

# Soil erosion study by using RUSLE model. (A case study in Quang Tri province, Central Vietnam)

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**Abstract.** Soil erosion modeling is effective in identifying areas that are most susceptible to soil loss, in order to appropriately manage and minimize the impacts of such degradation. This paper has outlined a study of quantifying soil loss using RUSLE methodology and GIS in one province of Vietnam. However the methodology has the potential to be applied to other areas for soil loss assessment. The mountainous regions of Quang Tri Province are highly susceptible to soil erosion. The complex topography and susceptibility to severe coastal weather conditions, combined with high population density and often poorly monitored agricultural and farming practices, make this environment particularly fragile.

*Keywords:* Soil erosion, RUSLE, ArcGIS, Quang Tri.

## 1. Introduction

Soil erosion is a widespread problem in much of South-East Asia, with many previous studies showing a strong correlation between poverty, population density and soil degradation [1]. Effective land-use management could lead to improved livelihoods for many people in these areas by mitigating the detrimental effects of soil erosion and improving the environmental sustainability in these areas. In order to effectively manage soil erosion, this paper identifies those areas which are most susceptible to soil loss using the RUSLE (Revised Universal Soil Loss Equation) model incorporated with GIS.

Soil erosion is the process in which surface materials are displaced, usually by wind or water. The natural phenomenon of erosion is accelerated by human activities that alter the natural mechanisms by which rocks are degraded and the soil is formed. This acceleration is caused by the destruction of plant cover and unsuitable farming techniques, and is particularly prevalent in areas experiencing high population density such as Vietnam. Vietnam is also highly susceptible to above average rainfall and large storm events causing flash flooding. These conditions combined with poor land-use management can lead to extreme degradation of the landscape due to severe soil loss. The process of soil erosion, however, can be curbed by correct management and land-use planning based on

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information including soil types, watershed flows and climatic conditions.

There are many erosion prediction methods; however previous studies have shown RUSLE to be the most applicable to worldwide conditions. It can be applied to topographically complex landscapes and is also supported by GIS, as well as providing methodology for regional level analysis of soils erosion. It has been widely used to predict soil loss on any field condition where soil erosion by water is possible and has been seen to be useful in predicting the effect of land use changes on erosion and how they may indirectly cause landslides and flooding. The RUSLE model has been used for predicting soil erosion throughout the US and more recently has been applied to climates and vegetation throughout the world. Here, RUSLE has been applied to Quang Tri Province of Central Vietnam.

## 2. Study Area

Quang Tri Province is located in the Central region of Vietnam with an area of 4756 km<sup>2</sup> and is bounded by the South China Sea to the east and Laos to the West. The topography of the province is diverse, with high mountainous regions in the west and flatter, sandy coastal areas to the east. The region experiences above average rainfall in the wet season (May-Oct), when in some months, rainfall can reach 1000mm, and severe flooding and storm events are often experienced. These factors make the high mountainous area particularly susceptible to high rates of soil erosion and natural disasters such as landslides as has been seen in the past.

## 3. Methodology

RUSLE is an erosion model designed to predict the long-term average annual soil loss from specific field slopes in specified land-use & management systems (i.e. crops, rangelands etc) [2]. It is used to guide the selection of conservation and management practices for specific sites, estimate possible reductions in soil loss when certain conservation practices are adopted, and defines the maximum slope length acceptable for a given cropping or management practice.

Combining RUSLE with ArcGIS allows the user to model soil erosion in an area of varying topology, vegetation and soils. According to Wischmeier & Smith (1978) the environmental factors affecting soil erosion are: rainfall erosivity (intensity and kinetic energy of rain); soil erodibility (dependent upon soil structure and texture, organic matter content, and permeability); topography; land cover (land use, canopy, and surface cover) and supporting practices (tillage techniques, terracing etc). The RUSLE model combines the factors in the following equation [3]:

$$A = R * K * LS * C * P, \text{ where:}$$

A = Total soil erosion (tonnes/ha/year)

R = rainfall erosivity factor (MJ mm h<sup>-1</sup> ha<sup>-1</sup> y<sup>-1</sup>)

K = soil erodibility factor (t ha h ha<sup>-1</sup> MJ<sup>-1</sup> mm<sup>-1</sup>)

LS = combined slope length and slope steepness factor (dimensionless)

C = cover management factor (dimensionless, ranging from 0-1)

P = support practice factor (dimensionless, ranging 0-1)

The RUSLE model has been critically applied using an integrated GIS approach in a raster environment in order to obtain maps for

each RUSLE factor. The following diagram shows the structure of the RUSLE model incorporated with GIS.

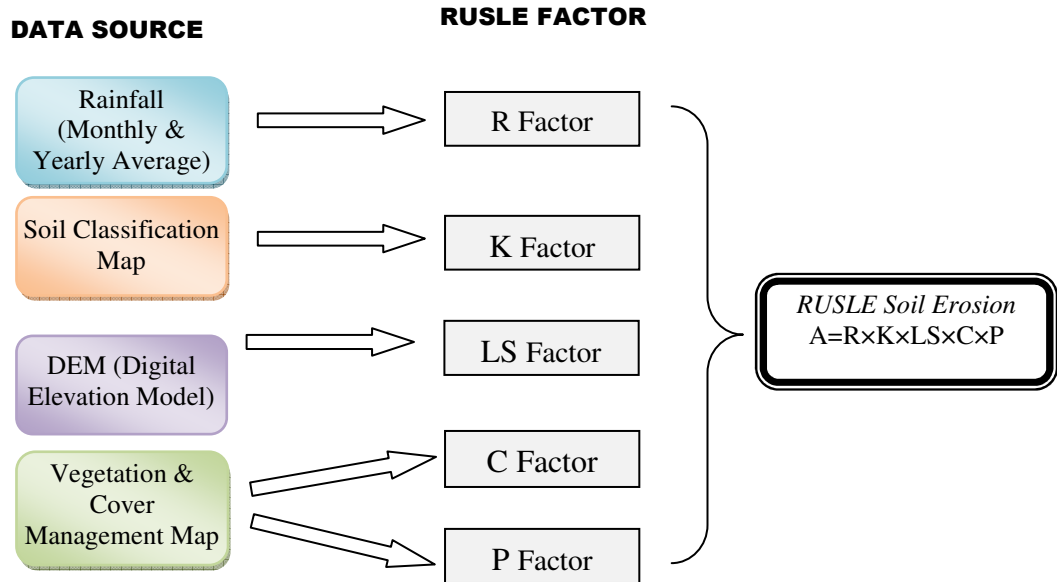


Figure 1. Structure of the RUSLE model incorporated with GIS.

### *R Factor*

The R factor used in RUSLE is a numerical descriptor of the ability of rainfall to erode soil based on rainfall-runoff characteristics [4]. It is determined by both the rainfall and the energy imparted to the land surface by the rain-drop impact. Wischmier found that 100th of the product of the kinetic energy of the storm (KE) and the 30 minute intensity (I30) is the most reliable single estimate of rainfall erosion potential and is termed IE30. In areas where there is not enough data or resources to develop the R factor from storm events, the R Factor can be calculated using a general approach as outlined in Renard & Freimund (1994) where:

R Factor values are calculated for any stations with recording rain gauges (as described by Wischmier & Smith, 1978).

A relation is established between the calculated R values and more readily available precipitation data (i.e. monthly and annual rainfall).

The relation is extrapolated and R values are estimated for areas with this precipitation data

An iso-erodent map is drawn where values are estimated by linear extrapolation.

The R factor values for Quang Tri have been estimated using annual rainfall data and the following equation, derived from R factor calculations previously calculated for areas of Vietnam.

$R = 0.082 \times P - 21$  (where P = annual rainfall).

The results are shown in the maps below:

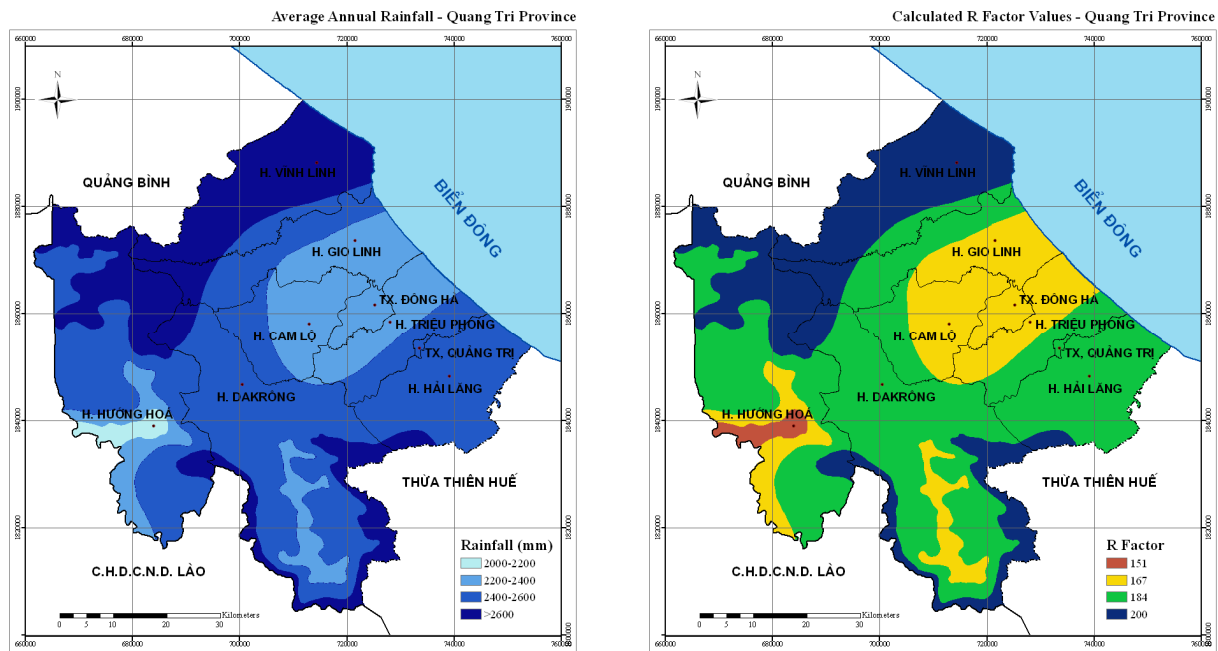


Figure 2. Annual average rainfall and R factor values.

*K Factor*

The soil nomograph as developed by Wischmeir and Smith (1989) and published in the Agriculture Handbook, relies on knowledge of the % sand, % organic matter, structure, and permeability of defined soils. This nomograph along with the soil Classification as published the Model Documentation has been combined with existing soils datasets to evaluate K Factor values for soils in Quang Tri Province, with calculated values ranging from 0-1 as shown below:

The K values correlate to soil erodibility, with highest K values reflecting soils most susceptible to erosion, and lowest values reflecting soils less likely to be eroded under strong rainfall or land use practices. Low values of K are seen to be coastal sandy soils and soils in stream networks, generally found at lower elevations, those with higher K values

are generally higher in silt content and are more easily eroded.

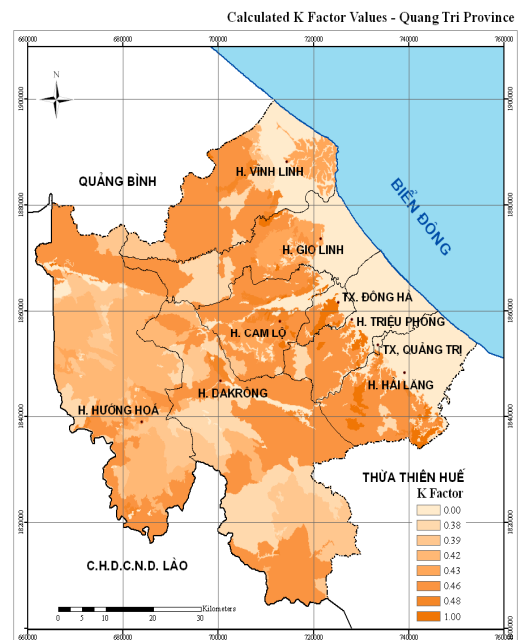


Figure 3. K factor values.

*LS Factor*

The LS factor is a combined measurement of slope length and gradient. It represents soil erodibility in relation to a standard unit plot and can be calculated from the Digital Elevation Model (DEM) dataset. slope, flow direction and flow accumulation maps can be derived from the DEM using ArcGIS, and the LS factor is calculated using the equation:

$$LS = (\text{length}/\text{resolution})^m \times (65.41 \times (\sin(\text{slope}(\text{deg})))^2 + 4.56 \times \sin(\text{slope}(\text{deg})) + 0.065$$

- Where  $m = 0.5$  (slopes  $\geq 5\%$ )
- 0.4 (slopes  $\geq 3\%$  &  $< 5\%$ )
- 0.3 (slopes  $\geq 1\%$  &  $< 3\%$ )
- 0.2 (slopes  $< 1\%$ )

For this study in Quang Tri Province, the LS factor was calculated by running an AML script in ArcInfo Workstation using a DEM of the Province.

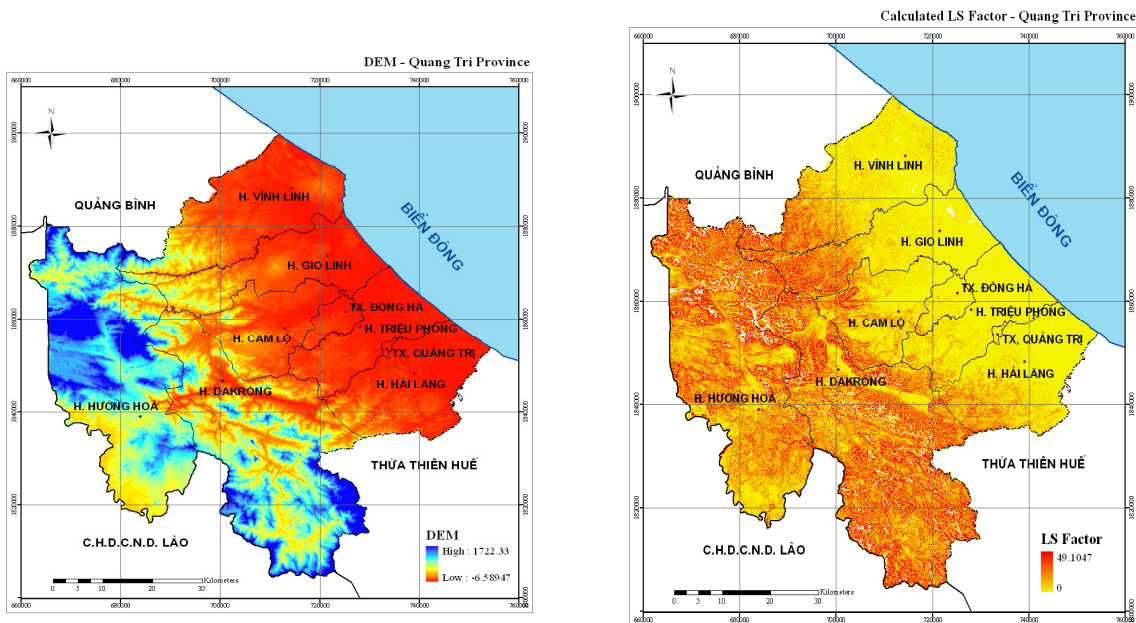


Figure 4. DEM and LS factor values.

*C factor*

The cover management factor represents the effect of plants, soil cover, below ground biomass, and soil disturbing activities on soil erosion. User inputs include effective root mass in top 4” of soil, percent canopy, average fall height, surface roughness value, percent ground cover. For this study, vegetation cover datasets have been used to assign C Factor values. The values range from 0-0.5, where the C factor for

natural forests and plantations are generally lowest due to greater vegetation cover and urban/settlement areas are generally higher due to land clearing and little natural vegetation cover in these areas.

*P factor*

The P factor is the erosion control factor. It is the ratio of soil loss using a specific erosion control practice such as contouring or terracing. Values for C and P have been modified from

those published in Nam et al (2003), for vegetation and cropping practices in Quang Tri Province, using land-use data for the area. Areas with control factors in place are given lower values, as procedures are implemented to

reduce natural erosion. Areas which experience no control management practices have a P Factor value of 1.0 as these are experiencing natural conditions.

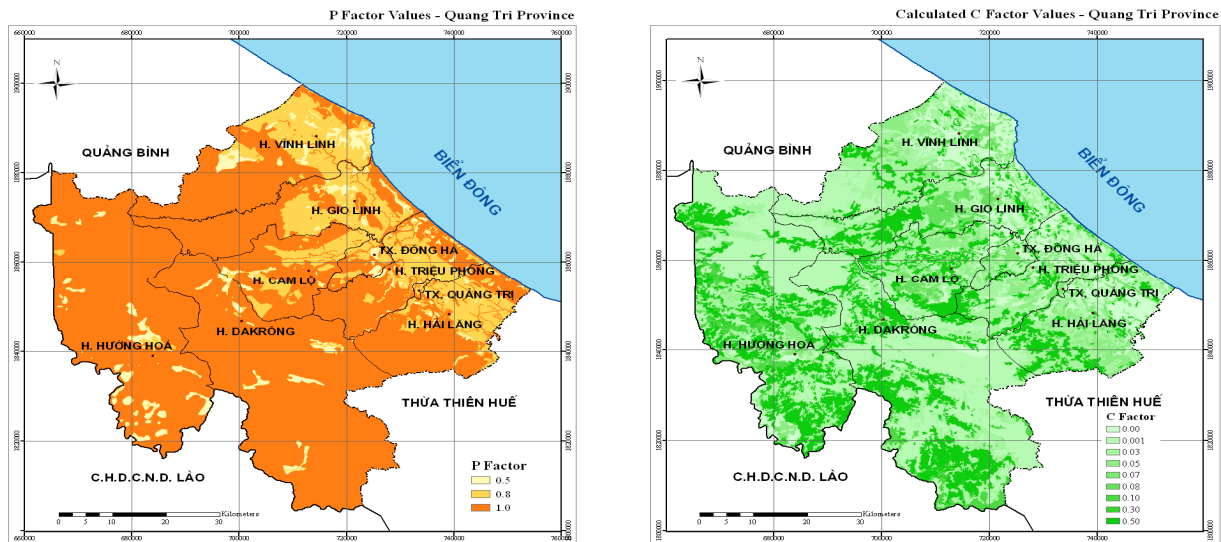


Figure 5. P and C factors values.

*Calculating Soil Loss*

The RUSLE model can be run using the Spatial Analyst extension and the Raster Calculator in ArcMap. In the Raster Calculator, the equation  $A = R * K * LS * C * P$  is used to equate the total soil erosion for the study area, with the output being an accumulation of soil loss throughout the province in tonnes-1/ha-1/year.

**4. Results**

The results from this study show that, the mountainous regions of Quang Tri province are highly susceptible to soil erosion. The complex topography and susceptibility to severe coastal

weather conditions, combined with high population density and often poorly monitored agricultural and farming practices, makes this environment particularly fragile.

Areas most prone to severe soil loss are found to be mountainous areas with steep slopes, particularly with settlement lands. Soil loss is also seen to be highly correlated to vegetation cover, with agricultural and disturbed lands experiencing higher rates of soil loss than those areas with natural vegetation cover or plantations.

The results of the case study are limited in accuracy due to limited availability of necessary data. The calculation of the R factor in RUSLE relies on storm intensity over a period of at least

20 years, with 15 minute intensity records of heavy storm events. As this data has not been available for the study area, a modified calculation of the R Factor has been used. The results of such a study may be improved as more detailed data is available. Although the

results from this study may be restricted in qualitative accuracy, the spatial variation in soil loss is representative of areas where soil is most susceptible to erosion and degradation. The results can be seen in the map below:

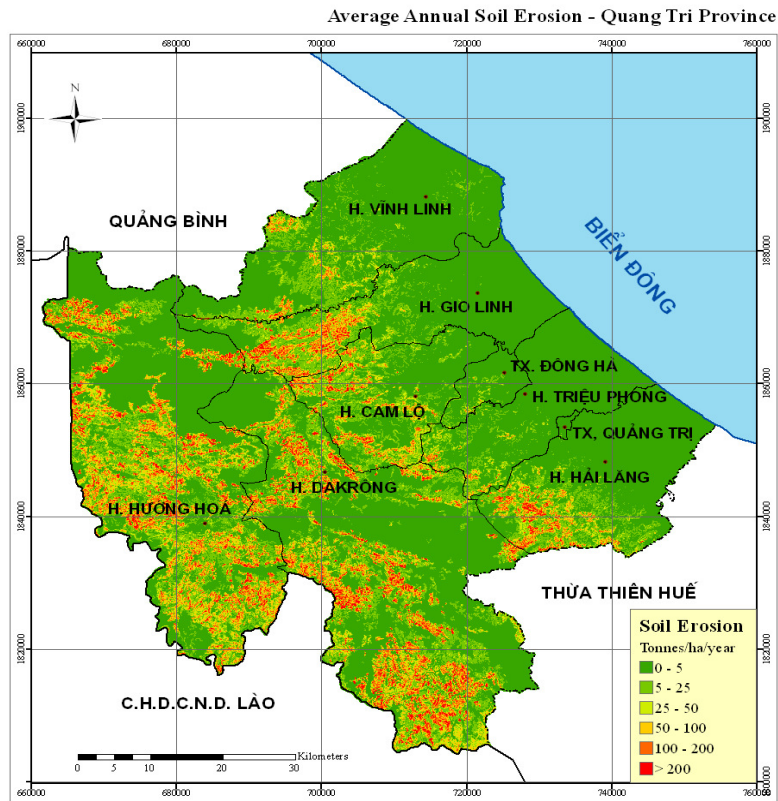


Figure 6. Average annual soil erosion in Quang Tri Province.

The results from this study have also been divided to show soil erosion on a district level. Quang Tri province is divided into 9 districts, namely; Hai Lang, Trieu Phong, Gio Linh, Cam Lo, Vinh Linh, Huong Hoa, Da Krong, Dong Ha Town and Quang Tri Town. Table 1 shows the percentage of soil erosion within each classification level for each district. Soil erosion occurs naturally throughout the environment,

and soil erosion below 5 tonnes/ha/year is an acceptable level of erosion under natural conditions. Soil loss between 5-20 tonnes/ha/year is generally the upper limit of acceptable soil loss and erosion above this level is likely to be detrimental to the environment. Of most concern are areas where the soil loss is over 200 tonnes/ha/year. These results are shown in the Table 1

Table 1. Percentage of Soil Loss by District at specified classification levels

<i>Soil Loss Classification</i>	<i>District Soil Loss (%)</i>									
	<i>Hai Lang</i>	<i>Trieu Phong</i>	<i>Dong Ha</i>	<i>Gio Linh</i>	<i>Cam Lo</i>	<i>Vinh Linh</i>	<i>Huong Hoa Town</i>	<i>ĐaKrông</i>	<i>Quang Tri City</i>	<i>Quang Tri PROVINCE</i>
1 < 5 ton/ha/year	82.79	90.83	88.82	79.01	70.23	85.45	71.30	76.88	98.71	78.34
2 5 - 20 ton/ha/year	8.60	5.85	8.87	9.96	15.88	10.27	9.70	7.01	1.10	9.09
3 20 - 50 ton/ha/year	2.73	1.35	1.39	3.41	19.34	2.14	4.53	4.18	0.09	3.55
4 50 - 100 ton/ha/year	1.66	0.95	0.57	1.56	2.76	0.95	3.71	2.65	0.09	2.31
5 100 - 150 ton/ha/year	1.10	0.44	0.20	1.43	1.75	0.46	2.85	1.95	0.01	1.66
6 150 - 200 ton/ha/year	0.95	0.24	0.11	1.38	1.45	0.29	2.23	1.82	0.00	1.40
7 > 200 ton/ha/year	2.17	0.35	0.04	3.26	2.97	0.44	5.67	5.59	0.00	3.66

## 5. Discussion

In Vietnam, soil erosion by water is one of the main causes of environmental concern. Heavy rainfall and large storm events cause flash flooding in the area, with disastrous effects on people and their livelihoods. Soil erosion modeling is effective in identifying areas most susceptible to soil loss, in order to appropriately manage and minimize the impacts of such degradation. This paper has outlined a study of quantifying soil loss using RUSLE methodology and GIS in one province of Vietnam, however the methodology has the potential to be applied to other areas for soil loss assessment.

In developing countries, the data required for the study of soil erosion using RUSLE is not often readily available (e.g. adequate rainfall data is calculated from 30 minute storm intensities over a period of at least 20 years). In these instances, modified values can be used to calculate the average annual soil loss of an area, although due to the limitations in data availability, these results should be taken in a

qualitative sense in order to implement a management plan to mitigate soil loss and its detrimental effects. Careful consideration must be taken to balance the social, economic and environmental impacts of soil loss and land management to ensure sustainable management of each of these aspects.

## References

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