ASSESSING SOIL LOSSES USING EROSION MODELS AND TERRAIN PARAMETERS: A CASE STUDY IN THAILAND

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ABSTRACT: Soil erosion, the most serious type of land degradation, occurs in all climatic regions. For assessing its magnitude various empirical and process-based models are available. The models differ greatly in structure and data requirements. For practical application, a model of low complexity may be desirable. But validating model results can be a major problem in absence of runoff plot soil loss data. A qualitative assessment by means of terrain parameters and simple field tests was applied to validate model results. Terrain parameters e.g. slope gradient, specific catchment area and stream power index, computed from digital elevation model were used. Stream power index represents the erosive power of terrain and simple field tests assess soil erodibility.

The method is applied in a case study in Thailand. Results of the erosion models, RUSLE and RMMF, applied in a raster-based GIS environment, were compared. In general, soil loss estimates by RMMF is lower than that of RUSLE. Sensitivity analyses show that RUSLE is very sensitive to cover factor than RMMF. On the other hand, RMMF is more sensitive to changes in slope gradient and rainfall amount than RUSLE. The soil loss estimates by two models vary significantly. The model results were compared with terrain parameter and simple field tests results. The study shows that terrain parameters in combination with simple field test results, can be useful tools in checking whether soil loss estimates by erosion models are justifiable.

1. INTRODUCTION

Land degradation is a global issue, which is manifested in various processes. Water erosion is by far the most serious land degradation type with a global estimate of about 11 million km^2 (Oldeman, 1994). In Thailand moderate and severe erosion rates are reported on 10.98 million ha and 6.44 million ha respectively (LDD staff, 2001). Erosion is common on hill slopes cultivated for upland crops and intensive use of soils. It is estimated that almost all land suitable for cultivation has been already used up in Thailand and the trend is to encroach the marginal lands, which make the situation even worse. During the rainy season soil loss has become a common feature. For computing soil losses Universal Soil Loss Equation is widely used (Laflen and Moldenhauer, 2003). It is popular because of its simplicity and low data requirements. But whether the model is applicable in all environmental conditions (e.g. in areas with steeper slopes and with high rainfall amounts) has got so far little attention. On the other hand several models starting from simple empirical ones to sophisticated models are available to assess soil erosion. Sophisticated models claim to give better estimate of soil losses since they are process-based and take into account physical processes involved in soil detachment and transportation. These models differ greatly in terms of their complexity, their input requirements and manner in which the physical processes are represented (Merritt et al., 2003). But a general problem for applying such models is data availability, which is often problem in developing countries. Even in developed countries such data may be restricted to only research stations. Frequently missing data have to be generated on the basis of assumptions, which hamper their application (Shrestha et al., 2004). The uncertainty associated with the input data makes the calibration and validation of spatially distributed erosion models even more difficult, which will not be solved by constructing more complex models (Jetten et al., 2003). This makes it necessary to look for model of relatively low complexity and plausible physical basis (Merritt et al., 2003).

In the present study performance analysis of two erosion models, RUSLE (Renard et al., 1997) and RMMF (Morgan, 2001) applied in a case study in Thailand, is presented. Both models are considered simple and empirical, although the later provides more physical base. Sensitivity analyses were carried out by studying the effect of changing erosion parameter values on model results to evaluate the relative stability of the models. Factor input parameters common to both models such as land cover, slope gradient and rainfall amount were used. Finally model results were evaluated with computed terrain parameter and simple field test results.

2. METHODS AND TECHNIQUES

2.1 Study area

The case study was tested in an area in Lom Kao district, Phetchabun province, Thailand (Fig.1). It is located approximately between 16°54'13" and 17° 04'54" North and between 101°09'34" and 101°24'21" East, covering approximately 520 km^2 area. The area is part of the central highlands comprising of High and Low Mountains, Hillands, Piedmonts and Valleys. The elevation ranges between 160 to 760 m asl. Two main rivers: the Pasak river in the eastern part and the Hua Nam Phung in the western part drain the area. Climate is humid tropical, with distinct rainy season (May to September) characterised by hot temperature and high humidity. Hottest month is April (max. average temperature of 37°C) and the coldest month is December (min. average temperature of 15°C). Annual average rainfall is 1200 mm (estimated using 1986-2001 data). The driest period is from November to February. Soils in the Mountains, Hilland and Piedmont areas are generally shallow. They are normally deep in the Valleys. Natural vegetation has been almost cleared of due to deforestation. Forest is classified as deciduous and dry forest, with medium and small trees including bamboo, bushes, and some scattered trees showing evidence of former tropical forest. Recently trees such as teak, eucalyptus, acacia, have been introduced. Apart from forest, other land use types include rainfed annual crops (corn, peanut, soybean, etc.) in uplands, rice fields in the lowland and fruit tree plantations (sweet tamarind, mango, litchi, etc.) confined to mainly Hilland and Piedmont areas.

2.2 Erosion modelling

For the present study two erosion models, RUSLE and RMMF, were applied. They were selected because of their simplicity and data required to run the models was not so difficult to obtain. The RUSLE is considered an improved version of USLE, developed by Wischmeier and Smith (1978). RUSLE maintains the basic structure of ULSE and computes annual soil loss in t/ha/yr as follows:

$$\text{Annual soil loss} = R*K*LS*C*L \qquad (1)$$

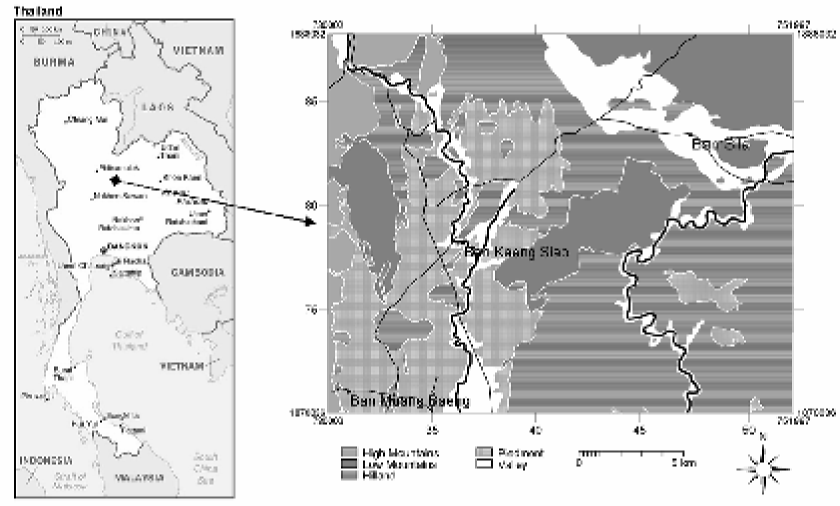

Fig. 1: Study area

where, R= factor for rainfall erosivity, K = soil erodibility, LS = topography, C = cover management, and P = supporting practice. The rainfall erosivity is calculated using storm kinetic energy and the maximum 30- minute storm intensity. For the present case study the relational equation suitable for Thailand according to Srikhajon et al (1994) is used which is R = 0.4669x – 12.1415. For estimating K value RUSLE also takes into account the availability of rock fragments.

The revised MMF is a simple empirical model for predicting soil losses. The model uses annual precipitation to determine the rainfall energy available for splash detachment and the volume of runoff. It computes the proportions of annual rain which reaches the ground surface after allowing for rainfall interception. The total energy of the effective rainfall ((KE; J/m^2) equals to kinetic energy of direct throughfall and that of leaf drainage. It assumes that runoff occurs when daily rainfall exceeds the soil moisture storage capacity and that daily rainfall amounts approximate an exponential frequency distribution. Soil particle detachment by raindrop impact (F; kg/m2) is calculated as:

$$F = K \times KE \times 10^{-3} \quad (2)$$

where K is soil erodibility. Soil particle detachment by runoff (H; kg/m^2) is computed as follows:

$$H = ZQ^{1.5} \sin S (1-GC) \times 10^{-3} \quad (3)$$

where z is the resistance/cohesion of soil, Q the runoff volume, S slope gradient, and GC the percent ground cover. Transport capacity of runoff (TC; kg/m^2) is calculated as:

$$TC = CQ^2 \sin S \times 10^{-3} \quad (4)$$

where, c is the crop cover factor. Finally, annual soil loss is taken as the lesser of the total soil detachment rate (F + H) and the transport capacity of the runoff (TC).

2.3 Assessing soil loss results

Sensitivity analysis was performed to see how models perform by changing parameter values by 5, 10, 15, 20 and 50% and calculating soil loss results in both models. In addition, terrain parameters were used to validate soil loss estimates. Terrain parameters were generated using digital elevation data. Depending on situations elevation data may need to be improved before generating terrain parameters (Hengl et al., 2004). While slope aspect gives information on flow direction and gradient indicates susceptibility to erosion, catchment area indicates magnitude of runoff volume. Computation of upslope contributing area, above a certain location (grid cell as shown in Figure 2a) helps in estimating the volume of overland flow, which would pass through that point. For this purpose, specific catchment area, A_f, can be used which is calculated as the drainage area per unit width. It is computed as the ratio of the contributing area to the contour length (Quinn et al., 1991) as:

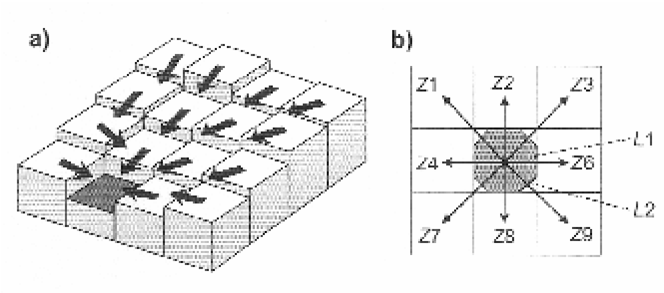

Fig. 2: Contributing cells to the observed location (a) and effective contour lengths at cardinal and diagonal directions (L1 and L2) (b) (Hengle et al., 2003).

$$A_f = A_m . p^2 / \Sigma L_i \quad (5)$$

where A_m is the cumulative drainage fraction from m neighbours, p is the pixel size, and ΣL_i is the sum of lengths of draining pixels. Cumulative drainage area needs to be computed in various iterations. Specific catchment area in combination with slope gradient, also called stream power index, reflects the erosive power of the overland flow. Stream power index is calculated according to Moore et al. (1993) as:

$$SPI = A_f . \mathrm{Tan}\beta \quad (6)$$

In addition, simple tests were carried out in the field to assess soil aggregate stability by submerging air-dry soil aggregates of size 1 cm diameter in water and checking if it is stable after 5 minutes, according to Bergsma (1986). Shear strength was also measured using torvane on saturated topsoil to indicate resistance to scour by runoff. Necessary data to run the models was collected during ITC student fieldwork in September-October 2002.

3. RESULTS AND DISCUSSIONS

Soil loss assessment results are given in Fig. 3. Average annual soil loss estimates by RUSLE ranged from 1 to 71 t/ha/yr and that by RMMF ranged from 0 to 20 t/ha/yr. With respect to landscape units soil loss estimates in t/ha/yr by RUSLE and RMMF are as follows: 24 verses 5 for High Mountains, 21 verses 6 for Low Mountains, 29 verses 9 for Hilland and 13 verses 3 for Piedmonts. With respect to land use types, estimates are as follows: 25 verses 10 for annual crops, 7 verses 3 for orchards, 5 verses 2 for tree plantations and 3 verses 1 for other land uses types including degraded forest. The result shows that soil loss estimates by RUSLE and RMMF vary significantly and that estimates by RMMF are consistently lower than that of RUSLE.

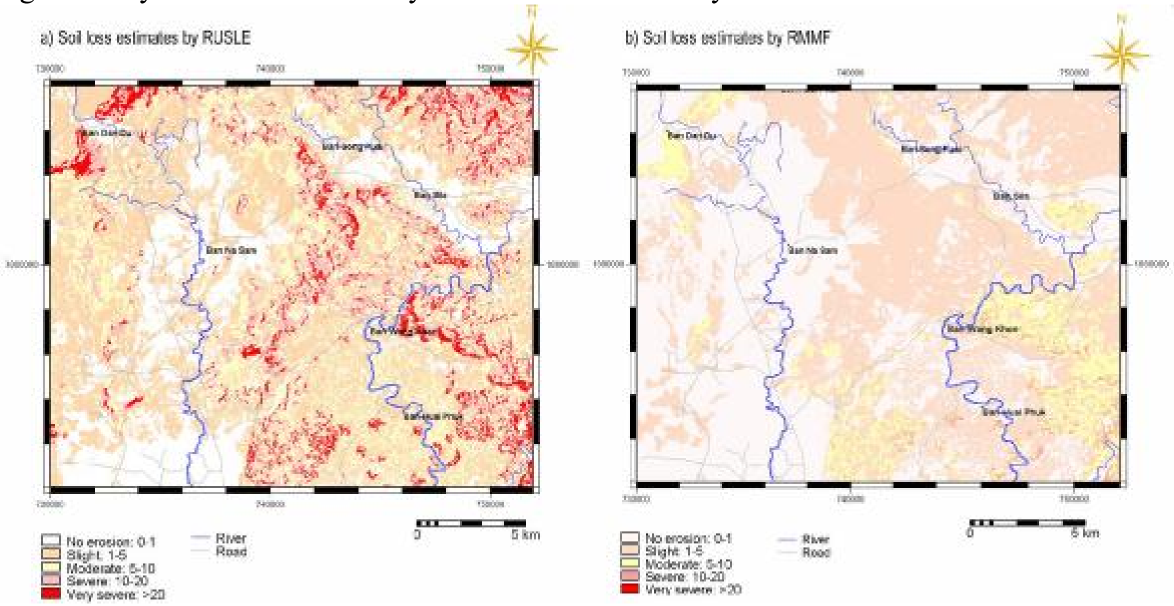

Fig. 3: Soil loss estimates by RUSLE (a) and by RMMF (b)

Sensitivity analysis results using changes in parameter values of land cover, slope gradient and rainfall amount show that RUSLE is very sensitive to cover factor than RMMF. On the other hand, RMMF is more sensitive to changes in slope gradient than RUSLE. Similarly, changes in rainfall amount results in considerable changes in soil loss rates as compared to RUSLE model results. This has to do with the transport capacity of the overland flow, included in the RMMF model, which is ignored in RUSLE.

Some comparative assessment of simple field tests, terrain parameters including stream power index, and erosion model results are given in table 1. RUSLE results seem to over-estimate soil losses at observation no. 7, 15 and 26, since soil is moderately stable and resistance to scour is moderate to high although terrain parameters indicate high erosion potential. Realistic assessment would be moderate. On the other hand, at observation no. 29 RMMF result seems to under-estimate soil losses since soil is highly erodible (soil aggregates are unstable and low rating in resistance to scour), slope gradient is 12 %, and stream power index is also not so low. Realistic soil loss assessment would be slight to moderate.

Table1: Comparative assessments of soil erosion and its parameters

Obs. no.	Resistance to detachment	Resistance to scour	Slope %	Specific. catchment area	Stream power index	RUSLE result	RMMF result
7	mod. stable	high	15	49	20.4	severe	slight
15	mod.stable	mod.	23	42	7.9	v.severe	mod.
26	stable	mod	21	169	37.5	severe	slight
29	unstable	low	12	57	7.4	slight	no erosion

4. CONCLUSION

Use of terrain parameters in combination with simple field test results helps in assessing the reliability of soil loss results of erosion models. The accuracy of the results however can only be validated with actual soil loss data obtained from runoff plots.

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