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Soil Erosion Assessment of River Catchment Area: A GIS Approach

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Abstract

The study demonstrates the potentiality of satellite remote sensing technique for preparation of more consistent and accurate baseline information on soil erosion. The calculation of annual soil erosion (E) shows that the annual soil erosion is also increased from 7.32 mm/year in 2000 to 8.97 mm/year in year 2005. On the basis of inputs, NDVI of study area and slope, the output of annual soil erosion of both years shows that mainly soil erosion increased in the northern part of the study area. The annual soil erosion is nearly same in the low land areas. The spatial information generated on soil erosion can be utilized for various reclamation measures and other uses for the different level planning.

Keywords: *Annual soil erosion, NDVI, remote sensing.*

1. Introduction

India is riverine country and soil erosion is a serious problem not only in India but it is a global issue because it happens everywhere in the world every day, every month, every year and every decade because of the deforestation, overgrazing and intensive agriculture due to population pressure, have caused accelerated erosion, natural phenomena inducing erosion such as exceptional rains, earthquake, and glacial-lake-outburst flooding. In India about 29% of the total eroded soil is lost permanently to the sea and 10% percent of it is deposited in reservoirs. The remaining 61% is dislocated from one place to the other. Accelerated soil erosion has adverse economic and environmental impact. Soil erosion is the sum of the terrain characterization signifies the sum of all physical features and conditions at or near the earth surface. Soil erosion can be defined as removal of top layer by natural agents like sun, wind, water and by man either natural or geographical erosion or artificial or accelerated soil erosion. Honda et.al (1999) evaluated the soil erosion problem in Thailand by using Normalized Difference Vegetation Index (NDVI) derived from Remote Sensing data (Landsat-TM) was used in the study to assess the vegetation cover in the watershed. Ravichandran et.al (2006) focused on the estimation of rate of soil erosion, using Revised Universal Soil Loss Eq. 2 (RUSLE2), in the Veppanapalli sub watershed of Krishnagiri catchment located in Tamil Nadu, India. Estimation of the soil erosion of Dikrong river basin of Arunachal Pradesh (India) using USLE Dabral et.al (2008). Douros et.al (2009) tested a modified version of the Universal Soil Loss Equation (USLE) for assessing the risks of erosion in Chalkidiki, Greece.

2. Study Area

The study site is selected keeping in view the area covering different forest types, structure and undergrowth conditions. Southern part of the Doon valley of the Dehra Dun district of Uttarakhand state (latitude 30° 2’ 45” to 30° 27' 30” N; longitude 78° 00' to 78° 20' E) was selected for the study. The terrain of the area is irregular and undulating. Figure 1 shows the location of the study area.

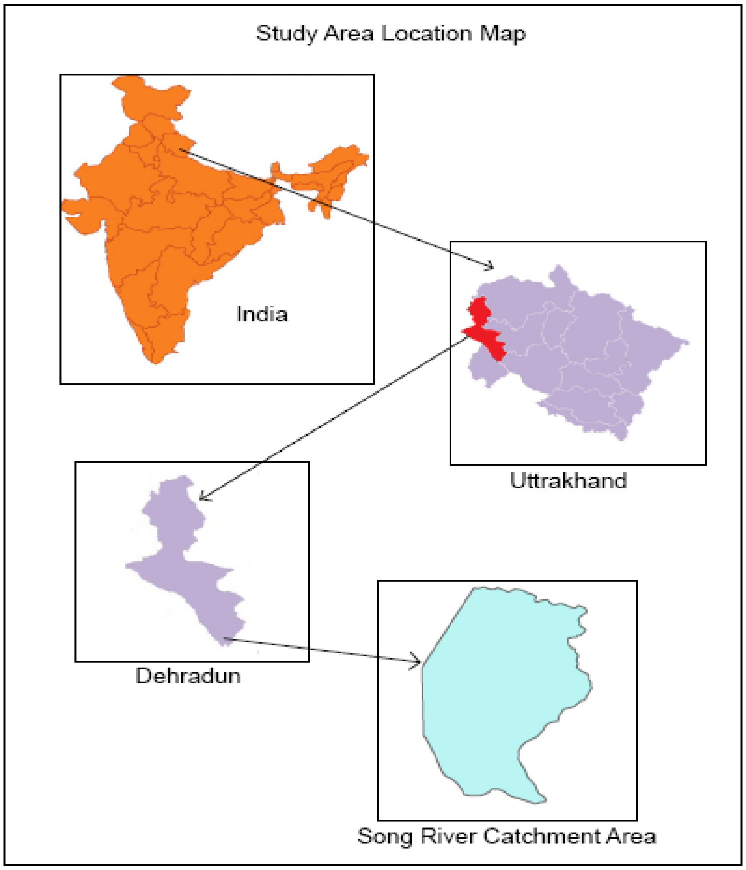

Figure 1: Study Area

The study area belongs to sub tropical semiarid of India's central and northern belt. It is also influenced by humid tropical monsoon. The average annual rainfall is about 1170 mm and average rainy days is about 72 days (as per IMD, Dehradun), most of which is received during the months of July to September due to South-west monsoon with maximum temperature of 29.4°C and minimum 15.1°C. The average temperature recorded is 23.3 degree centigrade June being the hottest month while January is the coldest one. The highest percentage of humidity i.e. 72 to 85 % is found during the rainy season at the lower range of humidity between 29 to 51.5 % is recorded in the summers.
In study area, roughly 70 % of the land is under Agriculture/forest use still the region is of little importance from the point of view of pastures.. The major land use of the study area is forest (open forest and dense forest), plantation (orchard mango), agriculture (wheat), scrub (barren land, fallow land and river bed), and settlement (habitation).
Physiography of the area varies from plain area until hilly, since the study area is a part of southern slope of Shiwalik Hill, the denudational, colluvial and alluvial process form Physiography of area. Relief of the area is very complex varies from 309 m to 2734 from mean sea level. The soil texture varies from loamy sand until clay loam

3. Material and Methods

3.1 Data Used

3.1.1 Satellite Image

The satellite images were used to compare the land cover changes in a time scale of 5 years. The first image was taken by the LANDSAT (Enhanced Thematic Mapper – ETM) satellite on the December

2000. The second satellite image available for the purpose of this study was acquired on December 2005. It contains 8 bands, 3 visible (blue, green and red), tree infrared, one thermal and one panchromatic band.

3.1.2 Survey of India Toposheets

SOI Toposheets on 1:50,000 scale are used for Geo-referencing and contour digitization.

3.2 Image Processing and GIS Software used

- ERDAS Imagine 9.1
- Arc Map 9.3
- MS Office 2007

3.3 Methodology

3.3.1 Geo-Referencing

Geo-reference the Landsat-ETM image of both years with SOI toposheet in ERDAS and then clipped by the study area shapefile (catchment area of Song river).

3.3.2 Digitization of Contours:

Contour interval represents the vertical distance between contour lines. Contours are digitized by identifying the contour lines on SOI toposheets. Shapefiles have been created using ARC Map 9.1. Contours are digitized in the interval of 20 m.

3.3.3 Digital Elevation Model and Slope Map Generation

DEM represents a regular array of elevation point. Then Digital Elevation Model is prepared by surface create command, inputting Contour shapefile, prepared from 1:50,000 scale topographic maps Slope measures the rate of change of elevation at a surface location. Similarly slope map was prepared from the same topographic maps.

3.3.4 Supervised Classification

Supervised classification is performed with a set of target class and then create the appropriate signatures from the data. Supervised classification was done of the images of both years (2000 and 2005) by providing sample sets.

3.3.5 Preparation NDVI Maps

The spectral reflectance difference between Near Infrared (NIR) and red is used to calculate NDVI. The formula can be expressed as

$$\mathbf{NDVI = (NIR - red) / (NIR + red)}$$

NDVI values range from -1.0 to 1.0, where higher values are for green vegetation and low values for other common surface materials. Bare soil is represented with NDVI values which are closest to 0 and water bodies are represented with negative NDVI values. Since NDVI provides useful information for detecting and interpreting vegetation land cover it has been widely used in remote sensing studies.
The Normalized Difference Vegetation Index (NDVI) used to assess the vegetative cover. To avoid negative values and for easy handling of digital data, NDVI value obtained for satellite image were re-scaled from equation.

$$\mathbf{NDVI= [(Band4-Band3/Band4+band3) +1] \times 100}$$

3.3.6 Calculation of E30 Value and Annual Soil Erosion:

The soil erosion model given in Equation was used to estimate the annual rate of soil erosion. This model is governed by slope gradient and vegetation index and the annual soil erosion rate (E) are defined as:

$$E = E_{30}\,(S/S_{30})^{0.9}$$

Where S= gradient of the point under consideration,

S_{30}=tan (30°),

E_{30}= rate of soil erosion at 30° slope

E30 Defined as given below

E30= Exp [Log0.264-log24.96/NDVImax-NDVImin)x (NDVI-NDVImin) +log 24.96Log17.12]

The maximum and minimum rates of soil erosion at 30° slope in the study area were 24.96 mm/year and 0.264 mm/year (Source: Based on IMD Data). Figure 2 shows the flowchart of methodology. Zhang et.al (2003) used the Liudaogou watershed, which is located in a cross zone of water-wind erosion on the northern loess plateau in China, as the study area. Soil erosion would found to occur on waste land, slope land and sparse shrub land with slope gradients of 15-25°.

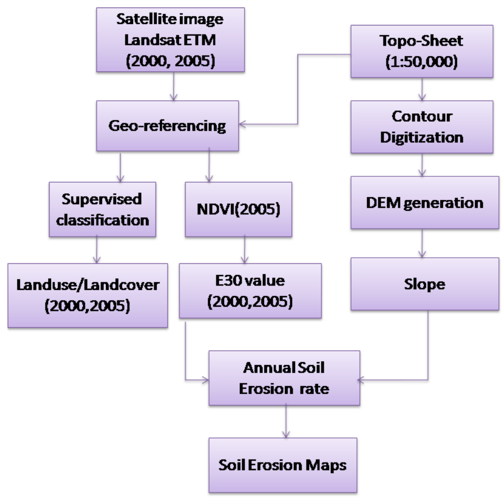

Figure 2: Methodology Flow Chart

4. Result

Soil means the top 15 centimetres thick mixture of clay, silt, organic matter, air, sand mineral and water which provide invaluable ecosystem services functions to the mankind. Soil is one of the fundamental natural resources. The mankind simply depends upon soil for all its activity, whether it is agriculture/ industry, infrastructure or any recreational purpose.soil perform significant role in growth and development of a plant. It provides water, nutrients and mechanical support for plants and trees in natyral forests and grassland. Soil serve as a natural store house for the plant, food and can help in sustaining a plant without any fertilizers for a long period of time. In recent year, this precious natural resources has been dwindling because of its erosion. Soil erosion, which is defined as the detachment and displacement of soil particles from the surface to another destination, appear to be one of the most important causes of siol degradation. Due to excess use of fertilisers, insecticides and pesticides there was great soil erosion over the years.

In our study, we use Landsat ETM for soil erosion estimation for catchment area of song river. In this image the 4th band is Near Infrared (NIR) and the 3rd band is Red band, when we pass NIR band from red and Red band from Green then standard False colour composite(FCC) is formed. The figure 3 and 4 shows the FCC of the study area in 2000 and 2005 respectively. The Landsat-ETM image has been visually and digitally interpreted using interpretation keys viz. tone, texture, shape, size, pattern and texture. By visual interpretation, it was identified that the hills covers the northern part of study area which are the lower Shiwalik hills. Drak red colour shows the forest cover and the bright red colour shows the healthy vegetation. The Song river emerges through these hills then it enter to the plains. There are two streams on the both sides of the Song river. There is large settlement area in the leftmost side which is Dehradun city and in the riverbed plain the land is mainly used for the agriculture purpose. In the end the Song river drains to the river Ganga. The lower part of study area also covered by lower shiwalik hills and had very healthy vegetation.

4.1 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) has been in use to measure and monitor plant growth (vigor), vegetation cover, and biomass production from multispectral satellite data. Image containing Near Infrared band (NIR) and Red band is input to the model which is Landsat ETM images of both the years, then the following model is applied and the output image is single band image shows the NDVI value of the study area.

The value of NDVI is rescaled by using following equation:

NDVI= [(Band4-Band3/Band4+band3) +1] x 100

The highest NDVI value in the 2000 is 167 and the lowest is 68. In 2005 the highest NDVI value is 160 and the lowest is 83. In NDVI image darker region in this map correspond to maximum NDVI and lighter one area to the minimum NDVI. Darker area is represent the forest area or agriculture land whereas lighter tone area is represent settlement, barren, land, water bodies and fellow land. The maximum value of NDVI in year 2000 is 167 where maximum value of NDVI in 2005 is 160. Because both the images are of same time of the year, we can say that the NDVI value of healthiest vegetation decrease a bit. But the mean of NDVI value are 124.2 and 126.8 in year 2000 and 2005 respectively, this is due to the increase in the minimum NDVI value which is 68 in 2000 and 83 in 2005.

4.2 Digital Elevation Model of the Study Area

Digital Elevation Models shows the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. In this study, digital contour with 20 m interval prepared from originally 1:50,000 scaled SOI Toposheet and with the help of contours DEM was created. The elevation in the study area varies from 309 meters to 2734 meters. In the northern part of study area there is high elevation (peaks) and in the southern part there is low elevation area. Slope is one of the elements of the physical environment and broadly defined as the steepness or the inclination of the land surface of an area. It is an important indicator of potential soil erosion hazard in the study area because it strongly influences the forces, which initiate the process of erosion. For this study, a slope map has been generated from DEM, which has a spatial resolution of 30 m. It was assumed that the calculation of slope from the 30m DEM would provide a proper approximation of slope for erosion hazard assessment. Then, it has been classified into five classes. Figure 3, shows classified slope map of the study area.

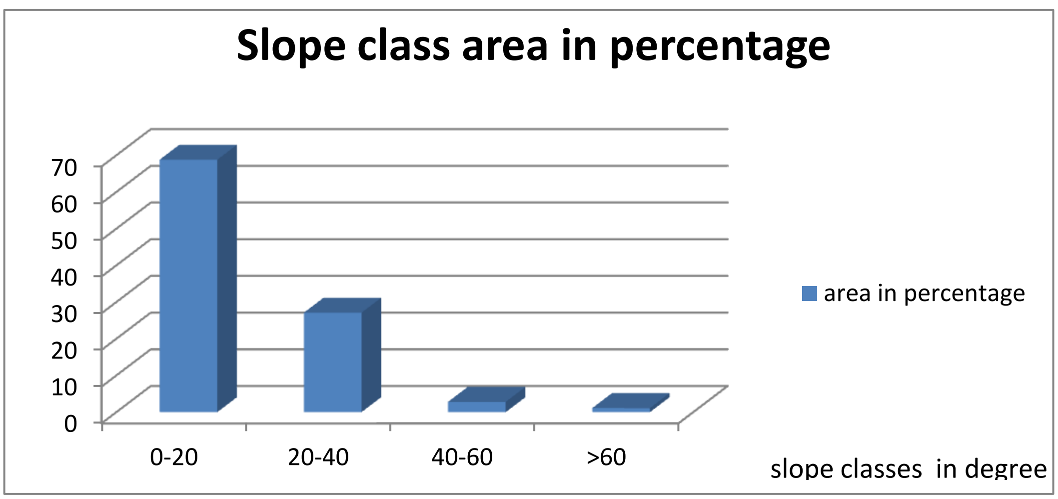

Figure 3: Graph showing spatial coverage of slope classes in Study Area

4.3 Annual Soil Erosion (E)

The annual soil erosion rate is calculated by inputting the E30 value calculated from the NDVI value and the slope of the study area. There are two maps of annual soil erosion created which are shown in figure 5 and figure 6 of year 2000 and year 2005 respectively. The model which is used to calculate the annual soil erosion is shown in figure 4. Firstly E30 values of both the years are calculated by input the NDVI values of both the years respectively. Then formula of annual soil erosion (E) is applied where the inputs are E30 value and the slope of the study area. Gunatilake et.al (2000) applied replacement cost and productivity change method for estimate the on-site cost of soil erosion in the upper Mabaweli watershed of Sri Lanka. Results show that, on the average, replacement cost method provides about 29% higher estimates for on-site cost.

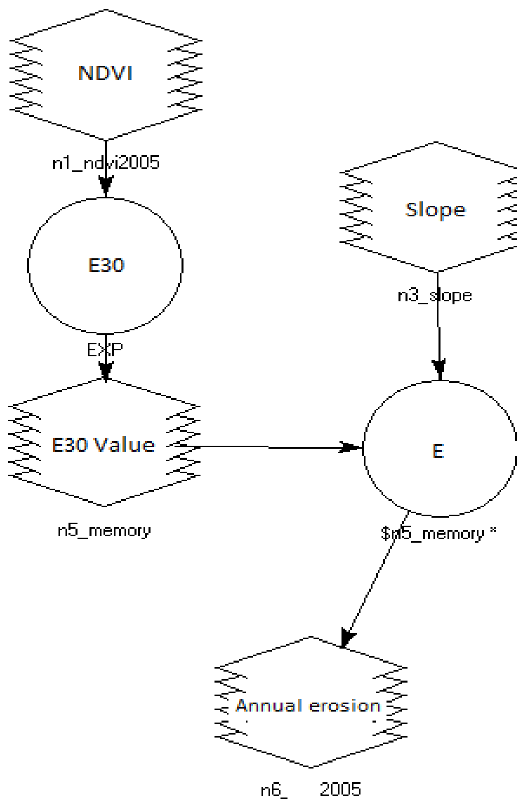

Figure 4: Model of Annual Soil Erosion Rate Calculation

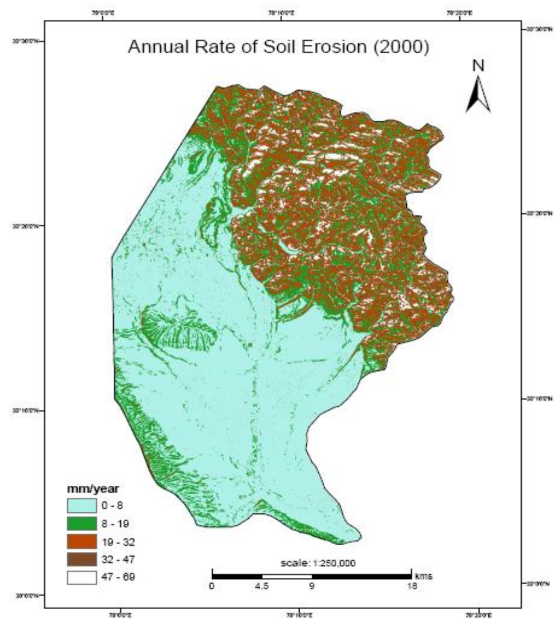

Figure 5: Annual Soil Erosion Rate of Year 2000

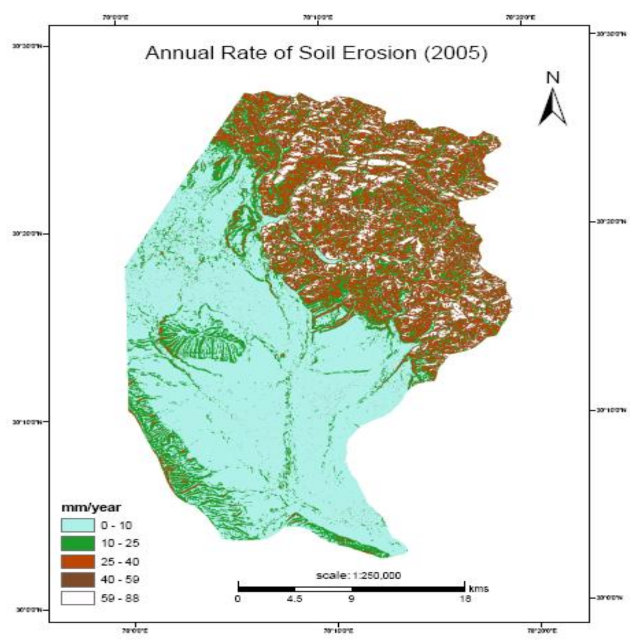

Figure 6: Annual Soil Erosion Rate of year 2005

5. Conclusion

The annual soil erosion maps are created of both the years is calculated which is high in the northern part of the study area. The annual soil erosion is high in the area which have high slope. The maximum value of E is 69 mm/year and 88 mm/year in year 2000 and 2005 respectively. At steep slopes where the vegetation covers is less, area is more suspected to soil erosion. In comparison, the eroded area in year 2005 is greater than year 2000. Dengiz et.al (2009) assessed vulnerable soil erosion risk with qualitative approach using GIS in Ankara-Guvenc Basin. The study area is located about 44 km north of Ankara and covers 17.5 km^2. The results showed that 44.4% of the study area is at high soil erosion risk, whereas 42% of the study area is insignificantly and slightly susceptible to erosion risk. In addition, it was found that only 12.6% of the total area is moderately susceptible to erosion risk. The figure 6 shows that the area of highest erosion is in the northern part of study area which is area of steep slope. The average rate of soil erosion is calculated by the following formula:

Average rate of soil erosion = (X/Y)

Where X = Sum of Values at all Pixels

And Y = Sum of all pixels

Table 1: Average annual Soil erosion of year 2000 and 2005

Description	Year	
	2000	2005
Total Number of Pixels	991144	991144
Sum of Values at all Pixels	7252200	8895517.4
Average Annual Soil Erosion (mm/year)	7.317	8.975

Computed from the 2000 and 2005 annual soil erosion maps (Figure 5 and Figure 6)

The average annual soil erosion rate in the study area increased from 7.315 mm/year in 2000 to 8.975 mm/year in 2005.

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