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Internet GIS, Based on USLE Modeling, for Assessment of Soil Erosion in Songkhram Watershed, Northeastern of Thailand

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ABSTRACT

A web-based geographic information system (GIS) was designed and implemented, which included a database designed to accommodate, organize and manipulate basic spatial data as well as interrelate data from various sources. The system was used to produce erosion susceptibility maps for regions of Upper Northeastern Thailand—an area that has suffered from inappropriate land use practice. GIS-based methods were proposed and applied to data from the Songkhram sub basin in the Songkhram watershed. 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 (DBMS) implementation, both of which were implemented by Postgres Plus software. The watershed was mapped into topographically and geographically homogeneous grid cells to capture watershed heterogeneity. The soil erosion in each cell was calculated using the universal soil loss equation by carefully determining its various parameters and classifying the watershed into different levels of soil erosion severity. The results showed that during the study period, the area had soil loss over a tolerance value (12.5 $t.ha^{-1}.yr^{-1}$) which ranged from the moderate class up to the very severe class of susceptibility. Moreover, it was also found that the amount of soil erosion increased from 762 km^2 in 2006 and to 1,123 km^2 in 2010. The outcome of the study was published on the Internet using UMN map server software as well as by using Google map.

Keywords: database management system (DBMS), geographic information system (GIS), soil erosion, universal soil loss equation (USLE), land degradation, land use and land cover, GIS Internet, Google map

INTRODUCTION

Land degradation is still a very common problem in areas of steep topography in Thailand because of the inappropriate land use practices applied. Soils in Northeastern Thailand are described as lateritic and sandy which differ according to location in both their quantity and quality for agricultural purposes. Land Development Department (2000) has previously analyzed the suitability of land use for agriculture throughout Thailand using soil management criteria. Mostly, estimated soil loss was used as the basis to classify the level of soil erosion

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susceptibility of an area. Factors that influence soil erosion are rainfall erosivity, soil erodibility, slope length and steepness, crop management and conservation practices. Thus, the reliability of estimated soil loss is based on how accurately the different factors are estimated or prepared. As every pixel of the earth's surface is different from its neighbors, it is crucial to subdivide any study area into smaller homogenous areas and to adopt the most accurate and efficient technique for soil loss estimation (Land Development Department, 2002).

Nowadays, the internet has become an important medium because it allows users to interact across the network and provides opportunities for easy and efficient retrieval of hypermedia information. Thanks to the multimedia capabilities of the World Wide Web (WWW), users all over the world have turned this technology into an important medium 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 when supported by graphical interfaces, sound, video and animation, among others (Burapha University, 1999).

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).

Erosion has been assessed widely using the universal soil loss equation (USLE; Wischmeier and Smith, 1978), a spatial assessment model. It has become particularly useful in evaluating the impacts 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 supporting conservation practices (P). The advantages of the USLE model have been reported (Millward and Mersey, 1999) and include its relatively simple data requirements and its compatibility with a geographic information system (GIS).

Coupling of a GIS and the USLE has been widely used and is a very effective approach for estimating the magnitude of soil loss and identifying spatial locations vulnerable to soil erosion (Fu *et al.*, 2006). Remote sensing complemented with field ground truthing and GIS provides the best methodological toolset to investigate soil erosion (Urgen, 2008).

Study area

The study area covered five provinces—namely, Udon Thani, Nong Khai, Bueng Kan, Sakon Nakhon and Nakhon Phanom provinces (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. The dominant land uses/land cover of the Songkhram River sub basin are field crops, forests, paddy fields and urban and built-up areas.

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 (Thai Meteorological Department, 2009). Maize is the dominant crop and some areas are also allotted for growing cassava, sugarcane and mung bean. Similarly, mango orchards account for the majority of fruit grown, but there are also small plantations where custard apple, tamarind, papaya, jackfruit and other fruits are grown. Water bodies and village/urban/resort areas also account for a

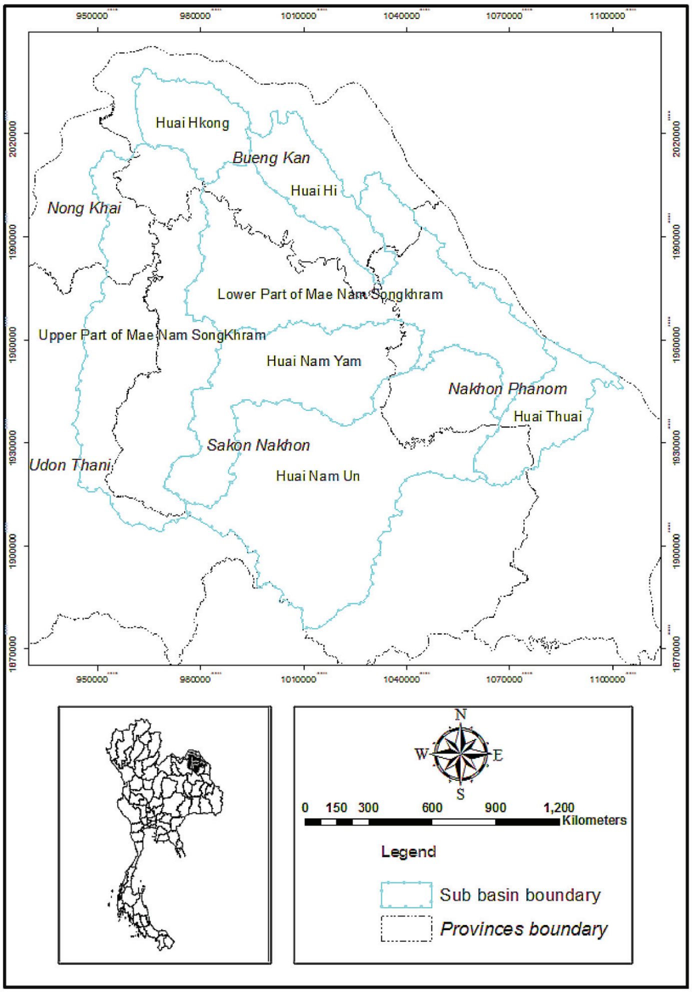


Figure 1 Map of Thailand including details of the study area.

small but insubstantial proportion of the study area (Urgen, 2008).

MATERIALS AND METHODS

The USLE was applied for soil erosion assessment (Equation 1):

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

where,
A = the soil loss in $t.ha^{-1}.yr^{-1}$, R = the rainfall–runoff erosivity factor in $MJ.mm.ha^{-1}.yr^{-1}$, K = the soil erodibility factor ($t.hr.MJ^{-1}.mm^{-1}$), LS = the slope length and steepness factor, C = the vegetative cover factor and P = the conservation support-practice factor. LS, C, and P are dimensionless.

The integration of input sources, and the processing of the factor maps and outputs for assessing the erosion are shown in Figure 2.

Rainfall–Runoff Erosivity

The digital rainfall data was obtained for Nong Khai, Nakhon Phanom, Sakon Nakhon, and Udon Thani provinces from the Thai Meteorological Department (2009). There were 61 rainfall measuring stations in the watershed which had been used to measure monthly rainfall data

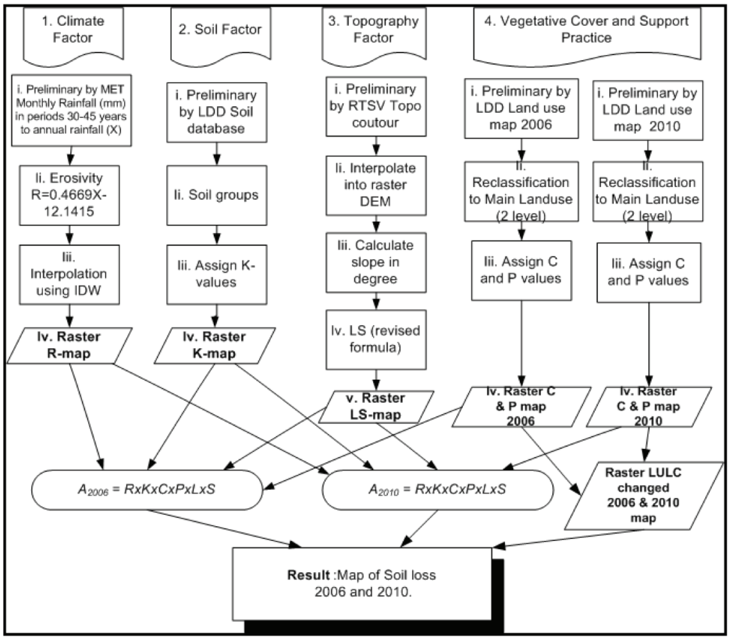


Figure 2 Integration of inputs, processes and results. Equation parameters (R, K, LS, C and P) are defined in Equation 1. (LULC = Land use land cover class)

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 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 2):

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

where, R = the rainfall-runoff erosivity factor in $MJ.mm.ha^{-1}.h^{-1}\ yr^{-1}$ and X = mean annual rainfall (mm).

The inverse distance weighted method of interpolation used by the Geographic Resources Analysis Support System (GRASS; version 7.0.svn Open Source Geospatial Foundation, Wilmington, DE, USA) package and an open source GIS (QGIS version 1.6.0, Open Source Geospatial Foundation, Wilmington, DE, USA) software were employed 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 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 value of ‘0’ 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 LS-factor layer was derived from the DEM using a revised equation for the study (Equation 3):

Table 1 Soil erodibility based on soil groups in Northeastern Thailand.

Group	Description	Erodibility (K)	Group	Description	Erodibility (K)
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	0.3	48	Group_48	0.24
18	Group_18	0.3	49	Group_49	0.24
19	Group_19	0.3	50	Group_50	0.26
20	Group_20	0.3	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	0.3
27	Group_27	0.18	58	Group_58	0.3
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).

(a) slope length

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

where,

λ = Slope length (cell size in meters),

m = 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 4 (Foster *et al*., 1977):

$$m = \beta / (1 + \beta) \quad (4)$$

where β can be computed from (McCool *et. al*., 1997) using Equation 5:

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

where,

θ = slope gradient map (degrees)

(b) steepness factor

This factor was computed using Equations 6 and 7 (McCool *et al.,* 1997):

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

$$S = (16.8\sin\theta - 5) \text{ for slope} \geq 9\% \quad (7)$$

where,

θ = 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 2006 and 2010 sourced from the LDD. The C-factor values set by LDD (2002) for various vegetation cover types were assigned accordingly as shown in Table 2.

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 P values used in the current study for the nine different classes according to LDD are provided in Table 2.

During the five year period from 2006 to 2010, each LULC classification had undergone a change in threat as shown in Figure 3, which also shows the distribution of land use and changes in land cover during the period 2006–2010 which has had a negative effect on the C-value. The map illustrated in Figure 3 represents only the negative changes. The positive changes represent 1,091.687 km^2 which are distributed in small polygons that are not visible at the scale shown. Consequently, this will affect the level of soil loss, increasing each classification as shown in Table 3.

Table 2 Vegetative cover (C) and field support practice (P) for land use land cover classes (LULC).

LULC Class	LULC Code	C Value	*P* Value
Mixed crops (MC)	A0	0.255	1
Paddy field (PF)	A1	0.280	0.1
Field crops (FC)	A2	0.525	1
Perennial trees (PT)	A3	0.150	1
Orchards (Oc)	A4	0.300	1
Horticulture crops (HC)	A5	0.600	1
Grassland (GL)	A7	0.100	1
Shifting cultivation (SC)	A9	0.250	1
Evergreen forest (EF)	F1	0.003	1
Deciduous forest (DF)	F2	0.048	1
Forest plantation (FP	F5	0.088	1
Agro forestry (AF)	F6	0.088	1
Natural grassland (NG)	M	0.015	1
Water body	W	0	0
Urban	U	0	0

Source: Land Development Department (2002).

RESULTS AND DISCUSSION

The five grid (60 × 60 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 five classes, with each class defining the degree of severity by a rating score with the affected areas in percentages shown in Table 4. The study obtained an average soil loss of 4.94 t.ha^{-1}.yr^{-1} in 2006 with a minimum and maximum of 0.00 and 700.70 t.ha^{-1}.yr^{-1}, respectively. Similarly, the study found an average soil-loss rate of 3.59 t.ha^{-1}.yr^{-1} in 2010 with a minimum and maximum of 0.00 and 692.91 t.ha^{-1}.yr^{-1}, respectively. The results indicated that the amount of soil loss was more in 2006 as reflected by the land use and land cover C-value. The erosion severity maps are shown in Figure 4. The change in the erosion rates over the period is shown in Table 5.

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

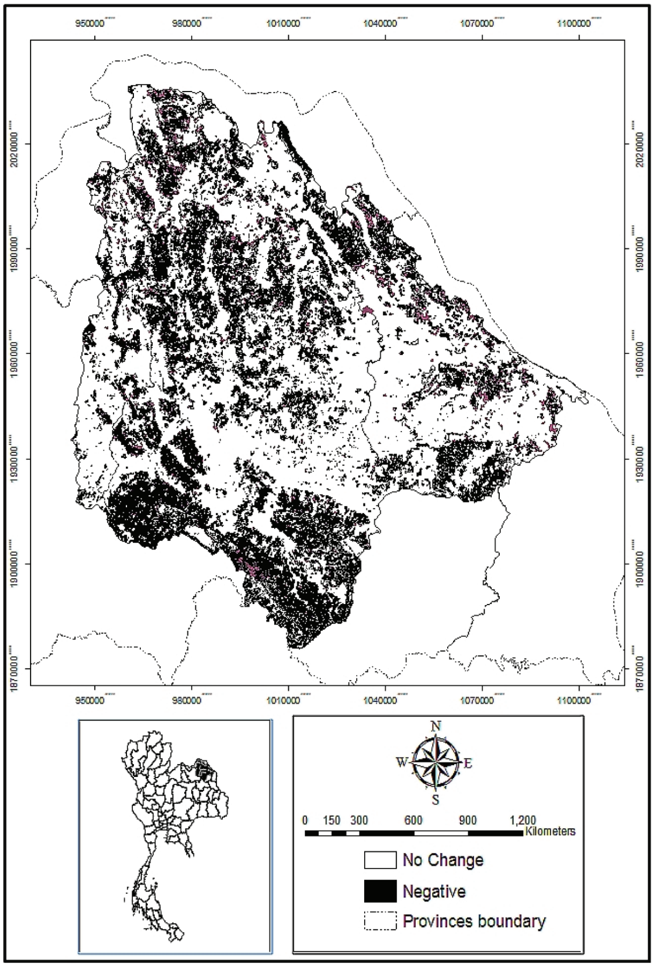


Figure 3 Map of land use land cover class changes in the study area from 2006 to 2010.

These results have already been published on the Internet since the GIS is implemented by the MS4W suite software, and the DBMS by Postgres Plus with an integrated uniform resource locator (URL). The information is currently available at http://irrc.csc.ku.ac.th as shown in Figures 5 and 6.

Field verification, which indicates the outcome reliability of applying the model, is shown in Figure 7. The map locations for the

Table 3 Land use and land cover (LULC) change from 2006 to 2010.

LULC Class	LULC Code	2006 (km^2)	2010 (km^2)
Mixed crops (MC)	A0	2.620	2.937
Paddy field (PF)	A1	6,935.146	6,407.455
Field crops (FC)	A2	1,912.384	637.441
Perennial trees (PT)	A3	1,163.331	2,326.018
Orchards (Oc)	A4	59.083	33.176
Horticulture crops (HC)	A5	4.279	14.741
Grassland (GL)	A7	9.347	43.892
Shifting cultivation (SC)	A9	8.867	12.957
Evergreen forest (EF)	F1	1,018.925	27.432
Deciduous forest (DF)	F2	963.121	2,086.380
Forest plantation (FP)	F5	0.328	5.386
Agro forestry (AF)	F6	0	0
Natural grassland (NG)	M	766.776	1,162.371
Urban	U	508.147	567.359
Water body	W	545.357	565.989

Source: Land Development Department (2002).

Table 4 Soil loss severity distribution in 2006 and 2010.

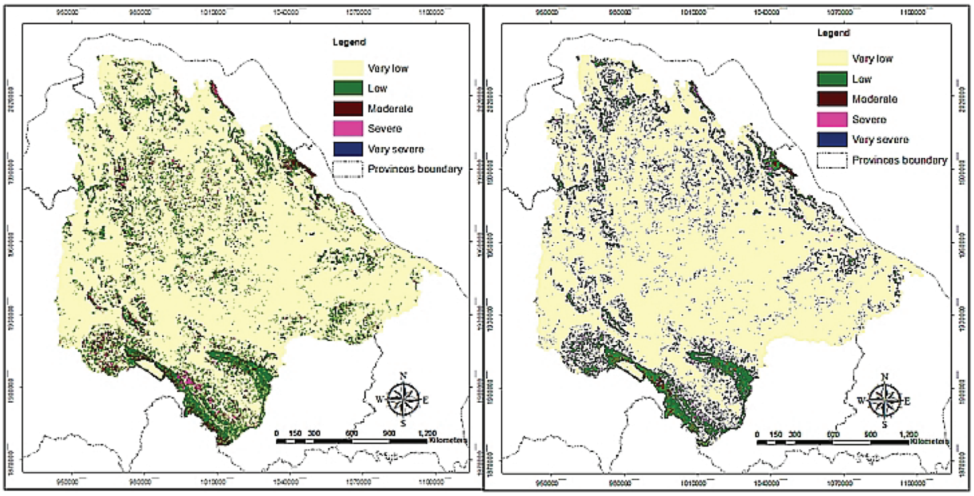
No.	Loss Rate ($t.ha^{-1}.yr^{-1}$)	2006 km^2	%	2010 km^2	%	Description
1	Below 6.26	11,268.100	81.152	11,861.600	85.443	Very low
2	6.26-31.25	2,100.560	15.128	1,644.330	11.845	Low
3	31.26-125	455.688	3.282	344.555	2.482	Moderate
4	125.01-625	60.752	0.438	32.011	0.231	Severe
5	Above 625.00	0.066	0.000	0.008	0.000	Very severe

Table 5 Soil loss severity change between 2006 and 2010 (km^2).

Year		2006					
	Severity	Very low	Low	Moderate	Severe	Very severe	Grand total
	Very low	10,936.200	839.144	75.794	3.188	0.000	11,854.326
	Low	302.266	1,197.750	137.308	11.612	0.000	1,648.936
2010	Moderate	27.998	54.256	239.741	24.569	0.055	346.619
	Severe	0.412	6.376	3.563	22.123	0.018	32.492
	Very severe	0.000	0.000	0.009	0.000	0.000	0.009
	Grand Total	11,266.876	2,097.526	456.415	61.492	0.073	13,882.382

"over tolerance" were identified on the URL satellite imagery from Google maps and showed that severe rill erosion was occurring on gently sloping agricultural land, where the texture type was defined as silty clay.

The soil loss severity was greatest where there was less 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.



(a) (b)

Figure 4 Soil erosion severity map (a) in 2006; and (b) 2010.

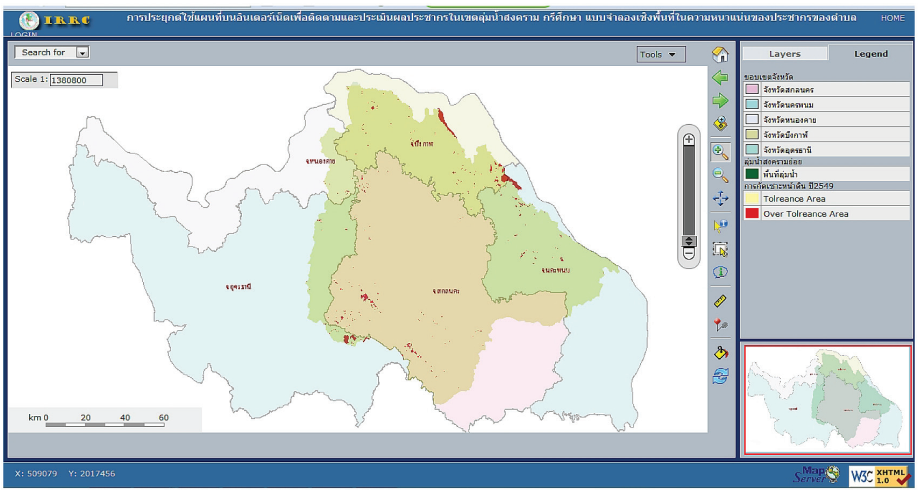


Figure 5 Published on web site in WWW service.

CONCLUSION

The higher erosion rate could be attributed to ever-increasing usage of land for agricultural purposes. From experience and the increased rates of planting in recent years, it can be deduced that the canopy cover especially for plantations, orchards and mixed deciduous forests in 2010 would be considerably higher than in 2006. However, due to the limitation of using the same C-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 degree 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.

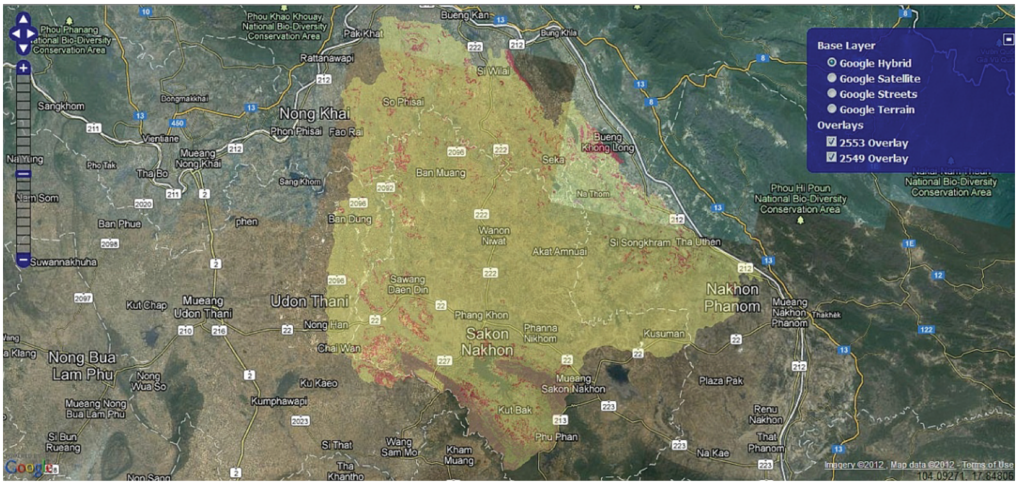


Figure 6 Published on Google maps in WWW service.

Figure 7 Location of over "Tolerance" value verified in (a) 2006 (2549 Red Color); and (b) 2010 (2553 Pink Color).

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