An Estimation of Soil Erosion in Gandamanur Watershed Using Geospatial Technology

1S.Poongodi, 2Dr. R.Rajkumar & 3Dr.R.S.Suja Rose

1Research Scholar, Department of Futures Studies, Madurai Kamaraj University, Madurai (India)
2Assistant Professor, Department of Futures Studies, Madurai Kamaraj University, Madurai (India)
3Assistant Professor, Department of Environmental remote sensing and Cartography, Madurai Kamaraj University, Madurai (India)

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Corresponding Author
Email: poongodi.era[at]yahoo.co.in

ABSTRACT
Soil erosion is one of the critical environmental problems and a major threat to many natural resources. Stream bank erosion is a kind of water erosion, in which soil is removed by the runoff flowing over the sides of the stream coming from the areas or by undercutting of soil below the water surface from the stream section. Quantitative analysis of soil loss and description of erosion prone areas are essential for conservation programme. The present study focuses on estimation of soil erosion in Gandamanur watershed of Theni District. The soil loss values estimated for Gandamanur watershed ranges from 0 to 219.7 ton/hec/yr with an average of 2.53 t/ha/yr (metric ton per hectare per year). High soil erosion found in steep slopes and streams. Integrated Remote sensing and GIS technology is applied to prepare various thematic layers of Revised Universal Soil Loss Equation (RUSLE) which is used to estimate the soil erosion at watershed level.

1. Introduction

Soil erosion is the process of detachment and transport of soil particles by erosive agents (Ellison, 1944). Soil erosion in tropical and semi-arid regions is a hazard generally associated with agricultural practices that lead to a decline in soil fertility and bring in a series of negative impacts to environment (Prasannakumar et al. 2012). Soil erosion plays a vital role in highland areas where alterations are required for cultivation practices. Thus, soil erosion is considered as one of the most critical environmental hazards of modern times. In India, about 53% of the total land area is prone to erosion and it has been estimated that about 5,334 metric tons of soil is being detached annually due to various reasons (Narayana et al., 1983). Remote sensing and GIS provides a convenient solution for this problem when incorporated with the RUSLE model. The RUSLE is a US based model applied universally to estimate the average annual rate of soil erosion on a field slope. It uses rainfall pattern, soil type, topography, crop cover system and conservation practices as key parameters. The combined use of remote sensing and Geographical Information System (GIS) techniques with RUSLE model makes soil erosion estimation and its spatial distribution possible within reasonable costs and better accuracy over larger areas (Millward and Mersey, 1999; Lin et al., 2002). Current developments in GIS make it possible to model complex spatial information. Roo and Jetten (1999) explained that the erosion process varies spatially and therefore grid cells must be used to capture spatial variation, which GIS is able to capture. RUSLE estimates, soil loss based on the product of rainfall erosivity (R), soil erodibility (K), slope length (LS), cover management (C), and conservation practice parameter (P). GIS functionality were extensively utilized in the preparation of erosion and natural resources inventory and their analysis for assessing soil erosion and soil conservation.

Planning. The main objective of the study is estimation of the average annual soil loss from the Upper Vaigai watershed and its spatial distribution.

2. Methodology and Data used

The climatic and terrain factors which are used in the equation were derived from rainfall data collected from Chennai ground water division and private tea estates, soil texture, organic matter, permeability etc... were collected from Tamilnadu Agricultural University, Coimbatore. LANDSAT 8 OLI/TIRS digital data of the year 2015 with resolution of 30 meter was used for assessment of vegetation parameters in the area. ASTER DEM was used to create the slope length and steepness of the study area. The cell size of all the data generated was kept in to 30 m _ 30 m, in order to make uniform spatial analysis environment in the GIS.

3. Study Area

The study area for the present work is Gandamanur watershed of Upper Vaigai basin, Theni District. The study area shown in Fig. 1 lies between 77° 28' 15" to 77°33' 33"N latitude and 9°35'00" to 9°46'00" E Longitude. The total area covered by approximately 7133.14 hectares. The geological settings of the study area are predominantly underlain by sedimentary rocks namely charnockite, homblende. The study area experiences sub-tropical semi-arid climate which is unpredictable having a normal average rainfall of 882.40mm. The basin receives rainfall under the influence of both southwest and northeast monsoon. Lowest rainfall received in January, with an average of 16mm. In October precipitation reaches its peak, with an average of 203mm. River Vaigai and its tributaries are the major water sources of this area and it originates from Vellimalai hill. The drainage structures have dendritic pattern as well as stream orders are found in semi dendritic pattern. River Vaigai is the major stream in the watershed.
data which is used to calculate annual average R factor values. In this study, the linear relationship established by Singh et al. (1981) and adopted by Parveen and Kumar (2012) was used to calculate the annual rainfall erosivity. The derived relationship is given below:

(Eq: 2) \[ R = 79 + 0.363R_N \]

Where \( R_N \) is the average annual rainfall in mm. In this study, 15 year (2000–2015) average annual rainfall data has been used to calculate the average annual R factor values. Since only five rainfall gauge stations are located in and around the study area, an interpolation of R-factor values is applied to have a representative rainfall erosivity map. Inverse distance weighted (IDW) interpolation technique was adopted in this study. The erosivity factor varies from 401.9 to 689.2 MJ ha/mm/hr/yr.

5.2 Soil erodibility factor (K)

It is a measure of the total effect of a particular combination of soil properties. Some of these properties influence the soil’s capacity to infiltrate rain, and therefore, help to determine the amount of rate of runoff; some influence its capacity to resist detachment by the erosive forces of falling raindrops and flowing water and thereby determine soil content of the runoff. The inter-relation of these variables is highly complex. The K factor in RUSLE model relates to the rate at which different soils erode. Erodibility is a function of soil texture, organic matter content and permeability. A nomograph prepared by Wischmeier and Smith (1978) is widely used to predict soil erodibility factor. The analytical relationship for the expression is given by the following regression equation.

(Eq: 3) \[ [2.1 \times 10^{-4} \times 12 \times OM^{1.14} + 3.25 \times S - 2] + 2.5 \times P - 3] \]

Where

OM is Organic Matter,
S is structural code,
P is permeability code and M is calculated as follows:

\[ M = (\% \text{silt} + \% \text{very fine sand}) \times (100 - \% \text{clay}) \]

The s and p parameters describe soil structure and permeability, as defined in the Soil Survey Manual (USDA 1951) and M is the particle size parameter. By using the above equations, the K value (tons MJ\(^{-1}\) hm\(^{-1}\)) was computed and subsequently the K factor map was prepared. (Fig 3) This factor depends upon soil composition and soil texture (Fig 4) and it helps in the quantitative estimation of soil erosion and it conveys the ability/vulnerability to erode. The derived K value range between 0 to 0.07 mg/h/mj/mm. Generally, soils rich in clay have low K values (resistant to erosion) and soils rich in sand content having high K values (leads to high soil erosion). The highest K value (0.105) is dominated by Sandy clay soil and lowest K factor calculated as 0.014 which is covered by the sandy loam induces higher soil Erodibility comparatively.

5.3 Slope length and steepness factor (LS)

Slope length and steepness factor (LS) accounts for the effect of topography on sheet and rill erosion. Hill slope gradient (S) and length (L) factors are sometimes combined into a topographic factor (LS) Slope Length factor: The LS factor is achieved by using the raster calculator in ArcGIS 10.2 followed by the method of fill sink, flow direction, flow accumulation and slope. The calculated LS factor should be divided by 100 to convert as real LS factor (Jha Raghunath, 2002). The formula adopted to calculate the LS value is described below

\[ \text{LS} = \left( \frac{\text{Flow Accumulation} \times \text{Cell Size/22.1}}{\left(\sin \left( \text{Slope of DEM}\right) \times 0.01745\right)/0.9} \right)^{0.2} \times 1.4 \times 1.4 \]

The L and S factor were computed together from the digital elevation model (DEM). In order to achieve the LS values, the

Slope was calculated using the maximum downhill direction method in which the slope value for each raster cell was obtained from the angle formed between the cells itself and the lowest neighbouring cell (30×30 m). The combined LS-factor was computed for the watershed by means of Arc Info ArcGIS Spatial analyst extension using the DEM following the equation (eq.3), as proposed by Moore and Burch (1986a, b). The computation of LS requires factors such as flow accumulation and slope steepness. The flow accumulation and slope steepness were computed from the DEM using ArcGIS Spatial analyst plus and arc hydro extension. Where flow accumulation denotes the accumulated upslope contributing area for a given cell, LS = combined slope length and slope steepness factor, cell size = of grid cell (for this study 30 m) and sin slope = slope degree value in sin. The LS-factor value in the study area varies from 0 to 28.96. Majority of the study area has LS value less than 5 and some specific areas only showing values higher than 10. Higher the LS value represents higher the steepness.

5.4 Cover – management factor (C)

C is the cover-management factor. The C-factor is used to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation plans. The C-factor indicates how the conservation plan will affect the average annual soil loss and how that soil-loss potential will be distributed in time during construction activities, crop rotations or other management schemes. The C-factor is based on the concept of deviation from a standard, in this case an area under clean-tilled continuous-fallow conditions. The Soil Loss Ratio (SLR) is then an estimate of the ratio of soil loss under actual conditions to losses experienced under the reference conditions. RUSLE accounts for surface roughness in the C value calculation. A surface roughness pond water in depressions and reduces erosivity of raindrop impact and water flow. If the depressions are sufficiently deep, much deposition occurs in them. Over time, roughness disappears as the depressions fill with sediment. and one soil subsides after the tillage operations that formed the depressions. The
importance of the C-factor is described by Toy et al., (1999): “The C-factor is perhaps the most important factor in RUSLE because: (1) it represents surface conditions that often are easily managed for erosion control, and (2) the values range from virtually 0 to slightly greater than 1, strongly influencing the soil-loss rate.” As cover (vegetative or manufactured) and soil biomass increases, the C-factor value decreases. Vegetation cover with slope steepness and length factor (Renard et al., 1994) are critical features that determine soil loss. The value of C depends on vegetation type, stage of growth and percentage of cover. In the present study, Normalized Differential Vegetation Index (NDVI) based assessment of C factor was carried out to calculate the C factor using the formula;

\[ \text{NDVI} = \frac{(B5 - B4)}{(B5 + B4)} \]

NDVI is a vegetation index to monitor the condition of vegetation or vegetation health. Vegetation cover can be estimated using vegetation indices derived from satellite images (Devatha et al., 2015). For the present study, Landsat 8 (2015) satellite images were used to create the NDVI map. Generally, NDVI values ranges from -1.0 to +1.0, where higher values represents high vegetation and low values denote less vegetation. The Normalized Difference Vegetation Index (NDVI), an indicator of the vegetation vigor and health to generate the C factor value image for the study area (Zhou et al., 2008; Kouli et al., 2009). The C factor value equal to 1 highlights bare fallow land with no vegetation and value near 0 shows high vegetative cover.

\[ \text{P} = \exp (-\alpha \times \text{NDVI} / \beta - \text{NDVI}) \]

Where \( \alpha \) and \( \beta \) are unit less parameters that determine the shape of the curve relating to NDVI and the C-factor. Van der Knijff et al. (2000) found that this scaling approach gave better results than assuming a linear relationship and the values of 2 and 1 were selected for the parameters a and b, respectively. This equation was successfully applied for assessing the C-factor of areas with similar terrain and climatic conditions (Prasannakumar et al.2011a, b). This factor can be used to check the canopy cover of vegetation. Landsat 8 OLI / TIRS Path / row 143 / 053 23rd February, 2015 were used for the cover factor estimation. Depending on seasonal rainfall distribution, low precipitation rates in the rainy season significantly affect the C-factor in the following year.

5.5 Conservation support practice factor (P)

The conservation practice factor (P) is an important and most uncertain parameter in RUSLE model (Renard et al.1997. The P-factor map generated is used for understanding the conservation practices being taken up in the study area. The conservation practice factor (P) represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope and is used to account for the positive impacts of those support practices. Supporting conservation factor relates to the practices which restrict water runoff and reduce the effective soil erosion. The conservation practice factor (P) represents various soil management practices employed in different land uses and land covers. The P factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. The value of P factor ranges from 0 to 1, the value approaching to 0 indicates good conservation practice and the value approaching to 1 indicates poor conservation practice. P factor indicates erosion conservation practices on the annual soil loss from the watershed. According to Renard et al. (1997), this factor has been used as a support practice in RUSLE. The values of P factor are related to the land use identified by land cover types. (Table :) The P factor in RUSLE is the ratio of soil erosion with a specific support practice to the corresponding soil loss with straight-row upslope and down slope tillage. The P factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity and hydraulic forces exerted by runoff on soil. The P values are assigned on the basis of land use land cover pattern of the study area. In the present study area, the main conservation method is the use of bunds around the agricultural fields. In the present study P
factor values were chosen based on the research findings from USDA Handbook No. 282, 1981 (Hasan Raja Naqvi, 2012 et al.,:). These values are added in the attribute table of land-use layer for further processing of RUSLE model.

6. Soil erosion estimation

All the RUSLE factors were multiplied using empirical formula given in the eq: 1 and soil erosion map was obtained. The final map represents the annual soil loss per hectare per year at pixel level. The soil loss classified into 3 classes based on the intensity of erosion such as low, moderate, high. The estimated soil loss for the study area varied from 219.7 tons/hectyear in the year 2015. The estimated pixel level soil loss values were grouped in to three classes based the reclassification method and the spatial distribution of soil loss map is generated using ArcGIS software (Table: 1). The spatial pattern of soil erosion classes indicate that the areas with high erosion risk are mainly located in the hill slopes and river banks.

Table: 1 Soil loss categories according to the Annual Average soil loss

<table>
<thead>
<tr>
<th>Rate of soil loss (t h⁻¹ y⁻¹)</th>
<th>Soil erosion class</th>
<th>Area in hectares</th>
<th>Area in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;73</td>
<td>Low</td>
<td>6142.69</td>
<td>86.11</td>
</tr>
<tr>
<td>73-146</td>
<td>Moderate</td>
<td>703.02</td>
<td>9.86</td>
</tr>
<tr>
<td>&lt;146</td>
<td>High</td>
<td>287.43</td>
<td>4.03</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7133.14</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Data compiled by researcher

7. Conclusion

A quantitative assessment of average annual soil loss in Gandamanur watershed was made using the well-known RUSLE with a view to know the spatial distribution in the study watershed. The use of GIS and remote sensing data enabled the determination of the spatial distribution of the RUSLE parameters. Annual average soil loss for the Gandamanur watershed is 219.7 t/ha/yr. Areas covered by high, medium and low erosion potential zones are 86.11%, 13.52% and 0.36% respectively. Hence, remote sensing and GIS technology can be used as an alternative to conventional method of soil loss estimation is useful for implementing soil conservation practices.

References