Estimation of Soil Loss in Teirei Watershed of Mizoram by using Universal Soil Loss Equation Model

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ABSTRACT—The fragile ecosystem of the tropical hilly regions has remained ‘victims of environmental degradation’. Erosion-induced deterioration to environment has gained popularity and concern of the scientific community. The present study, carried out at the Teirei Watershed of Mizoram, aims at the estimation of soil erosion with the application of mathematical model—the Universal Soil Loss Equation that analyzes the multiple resultant factors of its environmental determinant factors such as Rainfall erosivity, Soil erodibility, Gravitational force of the slopes, Runoff velocity, Protection by canopy covers, and the anthropogenic management practices including organic, biological, physical and chemical applications. The soil loss model reveals that the area comes among the most severely eroded regions of the world. The high intensity of rainfall in the tropical northeast Himalaya and the topographical attributes of the lithosphere within the constituent sandstone, shale and conglomerates of fluvial deposits form geologically weak, unstable and hence highly prone zones of erosion.

Keywords: Erodibility, Erosivity, Soil Loss, Thematic Layers, Remote Sensing

INTRODUCTION

Soil erosion is a complex dynamic process by which soil particles are detached from others, carried away by eroding agents and deposited in distant place. It is a contemporary global environmental problem which is adversely affecting all natural and anthropogenic ecosystems, including forestry and agriculture. Its effects are pervasive, and its damages are long lasting that soil erosion ranks as one of the most serious environmental problems in the world.

The eastern Himalaya encompassing the Northeast Indian States and containing parts of the global Biodiversity Hotspots [1] have remained ‘victims of environmental degradation’ due to operations of chemistry amongst the negative aspects of the earth’s spheres resulting to severe soil erosion which further lead to deterioration of natural resources. The topography and climate are conducive to accelerate soil erosion which has been recognized as a serious threat to the environment. As a consequence of its ruggedness and the influence of monsoonal rainfall coupled with loss of forest cover, the fragile catchments have become prone to low water retention and high soil loss associated with runoff. The diversity of plants, animals and microbes is diminished because soil erosion degrades soil quality in natural, agricultural and forest ecosystem thereby reducing the productivity of the land. Ultimately, the stability of entire ecosystem is threatened.

Soil erosion has a number of direct and indirect impacts on the growth and depletion of vegetation or ecosystem in a broader sense. There are certain aspects of soil chemistry which are germane to sustainable soil use for better environment. Soil minerals are the only primary source of most elements required in plants growth and the chemical reactions in the soil decompose the organic compounds deposited in and on the soil by dead vegetation, microorganisms and fauna. Soils also provides the plants roots with essential elements as inorganic, ionic forms and do so rapidly enough to sustain desired growth rates. Thus soil erosion, by removing minerals in the soil, reduces the chance for decomposition of biological remnants and deprives the plants’ roots from getting essential elements, thereby causing deterioration to green environments.
MATERIALS AND METHODS

Soil erosion is the resultant of collective interactions of several determinant factors. The Universal Soil Loss Equation (USLE) is employed in the present soil loss analysis. The potential for erosion is dependent on many factors including soil types, slope and the energy or force of precipitation expected during a period of surface disturbance [2]. The equation is the simplest mathematical model [3] and the single most popular empirically based model used globally for erosion prediction and control [4]. This mathematical model is based on the quantification of the factors such as soil and topography, vegetation and rainfall and their relation to regional and temporal characteristics [5]. The equation is represented as:

\[ A = RKLSCP \]

where,

- \( A \) = Average Annual Soil Loss Rate (t ha\(^{-1}\) year\(^{-1}\))
- \( R \) = Rainfall Erosivity (MJ mm ha\(^{-1}\) h\(^{-1}\) year\(^{-1}\))
- \( K \) = Soil Erodibility (t ha\(^{-1}\) h\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\))
- \( L \) = Slope Length (Runoff Velocity)
- \( S \) = Slope Steepness (Gravitational Effect)
- \( C \) = Crop Management (Canopy Protection Service)
- \( P \) = Conservation Support Practices

The thematic layers for each of the determinant factors have been generated using the advanced techniques of remote sensing, GIS and GPS coupled with intense field investigations. Integration and interpolation of the thematic layers (grids) have been performed by overlaying techniques to derive at the final numeric values of annual soil loss. To compute the factors of soil loss, various standard methods proposed by eminent workers have been adopted.

1. **Factor R**: To calculate the ‘R’ factor, rainfall intensity data at regular interval is pre-requisite for at least 20 years so that natural climatic variations can be accommodated[6]. Meteorological data for 27 years has been used to calculate the ‘R’ value using the equation of Singh, et al. [7]:

\[ R = 79 + 0.363 \times (P) \]

where,

- \( R \) = Rainfall Erosivity
- \( P \) = Annual Precipitation in mm., and

2. **Factor K**: This soil erodibility factor has been computed using the nomograph developed by Wischmeier et.al.[8] and also the following formulae of the USLE Soil erodibility equation developed by Lal and Elliot [9]:

\[ K = 2.8 \times 10^{-7} \times M^{1.4} \times (1.2 - a) + 4.3 \times 10^{-3} \times (b - 2) + 3.3 \times (c - 3) \]

3. where,

- \( K \) = Soil Erodibility, the K –Factor;
- \( M \) = Amount of soil particles (% Silt + % Very Fine Sand OR 100 - % Clay);
- \( a \) = Organic matter content (%);
- \( b \) = Soil structure Code (values ranging from 1 to 4), and;
- \( c \) = Soil permeability or drainage Class (values ranging from 1 to 6).

4. **Factor L**: The ‘L’ and ‘S’variables have been calculated by Wischmeier & Smith[10] formulae as:

\[ L = \left(\frac{x}{22.1}\right)^\wedge \]

where,

- \( L \) = the Value of USLE factor – L;
- \( x \) = the Slope length in metres, and;
- \( \wedge \) = the varying value of exponent of slope gradients.

5. **Factor S**: Computation of the ‘S’ value is done by using the slope angle of inclination in percent as:

\[ S = \left(0.43 + 0.30s + 0.043s^2\right) / 6.613 \]

where,

- \( S \) = the Value of USLE factor –S;
- \( s \) = the Angle of slope inclination in percent.

6. **Factor C**: Calculation of the ‘C’ value has to consider canopy heights, density and different ground surface cover. Using the classification of different land cover systems and their attributed value given by Rao[11] and the USDA – SCS[12], the value of factor ‘C’ is calculated for different land cover units within the study site with minor modifications based on the local conditions.
Table 1: Land Cover and ‘C’

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>‘C’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture (Paddy)</td>
<td>0.280</td>
</tr>
<tr>
<td>Degraded Forest</td>
<td>0.008</td>
</tr>
<tr>
<td>Dense Forest</td>
<td>0.004</td>
</tr>
<tr>
<td>Fallow Agriculture</td>
<td>0.180</td>
</tr>
<tr>
<td>Jhumming</td>
<td>0.330</td>
</tr>
<tr>
<td>Open Forest</td>
<td>0.008</td>
</tr>
<tr>
<td>Settlements</td>
<td>1.000</td>
</tr>
<tr>
<td>Water Body</td>
<td>0.280</td>
</tr>
</tbody>
</table>

7. **Factor P:** Within the study area, no major conservation practices are followed except on a minute scale, negligible for mapping. The value 1 has been assigned to factor-P in order to follow the homogeneity throughout the area.

**RESULTS AND DISCUSSION**

The watershed of Teirei is characterized by diversified physical conditions whose contribution towards soil erosion range widely.

**Rainfall Erosivity**

The area receives a very high amount of precipitation owing to its tropical location. Comparing with other parts of the world the amount of rainfall during the recorded 27 years and their computed erosivity is very high. Iso-erodent map (Fig. 1 A) shows that erosivity is high on the east and gradually decreases towards west. The westward facing slopes, being the windward-side, receive higher precipitation than the rain-shadow.

**SOIL ERODIBILITY**

Analysis of the soil texture, organic matter content, permeability and structure (Fig. 1 B) revealed that the soils which are located on flat lands and gentler slopes formed by young immature sediments derived from higher elevation are having higher susceptibility to erosion. Erodibility is highest along the river course and also along the adjacent slopes.

**Slope Exerted Gravity and Runoff Velocity**

Spatial distribution of the factor LS is the most uneven among the USLE factors for the study area (Fig. 1 C). The factor is also one of the most effective determinants of soil loss due to its varying and high range of values. In fact, the geo-exogenetic forces carved out diverse topographical features where the slope gradients in many places exceed 100%.

Fig. 1: Thematic Layers for USLE Calculation
Canopy Protection & Land Cover System

The different existing land use practices in the area are largely influenced by topographical factors (Fig. 1 D). Most of the flat-lands are utilized for wet-rice cultivation; the adjoining gentle to steep sloping areas with comparatively easy accessibility from settlements are used for jhumming system. Plantations are confined to the areas adjoining the main-roads whereas open forests, in general, belong to the areas which were once utilized for jhum cultivation, and dense forests are associated with unculturable steep slopes as well as reserved areas of the government and village communities.

Management Practices

Conservation measures to tackle erosion problems are practiced at few sites especially where permanent land-based activities are undertaken. These measures include multiple cropping of horticultural crops with high and low height canopy as well as other commercial crops as ground-cover or undergrowth. Other conservation practices are terrace construction and land leveling at local and minor scale to reduce runoff velocity. However, as the spatial scale of these activities is very small, they are negligible for mapping.

Table 2: Distribution of Soil Erosion

<table>
<thead>
<tr>
<th>Erosion Intensity</th>
<th>Soil Loss (ton ha(^{-1}) yr(^{-1}))</th>
<th>Area (km(^{2}))</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Slight</td>
<td>00–10</td>
<td>142.25</td>
<td>20.90</td>
</tr>
<tr>
<td>Slight</td>
<td>10–20</td>
<td>133.00</td>
<td>19.56</td>
</tr>
<tr>
<td>Moderate</td>
<td>20–40</td>
<td>256.00</td>
<td>37.65</td>
</tr>
<tr>
<td>Severe</td>
<td>Above 40</td>
<td>134.50</td>
<td>19.78</td>
</tr>
<tr>
<td>Unclassified</td>
<td>Dynamic</td>
<td>14.25</td>
<td>0.21</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>Dynamic</strong></td>
<td><strong>680.00</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

Out of the total area of the watershed, about 21% falls under very slight intensity zone of soil erosion. Approximately 32% of this zone is under dense forest with moderately sloping lands, whereas the remaining 68% of this zone is covered by open forest on 0% to 15% slope gradients. This shows that most of this zone concentrates within areas where the slopes are gentle. Areas under this group are, therefore, distributed either on the lesser slope gradients of the river course and tributaries or the densely vegetated areas. They are found to concentrate along the syncline between the two parallel ridge lines, the middle reaches of the eastern ridge line and the extreme southwestern part of the watershed.

The zone with slight intensity of soil erosion covers about 133 km\(^{2}\) (19.5%) of the watershed. Out of this zone, about 54.7% falls under thick vegetative cover on steep to very steep slopes and 45.3% comes under open forest on strongly sloping to moderately steep slopes. These values depict that this zone is exclusively associated with either dense forest on steep slopes or open forest on gentler slopes. The spatial distribution of this zone tends to have close association with the zone of very slight intensity as these two zones are found to exist together—adjacent to each other except in the southwestern part of the watershed.

The area with the largest areal extent falls in the moderate intensity zone of soil erosion with a loss of 20 to 40 tons ha\(^{-1}\) year\(^{-1}\) covering an area of about 256 km\(^{2}\) which is 37.65% of the total area of the watershed. As high as 98% of this zone falls entirely under open forest with slope gradients of above 25% and the remaining comes under the predominant jhumming with few plantation sites situated on nearly flat lands and gently sloping lands. This zone occupies mostly the northern three-quarters of the watershed between the zones of slight and very slight erosion intensity. This means that the zone exists on both sides of the river next to the areas of low erosion intensity and along the downslope of the main ridge lines.

The severe intensity zone of erosion with soil loss higher than 40 tons ha\(^{-1}\) year\(^{-1}\) sharing approximately 20% of the watershed is mostly dominated by jhumming and open forest. Considering its associated vegetation cover, almost three-fourth of this zone falls under the traditional shifting agricultural system and the remaining area is shared by plantations and open forests on steep to very steep slopes. Few wet rice cultivation sites also come under this category owing to their immense sheet erosion caused by torrential rainfall.

The average soil loss under different land use practices in the study area is very high which is quite detrimental to the growth of vegetation thereby adversely affecting the potential development of land utilization.
CONCLUSION

The computed soil loss data and final erosion intensity map, interestingly, follows the pattern of slope distribution and more importantly the pattern of vegetation density. This shows that the rate of soil erosion in hilly terrain is highly associated and determined by the protective services of plants and trees and also the gravitational influence of slope towards run-off velocity.

The erosion-caused degradation include reduction in effective rooting depth, plant-available water, nutrient reserves, organic matter content, and structural properties which are potential threat to sustainability of ecosystem. Thus, soil erosion being the major cause of soil and environmental degradation, a process of reducing soil energy, its conservation measures from all possibilities which are at the disposal and adaptability of the forest dwellers should be adopted. Such suggestions for conservation should take into account the viability on the existing physical conditions, the economic possibility, and the social acceptability and most of all the sustainability in different spheres. Three major problems always arise towards any attempt for environmental conservation. First comes the physiographic constraints of steep slopes and inaccessibility; second obstacle constitutes economic deficiency which do not permit the subsistent marginal farmers to take up alternatives other than jhumming that provide their daily needs, and; thirdly, jhumming is the aged-old traditional agriculture practice that is firmly bonded with forest tribes, that acceptability and adaptability of alternative farming system should be the foremost important measure to be considered.

REFERENCES