Spatial Modeling for Soil Erosion Risk in Upper Chi Basin, Northeast Thailand

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Abstact: For the past two decades, encroachment of agricultural activities on forest reserves has become an acute problem in the Upper Chi Basin, Northeast Thailand. Not only does encroachment account for forest degradation but also soil erosion as well. The study was then conducted with objective of modeling and predicting soil erosion risk in the Upper Chi Basin. The study area, an area of about 2,503 sq.km, includes hilly landscape and gently undulating topography with a diversity of land use patterns. The Universal Soil Loss Equation (USLE) model was applied to spatially model and to predict the erosion risk areas. Each of factors as defined in the USLE was collected and was digitally encoded in a GIS database to eventually create the thematic layers. Each factor was assigned the values based on a number of experiments and empirical researches. The overlay operation with the application of the USLE model produces a resultant polygonal layer representing the soil erosion risk. These can be grouped into 5 classes of soil loss. As a result it has become increasingly apparent that GIS application can provide the means to predict and to model the soil erosion risk effectively.
Keyword: Soil erosion and GIS.

1. Introduction

For the past few decades, encroachment of agricultural activities on forest areas and misuse of lands has become an acute problem in Thailand. Thailand used to have abundant forest areas which used ineffectively to expand the cultivated areas. The forest area has been depleted rapidly from 50% in 1960 to 25% in 1990 clearing of forest has had serious consequences on surface water hydrology and accelerated the soil erosion, particularly on steeply sloping land with no conservation measures. The report shows an annual soil loss of about 16 million hectares for the year 2002 mostly in the slope complex areas. (LDD, 2003).

For years Land Development Department has realized the soil loss problems and implemented continuously the conservation measures. Soil conservation experiments have been conducted in a number of areas with intermitten and non-systematic procedures. The information obtained can use to predict and generate the areal extent and quantity with limitation even though the comprehensive conservation plan was formulated in the national level, the plan implementation was likely to implement behind schedule. Allocation of the government budget for the conservation is thought to be indirect and is not substantial assistance. A vision in sustainable development has been defined in a number of government agencies with lack of implementation. The protection measures are not considered as a priority in relation to the solving measures. With the advent of technology, integrated information and spatial modelling can be systematically performed with higher accuracy. These lead to establish the information essential to support the action plan. In this regard, the planning process should be formulated with consideration of spatial information which reflects the severity of the problems.

The USLE developed by Wishchemier et al.(1978) is widely accepted. To assess the soil loss based on an integration of the factors concerned. In the past, difficulties in the processing due to complex criteria and time consuming were found. Currently, the high capability of hardwares and softwares, helps assist effectively the establishment of data base, integration of the data layer and simulation of the area as criteria set. Moreover the rapid generation of Digital Elevation Model (DEM) in combination of updated satellite data offers the opportunity in formulation the soil loss in accordance with its severity. (Remli et al., 2004)

Ultimately, information support with high accuracy leads to better plan for sustainable development.

2. Objectives

The objective of this study is to spatially model and predict soil erosion risk using GIS.

3. Study area

The study area is located in the Upper Chi Basin, Northeast Thailand and covers an area of about 2,503 sq.km. (Fig.1) The landscape is characterized by small hill in the northwest of the area with an elevation 1349 meters (MSL). In addition, in the lower part of the area is restricted to the gently undulating topography with intermitten isolated patch of forest remnants. Mean annual rainfall is 950-1300 m.m. The most extensive area is engaged in rain-fed agricultures. The lowland is restricted to paddy rice while the field crops (cassava and sugar-cane) are found in the upper part with well drainaged soil. The soils are low in fertility and have light texture.

Fig.1 Study area (Upper Chi Basin, Northeast Thailand)

4. Methodology

Soil loss assessment for the Upper Chi is based on the Universal Soil Loss Equation(USLE) with procedures as provided in the USDA Handbook No.537 (Wischemier and Smith, 1978). The USLE is defined as follows

$$A = R\,K\,L\,S\,C\,P$$

A = soil loss (tons/ha/yr)
R = rainfall erosivity factor
K = soil erodibility factor
LS = slope and slope length factor
C = vegetative cover factor
P = conservation practice factor

This equation is widely used worldwide for soil loss prediction which based on empirical research and field experiments. Some of these factors are varied according to the region. The experiment support help identification of valued assigned in the equation. This study attempts to create each factor as a layer in the GIS and to spatially model the soil loss. Determination of the various factors are then based on a number of studies and are described below.

1) Rainfall erosivity factor (R-factor)

R-factor defined by Land Development Department (LDD, 2000) was adopted for this study.

$$R = 0.4669x - 12.1415$$

Where R = rainfall erosivity factor
x = mean annual rainfall (m.m)

The collection of rainfall data of 23 meteorological stations within the Upper Chi and its vicinity was undertaken. Rainfall data of 8-29 years was used to calculate the R-factor for each station. The Kringing interpolation method was applied to establish the spatial layer of the R-factor.

2) Soil Erodibility factor (K-factor)

This approach used the K-factor as identified by Srikhajon et al.(1984) for the area of detailed soil texture available. In the slope complex areas where the soil texture data is unavailable the K-factor based on geological formations as identified by LDD (LDD, 2002) was applied in this study.

3) Slope and slope length factor (LS-factor)

A number of papers provide information on the advantages and disadvantages of equation used as described by Remortel et al (2001), Wischemier and Smith (1978), Myint et al (1997) and McCool et al (1989)

With a number of reason, we used the equation developed by McCool et al(1989) for our approach as follows

$$LS = (l / 22.13)^m (10.8 \sin \beta + 0.03) \text{ for slope} < 9\%$$
$$LS = (l / 22.13)^m (16.8 \sin \beta - 0.5) \text{ for slope} \geq 9\%$$
$$m = f / (l + f)$$
$$f = (\sin \beta / 0.0896) / [3.0 (\sin \beta)^{0.8} + 0.56]$$

where l = slope length (m)
β = slope gradient (degree)

To prepare the LS-factor layer L factor and S factor was generated from digital elevation model. These are, in turn, generated from elevation contours of topographic maps at 1:50,000 scale. The LS-factor layer is then generated from the equation as above.

4) Vegetative cover factor (C-factor)

Spatial vegetative cover type was extracted from Landsat TM imagery acquired in 2003 in combination with the ground truth survey. Based on the C-factor developed by LDD (LDD, 2000) values for the various vegetation cover types are assigned accordingly.

5) Conservation practice factor (P-factor)

Referring to the study conducted by LDD (LDD, 2000), the P-factor was determined to be 0.1 for paddy field. For all other vegetative cover types, no erosion control was found and are assigned the value 1.

Attribute valued of the factor layers in the Upper Chi are summarized in table 1

Table 1 Attribute values of the factor layers in the Upper Chi Basin

R-factor	K-factor*		LS-factor	C-factor**	P-factor**
373.61	C(low)	= 0.15	0.030	F1 = 0.019	F1 = 0.1
433.28	C(up)	= 0.24	26.148	F2 = 0.048	F2 = 1.0
457.89	CL(up)	= 0.24	52.266	F3 = 0.048	F3 = 1.0
461.53	L(low)	= 0.26	78.383	F4 = 0.088	F4 = 1.0
469.61	L(up)	= 0.24	104.501	P = 0.100	P = 1.0
493.32	LS(low)	= 0.26	130.619	R = 0.280	R = 0.1
534.41	LS(up)	= 0.24	156.737	C = 0.600	C = 1.0
588.99	SCL(low)	= 0.26	182.854	U = 0.000	U = 0
615.05	SCL(up)	= 0.24	235.090	W = 0.000	W = 0
646.79	SiC(low)	= 0.15			
692.22	SiCL(low)	= 0.35			
	SiCL(up)	= 0.25			
	SiL(up)	= 0.25			
	SL(up)	= 0.24			
	Jpk	= 0.29			
	Jpw	= 0.29			
	Jsk	= 0.29			
	Kpp	= 0.29			
	Pnd	= 0.13			
	Ppn	= 0.13			
	TRhl	= 0.29			
	TRnp	= 0.24			
	U	= 0			
	W	= 0			

Remark * Textural class; C = Clay, CL = Clay Loam, L = Loam, LS = Loamy Sand, SCL = Sandy Clay Loam, SiC = Silty Clay, SiCL = Silty Clay Loam, SiL = Silty Loam, SL = Sandy Loam, U = Urban, W = Water body,
Geological formation; Jpk = Phu Kradung Formation, Jpw = Phra Wihan Form., Jsk = Sao Khua Form., Kpp = Phu Phan Form., Pnd = Nam Duk Form., Ppn = Pha Nok Khao Form., TRhl = Huai Hin Lat Form., TRnp = Nam Phong Form.,

** F1 = Dry evergreen forest; F2 = Deciduous Dipterocarp Forest ; F3 = Mixed Deciduous Forest; F4 = Forest plantation; P = Grass land; R = Paddy field; C = Field crop; U = Urban area; W = Water body

Fig.2 illustrates the establishment of GIS databases for each of the USLE factors and the spatial overlay of the factors. Application of the USLE model to the five layers yielded a soil erosion with 8 classes according to the resultant values proposed in table 2

Table 2 Soil loss evaluation

Value (t/ha/yr)	Evaluation
< 10	very mild
10-20	mild
20-30	moderate
30-40	
40-50	severe
50-100	
100-150	very severe
>150	

5. Result and discussion

The soil erosion map resulting from the overlay of the USLE factors in the Upper Chi is presented in Fig 3. The corresponding quantitative soil loss is shown in Table 3.

This study provides overall soil loss in the area as a result of the integrated factors spatially and quantitatively. Very severe soil loss cover an area of about 5.7% for which the total soil loss exceeds 45% of the watershed area. Soil conservation measures were then placed emphasis on the very severe and severe soil loss. It is evident that the information obtained includes the soil loss in terms of quantity and locational boundary. Moreover, the areas susceptible to erosion can be accessed to plan the soil conservation program in combination with an appropriate allocation of the budget. It has become increasingly apparent that computer-based GIS provides the mean to the planning process for conservation. The factor layers that can manage by human action i.e vegetation cover and conservation practice should be taken into the account for conservation measures. However, in terms of modeling soil erosion with high accuracy field experiment is a must. This is to correctly assign the values for each of the USLE factors. It should be noted that the potential source of modeling error is not only in the values defined for each factor but also in the scale used in each layer.

Table 3 Soil loss in the Upper Chi Basin

Evaluation class	Rate (t/ha/yr)	Area (ha)	%	Soil loss (ton)	%
Very mild	< 10	126,162.52	50.41	185,128.37	2.82
Mild	10-20	43,236.52	17.27	696,866.42	10.63
Moderate	20-30	26,426.72	10.56	688,949.68	10.51
	30-40	14,542.00	5.81	453,276.21	6.92
Severe	40-50	8,583.08	3.43	351,906.28	5.37
	50-100	17,065.12	6.82	1,214,993.76	18.54
Very severe	100-150	4,956.32	1.98	568,560.02	8.67
	>150	9,323.20	3.72	2,395,269.80	36.54
	Total	250,295.48	100.00	6,554,950.54	100.00

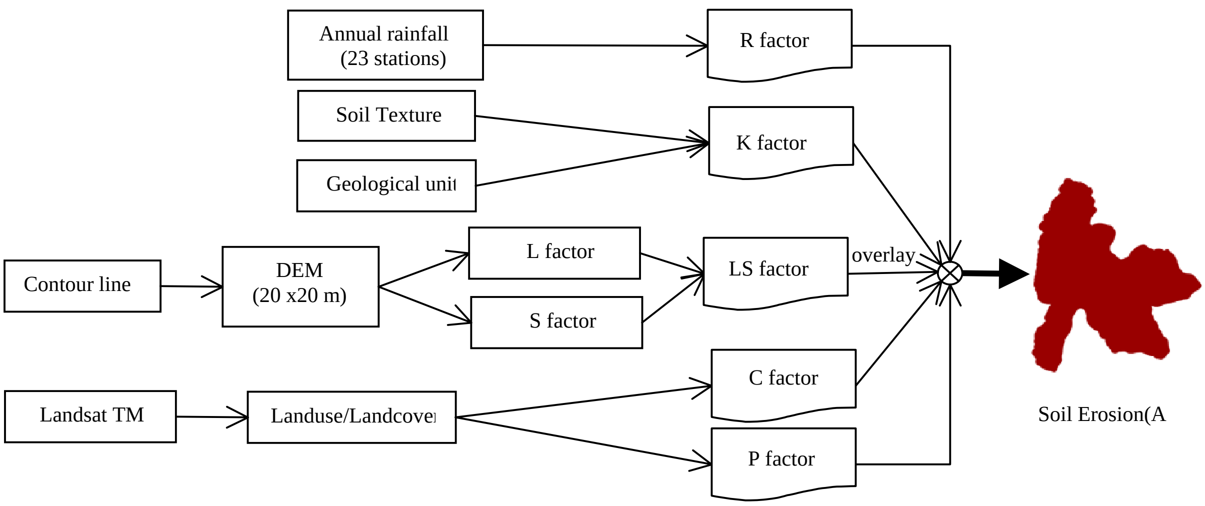

Fig. 2 Schematic chart of soil erosion assessment.

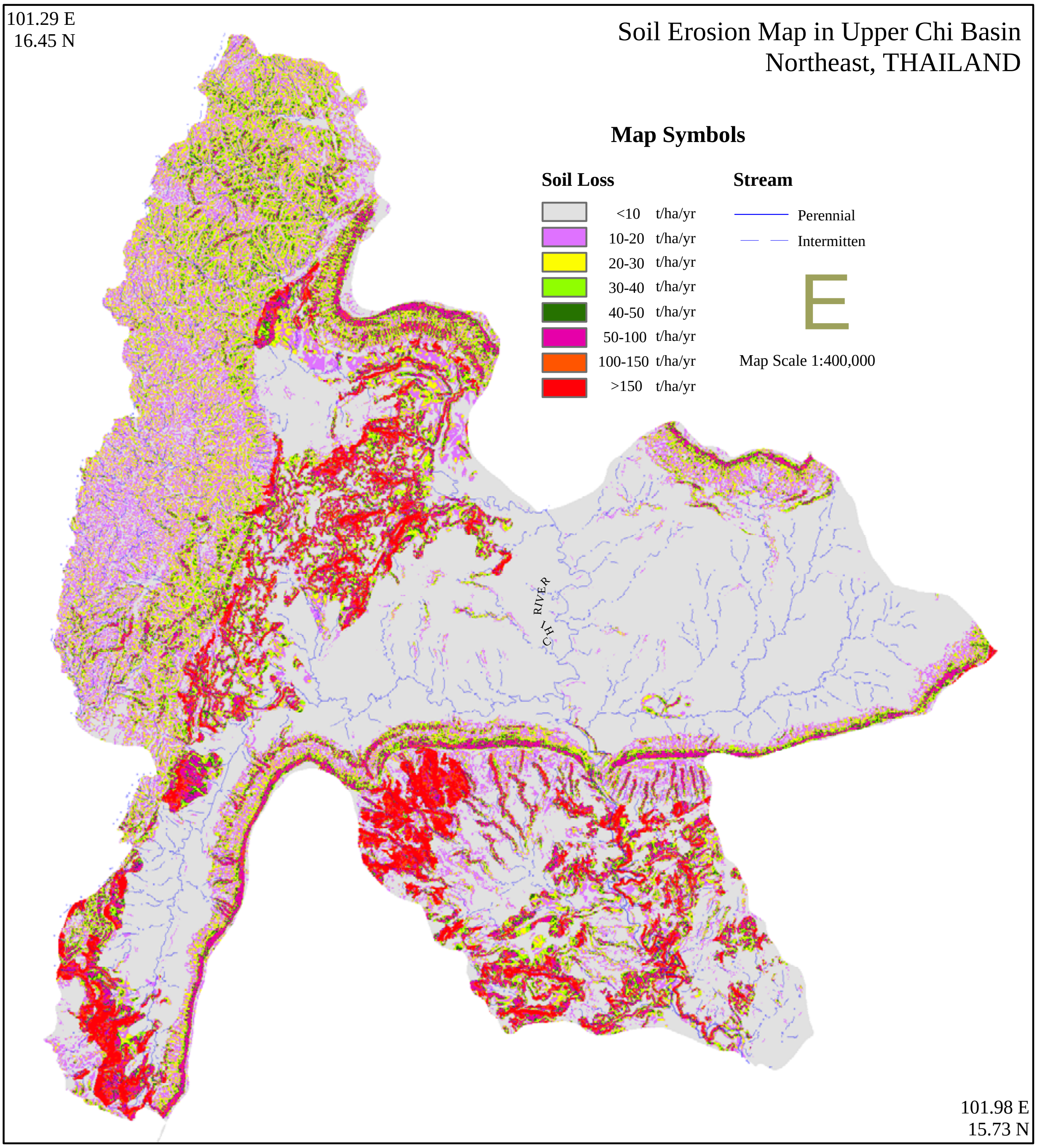

Fig. 3 Soil erosion map in Upper Chi Basin.

6. Conclusion

In conclusion with the GIS functionalities it is possible to spatially and quantitatively synthesize multi-layers of data and to eventually perform the integration of the USLE factors as criteria set. Information obtained can be retrieved and updated for bettering the management procedure that may exist. In terms of conservation of the area the users have knowledge base in each factor concerned and understand the factor interaction. These can help support the administration for the overall area of interest.

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