

Impacts of Land Use Changes on Soil Erosion in Pa Deng Sub-district, Adjacent Area of Kaeng Krachan National Park, Thailand

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Abstract: Soil erosion has been considered as the primary cause of soil degradation since soil erosion leads to the loss of topsoil and soil organic matters which are essential for the growing of plants. Land use, which relates to land cover, is one of the influential factors that affect soil erosion. In this study, impacts of land use changes on soil erosion in Pa Deng sub-district, adjacent area of Kaeng Krachan National Park, Thailand, were investigated by applying remote sensing technique, geographical information system (GIS) and the Universal Soil Loss Equation (USLE). The study results revealed that land use changes in terms of area size and pattern influenced the soil erosion risk in Pa Deng in the 1990–2010 period. The area with smaller land cover obviously showed the high risk of soil erosion than the larger land cover did.

Keywords: land cover; land use changes; soil erosion; Universal Soil Loss Equation

Soil erosion is a complex process that physically takes place by the movement of soil particles from a given site. Soil erosion can affect soil quality and induce soil deterioration by the loss of topsoil that is enriched with organic matter. Therefore, the soil erosion can cause a reduction of crop productivity. Factors which are considered as the main causes of soil erosion are climate, soil type, topography, vegetation and human activities. In the areas where climate, soil type and topography are similar, differences in soil erosion rates are commonly related to land use or land cover (DEL MAR LÓPEZ *et al.* 1998). Since soil erosion generally occurs when the soil is displaced by rain and transported from the specific area, therefore rainfall is considered as the driving factor of soil erosion. However, the factor that significantly affects the soil displacement by rain is land cover or vegetation cover. The reduction of vegetation cover can increase soil erosion. This relationship is a reason why vegetation cover and land use have been widely included in soil erosion studies (KOSMAS *et al.* 1997; DEL MAR LÓPEZ *et al.* 1998; SZILASSI *et al.* 2006; ZHOU *et al.* 2008; SOLAIMANI *et al.* 2009; SU *et al.* 2010). Many studies found that land use can greatly affect the intensity of runoff and soil erosion (KOSMAS

et al. 1997; MARTÍNEZ-CASASNOVAS & SÁNCHEZ-BOSCH 2000; COTLER & ORTEGA-LARROCEA 2006; CEBECAUER & HOFIERKA 2008; ZHOU *et al.* 2008; GARCÍA-RUIZ 2010; MOHAMMAD & ADAM 2010). Vegetation controls soil erosion by means of its canopy, roots and litter components; erosion also influences vegetation in terms of the composition, structure and growth pattern of the plant community (GYSSEL *et al.* 2005). Similarly, natural vegetation is more effective than most plantings in reducing soil erosion because of its stratified structure. Such a structure can absorb much more of the raindrop energy by multi-interception than can a structure with a single layer (ZHONGMING *et al.* 2010).

In Thailand, soil erosion by water has been considered as one of the most influential causes of land degradation due to losses of surface soil and plant nutrients (Land Development Department 2000). The main agency for assessing soil erosion and setting soil conservation measures in Thailand is Land Development Department (LDD), Ministry of Agriculture and Cooperatives. LDD recommended the Universal Soil Loss Equation (USLE) (WISCHMEIER & SMITH 1978) is a suitable empirical model for estimating soil erosion by water as a function of six

factors, i.e. the rainfall and runoff erosivity factor, the soil erodibility factor, the slope length factor, the slope steepness index, the land cover/management factor and the soil conservation factor. In addition, soil conservation measures proposed by LDD were both mechanical measures, such as contour cultivation, tied ridging, bedding and terracing, and agronomic measures, such as cover cropping, mulching, intercropping and vetiver grass growing. However, the implementation of soil conservation measures is not widely applied in Thailand due to the absence of well-trained staff and lack of financial support. Moreover, in-deep approach and spatial analysis of soil erosion process are not intensively conducted in Thailand, which causes that the soil conservation measures are not efficiently practised in most areas in Thailand. For this reason, the soil erosion problem expands extensively in Thailand.

The objectives of this study are to investigate the land use changes and to assess the risk of soil erosion on different land use types in the study area. The quantitative soil loss can be modelled by the Universal Soil Loss Equation (USLE) (WISCHMEIER & SMITH 1978), which is the most widely used for soil loss evaluation by taking into consideration rainfall, soil properties, topography, land cover, and conservation practice.

In addition, this study was conducted under the project of Huay Sai Royal Development Study Centre and the study area is a part of Huay Sai Royal Development Study Centre. Therefore, the results of this study will be forwarded to Huay Sai Royal Development Study Centre and relevant agencies in the study area in order to apply as the database

for setting and implementing soil conservation measures that are suitable for this site. Moreover, the results will be utilized for laying down mitigation measures for the soil erosion problem in the study area. Afterward, the evaluation of suitable mitigation measures for soil erosion will be conducted in cooperation with Huay Sai Royal Development Study Centre in order to ensure the effective implementation of soil erosion prevention.

MATERIALS AND METHODS

Study area

The study was performed in Pa Deng Sub-district, Kaengkrachan District, Petchaburi Province, western edge of Thailand, which lays between 99°20'E to 99°37'E longitude and 12°33'N to 12°45'N latitude at a height of 140 m above mean sea level (see Figure 1). The study area, Pa Deng, covered approximately 41 782 ha. Geologically, Pa Deng is a piedmont plateau which slightly slopes from west to east. Most areas in Pa Deng are sloping complex lands with the gradient of more than 35%. Due to their slope, soils in these areas have not been surveyed and classified yet. Besides, the land in Pa Deng has been classified as undulating and rolling terrain. The topsoil texture is sandy loam or loam with medium to high soil permeability. Agriculture, i.e. monocropping and livestock farming, is the main occupation of a majority of the population. Some parts of Pa Deng are in natural forest and Kaeng Krachan National Park area, which is the

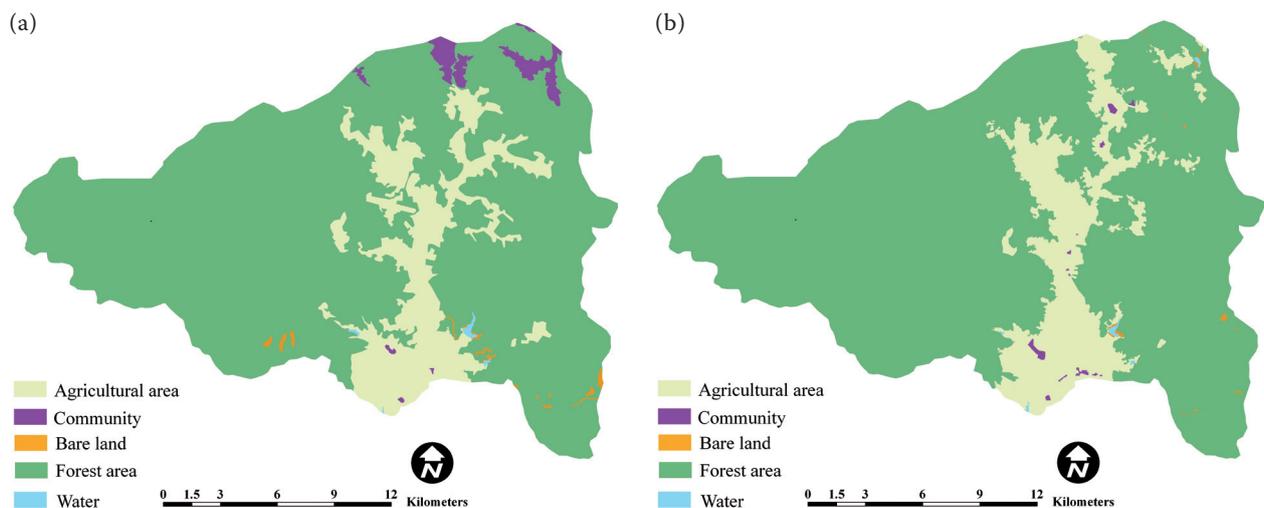


Figure 1. Land use of Pa Deng (a) in 1990, (b) in 2010

tropical rain forest. Pa Deng is surrounded by the mountains with the plain at the centre. The western boundary of the site is the Tanowsri Mountain Range, which stretches from north to south. Mean annual temperature and annual rainfall are 27°C and 1070 mm, respectively. The rain usually falls from May to November. The field observations revealed that agricultural lands in Pa Deng show a high risk of soil erosion due to the absence of soil conservative measures, both mechanical and agronomic measures, and its rolling terrain. In addition, the plain area of Pa Deng, which can be utilized, is approximately only 15% of the total area whereas the population of Pa Deng increases continuously at a 2.80% growth rate. For this reason, it may lead to the expansion of agricultural area and the invasion of forest and foothill area by agricultural area. This may cause that the soil erosion in Pa Deng will become more stressful.

Investigation of land use types

Both the remote sensing technique and field survey were applied for interpreting the satellite images taken by Landsat-5 TM in order to investigate the land use of the study area in 1990 and 2010. The two images were made to classify the various land use types in ENVI using supervised and unsupervised classification techniques. The images were classified into five classes, namely forest area, agricultural area, community, bare land and water body.

Soil erosion risk assessment

The soil erosion risk was assessed on the basis of the factors defined by the USLE (WISCHMEIER & SMITH 1978). The USLE evaluates the long-term average annual soil loss (A) by sheet and rill erosion. The USLE is defined as

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

where:

- A – average annual soil loss (mass/area/year)
- R – rainfall and runoff erosivity factor
- K – soil erodibility factor
- L – slope length factor
- S – slope steepness index
- C – land cover/management factor
- P – soil conservation factor

In Thailand, the Land Development Department (LDD) adjusted and validated this model to be appropriate to the local conditions (Land Development Department 2000). According to the study of LDD (2000), each factor can be defined as follows.

The rainfall and runoff erosivity (R) is determined as a function of the total storm kinetic energy (E) and its maximum 30-min intensity ($I_{\max 30}$). Due to this definition, LDD (2000) developed many equations and then proposed an equation which is suitable for the amount of rainfall in Thailand:

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

where:

- R – rainfall and runoff erosivity (Mg/ha/year)
- X – average annual rainfall (mm/year)

The average annual rainfall of the study area was calculated based on the 30-year period (from 1981 to 2011) rainfall which is collected from the adjacent weather station.

The soil erodibility factor (K) is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. The K factor is determined corresponding to the top soil property, land form and physical geography (SRIKHAJON 1984) and also the geography of the area is considered (Land Development Department 2000). STEWART *et al.* (1975), as reported by MILLS and THOMAS (1985) and MITCHELL and BUBENZER (1980), and NOVOTNY and CHESTERS (1981), also developed a table indicating the general magnitude of the K-factor as a function of organic matter content and soil textural class. GOLDMAN *et al.* (1986) noted that if the site inspection or data analysis indicate significant variations in the soil erodibility, different K factors can be assigned to different areas of the site. The value of the soil erodibility factor ranges from 0.02 to 0.69 (GOLDMAN *et al.* 1986; MITCHELL & BUBENZER 1980). The national database of K factor which was provided by LDD (2000) can be summarized that the K factor of soil in Thailand ranges from 0.04 to 0.56.

The slope length factor (L) is expressed as the ratio of expected soil loss to that observed for a field of 22 m length. In USLE, L factor is given by

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

where:

- λ – distance from the onset of overland flow to the location where deposition occurs or when runoff enters a channel that is bigger than a rill.

In the USLE, m varies with the slope gradient. It has a value of 0.2 for gradients smaller than 1% and increases to a value of 0.7 for gradients greater than 21% (WISCHMEIER & SMITH 1978).

The slope steepness index (S) is the ratio of expected soil loss to that observed for a field of the specified slope of 9%. If the gradient is smaller than or equal to 9%, the S factor in USLE is given by

$$S = 0.065 + 0.045s + 0.0065s^2 \quad (4)$$

while if the gradient is greater than 9%, the S factor is given by

$$S = 6.4\{\sin [\text{atan} (s/100)]\}^{0.75}\{\cos [\text{atan} (s/100)]\} \quad (5)$$

where:

s – slope (%) (WISCHMEIER & SMITH 1978)

The national database of both L and S factors for all slope gradients corresponding to soil series found in Thailand has been summarized by LDD as LS factor. The LS factor of land in Thailand ranges from 0.226 to 4.571.

The land cover/management factor (C) is an index for the protective coverage of canopy and organic material in direct contact with the ground. It is measured as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled land under clean-tilled continuous fallow conditions (SONNEVELD & NEARING 2003). High values of C factor occur on bare land while low values are found in the area of dense forest or grain cover (PARK *et al.* 2011). Therefore, the change of land use types can affect the C factor. The national database for C factor proposed by LDD showed that the C factor ranges from 0.001 (tropical rain forest) to 1.000 (bare land). Because most regions in Thailand have no conservative practice management, therefore the P factor has

been defined as 1.0 (Land Development Department 2000).

All factors required for the USLE were prepared as data layer for Arc GIS. Then these data layers were overlaid and calculated for soil loss per year according to the USLE equation. The soil loss risks were categorized and mapped in order to be applied as database for spatial management and planning for the control of soil erosion.

RESULTS

Land use types and its changes

The application of the remote sensing technique for interpreting the satellite images taken by Landsat-5 TM in 1990 and 2010 revealed that the land use in the study area could be classified to 5 types as follows.

- Forest area where most areas are the tropical rain forest in natural forest and Kaeng Krachan National Park area.
- Agricultural area where most of the crop area is under monoculture such as pineapple and maize. This area also includes the residences of agriculturists such as one-story and two-story houses with cover of approximately 30 m² per house.
- Community which consists of residential buildings.
- Bare land covering the non-vegetation area.
- Water bodies covering natural and man-made water bodies.

According to the land use study of the two periods, it was found out that the largest area of the site in 1990 and 2010 was the forest area which covered 83.55% of total area in 1990 and 84.65% of total area in 2010. Details of land use of the site are shown in Table 1 and Figure 1.

Table 1. Land use of the site in 1990 and 2010

Land use	Area (ha)		Relative change of land use (%)
	1990	2010	
Forest	34 909.56	35 366.37	1.31
Agricultural area	5 989.24	6 230.86	4.03
Bare land	149.47	46.12	–69.14
Community	675.87	94.33	–86.04
Water	57.84	44.30	–23.41
Total	41 781.98		–

Table 2. Spatial changes in land use from 1990 to 2010

Land use type in 1990	Area of land use in 2010 (ha)			
	forest	agricultural area	bare land	community
Forest	33 937.78	947.75	22.32	0.53
Agricultural area	1 097.69	4 802.74	3.45	77.19
Bare land	128.72	15.99	4.74	–
Community	198.48	446.05	6.33	16.61

Table 3. Soil erosion risk categories of the site in 1990 and 2010

Category	Area (ha)		Relative change of area (%)
	1990	2010	
Low risk (0–12.5 Mg/ha/year)	35 785.09	35 669.79	–0.32
Slightly low risk (12.5–31.25 Mg/ha/year)	1 316.36	1 626.49	23.56
Moderately risk (31.25–93.75 Mg/ha/year)	1 780.17	1 639.00	–7.93
High risk (93.75–125 Mg/ha/year)	420.91	565.80	34.42
Very high risk (< 125 Mg/ha/year)	2 479.45	2 280.90	–8.01
Total	41 781.98		–

It can be summarized from Table 1 that in 2010 the community area and bare land significantly decreased to 86.04% and 69.14%, respectively, when compared to the community area and bare land in 1990, while the forest and agricultural area slightly increased by 1.31% and 4.03%, respectively.

In addition, the spatial changes of land use from 1990 to 2010 were investigated as shown by results in Table 2. It was revealed that the forest area in

1990 became bare land (0.064%), agricultural area (2.715%) and community area (0.002%) in 2010. Moreover, the agricultural area in 1990 became forest area (18.328%), bare land (0.058%) and community area (1.289%) in 2010. Furthermore, bare land in 1990 was changed to forest area (86.116%) and agricultural area (10.700%) in 2010. Besides, the community area in 1990 was changed to forest area (29.367%), agricultural area (65.997%) and

Table 4. Soil loss area changes due to changes in land use types from 1990 to 2010

Land use types change from 1990 to 2010	Relative change of soil loss area (%)
Forest → bare land	99 000
Forest → agricultural area	33 900
Forest → community	–100
Agricultural area → forest	–99
Agricultural area → bare land	194
Agricultural area → community	–100
Bare land → forest	–100
Bare land → agricultural area	–66
Community → forest	100
Community → agricultural area	100
Community → bare land	100

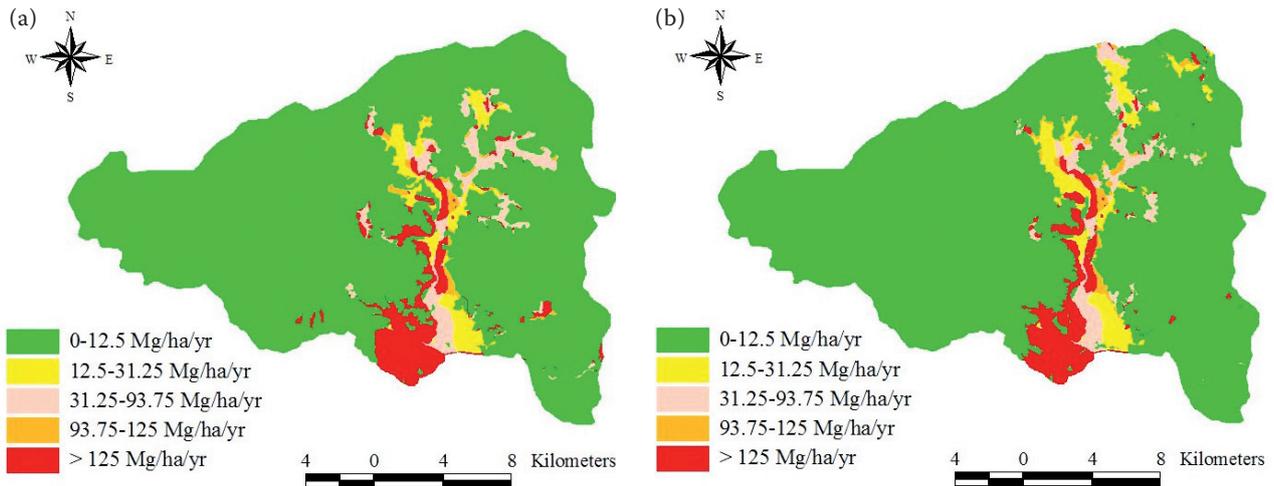


Figure 2. Soil erosion risk (a) in 1990, (b) in 2010

bare land (0.936%) in 2010. The changes in the area of water bodies were neglected because the area of water bodies was not considered in soil erosion risk assessment.

Soil erosion risk in the study area

The assessment of soil erosion risk in the study area by applying the USLE revealed that the low soil erosion risk category (0–12.5 Mg/ha/year) occupied most of the area in both 1990 and 2010 (approximately 85% of total area) as documented in Table 3 and Figure 2. Since the community areas were mostly occupied by buildings, therefore the community areas were considered as no soil loss area.

The relative changes in soil loss areas due to changes in land use types from 1990 to 2010 are shown in Table 4. It can be concluded from Table 4 that the soil loss increased when the land cover decreased, e.g. when the forest area in 1990 became bare land in 2010. On the other hand, the soil loss decreased when the land cover decreased, e.g. when the agricultural area in 1990 became forest in 2010.

DISCUSSION

Changes in land use types

In the 1990 to 2010 period, the population of Pa Deng increased at a 2.80% growth rate per year

(Department of Provincial Administration 2011). The population growth has led to the increase of agricultural area while the area also included the residences of agriculturists as mentioned before. Figure 1a, b illustrates that the population of Pa Deng expanded their cultivated area in the 1990 to 2010 period. Moreover, in the 1990s the government took serious action against deforestation especially in the natural forest area, therefore the bare land in 1990 was rehabilitated and then it became forest in 2010. Moreover, it can obviously be seen in Figure 1 that there were settlements and cropping in the plain area at the centre of Pa Deng between the natural forest and Kaeng Krachan National Park where the fertility forest is present. Therefore, the soil erosion assessment of this area is an important database for spatial management and planning in order to control soil erosion that leads to the degradation of land which may be followed by deforestation.

Impacts of land use changes on soil erosion

Table 4 reveals that the soil erosion risk decreased when the land use changed from bare land in 1990 to forest in 2010. On the other hand, the soil erosion risk increased when the land use changed from forest in 1990 to agricultural area in 2010 or from community in 1990 to agricultural area in 2010. These results showed that the land cover could efficiently protect the soil against erosion loss. Most of the high-risk areas had significantly smaller land cover than the low-risk areas. ZHOU *et al.* (2008) suggested that in a mountainous area

watershed, high erosion tends to occur when more than 30% of soil is exposed; the soil vegetation cover of more than 78% can greatly reduce erosion by water. Therefore, it may be concluded from the study results that cover cropping is one of the most suitable soil conservation measures for the agricultural area in Pa Deng; because monocultures are grown on most of the crop area in Pa Deng, the cover crops such as vetiver grass and bean family can also improve soil conditions. In addition, in order to ensure the more efficient implementation of soil conservation, a suitable cropping pattern and crop calendar must be applied conformably to the topography and season, respectively.

The reasons how the vegetation cover affects the soil erosion can be explained in various ways. For instance, litter production and organic matter accumulation could reduce the soil-water loss (WEI *et al.* 2007). Litter not only directly protects the surface soil from splash erosion, weakens the kinetic energy of raindrops and slows runoff velocities, but also conserves surface rainwater due to its strong moisture-holding capacity (Hou *et al.* 1996 as cited in WEI *et al.* 2007). Meanwhile, plant roots may form a dense network in topsoil that physically binds soil particles, and the soil-root matrix has been proved to be stronger than the soil or roots separately. In addition, plant root systems also influence the properties controlling soil erodibility, e.g. soil aggregate stability, infiltration capacity, soil bulk density, soil texture, organic content and chemical composition (GYSSELS *et al.* 2005). Moreover, the more complex structure of canopy can intercept 10 to 20% more of the rainfall (DE JONG & JETTEN 2007 as cited in ZHONGMING *et al.* 2010).

CONCLUSION

Different land use types in terms of area size and pattern influenced the soil erosion risk in Pa Deng in the 1990–2010 period. The area with smaller land cover obviously showed the higher risk of soil erosion than the larger land cover did. Therefore, in order to prevent the soil erosion, the land cover management and soil conservation measures, such as cover cropping, are highly recommended to be implemented widely in the agricultural area.

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