Kasetsart J. (Nat. Sci.) 48 : 241 - 253 (2014)

Online Geospatial Database and Processing of Universal Soil Loss Equation Modeling for Optimum Assessment of Soil Loss in Songkhram Sub-Watershed, Northeastern Thailand

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ABSTRACT

An online geospatial database and processing system of universal soil loss equation modeling was designed and implemented, which included a distributed database designed to accommodate, organize and manipulate spatial data as well as interrelate data from various sources distributed by government offices. The system was used to produce erosion susceptibility maps for regions of Upper Northeastern Thailand—an area that has suffered from inappropriate land use practices. The OpenGeo software suite was used for online integration of the distributed database. GIS-based methods were proposed and applied to data from the Songkhram sub basin in the Mekong River basin. ArcGIS software was used to derive land use, land cover and topographical data for the watershed. An open source GIS (QGIS) and the Geographic Resources Analysis Support System (GRASS) package were used to carry out geographical data analysis and database management system implementation, both of which were implemented using the OpenGeo software suite. The watershed was mapped into topographically and geographically homogeneous grid cells to capture watershed heterogeneity. The results showed that during the study period, the area had soil losses that exceeded the tolerance level ranging from the moderate class up to the very severe class of susceptibility. Moreover, it was also found that the amount of soil erosion decreased to 499 km^2 in 2010 from a predicted 1,123 km^2.

Keywords: optimal soil loss, distributed geodatabase, online geospatial processing, geographic information system (GIS), soil erosion, universal soil loss equation (USLE), land degradation, land use and land cover

INTRODUCTION

The following information has been sourced from Land Development Department (2003). The physical properties of soil in Northeastern Thailand are lateritic and sandy and are distributed within the topography with different quantities and qualities for agriculture. The Thai government Land Development Department (LDD) has previously analyzed the suitability of land use for agriculture using soil management and in 1980, the LDD reported that there were around 30,000,000 rai (approximately 4.8 million ha) of agricultural land in used which were in unsuitable areas.. Almost half of the unsuitable areas (about 2 million ha) were located in the Northeast. In 1992, the LDD reported that there were about 35.6 million rai (approximately 5.7 million ha) of

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Received date : 14/06/13 Accepted date : 06/01/14

agricultural land which were in unsuitable areas of which about 21.2 million rai (approximately 3.4 million ha) were in the Northeast. These areas are a major cause of the current serious soil erosion problem in the Northeast and have directly impacted on soil resources. Table 1 shows rate of soil erosion for major land use types in the Northeast in 1992.

Nowadays, the integration of information technology and geographic information systems (GIS) allows data and information to be transferred via the Internet. In addition, open source software is more available to develop appropriate GIS applications, especially distributed geospatial processing.

Many government offices have developed information systems to distribute spatial and nonspatial data for GIS applications such as the land use and soil properties database of the LDD, the topography dataset of the Royal Thai Survey Department (RTSD) and the rainfall dataset of the Meteorological Department. However, all of these dataset cannot be used directly online for specific distributed geospatial processing.

The problem of soil erosion on agricultural lands can only be effectively addressed through long-term strategic agricultural planning, based on a sustainable management approach at the regional level. This approach involves the assessment of soil losses over the region to identify and prioritize areas for attention, followed by the evaluation and recommendation of appropriate sustainable management strategies.

Management of soil resources involves many stages of decision-making and expertise from various fields and hence requires collaboration among the parties involved. In addition, public participation is essential as a means of improving information and to facilitate the adaptability of soil erosion management. GIS data made accessible on the Internet by online distributed geospatial processing technology, offer an effective medium for public participation in and collaboration on soil erosion management.

Currently, the Internet is considered an important medium as it enables users to interact across the network and has provided opportunities for retrieval of hypermedia information in an easy and effective way (Burapha University, 1999). Through the multimedia capabilities of the World Wide Web, users all over the world have turned this technology into an important source to access and acquire information as well as interact using diverse types of visual representations such as images, maps, diagrams and graphs which are as easy to implement as text supported by a graphical interface, sound, video and animation (Burapha University, 1999).

Table 1 Rate of soil erosion in Northeastern of Thailand in 1992.

Land use type	Area (ha)	Rate of soil erosion ($t.\ ha^{-1}.yr^{-1}$)
Forest	2,179,871	43.00
Paddy field	6,075,655	1.19
Field crops	2,152,788	132.19
Perennial trees	295,057	84.38
Horticultural crops	33,454	14.13
Grassland	63,171	5.63
Idle land	331,000	140.69
Built up area and miscellaneous	5,754,437	NA

NA = Not applicable.
Source: Land Development Department (2003)

Soil erosion in each cell of the Songkhram River subbasin was calculated using the universal soil loss equation (USLE) by carefully determining its various parameters and classifying the Songkhram sub-watershed into different levels of soil erosion severity (Nontananandh and Changnoi, 2012). The results published on the Internet showed that during the study period, the area had soil losses that exceeded the tolerance level (12.5 $t.ha^{-1}.yr^{-1}$) ranging from the moderate class up to the very severe class of susceptibility. Moreover, it was also found that the amount of soil erosion had increased from 762 km^2 in 2006 to 1,123 km^2 in 2010.

Soil erosion, the most serious type of land degradation, occurs in all climatic regions and 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 ha, or roughly 56% of the land experiencing human-induced degradation (Oldeman *et al.*, 1991).

Study area

The study area covered five provinces—Udon Thani, Nong Khai, Bueng Kan, Sakon Nakhon and Nakhon Phanom (Figure 1)—where land degradation problems exist. The western part of the study area is dominated by the mountain ridges of Phupan Mountain, while the eastern part consists of the Songkham River watershed, with elevations varying from 100 to 980 m above mean sea level and the average annual rainfall is about 1,200 mm, with 80% concentrated in the rainy season. The mean monthly maximum temperature in the study area ranges from 27 °C in December to 37 °C in June and the mean monthly minimum temperature ranges from 14 °C in December to 24 °C in June. The dominant land uses/land cover of the Songkhram River subbasin are field crops, forests, paddy fields and urban and built-up areas (Nontananandh and Changnoi, 2012).

Maize is the dominant crop and some areas are also allotted for growing cassava, sugarcane and mung bean while mango orchards account for the majority of fruit grown, but there

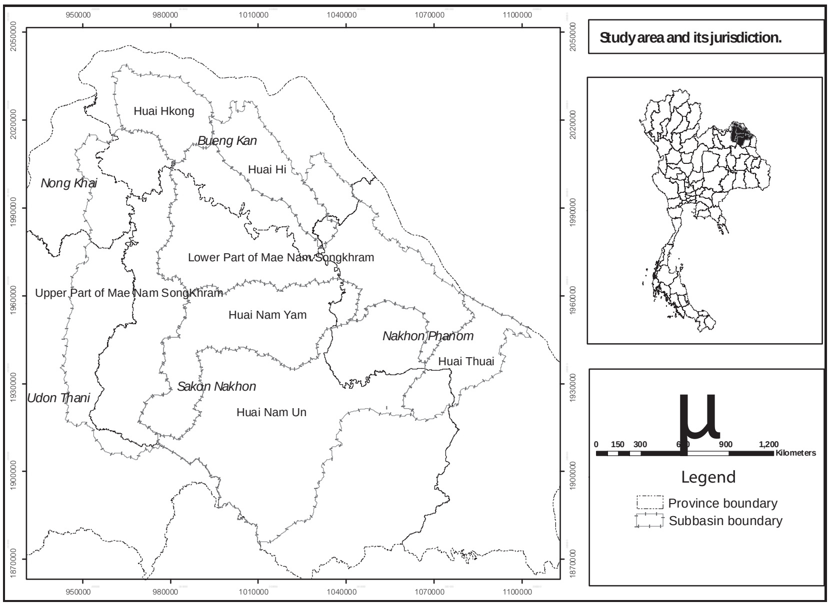

Figure 1 Map of Thailand including details of the study area.

are also small plantations where custard apple, tamarind, papaya, jackfruit and other fruits are grown while water bodies and village/urban/resort areas also account for a small but insubstantial proportion of the study area (Urgen, 2008).

MATERIALS AND METHODS

Data collection and preparation

Existing data related to soil loss analysis were compiled consisting of: administrative boundaries, topography, rainfall, existing land use, soil series (Table 2) and soil group and geological data. Then, soil loss factors were extracted for present soil loss analysis and optimum soil loss analysis (Table 3).

Research framework

Two main software modules were implemented: (1) the Geo-Spatial Information Integration (GSII) module (2) the Online Geospatial Processing (OGP) for Agricultural Soil Erosion Management (ASEM) module as shown in Figure 2. Both of are linked.

The GSII module, which consists of computer programs, was implemented using the OpenGeo software suite, which is a Free and Open Source Software for Geospatial (FOSS4G) available from an Internet webserver (http://suite.opengeo.org/dashboard/; sourced: 11 April 2012) based on the open source system (OpenGIS) of the Open Geospatial Consortium. The output from this module was a web application portal consisting of integrated tools with a distributed geodatabase under the web map server. According to the basis of interoperability (Figure 2), the web feature service (OGC-WFS) is applied for geodatabase exchange among government agencies. In this study, the GSII module established GIS units to provide a spatial and non-spatial database to integrate feature data sets from the Department of Provincial Administration (DOPA), LDD, RTSD, and the Thai Meteorological Department (TMD). The process involved simulated databases for interoperability implementation.

The OGP for the ASEM module, which consisted of computer programs, was developed and extended the UMN MapServer using open source software. It offers broad functionality and multiple configurations using a UMN MapServer application based on the PHP/MapScript and Common Gateway Interface (CGI) with the

Table 2 Data collection for soil loss analysis.

Data	Data format	Year	Scale	Source
Administrative boundary	GIS digital file	2000	1:50,000	Department of Provincial Administration
Topographic data	GIS digital file	2000	1:50,000	Royal Thai Survey Department
Rainfall	Spread sheet	2006	NA	Thai Meteorological Department
Existing land use	GIS digital file	2006	1:50,000	Land Development Department
Soil series	GIS digital file	2004	1:50,000	Land Development Department
Soil group	GIS digital file	2004	1:50,000	Land Development Department
Geology	GIS digital file	2004	1:50,000	Department of Mineral Resources

NA = Not applicable.

Python programming language (available from https://www.python.org/) including basic tools to allow input, query and select attribute, and display map, among others. The output from this module is geospatial information web analytical tools which consist of two sub-modules:

1. USLE model analysis sub-module. This is an algorithm for soil loss analysis based on USLE.

2. OGP model analysis sub-module. This is an algorithm for optimum soil loss management in agriculture based on soil loss analysis and is developed by the decision maker.

Universal soil loss equation model

The soil loss assessment used in the USLE model for present soil loss (PSL) and optimum soil loss (OSL) analysis was in grid format with a 40 m cell size using Equations 1 and 2, respectively:

$$PSL = R*K*LS*C_{present}*P_{present} \quad (1)$$

$$OSL = R*K*LS*C_{optimal}*P_{optimal} \quad (2)$$

where PSL is the present soil loss (tonnes per hectare per year), OSL is the optimum soil loss (tonnes per hectare per year) and R is the rainfall-runoff erosivity.

The digital rainfall data were obtained for Nong Khai, Nakhon Phanom, Sakon Nakhon, and Udon Thani provinces (Thai Meteorological Department, 2009). There were 61 rainfall measuring stations in the watershed which had been used to measure monthly rainfall data from 1979 to 2002. The monthly rainfall data were reduced to annual mean rainfall in millimeters for the evaluation of erosivity at each of the 61 stations. Since there were few stations in the study

Table 3 Data preparation for soil loss analysis.

Model	USLE factor	Description	Methods
Present Soil Loss (*PSL*) analysis	*R* factor	Rainfall and runoff erosivity factor	Interpolation of mean annual rainfall data.
	K factor	Soil erodibility factor	Extraction from soil texture and geology data.
	LS factor	Slope length and slope steepness factors	Extraction from DEM.
	$C_{present}$ factor	Cropping and management factor of present land use types	Extraction from land use data.
	$P_{present}$ factor	Conservation practice factor of present land use types	Extraction from land use data.
Optimum Soil Loss (*OSL*) analysis	*R* factor	Rainfall and runoff erosivity factor	Interpolation of mean annual rainfall data.
	K factor	Soil erodibility factor	Extraction from soil texture and geology data.
	LS factor	Slope length and slope steepness factors	Extraction from DEM.
	$C_{optimal}$ factor	cropping and management factor of optimum land use types	Extraction from selected land used based on soil group data.
	$P_{optimal}$ factor	Conservation practice factor of optimum land use types	Extraction from selected land used based on soil group data.

USLE = Universal soil loss equation; DEM = Digital elevation model.

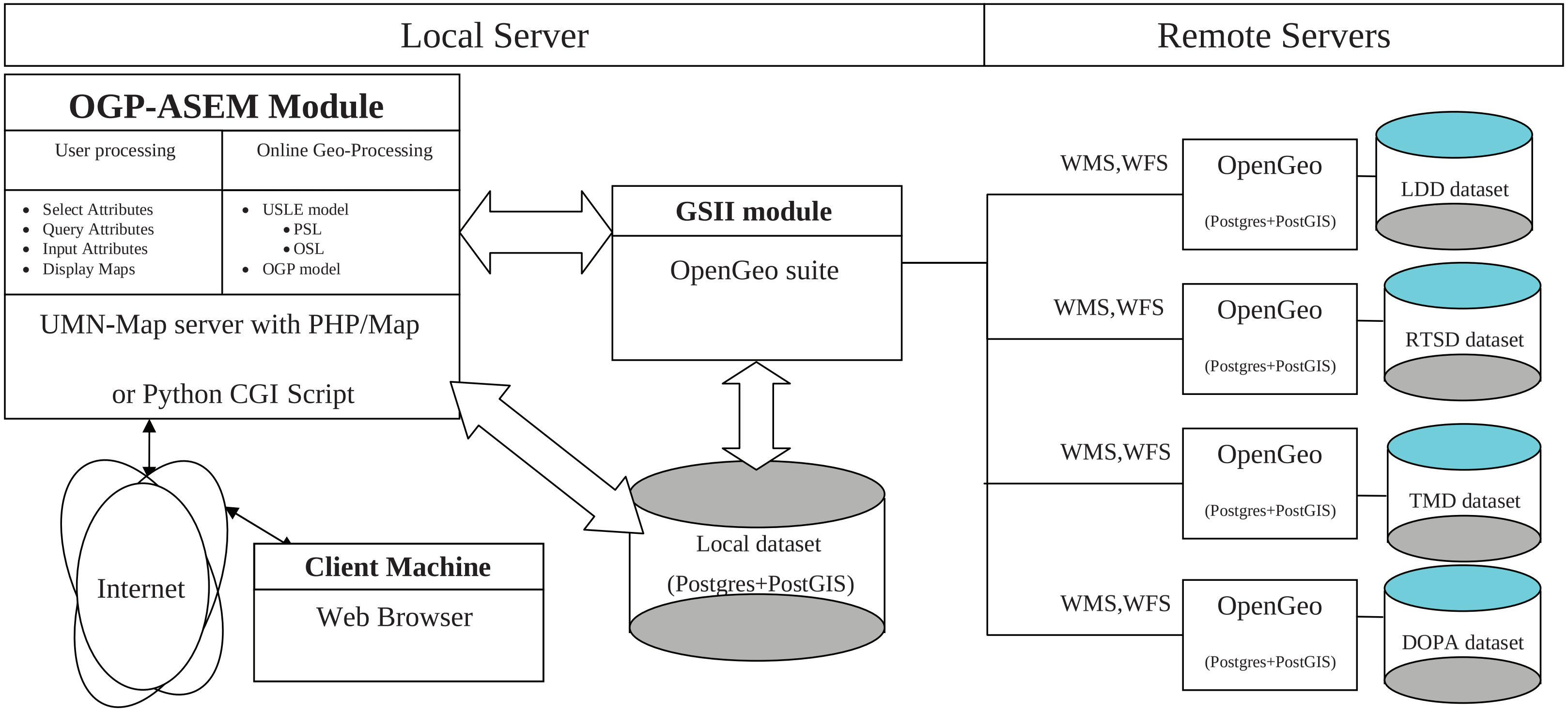

Figure 2 Two main components of the research framework—the Geo-Spatial Information Integration (GSII) module and the Online Geospatial Processing (OGP) for Agricultural Soil Erosion Management (ASEM) module. UMN = University of Minnesota; PHP = Hypertext preprocessor; CGI = Common gateway interface; WMS = Web map service; WFS = Web feature service; Postgres = object-relational database management system (ORDBMS); PostGIS = Spatial objects for the PostgreSQL database; LDD = Land Development Department; RTSD = Royal Thai Survey Departemnt; TMD = Thai Meteorological Department; DOPA = Department of Provincial Administration.

area, rainfall data from neighboring stations were also used. The R factor was determined using an equation defined by the Land Development Department (2000) for Northeastern Thailand, which was considered the best available for the study (Equation 3):

$$R = 0.4669\ X – 12.1415 \quad (3)$$

where, R is the rainfall-runoff erosivity factor in megajoules millimeters per hectare per year) and X is the mean annual rainfall in millimeters.

The inverse distance weighted method of interpolation used by the Geographic Resources Analysis Support System (GRASS; version 7.0.svn; available from: http://grass.osgeo.org) package and an open source GIS (QGIS; version 1.6.0; available from: http://qgis.org) software were used to establish the spatial layer of the R factor.

Soil erodibility

The 2004 digital soil map at a scale of 1:50,000 was obtained from the LDD. The soil erodibility (K) values used for the study areas are shown in Table 1 based on soil groups. For water bodies, rocky land, man-made structures and urban human settlement polygons (such as schools and villages), a zero value was assigned for erosion.

Slope length and steepness

Digital topographic 20 m contours at a scale of 1:50,000 were obtained from the Royal Thai Survey Department. The digital topographic contours were interpolated into a raster digital elevation model (DEM) and the slope in degrees was calculated using the Topography-to-Raster map function in the ArcGIS software. The slope length and steepness (LS) factor layer was derived from the DEM using a revised equation for the study (Equation 4):

(a) slope length

$$L = (\lambda / 22.13)^{m}, \quad (4)$$

where λ is the slope length (cell size in meters), m is a variable slope-length exponent related to the ratio β of rill erosion (caused by flow) to inter-rill erosion (principally caused by raindrop impact) according to Equation 5 (Foster *et al*., 1977):

$$m = \beta / (1 + \beta) \quad (5)$$

where β can be computed from (McCool *et. al*., 1997) using Equation 6:

$$\beta = (\text{Sin}\theta / 0.0896) / (3.0(\text{Sin}\theta)^{0.8} + 0.56) \quad (6)$$

where θ is the slope gradient map (degrees)

(b) steepness factor

This factor was computed using Equations 7 and 8 (McCool *et al.*, 1997):

$$S = (10.8\text{Sin}\theta + 0.03) \text{ for slope} < 9\% \quad (7)$$

$$S = (16.8\text{Sin}\theta - 5) \text{ for slope} \geq 9\% \quad (8)$$

where θ is the slope gradient map (degrees).

The Map-Algebra function in the ArcGIS software was used for factor calculations because it has many user-friendly functions.

Vegetative cover

The vegetative cover factor (C) is perhaps the most important USLE factor because it represents conditions that could be managed most easily to reduce erosion. The map of the land use/land cover classes (LULC) was prepared from the land use maps in 2010 sourced from the LDD. The present C factor values set by LDD (2002) for various vegetation cover types were assigned accordingly as shown in Table 4 and optical values using by soil groups as shown in Table 3.

Field support practice

The support practice factor (P) is a soil-loss ratio for a specific support practice to the corresponding soil loss with up-and-down slope tillage (Renard *et al*., 1997). In Thailand, a value for P has not been established for any agricultural cover types except for paddy. In cases where there was no practice, the maximum value of 1 was assigned. The present values of P used in the current study for the nine different classes according to the LDD are provided in Table 4 and optimal values of the P factor as recommended by LDD (2002).

Distributed geospatial processing model

The distributed geospatial processing model for agricultural soil loss management was designed in two steps of soil loss evaluation based on the USLE model:

(1) Present soil loss evaluation

Present soil loss (PSL) was automatically computed using the present land use identified by the LDD to identify critical areas of soil erosion as follows:

1. PSL calculated based on present land use of LDD by Equation (1).

2. Severity of soil erosion was classified based on the LDD soil loss severity by geospatial analysis using a tolerance value (12.5 $t.ha^{-1}.yr^{-1}$).

3. Critical areas exceeding the tolerance value in the study area were identified as having the optimum soil loss by geospatial analysis.

(2) Optimum soil loss evaluation

Optimum soil loss (OSL) was semi-

Table 4 Soil erodibility based on soil groups in Northeastern Thailand.

Group	Description	Erodibility	Group	Description	Erodibility
1	Group_1	0.15	32	Group_32	0.26
2	Group_2	0.15	33	Group_33	0.37
3	Group_3	0.15	34	Group_34	0.26
4	Group_4	0.15	35	Group_35	0.24
5	Group_5	0.15	36	Group_36	0.24
6	Group_6	0.36	37	Group_37	0.24
7	Group_7	0.36	38	Group_38	0.24
8	Group_8	0.15	39	Group_39	0.24
9	Group_9	0.21	40	Group_40	0.24
10	Group_10	0.15	41	Group_41	0.04
11	Group_11	0.15	42	Group_42	0.14
12	Group_12	0.15	43	Group_43	0.04
13	Group_13	0.15	44	Group_44	0.04
14	Group_14	0.15	45	Group_45	0.18
15	Group_15	0.36	46	Group_46	0.25
16	Group_16	0.34	47	Group_47	0.29
17	Group_17	0.30	48	Group_48	0.24
18	Group_18	0.30	49	Group_49	0.24
19	Group_19	0.30	50	Group_50	0.26
20	Group_20	0.30	51	Group_51	0.26
21	Group_21	0.35	52	Group_52	0.25
22	Group_22	0.06	53	Group_53	0.18
23	Group_23	0.16	54	Group_54	0.25
24	Group_24	0.05	55	Group_55	0.24
25	Group_25	0.26	56	Group_56	0.24
26	Group_26	0.18	57	Group_57	0.30
27	Group_27	0.18	58	Group_58	0.30
28	Group_28	0.13	59	Group_59	0.35
29	Group_29	0.25	60	Group_60	0.29
30	Group_30	0.25	61	Group_61	0.29
31	Group_31	0.25	62	Group_62	0.25

Source: (Land Development Department, 2002).

automatically computed using the soil properties of the LDD to calculate the optimum soil loss erosion based on the optimum land cover types according to the following conditions:

1. If present land cover types matched the type of land cover in the form of a minimum C factor, then they were used to calculate OSL.

2. If present land cover types did not match the type of land cover in the form of a minimum C factor, then new land cover types were identified based on soil properties for an adjusted land cover factor with its P factor as shown in Figures 3 and 4.

3. OSL was based on the selected land cover type using Equation (2).

For forecasts from the present (2010) into the future, each LULC classification underwent a change in threat as shown in Figure 5, which also shows the distribution of land use and changes in land cover forecast from the present (2010) into the future which have a negative effect on the values of C and P. The map illustrated in Figure 5 represents only the critical areas—namely, positive changes to optimum soil loss—representing 624 km^2.

RESULTS AND DISCUSSION

The five grid (40 × 40 m) factor maps after verification were overlaid in the raster GIS platform and the final soil loss grid map obtained was reclassified using a manual method into two classes, with each class defining the degree of severity by a rating score, shown in Table 6. The results indicated that the amount of soil loss was less for the present (2010) as reflected by the land use and land cover C and practice support P values and showed that the area of soil erosion decreased to a prediction of 499 km^2 from 1,123 km^2 in 2010, as the area having soil loss greater than the tolerance value.

Locations on the map with optimum soil erosion indicate areas with low erosion rates where the vegetation cover and the optimal practice support could be sufficient to provide maximum protection from rainfall impact. However, these locations had a tolerance value that exceeded 12.5 $t.ha^{-1}.yr^{-1}$ for their soil loss severity class (LDD, 2002).

Table 5 Vegetative cover (C) and field support practice (P) for land use land cover classes (LULC).

LULC	LULC Code	C value	P value
Mixed crops (MC)	A0	0.255	1.0
Paddy field (PF)	A1	0.280	0.1
Field crops (FC)	A2	0.525	1.0
Perennial trees (PT)	A3	0.150	1.0
Orchards (Oc)	A4	0.300	1.0
Horticulture crops (HC)	A5	0.600	1.0
Grassland (GL)	A7	0.100	1.0
Shifting cultivation (SC)	A9	0.250	1.0
Evergreen forest (EF)	F1	0.003	1.0
Deciduous forest (DF)	F2	0.048	1.0
Forest plantation (FP	F5	0.088	1.0
Agro forestry (AF)	F6	0.088	1.0
Natural grassland (NG)	M	0.015	1.0
Water body	W	0.000	0.0
Urban	U	0.000	0.0

Source: Land Development Department (2002).

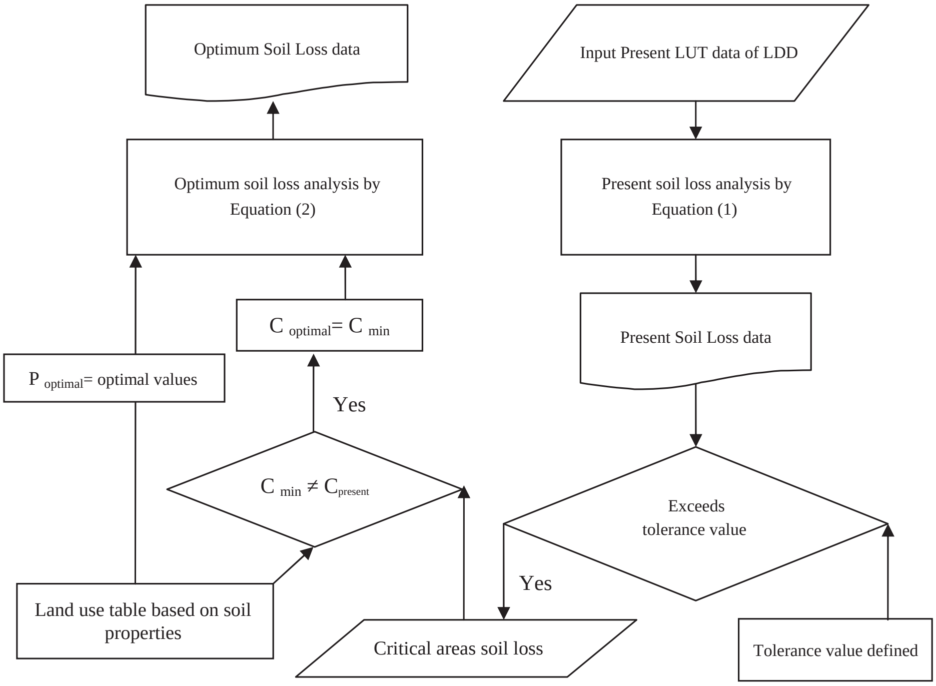

Figure 3 Flowchart for geospatial processing for agricultural soil loss management.

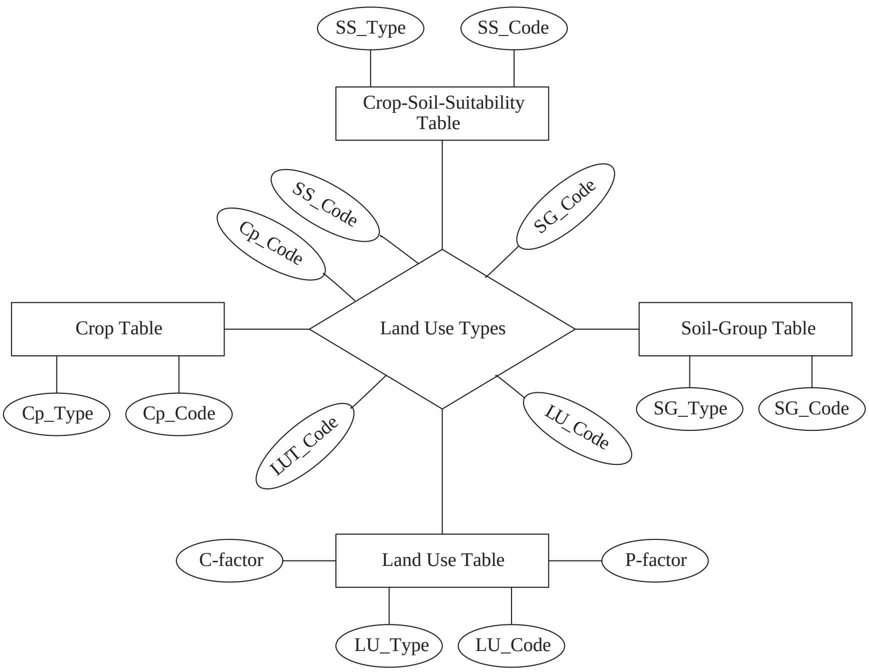

Figure 4 Entities-Relationship diagram of land use and soil properties. Cp_Type = Crop practice type; Cp_Code = Crop practice code; SS_Type = Crop-Soil type; SS_Code = Crop-Soil code; SG_Type =Soil-Group Type; P-factor = Crop practice factor; C-factor = Crop cover factor; LU_type = Land use type; LU_code = Land use code.

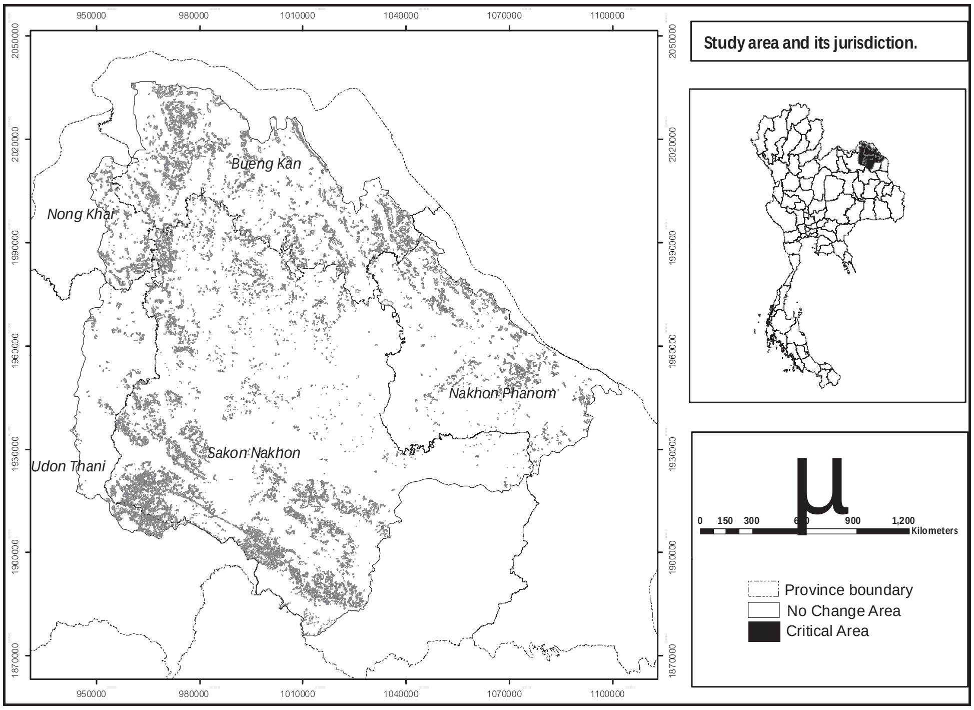

Figure 5 Map of the optimum soil loss change in the study area from presents (2010) and forecast in future.

Table 6 Soil loss severity comparison between present (2010) and future.

Soil loss rate	Present (2010) ($t.ha^{-1}.yr^{-1}$)	Future ($t.ha^{-1}.yr^{-1}$)
Minimum	0.00	0.00
Maximum	692.91	157.91
Average	3.59	1.52

The soil loss severity exceeded the tolerance value for Thailand where there was little or no canopy cover and high rainfall and steep slopes or 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 degradation where water and soil conservation measures are required and preliminary basin management strategies need to be developed. These locations can also be adversely affected by erosion processes or can be potential sources of erosion. In an agricultural context, these areas are located where crop growth and yield will be less. The information is currently available at http://webims.csc.ku.ac.th/irrc/.

CONCLUSION

The higher erosion rate could be attributed to the ever-increasing usage of land for agricultural purposes. From experience and the observed increased rates of planting in recent years, it can be deduced that the canopy cover especially for plantations, orchards and mixed deciduous forests at present (2010) would considerably change practice support and cropping to optimal soil erosion. However, due to the limitation of using the same C value and P value irrespective of the canopy cover type for the same type of land use and cover type, the erosion rate estimate remained the same, while the change map indicated both increases and decreases in erosion rates. Due to the phenomenal rate of growth, it has been difficult to obtain a meaningful classification because the land cover classes have the same level of severity. However, the precision of the soil loss estimation using the USLE depends on the accuracy of the input factors. Therefore, if the regional factors of soil erosion were to be substituted with local factors, the results would be more precise. Therefore, the next research must develop an Internet application, namely a web application, to service a spatial decision support system. Such tools will help inter-operation and facilitate interoperability of data sets and provide more accurate online spatial analysis and soil erosion forecasting.

ACKNOWLEDGEMENTS

The authors would like to thank the Land Development Department, the Thai Meteorology Department, the Ministry of Interior, the Ministry of Natural Resource and Environment and the Royal Thai Survey Department for the databases used in this study. In addition, generous financial support is recognized from the Royal Thai Government and Kasetsart University Chalermprakiat Sakon Nakhon province campus.

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