SPATIAL MODELING FOR SOIL EROSION ASSESSMENT IN UPPER LAM PHRA PHLOENG WATERSHED, NAKHON RATCHASIMA, THAILAND†

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Abstract

The integration of RS/GIS with Universal Soil Loss Equation (USLE) for soil erosion assessment has been carried out in Upper Lam Phra Phloeng watershed in Nakhon Ratchasima. The study basically aimed to spatially model soil loss to be used for soil conservation purposes. Herewith, two Landsat-5 TM imageries in 2000 and 2008 were classified by using hybrid techniques for land use and land cover classes for vegetation cover and field support practice factors of USLE. Also, other USLE factors which included rainfall-runoff erosivity, slope length and steepness and erodibility were extracted based on mean annual rainfall, DEM, soil and geological data. The land use and land cover in 2000 and 2008 were extracted with their change. Soil loss maps in 2000 and 2008 were produced based on USLE indicated the amount of soil loss in 2000 was more than 2008. Furthermore, severity of soil loss was reclassified into 5 classes: very low, low, moderate, severe and very severe. The result obtained 19.25% *moderate*, 5.68% *severe* and 0.02% *very severe* in year 2000. While the result obtained 17.84% *moderate*, 5.35% *severe* and 0.02% *very severe* in year 2008. *Moderate, severe* and *very severe* locations were here emphasized for the soil and water conservation practices. The change of soil loss severity between 2000 and 2008 map was also generated for indicating both increase and decrease in soil loss rate.

Keywords: **Soil erosion, GIS&RS, USLE, Upper Lam Phra Phloeng Watershed**

Introduction

Soil erosion, the most serious type of land degradation, occurs in all climatic regions. Soil erosion is widely considered to be a serious threat to the long-term viability of agriculture in many parts of the world (El-Swaify *et al.*, 1985). Erosion by water is a primary agent of soil degradation at the global scale, affecting 1,094 million hectares, or roughly 56% of the land experiencing human induced degradation (Oldeman *et al.*, 1991).

For the assessment of erosion, USLE (Wischmeier and Smith, 1978), a spatial assessment model is used widely. It has become most particularly useful in evaluating the impacts

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of intensified land use on soil loss. It is designed to predict long-term average annual soil loss from field slopes under a specific land use and management system, based on the product of rainfall-runoff erosivity (R), soil erodibility (K), slope length and steepness (LS), surface cover and management (C) and support conservation practices (P). The USLE model has advantages because its data requirements are not too complex or unattainable, it is relatively easy to understand, and it is compatible with GIS (Millward and Mersey, 1999).

Coupling GIS and USLE has been widely used and is very effective approach for estimating the magnitude of soil loss and identifying the spatial locations vulnerable to soil erosion (Fu *et al.*, 2006). Remote Sensing complimented with field ground truthing and GIS provides the best methodological toolset to investigate soil erosion (Wolfgang, 2002).

Study Area

The area stretches approximately from 101° 28′ 57″ to 102° 12′ 12″ towards east and 14° 18′ 26″ to 14° 52′ 07″ north in WGS 84 coordinate system with the total acreage of 782.32 Sq. Km. It falls under the jurisdiction of three main districts of Wang Nam Khieo, Pak Chong, and Pak Thong Chai of Nakhon Ratchasima province as shown in Figure 1. The area is characterized by a hilly topography with undulating slope and flat areas. The area is bounded by Pha Khao Phu Luang National Reserve Forest in the north and Khao Yai National Park in the south. The elevation ranges approximately from 200 m to 1,300 m above Mean Sea Level (MSL). The area experiences three seasons in a year: cool dry, hot dry and rainy season, with an average of 1,000 mm annual rainfall.

The mean monthly maximum temperature in the study area ranges from 27°C in December to 37°C in June and minimum temperature from 14°C in December to 24°C in June. Maize is the dominant crop grown and some areas are also allotted for planting cassava, sugarcane, and mungbean.

Similarly, mango orchards are majority amongst the fruits, but there are also small plantations like custard apples, tamarind,

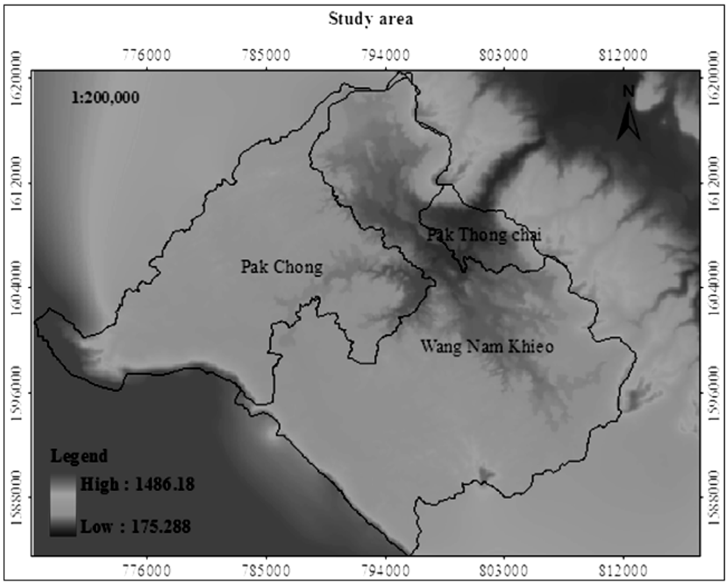

Figure 1. Study area and its jurisdiction

papaya, jackfruits and others. The water bodies and village/urban/resort areas also account for some percentage in the area although there is no significant coverage in the study area.

Materials and Methods

USLE was applied for soil erosion assessment and it is written as:

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where,

A is the soil loss in t/ha/year,

R is the rainfall–runoff erosivity factor in MJ mm/ha/h per year,

K is the soil erodibility factor (t h/MJ mm),

LS is the slope length and steepness factor,

C is vegetative cover factor and

P is the conservation support-practice factor.

The LS, C, and P are dimensionless. The integration of input sources, how to process the factor maps and outputs for assessing the erosion is provided in Figure 2**.**

Rainfall–Runoff Erosivity, R

The digital rainfall data was obtained from Nakhon Ratchasima and Chonburi Hydrology and Water Management Office websites of Royal Irrigation Department (RID). The monthly rainfalls have been reduced to mean annual rainfall in millimeters for the erosivity at each common 10 stations. Since there were less number of stations in the study area, the rainfall from the neighbouring stations were also used. Table 1 shows the mean annual rainfall and derived rainfall-runoff erosive values for year 2000 and 2008 respectively. For R-factor, equation defined by Land Development Department (LDD) (2000) for Northeastern part of Thailand has been taken as best choice for this study. The equation is written as:

$$R = 0.4669\ X - 12.1415 \quad (2)$$

where,

R is rainfall-runoff erosivity factor in MJ mm/ha/h per year and

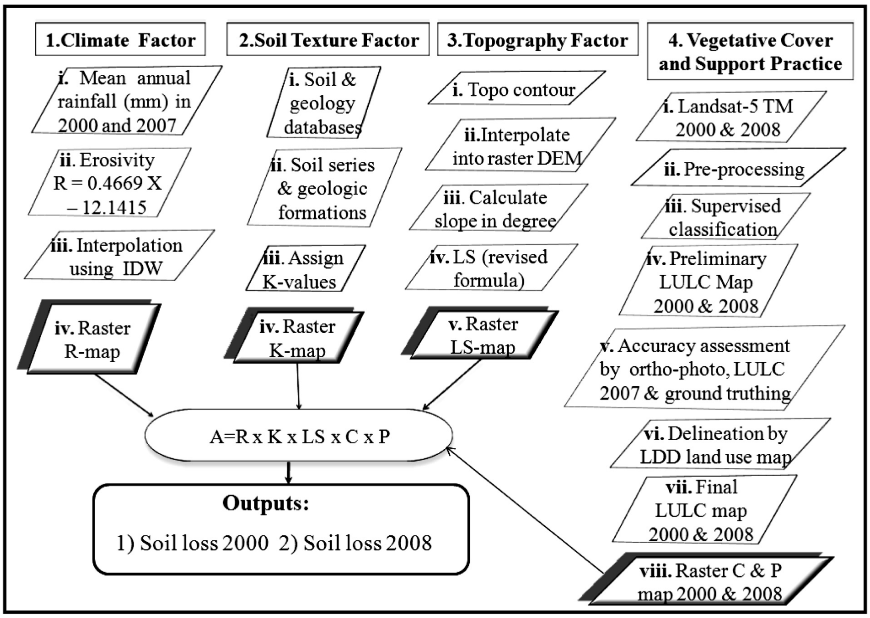

Figure 2. Integration of inputs, processes and results

X is mean annual rainfall (mm)

The Inverse Weighted Distance (IWD) method of interpolation has been employed to establish the spatial layer of the R-factor.

Soil Erodibility, K

The digital soil map at 1: 25,000 scale for 2004 originally obtained from LDD was used as base data. K values were based on soil series texture and geological formations published by LDD at 1:50,000 were used for the study as shown in Table 2 and Table 3. For slope complex, like forests and high mountainous areas k-values set for different soil groups (series) and geological formations were identified and used. For water body, rock land, man-made structures and urban human settlement polygons like schools and villages, a value of **"0"** was assigned as erosion is assumed to be null on these kinds of surfaces.

Slope Length and Steepness, LS

Here, the digital topographic contours with 20 m interval initially obtained from Royal Thai Survey Department (RTSD) at scale 1:50,000 have been utilized. Digital topographic contours were then interpolated into raster DEM after which slope in degree unit was calculated using ArcGIS. For preparing the LS-factor layer from digital elevation model, the revised equation was used for the study as follows:

(a) Slope Length,

$$L = (\lambda / 22.13)^{m} \quad (3)$$

Where,

m is a variable slope-length exponent related to the ratio β of rill erosion (caused by flow) to interrill erosion (principally caused by raindrop impact) by the following equation (Foster *et al.*, 1977):

$$m = \beta / (1 + \beta) \text{ and} \quad (4)$$

β can be computed from (McCool *et. al.*, 1989) as

$$\beta = (\mathrm{Sin}\,\theta / 0.0896) / (3.0(\mathrm{Sin}\,\theta)^{0.8} + 0.56) \quad (5)$$

(b) Steepness factor, S is computed from (McCool *et al.,* 1987)

$$S = (10.8\mathrm{Sin}\,\theta + 0.03) \text{ for slope} < 9\% \quad (6)$$

$$S = (16.8\mathrm{Sin}\,\theta - 0.5) \text{ for slope} \geqslant 9\% \quad (7)$$

Table 1. Annual mean rainfall and derived rainfall-runoff erosive values (R) in year 2000 and 2008

No.	Station	Code	Mean annual rainfall in 2000	Rainfall-runoff erosive(R) in 2000	Mean annual rainfall in 2008	Rainfall-runoff erosive(R) in 2008
1	Pak Thong Chai	431,005	932.20	423.10	862.7	390.65
2	Khoa Yai	431,031	2,165.0	998.60	1,781.3	819.55
3	RM_145	25,751	1,386.0	635.10	1,075.0	489.80
4	Huai krok De	25,930	1,258.0	575.00	1,184.0	541.00
5	LPP dam (m33)	25,511	1,115.2	508.55	1,283.0	587.00
6	RM_147	25,781	1,106.0	504.00	1,043.0	475.00
7	RM_146	25,771	1,530.0	702.30	1,207.0	551.50
8	Chokchai Farm4	25,651	1,418.4	650.11	960.90	436.50
9	Ny1B	22,341	2,083.5	960.64	1,904.0	877.00
10	Kgt 14	n.a	2,407.5	1,111.92	1,902.0	876.00

Table 2. Soil erodibility (K) value based on soil series and geological formations in Northeastern Thailand

Group	Soil series	Texture	Erodibility (K)
22	Sri Thon (St)	Loam	0.35
29	Pak Chong (Pc)	Clay	0.15
29	Ban Chong (Bg)	Clay	0.15
31	Wang Hai (Wi)	Clay loam	0.36
35	Dan Sai (Ds)	Sandy clay loam	0.20
40	Pak Thong Chai (Ptc)	Loamy sand	0.05
44	Chan Tuk (Cu)	Loamy sand	0.05
47	Muak Lek (ML)	Clay	0.15
	Li (Li)	Silty Clay	0.27
48	Wangnam Khieo (Wk)	Loamy sand	0.05
52	Takhli (Tk)	Loam	0.35
55	Wang Saphung (Ws)	Clay	0.15
56	Phon Ngarm (Png)	Sandy loam	0.26
	Bo Thai (Bo)	Sandy loam	0.26
62	Slope Complex (SC)*	n.a.	(See Table 3)

Table 3. K based on major rock types of each of the geological formations

Symbol	Formation	K	Major rocks	Remarks
Jpw	Phra Wihan	0.29	Sedimentary and metamorphous	Most formations were unnamed as the database was not formally published.
Jpk	Phu Kradung	0.29	Sedimentary and metamorphous	
P	Unnamed	0.29	Sedimentary and metamorphous	
P2	Unnamed	0.29	Sedimentary and was not	
P3	Unnamed	0.29	Sedimentary and metamorphous	
PTRan	Andesite	0.13	Igneous	
PTRrh	Rhyolitic	0.13	Igneous	
Qa	Quaternary	0.37	Alluvial deposit, gravel, sand, slit and clay.	
TRgr	Granite	0.13	Igneous	
TRgr1	Granite1	0.13	Igneous	
TRgr2	Granite2	0.13	Igneous	
TRgr3	Granite3	0.13	Igneous	
Trhl	Huai Hin Lat	0.29	Sedimentary and metamorphous	

where,

λ = Slope Length (cell size in meters),

θ = Slope gradient map (degree)

ILWIS 3.4 software (Open source from http://www.ilwis.org) has been used for factor map calculations as it has many user friendly functions.

Vegetative Cover, C

The C factor is perhaps the most important USLE factor because it represents conditions that can be managed most easily to reduce erosion. The LULC map was basically prepared from Landsat-5 TM in 2000 and 2008 using supervised classification. Some classes which could not be classified due to other limitations were used from the land use map in 2007 of LDD. The C-factor values set by LDD (2000) for the various vegetation cover types have been assigned accordingly as shown in Table 4. The land use and land cover change is provided in Table 5.

Field Support Practice, P

The support practice factor, P is the soil-loss ratio with a specific support practice to the corresponding soil loss with up-and-down slope tillage (Renard *et al.*, 1997). In Thailand, the value for P has not been established for all agricultural cover types except for paddy. For no practice, maximum value of 1 was assigned. The P values for nine different classes used are given below according to LDD provided in Table 4.

Results and Discussions

The five grid (30 m) factor maps after verification have been overlaid in the raster GIS platforms and the final soil loss grid map thus obtained has been reclassified using manual method into 5 classes each defining the degree of severity by rating score with areas affected in percentages as shown in Table 6. The study obtained an average soil loss of 31.40 ton/ha/year in the year 2000 with minimum of 0.014 ton/ha/year and maximum of 923.26 ton/ha/year. Similarly, the study obtained an average soil loss rate of 29.46 ton/ha/year in year 2008 with minimum of 0.014 ton/ha/year and maximum of 914.61 ton/ha/year. The result indicated that the amount of soil loss was more in year 2000 and so was the rainfall. The erosion severity maps are shown in Figure 3 and Figure 4, respectively. The change of erosion rates for two years is shown in Table 7.

The soil loss severity will be in those spatial locations, where there is less or no canopy cover, with high rainfall and steep slopes or with silty and fine sandy soils. The severely and very severely eroded locations on the map indicate the areas with high erosion rates leading to land

Table 4. Vegetative cover (C) and field support practice (P)

Land cover class	C Value	P Value	Remarks
Dry Evergreen Forest	0.019	0.1	* C value of 0.502 was
Mixed Deciduous Forest	0.048	1.0	used for land use map
Forest plantations	0.088	1.0	2000 as the field crop
Orchards	0.15	1.0	was mainly corn.
Paddy	0.28	0.1	Since several field
Grassland	0.015	1.0	crops were grown and
Agricultural (Field Crops)	0.502/0.6*	1.0	land use has changed
Urban area	0	0	in 2008, value of 0.60
Water bodies	0	0	was applied.

Table 5. Land use and land cover change from 2000 to 2008

Area (Sq. Km)	2008									
2000	**FC**	**MD**	**DE**	**G**	**O**	**P**	**Pl**	**U**	**W**	**Total**
FC	339.8	0.0	0.0	4.4	16.7	0.0	1.2	0.0	1.8	363.9
MD	0.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	30.1
DE	0.0	0.0	170.4	0.0	0.0	0.0	1.6	0.0	0.1	172.1
G	0.0	0.0	0.0	49.6	0.0	0.0	0.0	0.0	0.4	50.0
O	0.0	0.0	0.0	0.0	64.3	0.0	0.0	0.0	0.2	64.5
P	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	2.3
Pl	0.0	0.0	0.0	0.0	0.0	0.0	64.2	0.0	0.1	64.3
U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.5	0.0	26.5
W	1.1	0.04	0.2	0.1	0.03	0.0	2.2	0.0	8.5	12.2
Total	**340.9**	**30.04**	**170.6**	**54.1**	**81.0**	**2.3**	**69.2**	**26.5**	**11.2**	**785.7**

FC: Field Crops *G: Grassland* *Pl: Forest plantations*
MD: Mixed Deciduous Forest *O: Orchards* *U: Urban area*
DE: Dry Evergreen Forest *P: Paddy* *W: Water bodies*

Table 6. Soil loss severity distribution in 2000 and 2008

Severity class	Loss rate (t/ha/y)	2000		2008		Descriptions
		Sq. Km	**%**	**Sq. Km**	**%**	
1	d” 6.25	366.55	46.85	390.07	49.86	Very low
2	6.26-31.25	220.61	28.20	210.78	26.94	Low
3	31.26-125.00	150.59	19.25	139.54	17.84	Moderate
4	125.01-625.00	44.43	5.68	41.84	5.35	Severe
5	> 625.00	0.15	0.02	0.12	0.02	Very severe

Table 7. Soil loss severity changed in two years in areas

Area (Sq. Km)	2008					
2000	**Very low**	**Low**	**Moderate**	**Severe**	**Very severe**	**Grand total**
Very Low	362.95	2.92	0.60	0.08	0.00	366.54
Low	21.71	195.79	3.10	0.00	0.00	220.59
Moderate	4.66	10.94	133.68	1.30	0.00	150.58
Severe	0.70	1.12	2.15	40.45	0.00	44.43
Very severe	0.02	0.00	0.00	0.01	0.12	0.15
Grand Total	**390.04**	**210.76**	**139.53**	**41.84**	**0.12**	**782.29**

degradation where water and soil conservation measures are required to develop preliminary basin management strategies.

These locations can also mean the areas are adversely affected by erosion process or source for erosion.

In an agricultural context, these areas are the locations where crop growth and yields are less.

On the contrary, the very low or lowly eroded locations on the map indicate the areas with low erosion rates. These spatial locations are the areas where the vegetation cover could be good enough for providing maximum protection from rainfall impact.

Conclusions

The higher erosion rate can be attributed to ever-increasing usage of land for agricultural purpose. From the practical experience, it can be deducted that the canopy cover especially for plantations, orchards, mixed deciduous forests in the year 2000 would be less whereas, canopy

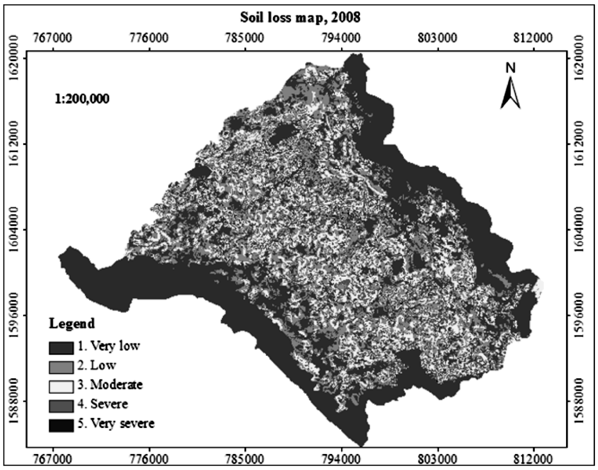

Figure 3. Soil erosion severity map in 2000

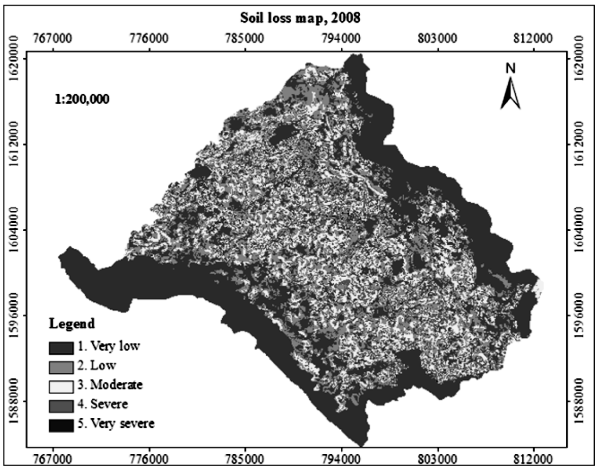

Figure 4. Soil erosion severity map in 2008

covers have grown bigger in year 2008. However, the limitation of using the same C-value irrespective of canopy covers for the same type of land use and cover type, the erosion rate estimate will, however, remain the same each year.

Due to growth phenology, it has been difficult to classify as land cover classes have the same signature. However, Landsat imagery was found suitable for land use and cover mapping at watershed level due to its seamless and large area coverage when it is cloud-free. However, the precision of soil loss estimation using USLE depends on the accuracy of input factors. Therefore, if regional factors of soil erosion are substituted by local factors, it will yield more precise results. The change map indicated both increase and decrease in erosion rates. Only moderate, severe and highly severely eroded locations were emphasized for the conservation purposes

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