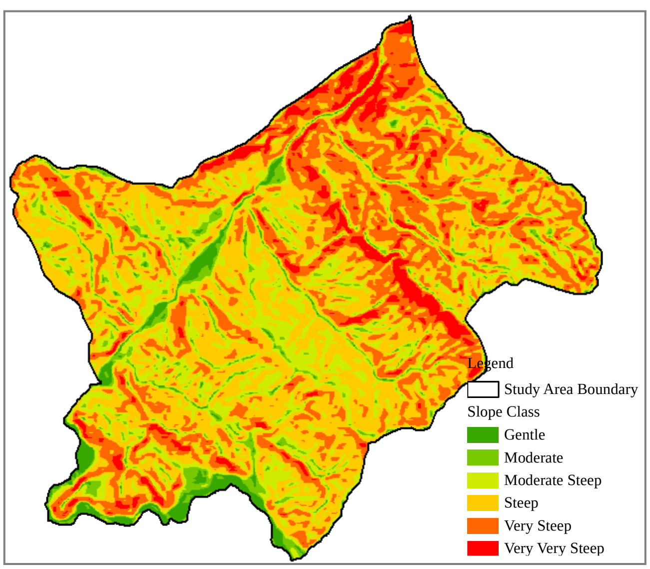

Figure 8

Slope map

Authors have calculated soil erosion using the USLE model in Raster

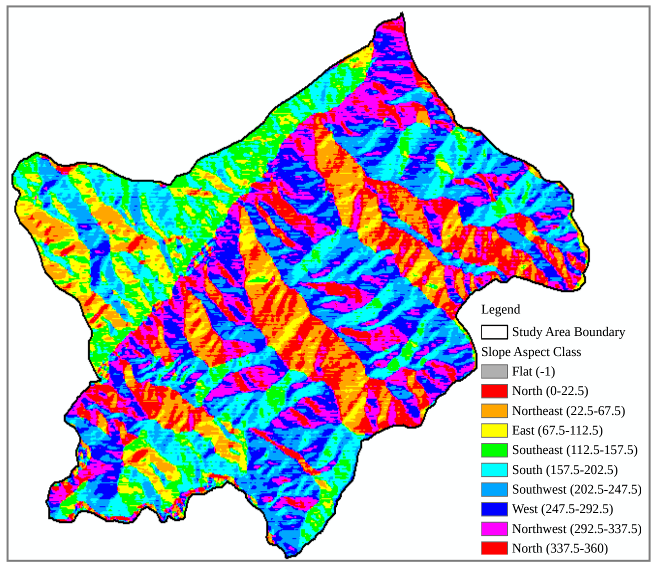

Figure 9

Slope aspect map

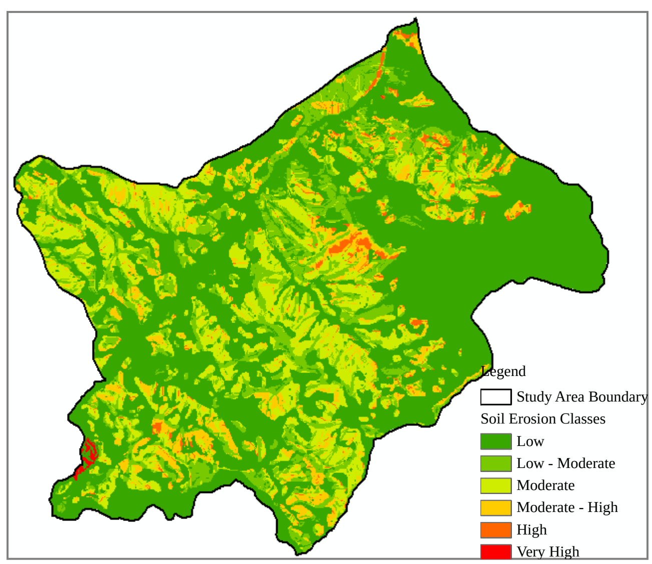

Figure 10

Soil erosion map

Calculator - Map Algebra - Spatial Analyst Tools in ArcGIS-10 software. The study provides overall insight into causes of soil erosion resulting from interaction of the USLE factors spatially and quantitatively. The total soil loss effective area in Siul river watershed is only 23.33% (Fig. 10). The study of soil loss should, therefore, be conducted in terms of quantity and extent. It has become increasingly apparent that computer based GIS and remote sensing can provide the means to model soil erosion effectively. Result of this study gives an erosion range of 1.71 - 65.16 tons/ha/yr. As compared to 31-125 tons/ha/yr. reported by Wichaidit [60], also using USLE model. Variation in the results is due apparently to variations in the values of each of the factors used, in particular, the slope classes and the C factor.

7. SURFACE RUNOFF MODELLING

Conservation structures in a watershed should be designed to handle flows of eater from rainfall or melting snow. Surface runoff constitutes the hydraulic load that the structure should withstand. Surface runoff is that part of precipitation which during and immediately after a storm event, appears as flowing water in that part of precipitation which and immediately after a storm event, appears as flowing water in the drainage network of a watershed. Such flow may result from direct movement of water over the surface of watershed, precipitation in excess of abstraction demands, or it may result from emergence of soil water into waterways. Before surface runoff may occur, precipitation should satisfy the demands of evapotranspiration, interception, infiltration, surface storage, surface detention and channel detention. Surface runoff occurs only when the rate of precipitation exceeds the rate of infiltration. After satisfaction of infiltration, water begins to fill the depression. As the depression are filled overland flow starts. The water depth builds is surface detention. As the water moves into the drainage network of a watershed there is a similar buildup of water in channel detention. The amount of water in surface and channel detention is returned to surface runoff as the flow subsides. The water in surface storage infiltrates into the soil but does not percolate down to reach the ground water table. It moves laterally to join the stream below and is called sub surface flow. The part of the water that percolates further down may reach the ground water. Depending upon the hydraulic gradient a portion of the ground water moves and joins the stream downwards. This is called ground water flow.

7.1. Soil conservation service (SCS - CN) method

The Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1956) is based on the water balance equation and two fundamental concepts. The first concept equates the ratio of the actual amount of direct surface runoff (Pe) to the total rainfall (P) (or maximum potential surface runoff) to the actual infiltration (F) to the amount of the potential maximum retention (S). The secondary concept is the initial abstraction (Ia) to the potential maximum retention. Thus, the SCS-CN method consists of (i) water balance equation, (ii) proportional equation concept, and (iii) Ia-S concept, which, respectively, can be expressed as:

$P = Pe + Ia + Fa$ ………………….... (2)

$Pe / (P - Ia) = Fa / S$ ………………….... (3)

$Ia = Lamda\ S$ ………………….... (4)

Where: P = Total rainfall, Ia = Initial Abstraction, Fa = Cumulative Infiltration excluding, Pe = Direct Runoff, and S = Potential maximum relation or infiltration.

All quantities in equation (2) - (4) are in depth or volumetric units.

Parameter S of the SCS - CN method depends on the soil type, land use, hydrologic condition, antecedent moisture condition (AMC). The initial abstraction accounts for the short-term losses, such as interception, surface storage, and infiltration. The existing SCS-CN method assumes lamda to be equal to 0.2 for practical applications. Many other studies carried out in the United States and other countries report lamda to vary in the range of (0, 0.3).

Combining equation (2) and equation (3), the popular from of the SCS-CN method is obtained as follows:

$Pe = (P - Ia)^2 / (P - Ia + S)$ ………………….... (5)

The SCS method with initial abstraction consideration is given below:

$Q = (P - 0.3\ S)^2 / (P + 0.7\ S)$ ………………….... (6)

Where, Q = Runoff depth (mm), P = Rainfall (mm), S = Maximum recharge capacity of watershed after 5 days rainfall antecedent, and Ia = 0.3S (Initial abstraction of rainfall by soil and vegetation, mm)

Equation (5) is valid for P>Ia, Pe = 0 other wise. Thus, the existing SCS-CN method with lamda = 0.2 is a one–parameter model for computing surface runoff from daily storm rainfall, originally developed using daily rainfall-runoff data of annual extreme flows some others described the physical significance of parameter S of equation (5) as the maximum difference of (P - Pe) that can occur for the given storm and watershed conditions. Since parameters S can vary in the range of $0<S<\infty$, it is mapped into a dimensionless curve number (CN), varying in a more appealing range $0<CN<100$, as follows:

$S = (1000 / CN) - 10$ ………………….... (7)

The maximum potential retention, S is calculated using following relationship:

$S = (25400 / CN) - 254$ ………………….... (8)

Where S is inches, and CN = Curve number

The underlying difference between S and CN is that the former is a dimensional quantity [L] whereas the latter is a non-dimensional quantity. Although CN theoretically varies from 0 to 100, the practical design values validated by experience lie in the range (40, 98)

$S = (25400 / CN) - 254$ ………………….... (9)

CN has been calculated from standard table for different land use and conservation practices. Since, it has different situations; the weighted CN has been worked out in the following manner:

Weighted Curve Number (WCN) = $\sum (CNi * Ai) / A$ ………………….... (10)

Where: WCN = Weighted Curve Number, CNi = Curve number from 1 to any no N, Ai = Area with curve number CNi, and A = the total area of the watershed

Thus, the WCN corresponding to Antecedent Moisture Condition - II (AMC-II) condition is taken for the watershed. The equivalent curve number for dry (AMC-I) or wet condition (AMC-III) has been deduced from the normal condition (AMC-II) from the following equation:

$CN (I) = \{4.2 * CN (II)\} / \{10 - 0.058 * CN (II)\}$ ………………….... (11)

$CN (III) = \{23 * CN (II)\} / \{10 + 0.13 * CN (II)\}$ ………………….... (12)

The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. Typical curve numbers for moisture condition II are listed in standard table for various land covers and soil type (SCS Engineering Division). These values are appropriate for a 5% slope.

7.2. Result of SCS model

To compute the surface runoff in Siul river watershed, the SCS model has been employed. The SCS model is based on daily rainfall data. For generation of HSG map, authors have used and overlapped the classified land use / land cover map & soil map. Consequently, 33 different land cover * HSG classes have been identified during the study period. For different land cover types and HSG, the runoff curve numbers for AMC II have selected from the standard table.

Curve number maps has been created linking the attribute values of CN to combine land cover * HSG map. Classified runoff potential maps can be generated by reclassifying the CN value into three zones: moderate (less than 50), high (51 - 75), and very high (76 - 100). In this case, no runoff potential zones of low and normal categories have been identified. In order to estimate the annual depth, all the parameters needed for the SCS model have calculated using the SCS equation. The monthly runoff depths and mean monthly discharge have estimated using the SCS model and tabulated in the Table 5. The total surface runoff in Siul river watershed is 861.38 mm.

Table 5 Monthly mean precipitation and surface runoff

S. No.	Months	Precipitation (mm)	Total Surface Runoff (mm)
1.	January	193.20	1.39

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2.	February	178.81	1.38
3.	March	138.82	0.01
4.	April	69.10	0.00
5.	May	42.21	0.00
6.	June	189.39	49.28
7.	July	556.91	322.43
8.	August	605.69	364.37
9.	September	319.68	122.47
10.	October	88.80	0.03
11.	November	8.21	0.00
12.	December	86.97	0.00
	Yearly	2,477.79	861.38

8. SEDIMENT YIELD INDEX MODELING

Investigation of basins for conservation planning is expensive, and therefore requires a selective approach to identify smaller hydrological units which would be suitable for more efficient and targeted resource management programmes [1]. The identification of these critical sub-basins which need soil and water conservation measures on a preferential basis is particularly important in hilly arid/semiarid basins subject to heavy rainfall. A criterion which can be used to determine priority for conservation planning, therefore, may be the maximum sediment yield of a basin. The use of the Sediment Yield Index (SYI) model developed by the All India Soil and Land Use Survey, Government of India, is a well-known means of providing criteria for priority delineation in river valley projects and flood prone rivers [2]. The SYI conceptualizes sediment delivery into the water body as a multiplicative function of potential soil detachment representing the erosivity factor (weightage value) and transportability of the detached material (delivery ratio value).

8.1. Sediment yield index (SYI)

The study area is composed of weathering-prone Pukhri Slates, Chamba Formation, Bhulai Formation, Salooni Formation country rock, facilitating easy transport of fine silt material. The silt yield in the area has been calculated using the following relation (Vito A Vanoni, 1975; Bali & Karale 1977). Sediment Yield Index (SYI) is calculated in percentage for all the micro-watersheds (Table 6).

$SYI = [(A_{ei} * W_{ei} * SDR) / A_w] *100$

Where: SYI = Sediment Yield Index, Aei = Area under Erosion Intensity Unit 'i', Wei = Weightage Value Assigned to Unit 'i', SDR = Sediment Delivery Ratio of Micro-Watershed, Aw = Area of Micro-Watershed

8.2. Sediment delivery ratio

The relationships between SDR and other factors have been established as curves. Watersheds with large drainage area and the fields with a long distance to the streams have a low sediment delivery ratio. This is because large areas have more chances to trap soil particles, thus the chance of soil particles reaching the water channel system is low. Roughly speaking, SDR is closely related to the power of -0.2 to the drainage area or the distance to the stream. Some others suggested the power of -0.1 and -0.3 in the function. The relationships have been generalized as curves called SDR curves. The SDR curves include SDR vs. drainage area and SDR vs. distance. The drainage area method is most often and widely used in estimating the sediment delivery ratios in previous research [57] used the data from 300 watersheds throughout the world to develop a model by the power function. This model is considered a more generalized one to estimate SDR.

$SDR = 0.42\ A^{-0.125}$

Where A = Drainage Area in Square Miles

The delivery ratio is an important parameter for the estimation of sediment yield index of a reservoir (Table 6). This value ranges from 0.28 to 0.95 for different micro- watersheds. This can be ascribed to the area, which is inversely proportional to the delivery ratio. Integrating the weightage values for the parameters such as topography, slope, vegetation cover and erosion have arrived at the weightage factors for each of the 16 micro-watersheds. The weightage factors vary from 1 to 13 depending upon geomorphological features of the micro-watersheds. The highest weightage factors (more than 10) are obtained for five micro-watersheds i.e. Td2b, Tf1d, Tf1f, Tf1h, and Th1a. Micro-watershed wise sediment yield index are shown in Table 6.

Table 6 Parameters for calculation of silt yield index of the study area

S. No.	MWS Code	MWS Area (Aw) (in Sq Kms)	Area under Erosion Intensity (Aei)	Weightage Value Assigned (Wei)	Sediment Delivery Ratio (SDR)	Sediment Yield Index (SYI)
1	Td2a	21.99	0.75	8	0.29	7.83
2	Td2b	25.84	0.98	10	0.28	10.56
3	Tf1a	5.35	0.16	4	0.34	4.14
4	Tf1b	24.75	0.81	9	0.28	8.33
5	Tf1c	10.66	0.34	5	0.31	5.02
6	Tf1d	27.09	1.06	11	0.28	12.00
7	Tf1f	25.41	1.38	13	0.28	19.73
8	Tf1g	28.22	0.47	7	0.28	3.26
9	Tf1h	14.16	1.26	12	0.30	32.12
10	Tf1j	10.67	0.43	6	0.31	7.52
11	Tf2a	2.23	0.05	3	0.38	2.78
12	Tf2b	5.57	0.01	2	0.34	0.09
13	Th1a	15.08	0.80	9	0.30	14.35
14	Th1b	13.57	0.44	6	0.30	5.93
15	Th1c	7.57	0.33	5	0.33	7.18
16	Th2h	0.00	0.00	1	0.95	6.39
Total		238.18	9.29			

9. LANDSLIDE HAZARD ZONATION

The landslide examination and hazard zonation mapping study involves preparation of number of thematic databases such as terrain slope, terrain height, drainage density/drainage pattern, soil type, vegetation type, geology/lithology, land use / land cover, transportation and climate of the area. The digitized maps are given as input into the ArcGIS-10. Here, the various thematic layers were prepared by using satellite imagery. The landslide hazard zonation maps have an important role in planning and development schemes in mountainous regions [3]. These maps are useful for identification of unstable zones in the mountainous regions. These input data for preparing risk maps, which are helpful in landslide hazards management. A landslide-susceptibility map indicates relatively potential zones such as low, medium, medium high, high and very high for landslide occurrence. There could be several approaches to prepare a landslide-susceptibility map. Several parameters and their classes are chosen and weights are assigned according to their potential to cause a landslide. The landslide susceptibility map has been prepared by computing landslide potential index and classifying landslide potential index into several landslide susceptible zones such as low, medium, high and very high. The landslide potential index is defined as:

Landslide Potential Index = $\sum_{i=1}^{n} (R_i * W_i)$

Where Ri denotes the rank for factor i and Wi denotes the weight of class of factor i. In this study the total number of factors (n) is 8, where weight of class varies from 0 to 8.

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9.1. Rank and weights of factors for landslide

The landslide hazards evaluation factor weights scheme is a numerical system which depends on the relevant factor. Ranks and weights of causative factors (parameters) need to be assigned in order to generate a landslide-susceptibility map. The relevant factor for landslide hazards zonation mapping shall include the major factors are terrain slope, terrain height, drainage density/drainage pattern, soil type, vegetation type, geology/lithology, land use / land cover, transportation and climate etc. the stability of an area depends on the combined effects of the factors indicated above. The maximum landslide hazards evolution factor weights for different categories are determined on the basis of their estimated significance in causing instability. The important factors responsible for the landslides area were assigned numerical values (rank) on a 1 to 8 scale in order of importance. Weights were assigned to the classes of the factors on 0 to 8 ordinal scales, where higher weight indicates a greater susceptibility to landslide occurrence. The details of ranks and weights for factors and their classes are presented in Table 7. After collecting pertinent data from the available sources described earlier, initial data maps were re-classed according to the weights given in Table 7.

Table 7 Rank and weights of factors for landslide

Factor	Classes	Ranks (R_i)	Weights (W_i)	Remarks
Terrain Slope		8		Steeper slopes (<40^0) are highly prone to landslide, but the slope below 10^0 have low susceptibility to the absence of debris over the slope surface.
	> 5		1	
	5 - 10		2	
	10 - 20		3	
	20 - 30		5	
	30 - 40		7	
	< 40		8	
Terrain Height		7		Terrain height more than 2000m is highly prone to landslide, because the presences of debris and fragments etc.
	< 1000		1	
	1000 - 1500 m		2	
	1500 - 2000 m		3	
	2000 - 2500 m		5	
	2500 - 3000 m		6	
	> 3000 m		8	
Drainage Density		6		When drainage is less, there is more possibility of infiltration, thereby increasing the pore pressure to result in landslide.
	Low		1	
	Low Medium		2	
	Medium		5	
	High		7	
	Very High		8	
Soil Type		5		Fine loamy soil is highly prone to landslide, due to colluvium parent material.
	Rock Outcrops		2	
	Sandy Soils		3	
	Coarse Loamy Soils		6	
	Loamy Skeletal Soils		7	
	Fine Loamy Soils		8	
Vegetation		4		Barren land has a higher susceptibility to landslides, and other has lower susceptibility.
	Dense Vegetation		1	
	Sparse Vegetation		5	
	Barren Land		8	
Geology		3		Pukhri Slates and Salooni Formation are highly susceptible due to the presence of debris, fault, trust, etc.
	Alluvial Plain		1	
	Dalhousie Granite		2	
	Manjir Conglomerate		3	
	Bhulai Formation		4	
	Kalhel Limestone		5	
	Chamba Formation		6	
	Salooni Formation		7	
	Pukhri Slates		8	
Landuse		2		Improper landuse such as scrub land, agricultural land, and vegetation have a higher susceptibility to landslides. Reserved/protected forest due to the presence of deep root bindings has lower susceptibility.
	Water Features / River		1	
	Reserved Forest		2	
	Protected Forest		3	
	Plantation		4	
	Open Forest		5	
	Settlement		6	
	Agricultural Land		7	
	Scrub / Barren Land		8	
Slope Aspect		1		North, northeast, northwest have a higher susceptibility to landslides due to wind direction, direct sunlight, rainfall
	Flat		1	
	South		1	
	South-West		2	
	South-East		3	
	East		4	
	West		5	
	North-West		6	
	North-East		7	
	North		8	

9.2. Total Estimated Landslide Hazard Zonation (TELHZ) Values

The landslide model is created and the ranks and weights are assigned to each category. Based on themes and its impacts different zones were delineated.

TELHZ Value = $T_{SL}+T_{HI}+D_{DE}+S_{TY}+V_{GN}+G_{EO}+L_{UC}+S_{AS}$

Where: LHZ Value = Sum of Ratings of all Causative Factors, T_{SL} = Terrain Slope, T_{HI} = Terrain Height, D_{DE} = Drainage Density, S_{TY} = Soil Type, V_{GN} = Vegetation Type, G_{EO} = Geology, L_{UC} = Land Use / Land Cover, and S_{AS} = Slope Aspect

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On the basis of TELHZ Value landslide hazard zonation map was classify in five categories, and shown in Fig. 11.

10. CONCLUSION

Remote sensng and GIS has become an indispensable scientific tool for mapping and monitoring of natural resource, and frequently used in the modeling, characterization, and prioritization of watershed for planning. The information generated with respect to geology, geomorphology, soil, topography, river morphology, land use / land cover through remote sensing and GIS can be interpreted for various themes viz. land capability analysis, morphometric analysis, soil erosion estimation, surface runoff calculation, sediment yield estimation, landslide hazard zonation, and crop suitability etc. for better management and conservation of these resources on watershed and village basis.

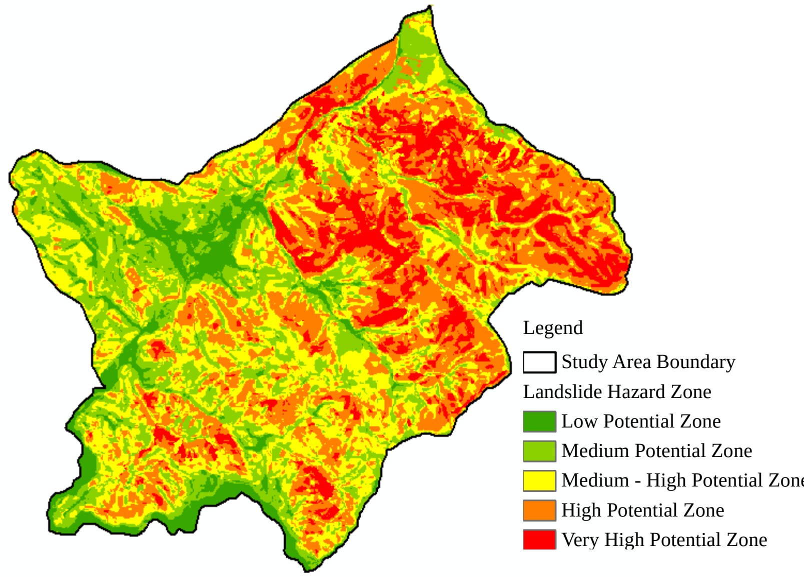

Figure 11
Landslide hazard zonation map

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