An Analysis of Multi-temporal Satellite Data for Land Cover Change and Its Impact on Soil Erosion over the Upper Namphong Watershed, Northeast Thailand

U. Chanket, C. Mongkolsawat
Geo-informatics Center for the Development of Northeast Thailand
Faculty of Science, Khon Kaen University
curawa@kku.ac.th, charat@kku.ac.th

Key words: Land Cover Change, Soil Loss, Multi Temporal Satellite Data, Upper Namphong and Northeast Thailand

Abstract

With increasing demand land for agriculture, the encroachment on the forest lands has been continuously evident. A consequence of the land cover (LC) changes has a profound effect on soil erosion which plays important role in the context of sustainable development of natural resources. The study thus aims to model the amount of soil loss as a result of land cover change with the use of multi - temporal satellite data and the Universal Soil Loss Equation (USLE). The study area, the Upper Namphong Watershed, is located in Northeast Thailand and covers about 4,424 Sq.Km. The multi - temporal satellite data used for LC changes were Landsat TM acquired in 1990 and 2001 and SPOT/HVR in 2007. The LC of each image scene was digitally performed using tree - decision method and verification with the ground investigation. The LC was digitally encoded in GIS database for further analysis. The USLE was used to determine the soil loss for the years 1990, 2001 and 2007. Comparison of soil loss for the three years studied as related to LC was made providing the impact of LC changes on the amount of soil loss in terms of spatial and quantitative contents. The study highlighted that severe erosion covered mostly in the steep slope with deforestation and misuse of land. The result provided spatial distribution of soil erosion for the three years and overall insight into causes of soil erosion as a result of LC changes in combination with the other USLE factors.

1. Introduction

The increasing rate of land cover land use change (LCLUC) and its impacts is the most important issues imply the sustainable development of natural resources. A large number of farmers in Thailand the immediate problems of today cost of living override any consideration of the future. They are geared to safety and utilize minimum input for subsistence. The development program in the subsistence economic initiated by his Majesty the King Bhumipol has been used countrywide in Thailand. However, intensive use of natural resources calls for detailed investigation of LCLUC and its impact. The soils in Northeast Thailand are inherently low in fertility and have light texture with vulnerable erodibiltiy. At present, demands on land production have been forced into the expansion of land use that is often in appropriate and results in degradation of forest and soils. Soil erosion prediction as a result of LCLUC is an immediate need to envisage the future trend in the sustainable development. A number of researches in many parts of the world try to quantify the LCLUC and its impact on soil erosion for sustainable development of landuse.

The study conducted by Solaimani K. et al (2009) emphasized the importance of LCLU changes in soil erosion over the Mediterranean basins, providing the relationships between land use patterns, erosion and the sediment yield. The role of land use change on water erosion was studied in Hungary, identifying the use of water erosion prediction project (WEPP) model in comparison to the USLE model. The USLE calculates 4-5 times more soil loss. (Demeny K. et al, 2008) Field experiments on soil loss under shifting cultivation conducted by Takahashi K. et al (1984) and Nagahori K. et al (1984) reported the severe rates of soil loss occurring mainly in the first year after clearing the forest. Due to dynamic nature of soil erosion, attention should be given in the factors involved and how to parameterize the factors. Using land cover change scenarios allows people to better understand the consequence of land use changes and their effects on non point source and erosion (Carter J. et al, 2005) Another study conducted by Bricquet J. P. (2003) on soil erosion under land use change from two catchments in Laos and Thailand was based on two scenarios of climate change and LCLUC. The results confirmed the very high sensibility of soil erosion to land use change as compared to climatic change. This study aims to model the impact of LCLUC on soil loss, using multitemporal satellite data and GIS.

2. The study area

The study area, the Upper Namphong watershed (UNW) lies between 101.61-102.68 east longtitudes and 16.33-17.24 north latitude and covers an area of about 4,424 km^2. (Fig 1) Physiographically, the elevation ranges from 180m to 1,300m, consisting small hill and gently undulating topography. The forest includes mixed deciduous, dry dipterocarp and evergreen types, mostly found on the mountain area. The degraded forest and re-growth can be found within the forest areas. The forest fragments of dry dipterocarp type distribute sporadically in the gently undulating topography. The annual rainfall ranges from 1,100-1,600 m.m. with mean of 1,200 m.m. Geologically, the area is underlain by Korat geologic group formed by thick sequence of Mesozoic rocks raning in age from upper Triassic to Tertiary. The majority of land use on the gently undulating alluvial plains is restricted to paddy field, caravan and sugar-cane with intensive farming of vegetables in the dry period where irrigation is available. The soils are inherently low in fertility and have coarse texture for the gently undulating plain. The soils formed on the hills are complex and classified as slope complex mapping unit.

Fig 1. The Study Area

3. Methodology

3.1 Data sources

3.1.1 Multi-temporal satellite data used in this study included Landsat TM acquired in January-February 1990 and January and March 2001 and SPOT HRV in December 2006 and January-February 2007.

3.1.2 Rainfall data within the study area over the year of 1990, 2001 and 2007 were collected by Dept of Meteorology.

3.1.3 Geological map 1:250,000 scale generated by Department of Mineral Resources.

3.1.4 Soil series map 1:50,000 scale was prepared by Land Development Department.

3.1.5 Topographic maps 1:50,000 scale, 20m contour interval, produced by Royal Thai survey Department were used for DEM generation.

3.2 Land cover and Land use Change

The approach of this study addresses land use change over the UNW area for three dates during 1990-2007 from moderate resolution Landsat TM and SPOT images. The procedure of methodology comprised preprocessing of satellite data land use classification of image for three dates, field verification and change analysis of land use, performing digital image analysis using hierarchical approach, and supervised classification, and analyzing the land use changes. Steps in the procedure are given as follows. (Fig 2.)

3.2.1 Preprocessing of satellite data

The Landsat TM data of 1990 scene preprocessing executed geometric correction, transforming the image coordinates to the ground control points selected from the corresponding. Topographic map and performing a resampling of the pixel with nearest neighbor algorithm. These provided the rectified images for which were used in the image to image geometric correction of the remaining two dates (Landsat TM 2001 and SPOT 2007) resulting co-registered and rectified images for three dates of 25 m. resolution image set.

3.2.2 Image classification /Analysis of land use change

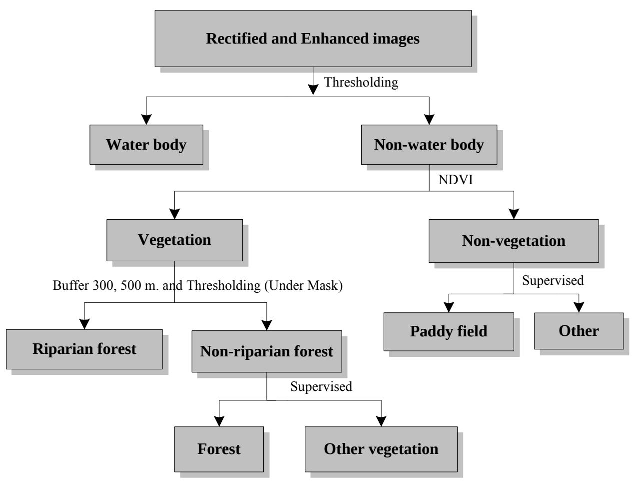

Fig 2. Procedure for Hierarchical and supervised method

The hierarchical approach and supervised method were used to assign the pixel value into land classes. Fig 2. shows the procedure used for this step. The digital processing of each image scene was digitally performed based on diverse criteria as follows.

Distinguishing between water body and non water body was executed from an analysis of the threshold of the pixel values. The vegetation and non-vegetation cover classes were differentiated over the area of non-water body, performing the normalized vegetation index (NDVI) analysis. The NDVI, widely used and accepted for vegetation study is defined as NDVI = (ρNIR - ρRED)/ (ρNIR + ρRED), where ρNIR and ρRED represent the reflectance values in the near infrared and red bands respectively. Providing the NDVI value, the differential of vegetation from non-vegetation can be defined. To distinguish the riparian vegetation, creation of 300 m. and 500 m. buffer beyond the streams and river was performed, resulting the masking areas under which the riparian vegetation could be classified.

The other vegetation included forest/rubber tree and non-forest (agriculture), generating the classes could be made by either supervised method or visual interpretation. The non-vegetation class, including paddy field, outcrops, range land, community and other was processed using supervised method with maximum likelihood ratio for decision criteria.

The thirty one sampling sites were investigated to examine the growth truth in detail on vegetation types, land use pattern and overall landscape on the 2007 satellite images. The Kappa coefficient was applied to test the reliability of the LCLU map.

3.2.3 The change analysis

The land use change procedure used involved a comparison of land use derived from the three dates of remotely sensed data. In this case the comparison of the change represents the change of the year 1990 and 2001, 2001-2007 and 1990-2007 including the statistical calculation of the change classes. A comparative detection of the land use changes in the UNW was conducted. Once the type and extent of land use changes has been determined, implication efforts can be initialed that describe and forecast future change.

3.3 Soil loss assessment

Soil loss assessment for the UNW was based on the USLE established by (Wischmeier et al.,1987) and the integration of the USLE factors was digitally performed using GIS. (Fig 3.) The USLE is presented in the form: A = R x K x LS x C x

Where A is soil loss

R is the rainfall erosivity index
K is the soil erodibility factor
LS is the slope length and slope factor
C is the crop management factor
P is the conservation practice factor

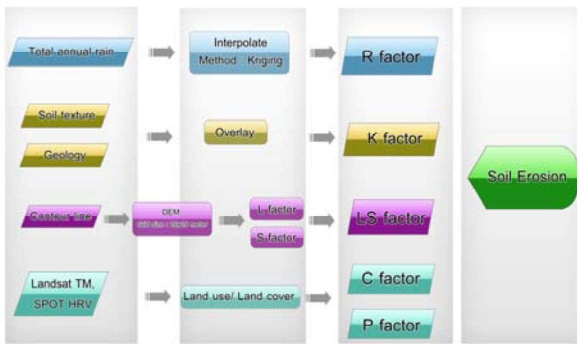

Fig 3. Schematic chart of soil erosion

This equation is widely accepted worldwide for erosion prediction that based on empirical research and field experiments. These factors are varied from place to place depending on the numerical values for each of the factors or variables. Determination of the various variables is described here below. Each variable is considered as a thematic layer in the GIS database to be used in the modeling process.

3.3.1 R-factor layer

R-factor for each location as defined by LDD (LDD, 2000) was used for this study

R = 0.4669x - 12.1415
x = mean annual rainfall (mm.)

The rainfall data of 28 meteorological stations covering the UNW and its vicinity areas were collected. For each station, the rainfall data available ranging 8-29 years were used to calculate the R-factor. To establish the spatial layer of the R-factor, the Kriging method was applied to the mean annual rainfalls for the interpolation.

3.3.2 K-factor layer

The K-factor layer was based on LDD soil map for the area of soil texture available on which the value assigned as identified by Srikhajon et al. (1984). For the slope complex mapping units where the soil texture data is not available, the values are then based on geologic Formaitons as identified by LDD (LDD, 2000).

3.3.3 LS-factor layer

Slope and slope length are interconnected and can be identified as a single LS-factor to represent one layer in the equation. In the context of establishing the LS-factor layer for the large area it is the most complicated and time consuming. This approach was then subdivided the UNW into sub-watershed for the preparation of the layer to avoid erroneous results. A number of papers provided information on the calculation of the LS-factor in the equation as described by Remortel et al. (2001) Wischemier and Smith (1978), Myint et al. (1997) and McCool et al. (1989).

The approach to this study adopted the equation developed by McCool et al. (1989).

LS = (l / 22.13)m (10.8 Sin ß + 0.03) for slope < 9% **where l** = slope length (m)

LS = (l / 22.13)m (16.8 Sin ß - 0.5) for slope > 9% **ß** = slope gradient (degree)

m = f / (l + f)

f = (Sin ß / 0.0896) / [3.0 (Sin ß)0.8 + 0.56]

With the availability of software package developed by Remortel et al. (2001), the spatial LS-factor could be performed using AML (Arc macro language) which applies the equation developed by McCool et al. (1989). Slope layer was generated from digital elevation model (DEM) (20x20 m. grid size) which was in turn performed using elevation contours of the topographic map at 1:50,000 scale. The establishment of spatial layer of LS-factor using the AML developed by Remortel on which the slope layer in combination with flow direction of water within the slope polygon was based. As a result, the LS-factor layer was then established.

3.3.4 C-factor layer

Land cover of the areas was compiled from 1:50,000 satellite data acquired in 1990, 2001 and 2007 and mapped at the 1:50,000 scale. The maps were digitally encoded in GIS database. The land cover classes include dry evergreen forest, dry deciduous forest, Mixed deciduous forest, plantation, grass land, paddy field, field crop, community area and water body. To establish the C-factor layer, the value for each class of the land cover was assigned as identified by LDD (LDD, 2000).

3.3.5 P-factor layer

Referring to the experiment conducted by LDD (LDD, 2000) the P-factor was set to be 0.1 for dry evergreen forest and paddy field. For other classes no conservation practice were found and set the value 1.

4. Results and Discussion

4.1 LCLUC in the Upper Namphong Watershed 1990, 2001 and 2007

The LCLUC in the Upper Namphong Watershed UNW, based on Landsat TM and SPOT HVR data set acquired in 1990, 2001 and 2007 shows the variation of forest clearing and re-growth. Table 1 shows land cover and land use for 1990, 2001 and 2007 and the comparison of LCLUC in the UNW at the study year. No significant changes in areas of the evergreen forest were found, the decline was 1.17% for 16 years (1990-2007). Considerable changes in the extent of the mixed deciduous and dry dipterocarp forest types for 16 years declining 9.23% and 8.05% respectively. It is worth note that during the period 1990-2001 the area of dry dipterocarp forest expanded by 7.19%. The majority of land use in the area is paddy field covering an area of over 40% of the total area. However the area of paddy field between 1990-2001 expanded slightly about 0.59% and between 2001-2007 declined by 14.67%. Comparison of the 1990, 2001 and 2007 LCLU maps revealed the distribution of land use type (Fig 4.). A board pattern of LCLU indicated the majority of forest cover found within the national parks and conservation areas with strict control measures. The encroachment of field crop on forest area and upper paddy field increased from 10.26% in 2001 to 19.09% in 2007. Reliability test of the LCLU map checked against the field observation is 70.98% kappa coefficient.

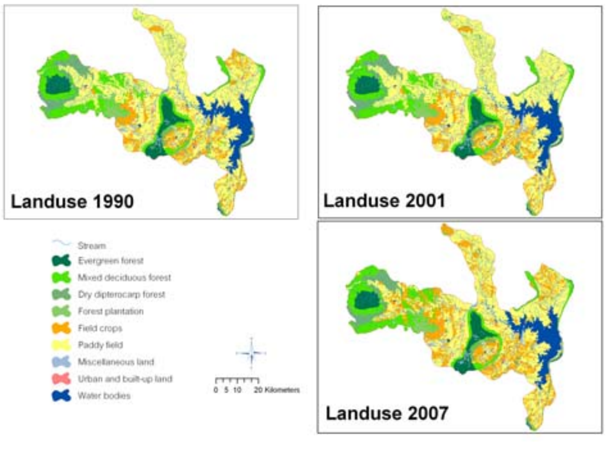

Fig 4. LCLUC for 1990, 2001 and 2007

Table 1. LCLUC in UNW 1990, 2001 and 2007

Landuse type	Area (%)			Change (%)		
	1990	2001	2007	1990-2001	2001-2007	1990-2007
Paddy field	46.933	47.212	40.286	0.59	-14.67	-14.16
Field crops	10.488	10.260	19.093	-2.17	86.09	82.05
Evergreen forest	6.152	6.018	6.080	-2.18	1.03	-1.17
Mixed deciduous forest	14.827	14.046	13.459	-5.27	-4.18	-9.23
Dry dipterocarp forest	7.367	7.897	6.774	7.19	-14.22	-8.05
Forest plantation	2.158	2.206	2.132	2.22	-3.35	-1.20
Miscellaneous land	2.405	2.657	2.274	10.48	-14.41	-5.45
Urban and built-up land	1.786	1.802	1.845	0.90	2.39	3.30
Water bodies	7.884	7.903	8.058	0.24	1.96	2.21

Total area of the Upper Namphong Watershed. = 442,400 ha.

The Land use patterns in this area are determined by land form, soil, topography, social attitudes and economic milieux. The low lands are restricted to paddy rice while the uplands, well drained area are used for field crops and perennial crops. Among those are cassava, sugar-cane, rubber tree and forest fragments. The drivers in changes are demands on land for agriculture price incentives, infrastructure development and unstricted law enforcement.

4.2 Impact of LCLUC on Soil Erosion

The soil erosion maps for 1990, 2001 and 2007 resulting from the spatial overlay of the factor layer with application of USLE model over the UNW is presented in Fig 5. The amount of soil loss and evaluation class of the corresponding maps were shown in Table 2. No significant difference in amount of loss between the years studied is found but greater potential of soil loss I evident for 2007 as a result of declining forest cover. Investigating the factor bringing about the increased loss for the given site in GIS database, a combination of vegetation cover and higher rainfall amount contributes significantly severe soil loss. It is worth note that the very severe and severe rates of soil loss occur mainly in the first year clearing the forest. This is due to loose soil surface or well formed aggregates moving down the slope. For the subsequent year soil loss in greatly reduced in relation to that in the first year even in the bare land. The reasons are the more compacted soil exposed the existence of roots and weeds which act as barrier against soil erosion (Takahashi T. et al 1984; Nagohori K. et al 1984). Monitoring forest clearing on yearly basis provides better estimation of soil loss. From ground observation the forest extent in the study area is mostly the re-growth vegetations, the virgin forest covers small extent. The study indicated that the soil loss in the UNW is the results in the forest clearing of re-growth vegetation. The amount of soil losses estimate is lesser extent than those calculated because the factor value used for vegetation cover based on the virgin forest.

However, field investigation revealed not the re-growth vegetations in together with there degradation, encroachment of agriculture on the re-growth is usually found. In terms of sustainable development, the cumulative soil loss summed over the preceding years with about 30-40% yearly soil loss is suggested based on the above mentioned and empirical study.

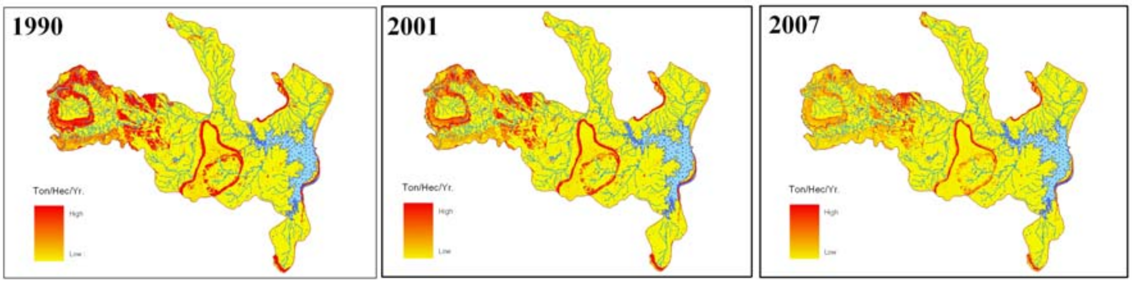

Fig 5. Soil erosion maps in the UNW 1990, 2001 and 2007

In 2007 the forest cover declined by 17.37% of the 2001, if the situation remained unchanged the expected soil loss will be increased to a critical level. The existing soils in the study area are inherently low in fertility, the increase of soil erosion as estimated will lead to require more fertilizer applied and other inputs for maintaining optimum crop yields. With the impact of the LCLUC in the areas, it should be recommended the extension of conservation practices and intensifying the law enforcement on logging.

5. Conclusion

The LCLUC over the UNW using multi-temporal satellite data has made considerable progress to provide information needed for effective management of soil resources. Results of this study include the LCLUC mapping, quantification of LCLUC and soil erosion mapping in terms of temporal and spatial distribution. The informations obtained enable the users whether in scientic, policy or management communities to address questions on the LCLUC and its impact on soil loss. With the GIS databases established investigation into insights of the main factor causing soil loss within a given area could be made.

Table 2. Soil loss in the UNW

Class	Rate(t/ha/y)	Area (%)		
		1990	2001	2007
Very mild	<10	84.714	84.623	83.832
Mild	10-20	4.191	4.232	4.055
Moderate	20-40	4.261	4.302	4.158
Severe	40-100	4.708	4.730	5.286
Very severe	>100	2.126	2.113	2.669
Total		100.000	100.000	100.000

6. References

Bricquet J.P., Boonsaner A., Chaplot V., Phommassack T. and Valentin C. (2003) Soil erosion under land use change from two catchments in Laos, and Thailand. IWMI-SEA, Kasetsart University, Bangkok, Thailand. From http://ugamp.nerc.ac.uk/promise/research/conference2003/abstract_pdf/bricquet.pdf

Demény, K., Jakab, G., Centeri, Cs. (2008) The role of land use change on water erosion in the Gödöllő Hillside. Poster presentation. 15th International Congress of ISCO, Soil and Water Conservation, "Climate Change and Environmental Sensitivity". Geographical Research Institute, HAS

Jamie Carter, David L., Margaret V. W., Ed D. and Bev W. (2005). THE NONPOINT-SOURCE POLLUTION AND EROSION COMPARISON TOOL: ASSESSING LAND USE CHANGE IN THE MAKAHA VALLEY, OAHU, HAWAII. Proceedings of the 14th Biennial Coastal Zone Conference New Orleans, Louisiana, July 17 to 21, 2005. From http://www.csc.noaa.gov/cz/2005/CZ05_Proceedings_CD/pdf%20files/posters/Carter.pdf

Land Development Department. 2000. Soil Erosion in Thailand. Land Development Department, Ministry of Agriculture and cooperatives.

McCool D.K., Foster G.R., Mutchler C.K., Meyer L.D. 1989. Revised Slope Length Factor for The Universal Soil Loss Equation. Trans. ASAE 1989;32:1571-1576.

Myint S.W., Thongthap C., and Eiumno A. 1997. Soil Nutrient Depletin Modelling using Remote Sensing and GIS: A Case Study in Chonburi, Thailand. In *Proceedings of the 18th Asian Conference on Remote Sensing*, Kuala Lumpur, Malaysia, 20-25 October, 1997, pp. R51-R53.

Nagahori, K., Takahashi, T., Mongkolsawat, C. and Losirikul, M., 1984. Run-off and Soil Loss in The First Year After Clearing and Burning Field Studies on Erosion Control in Shifting Cultivation and Its Sustained Upland Farming in The Monsoon Tropics in Northeast in The Monsoon Tropics in Northeast in The Monsoon Tropics in Northeast Thailand (I).Transcaction of The Japanese society of Irrigation, Drainage and Reclamation Engineering.No. 111, pp 43-53.

Salaimani K., Modallaldout S. and Lotfi S. (2009) Soil Erosion Prediction Based on Land Use Changes (A Case in Neka Watershed). American Journal of Agricultural and Biological Sciences 4 (2): 97-104, 2009. From http://www.scipub.org/fulltext/AJAB/AJAB4297-104.pdf

Srikhajon M., Somrang A., Pramojanee P., Pradabwit S., and Anecksamphant C. 1984. Application of the Universal Soil Loss Equation for Thailand. In Proceeding of the Fifth ASEAN Soil Conference at Bangkok, Thailand on June 10-23, 1984.

Remortel Van R.D., M.E. Hamilton, and R.J. Hickey. 2001. Estimating the LS Factor for RUSLE Through Iterative Slope Length Processing of Digital Elevation Data within ArcInfo Grid. Cartography Vol. 30, No.1, Pg. 27-35.

Takahashi, T., Nagahori, K., Monkolsawat, C., and Losirikul, M., 1984. Discussions on Soil Conservation Practices for Establishing Sustained Upland Farming Field Studies on Erosion Control in Shifting Cultivation and Its Sustained Upland Farming in The Monsoon Tropics in Northeast Thailand (II). Transaction of the Japanese Society of Irrigation, Drainage and Reclamation Engineering. No.111, pp 55-62.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall Erosion Losses. USDA Agriculture Handbook No.537.