Soil Erosion Modelling in the Mae Pan Subcatchment in Northern Thailand

Merritt, W.S.,[1] **Schreider, S.Yu.,**[2] **Sathaporn Jaiaree,**[3] **and Nontaporn Nongharnpitak**[3],
[1]Centre for Resource and Environmental Studies (CRES) and [2]Integrated Catchment Assessment and Management (ICAM) Centre, The Australian National University, Canberra ACT 2601, Australia.
[3]Department of Land Development, Thailand.

Abstract This paper describes the methodology and initial results of erosion modelling in the Mae Chaem catchment of the Ping River Basin, Northern Thailand. The research is a component of a collaborative Integrated Water Resource Assessment and Management (IWRAM) project which will develop and apply an integrated approach to water resources assessment and management in the Upper Ping River Basin. This study aims to develop a preliminary method to estimate the importance of land cover changes to sheet erosion and sediment loads. An approach based on the Universal Soil Loss Equation (USLE) treating the entire subcatchment as a single grid cell was used. These estimates will be refined in future work when a more detailed grid based approach is developed. The strength of this approach is that the USLE can be used to develop indicators of potential erosion for the catchment in relation to rainfall and land cover scenarios.

1. INTRODUCTION

Accelerated soil erosion in the highland regions of Thailand due to increasing intensities of land use has long been identified as a serious problem (Lal 1975; Liensakul *et al.* 1993). These highlands are highly prone to erosion due to the steep slopes and soils that are exposed to an erosive monsoonal climate for up to seven months of the year. The inherent susceptibility of this region has serious implications for water quality and crop production in the Ping River Basin.

Much research has been undertaken in northern Thailand on the effect of land use change and other anthropogenic activities on the rate of erosion from the highlands. Particular emphasis has been placed on the change from traditional shifting cultivation systems to more intensive production oriented agricultural practices (Liengsakul *et al.* 1993; Hussain and Doane 1995). With increasing population and land use pressures in the highlands of Thailand continued pressure on highland soils is to be expected.

The work presented here is intended to provide a preliminary analysis of sheet erosion within the Mae Pan subcatchment, using GIS maps, as well as propose methodology for extension of this work. The first step in developing a more comprehensive erosion model is to estimate relative changes in soil erosion (treating Mae Pan as a single grid cell) from land use and topographic information for three times slices when land use data are available. At a later date erosion will be estimated using a grid-based approach and these predictions will be compared with measured data. Future research will aim to quantify the relative contributions of road erosion and sheet erosion to the overall sediment budget for the subcatchment of Mae Pan, located in the Mae Chaem catchment in northern Thailand.

2. SITE DETAILS

2.1 General catchment description

The erosion model presented is applied in Mae Pan, a subcatchment of the Mae Chaem catchment in northern Thailand. The Mae Pan subcatchment with an area of 45 km^2, above the junction of the Mae Chaem and Mae Pan rivers, is located in the central region of the Mae Chaem catchment. The majority of the catchment is intensively farmed and the remaining vegetative cover is characterised by scrubby bush with forested areas on the steeper slopes. Sediment time series were analysed for four stations in the Mae Chaem catchment. The four stations were Nam Mae Mu at Ban Mae Mu (referred to as Mae Mu), Nan Mae Chaem at Ban Huai Phung (Huai Phung), Nan Mae Pan at Ban Kiu Ton Po (Mae Pan) and Nan Mae Chaem at Ban Kong Kan (Kong Kan). The map of the Mae Chaem catchment, subcatchments considered in the IWRAM project and station locations is presented in Figure 1.

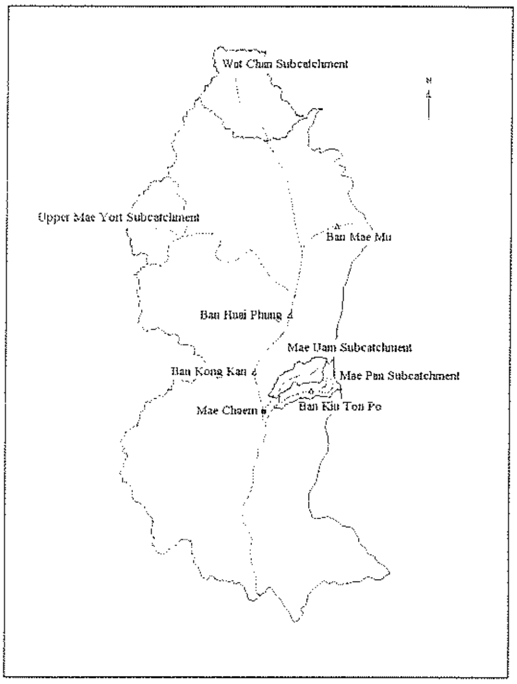


Figure 1 Map of Mae Chaem catchment, showing subcatchment boundaries and station locations.

3. EROSION PREDICTION

3.1 Sheet erosion

Sheet erosion was estimated using a USLE based approach, modified to suit conditions typical of the northern Thailand highlands. USLE estimates the average annual soil loss using;

$$A = R\,K\,LS\,C\,P$$

where A is the soil loss averaged over slope length, R is rainfall erosivity, K is the soil erodibility, LS is the topographic factor dependent on slope length and slope gradient, C is dependent on vegetative cover and management and P is dependent on conservation practices (Wischmeier and Smith 1978). The model is easy to implement and has been shown to be able to be incorporated into more integrated models or decision support systems.

A number of limitations to the USLE equation exist. The model is not event-based and as such can not identify those events most likely to result in large-scale erosion. Gully erosion and mass movement is not considered in the erosion process and the deposition of the sediment is not considered to occur within the area under consideration. Although it is apparent that the USLE has a number of limitations, the data availability within the subcatchments used in this study is such that is inappropriate to use more data intensive erosion models. The main strength the USLE is that it can be used to develop indicators of potential erosion across catchments in relation to rainfall and land cover scenarios.

USLE has been used over a range of scales from small plots, from which the original equations were developed, to large scale projects to determine soils erosion hazard within a catchment. Over large scales, the area to which the model is applied is broken into segments in which the USLE factors are, or are assumed to be, uniform. For example, the Agricultural Non-Point Source (AGNPS) model, which uses USLE to predict erosion, applies a grid cell representation of the catchment with a cell resolution of 0.4 to 16 ha. Other large scale applications of USLE have effectively broken the catchment down into a Potential Soil Erosion (PE) map by overlaying soil map with a topographic map to obtain the erosion susceptibility (KLS). This has been used as a basis for dividing the catchment into segments.

Rainfall Erosivity (R)

In this study, R was determined using the equation proposed by El-Swaify *et al.* (1987) relating rainfall erosivity to annual precipitation, P(mm), through the regression;

$$R = 38.5 + 0.35(P).$$

This equation has been applied in Thailand (Navanughra 1993; Liengsakul *et al.* 1993; NRC 1997) and is more likely to reflect the rainfall erosivity in tropical climates the EI_{30} index presented in Wischmeier and Smith (1978). For the time slices used in this study, (1985, 1990, and 1995), the R factors were estimated as 492.9, 447.5 and 523.5 respectively.

Soil Erodibility (K)

Soil erodibility will, for the purpose of this first-pass approach, be assumed to be constant. In terms of soil texture, upland soils in Thailand are dominated by light to medium textured soils (Chaiwanakupt and Chiangprai 1990). Yu *et al.* (1990) used the GUEST erosion model to determine the soil erodibility parameter and evaluate the potential of the model for predicting soil loss on an event basis in Chiang Dao in Chiang Mai Province, Thailand. Mean soil erodibility was calculated as 0.248. For the first pass approach this value of K was used.

At this stage, the main interest is in identifying the relative changes in erosion for the time slices due to land use changes and rainfall. Future extension of this work will employ K factors based on slope and geology for the Mae Chaem catchment (yet to be undertaken by the Department of Land Development in Thailand).

Topographic Factor (LS)

Slope within Mae Pan ranges from 0.002° to 53.5°. Consequently, the Wischmeier and Smith (1978) equation, which was developed on slopes of 3-18%, needs to be adapted to be used for slopes outside of this range. The topographic factor was calculated using the Wischmeier and Smith (1978) *LS* factor equation for slopes less than 8% and the Hellden (1987) equation for slopes greater than 8% as proposed by Funnpheng (1991). That is, for slopes less than 8%;

$$LS = ((L_{(m)})^{0.5}/22.13)(0.065+0.0456(S)) + 0.0065(S)^2$$

and for slopes greater than 8%;

$$LS = (0.799 + 0.0101(L_{(m)}))(0.344 + 0.798(S))$$

where S is percentage slope gradient, and slope length, L, is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or that runoff water enters a well defined channel (Wischmeier and Smith 1978).

These equations have been used in a number of erosion studies in northern Thailand (e.g. NRC 1997). Mean slope gradient (30%) for the Mae Pan subcatchment was obtained from GIS whilst slope length was estimated using a contour map of the subcatchment (See Section 3.2).

Crop and Management Factor (C)

The *C* factors were determined from land cover information obtained from GIS and *C* values reported in previous soil loss prediction studies in northern Thailand (Table 1). In terms of the land cover maps shown in Figure 3, paddy and upland fields are combined and assigned the *C* factor for agriculture determined by NRC (1997). No further information regarding the state of the 'upland fallow field' was available from the GIS. The time that has lapsed since the fallow field was used would be expected to have a large impact on erosion due to the changes in the C factor. Given this, erosion estimates for the whole Mae Pan were calculated twice, once assuming the fields were recently abandoned, (i), and once assuming heavy regrowth, (ii) (See Table 1).

Table 1 *C* factors employed in first pass approach to erosion modelling in Mae Pan (from NRC 1997).

Land Cover Class	*C* factor
Forest	0.001
Paddy + Upland fields	0.15
Urban	0.45
Upland fallow fields (i)	0.8
Upland fallow fields (ii)	0.001

In this preliminary assessment of the total sheet erosion for Mae Pan, erosion was estimated using an weighted *C* factor where

$$C_W = \Sigma(\text{area of land use}) \times C\ \text{factor}.$$

Support Practices Factor (P)

For a first pass it was assumed that there are no conservation practices in place within the study area (i.e. P=1). This assumption is not unwarranted given the limited adoption of conservation practices in the region. At a later date, P factors may be implemented if conservation practices are identified as having been adopted to improve erosion estimates or potentially for developing scenarios relating to the adoption of and success of conservation practices.

3 RESULTS

3.1 Sediment and Discharge Analyses

Table 2 Average Annual Suspended Sediment in tons for the four stations.

Station	Average Annual Suspended Sediment (tons)	Years of data
Mae Mu	1660	11
Mae Pan	2860	11
Huai Phung	69800	13
Kong Kan	129220	12

Daily sediment loads were generated from ratings curves for the four stations (Mae Mu, Mae Pan, Huai Phung and Kong Kan) within the Mae Chaem catchment. The station at Ban Kong Kan is located approximately 5 km to the north of Mae Chaem, while the station at Ban

Huai Phung is located north of Kong Kan. The Mae Mu and Mae Pan stations show lower annual suspended sediment yields than the Huai Phung and Kong Kan stations, correlating with their position within the catchment (Table 2). The mean monthly suspended sediment loads increase up to a maximum in August and September. This follows a similar pattern to rainfall, although a lag between peak rainfall and peak suspended sediment load exists.

3.1 Land use analysis in Mae Pan subcatchment

Three time slices (1985, 1990, 1995) of land cover information, the main input for erosion modelling in this first pass approach, were obtained for the entire Mae Chaem catchment from the National Research Council (NRC) of Thailand. From the topographic information, watersheds for the land draining to the Kong Kan station and the Mae Pan catchment were defined.

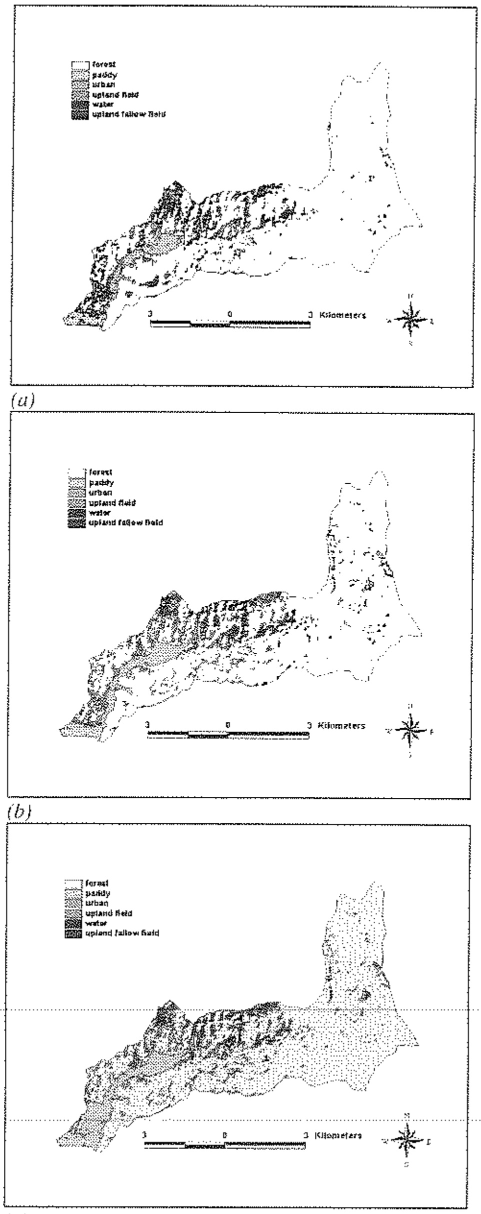
The land cover maps for the three time slices for Mae Pan (Figure 2) show that the area under paddy has been extended throughout much of the valley regions in Mae Pan. Additionally, upland agriculture increased between 1985 and 1995. This is illustrated in Table 3. The conversion of forested land to agriculture in Mae Pan is not as extreme as that observed in the land draining to Kong Kan station where the area under forest decreased by 10% over the 10 year period.

Table 3 Percentage land cover in Mae Pan

Land Cover Class	Percentage Area		
	1985	1990	1995
Forest	88.18	82.13	82.23
Paddy	4.69	5.69	7.76
Urban	0.02	0.15	0.20
Upland field	6.64	8.26	4.82
Water	0.01	0.02	0.02
Upland fallow field	0.46	3.76	4.96

3.2 Analysis of Topography

Figure 3 shows the slope characteristics of the Mae Pan subcatchment, generated from GIS. Much of the subcatchment is steeply sloping land particularly in the northern and eastern regions. The majority of the slopes exceed the ranges of slopes for which the USLE was originally developed and thus required the use of other equations more appropriate for mountainous areas.



(a)

(b)

(c)

Figure 2 Land Cover for Mae Pan subcatchment for (a) 1985, (b) 1990, and (c) 1995.

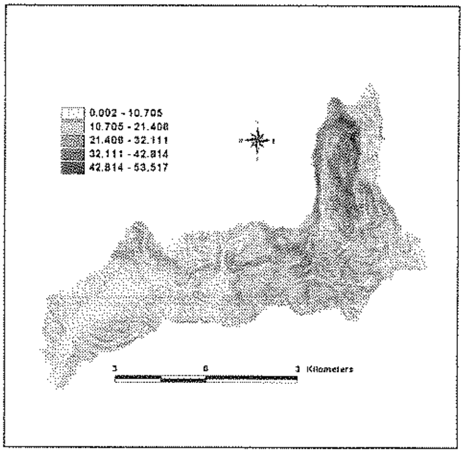


Figure 3 Slope (in degrees) for Mae Pan.

For purposes of simplification, average slope for the catchment (30%) and a single slope length (15737 m) for the whole catchment was used in the first pass approach. While it is recognised that this may lead to inaccuracies in total erosion estimates, the focus of this preliminary study is on the relative changes in erosion due to differences in land cover and rainfall for the three time slices.

4.3 Preliminary Erosion Estimates

Table 4 shows the effect of the time period following abandonment of upland fields on the weighted *C* factor. As the period following abandonment increases the *C* factor diminishes and this had a large impact on the final erosion calculation for the Mae Pan subcatchment (Table 5). This illustrates the importance of time period from abandonment. Much of the conversion of forest to other land uses after 1985 are reflected in the land cover classification 'upland fallow fields' (See Table 3). When heavy regrowth is assumed (C=0.001) there is, in terms of modelling using the USLE, effectively little land cover change between the time slices and therefore differences in the erosion estimates are not extreme. This identifies a requirement for more detailed land cover information in erosion studies that involve shifting cultivation. The cases (i) and (ii) in Table 4 and 5 assume (i) upland fallow fields were recently abandoned and thus have little vegetation cover (C=0.8) and (ii) upland fallow fields have heavy regrowth (C=0.001). These two cases (i and ii) are the 'end points' of the potential erosion losses for these three time slices.

Table 4 Weighted C values used to calculate erosion.

Time slice	Weighted C value	
	(i)	(ii)
1985	0.03	0.026
1990	0.06	0.029
1995	0.06	0.021

Table 5 Total sheet erosion estimates for Mae Pan.

Time slice	Erosion (tonnes)	
	(i)	(ii)
1985	14555	12329
1990	25830	12484
1995	30217	10575

4 DISCUSSION

This paper has presented a methodology for the prediction of sheet erosion for the Mae Chaem catchment in northern Thailand, as part of the IWRAM project for integrated water resources assessment and management. The strength of this approach is that the USLE, as presented here, can be used to develop indicators of potential erosion for the catchment in relation to rainfall and land cover scenarios.

Additionally, preliminary assessment of the total sheet erosion within Mae Pan, a subcatchment of Mae Chaem, was presented for the same time slices as for the land cover data (1985, 1990 and 1995). This provides a preliminary analysis of the changes in erosion over the subcatchment due to differences between land cover and rainfall for these time slices. These erosion estimates for the Mae Pan subcatchment can not be compared with sediment load data for the catchment as the location of the station is located in the middle of the subcatchment, with only 22.5 km^2 of the total subcatchment area located upstream of the station.

An outcome of this preliminary erosion work has been to highlight potential problems in basing the *C* factor on land cover data obtained from a GIS. The categorisation of upland fallow fields gives no additional information on the period of time that has lapsed since abandonment of the upland field, and thus the vegetation characteristics of the field at the time of land cover mapping. Obviously the *C* factor for the fallow field will vary over time from high values when the soil is bare to low values when the forest regrowth is thick. Taking two extreme values for this *C* factor considerably affected the weighted *C* factor used in the erosion estimates. This in turn, has a large effect on the relative changes in erosion shown in Table 5. For more accurate assessment of erosion further information on the state of these upland fallow fields is required.

The main limitation with the initial estimates of erosion is that they do not provide an indication of the erosion 'hotspots' within the subcatchment. Additionally, the use of averaged slope gradient and slope length is questionable, given the large variation in slope within the catchment. These initial estimates will be extended to a grid based approach in an attempt to address these deficiencies. However, these preliminary estimates serve to indicate that the land cover changes within

Mae Pan have increased the potential for erosion.

Future research will involve the calibration of a USLE based model, improvements in parameter estimation, and employment of field data. The importance of erosion generation from roads is likely to increasingly contribute to the overall sediment yield of a catchment arising from agricultural intensification and resultant road network expansion. Once a means of distinguishing between sheet and road erosion sources has been identified the next stage will be to incorporate the USLE based model with a road erosion model (yet to be developed). This should provide an indication of the relative contribution of each erosion source to the total sediment yield observed for the subcatchment. Ultimately, the combined erosion modelling approach will be expanded to the entire Mae Chaem catchment.

6 ACKNOWLEDGMENTS

The authors thank Dr. Nand Awadhal and Dr. Claude Dietrich for their input in discussions regarding the first stage of erosion prediction and Rebecca Letcher for her comments on the paper.

7 REFERENCES

Chaiwanakupt, S., and Changprai, C. 'Resources and problems associated with sustainable development of uplands in Thailand'. *Proceedings of a seminar 'Technologies for Sustainable Agriculture on Marginal Uplands in Southeast Asia'*, Ternate, Cavite, Phillipines, December 10-14, 1990.

El-Swaify, S.A., Gramier, C.L., and Lo, A. 'Recent advances in soil conservation in steepland in humid tropics'. *Proceedings of the International Conference on Steepland Agriculture in the Humid Tropics.* Kuala Lumpur, MADI, 87-100, 1987.

Hussain, M.J., and Doane, D.L. 'Socio-ecological determinants of land degradation and rural poverty in Northeast Thailand'. *Environmental Conservation*, **22**(1), 44-50.

Funnpheng, P., Patinavin, S., MekpaiGoonwattana, P., and Pramonjee, P. 'Application of remote sensing and GIS for appraising soil erosion hazard'. *Proceedings of the International Conference on Conservation and Sustainable Development.* April 22-26 1991, Khao Yai National Park, Thailand 79-91, 1991.

Hellden. 'An assessment of woody biomass community forest and soil erosion in Ethiopia'. Department of Geography, University of Lund, Sweden, 75 p, 1987.

ICAM. Integrated Water Resource Assessment and Management Framework: A case study of the Ping Basin, Northern Thailand (Subcatchment Profiles and Proposed Case Studies). Integrated Catchment Assessment and Management Centre, 1998.

Lal, R. 'A brief review of erosion research in the humid tropics of South East Asia'. In *Soil Conservation and Management in the Humid Tropics.* (Eds. Greenland and Lal, R). John Wiley and Sons, 1975.

Liengsakul, M., Mekpaiboonwatan, S., Pramojanee, P., Bronsveld, K., and Huizing, H. 'Use of GIS and remote sensing for soil mapping and for locating new sites for permanent cropland - A case study in the highlands of Northern Thailand'. *Geoderma* **60**, 293-307, 1993.

Navanughra, C. Application of Geographic Information System for soil conservation – oriented land use planning in Doi Tung, northern Thailand. 231pp, 1993.

NRC, Thailand landuse and land cover change case study, Bangkok, National Research Council of Thailand, 1997.

Wischmeier, W. and Smith, D. Predicting rainfall erosion losses: Guide to Conservation Farming, USDA Handbook 537, 1978, Washington DC.

Yu, B., Sajjapongse, A., Yin, D., Eusof, Z., Anecksamphant, C., Rose, C.W., and Cakurs, U. 'Application of a physically based soil erosion model, GUEST, in the absence of data on runoff rates II. Four studies from China, Malaysia and Thailand'. *Australian Journal of Soil Research* **37**, 13-31, 1999.