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Estimation of Soil Erosion Using Remote Sensing and GIS, Its Valuation and Economic Implications on Agricultural Production

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ABSTRACT

Soil erosion is a serious environmental problem in Northern Thailand causing a threat to sustainable agriculture. Faulty agricultural practices, high annual rainfall and the undulating topography of Northern Thailand are the key factors contributing to a high annual rate of soil erosion. For finding the status and extent of the erosion problem in the Mae Ao watershed of Northern Thailand, the annual rate of soil erosion was estimated using remote sensing data. Since the vegetative cover is a major factor of soil erosion, therefore, a Normalized Difference Vegetation Index (NDVI) derived from Remote Sensing data (Landsat-TM) was used in this study to assess the vegetative cover in the watershed. A soil erosion model was developed to integrate NDVI and land slope for estimating the annual soil erosion rate. Results indicated that the changes in agricultural pattern from traditional crops to orchard plantation and adoption of soil conservation measures in the Mae Ao watershed decreased the annual soil erosion rate. Estimated reduction in soil erosion rate from 1.24 mm/year in 1992 to 0.91 mm yr^{-1} in 1996 in the area also lowered the external cost of soil erosion by 4,210,284 Baht. The cost of soil erosion in 1992 and 1996 were estimated as 16,010,244 Baht and 11,799,960 Baht, respectively, using replacement cost technique. The net farm income in the study area was increased from 38,262,654 Baht in 1992 to 62,740,702 Baht in 1996. However, the net farm income was reduced to 22,645,290 Baht in 1992 and 50,956,127 Baht in 1996, if the external cost of soil erosion was taken into account.

INTRODUCTION

The Northern region of Thailand is very vulnerable to soil erosion due to its undulating topography, steep slopes and high rainfall. The alarming rate of soil erosion in this region calls for urgent attention to this problem. Existing methods for identifying the erosion affected areas are based on physical surveys, but in practice, when the erosion problem is very extensive in mountainous areas like Northern Thailand, it is not only a difficult task to make an inventory, but also quite time consuming. Remote sensing can be effectively used to overcome such problems. Satellite data, with its favorable synoptic view and repetitive coverage offers the possibility of mapping, monitoring and estimating soil erosion easily.

The objective of this study was to find out the effect of the integrated watershed development project initiated by His Majesty the King of Thailand in 1991 on the extent of soil erosion in Mae Ao watershed. The study area was located in the Pa Sang and Ban Hong district of Lamphun province stretching from longitude of 18°16′20″ to 18°28′00″ in the North and from latitude of 98°47′49″ to 98°58′12″ in the East covering an area of 203.98 km^2.

RESEARCH METHODOLOGY

E_{30} model for estimating soil erosion using NDVI

The soil erosion model given in Equation 1 was used to estimate the annual rate of soil erosion in the Mae Ao watershed (Honda, 1993, 1996 and 1998). This model is mainly governed by slope gradient and vegetation index and the annual soil erosion rate (E) is defined as:

$$E = E_{30}\ (S/S_{30})^{0.9} \qquad (1)$$

where S= gradient of the point under consideration, S_{30}= tan (30°), and E_{30}= rate of soil erosion at 30° slope and defined as given below

$$E30 = Exp[(\frac{Log0.132 - Log17.12}{NDVImax - NDVImin}) \times (NDVI - NDVImin) + Log17.12] \qquad (2)$$

The maximum and minimum rates of soil erosion at 30° slope in the study area collected from field stations were 17.12 mm/year and 0.132 mm/year in the study area as shown in Equation 2.

The Normalized Difference Vegetation Index (NDVI) as defined by Equation 3 was used to assess the vegetative cover. To avoid negative values and for easy handling of digital data, NDVI value obtained for Landsat-TM data (30m spatial resolution) were re-scaled as shown in Equation 3.

$$NDVI = [(\frac{Band4 - Band3}{Band4 + Band3}) + 1] \times 100 \qquad (3)$$

Correction of NDVI

Theoretically, matured vegetation should have the same vegetation index in multi-temporal data. But in practice, this

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is not possible due to variations in sun angle, atmospheric effects etc. Two Landsat TM images from 1992 and 1996 were used in this study and the necessary radiometric correction was done by using the 1996 Landsat TM data as the base image. Various land cover areas were identified in both images and homogeneous regions for each of the land covers area were selected to estimate the average value of reflectance. The average reflectance from bare-soil areas was found to be minimum, whereas the average value of reflectance from longan (a tropical citrus fruit) orchard areas was maximum for both the observation years. Using Equation 4, linear interpolation was carried out to make radiometric correction of 1992 Landsat TM data.

Corrected NDVI of 1992 =

$$[(\frac{Maximum96 - Minimum96}{Maximum92 - Minimum92}) \times (NDVI92 - Minimum92)] + Minimum96$$

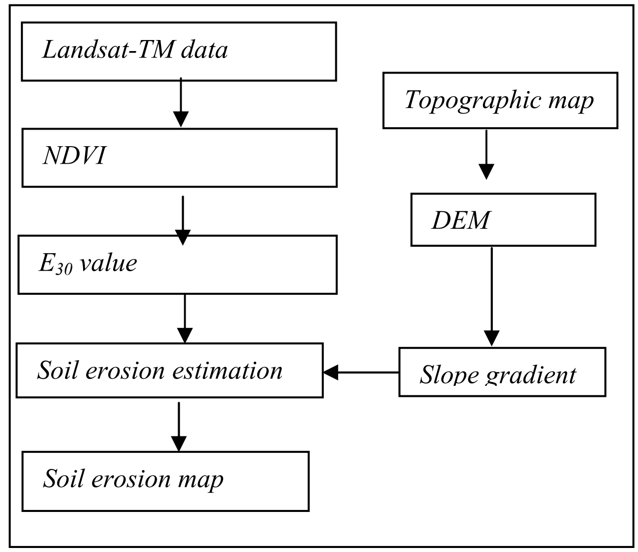

Figure 1. Methodology for estimating the annual soil erosion rate

Estimation of Soil Erosion

By calculating the E_{30} value for each pixel using Equation 2, soil erosion from each pixel with a different slope was calculated using Equation 1. A raster map of slope gradient was prepared with a pixel size of 30m (same as Landsat-TM data), using a Digital Elevation Model (DEM) to provide the slope information for Equation 1. Step by step procedures for estimating the annual soil erosion rate in the study area are shown in Figure 1. Since the soil erosion for each of the pixels could be estimated individually, therefore, this method provided a greater flexibility in estimating the soil erosion rate for any area within the watershed.

Valuation of Soil Erosion

Soil erosion causes a reduction in soil nutrients and thus soil productivity is adversely affected. The replacement cost technique (Dixon et al., 1994) was used to estimate the cost of soil erosion, where economic valuation of losses from soil erosion was accomplished indirectly by looking at what cost society had to pay to retain the land productivity at levels prior to the erosion. Thus, economic valuation of loss was assessed on the basis of the cost of replacing nutrients taken away by the eroded soil. The amount of Nitrogen (N), Phosphorus (P) and Potassium (K) lost due to soil erosion was calculated for estimating the cost of soil erosion.

Two basic data sources were used for evaluating thecost of soil erosion: (1) soil mapping units with the respective composition of Nitrogen, Phosphorus and Potassium and (2) annual soil erosion rate in each soil mapping units. A flowchart describing the methodology for estimation of cost of soil erosion is shown in Figure 2.

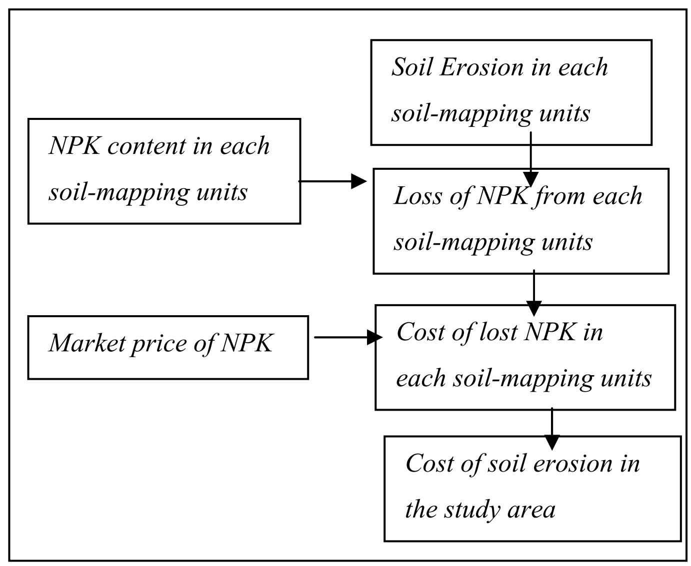

Figure 2. Methodology for estimating the cost of soil erosion

Economic indicators for assessing economic implications

Three economic indicators were used to evaluate farm performance: (1) Gross farm income, (2) Net farm income and (3) Family income. Gross farm income is the sum of everything produced in a farm including everything sold, stored, and consumed in cropping and livestock enterprises. Net farm income was calculated by deducting variable and fixed costs from the gross farm income. Family income was estimated by adding off-farm and non-farm income incomes to net farm income.

RESULTS AND DISCUSSIONS

Estimation of annual soil erosion rate

The average annual rate of soil erosion in the study area in1992 and 1996 is shown in Figure 3 and Figure 4, respectively. The average annual soil erosion rate in the study area decreased from 1.24 mm/year in 1992 to 0.91 mm/year in 1996. This reduction in soil erosion rate was due to the conservation measures and plantation program taken up in the area.

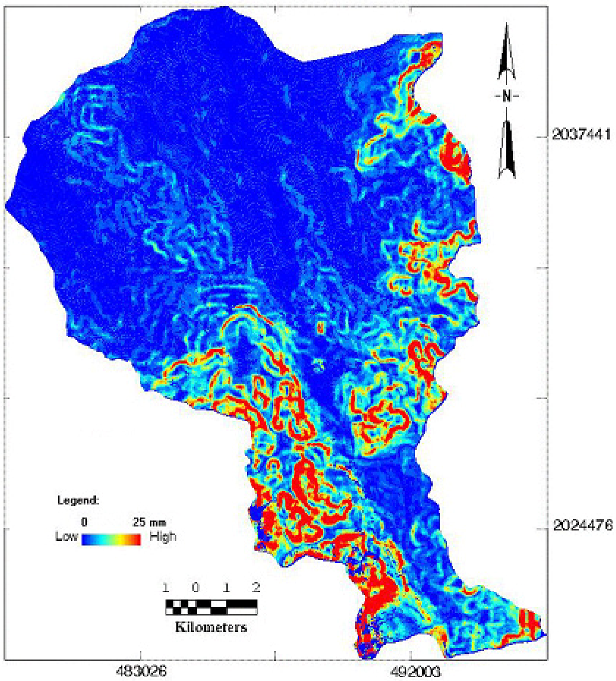

Figure 3. Soil erosion map showing average annual rate of erosion in 1992.

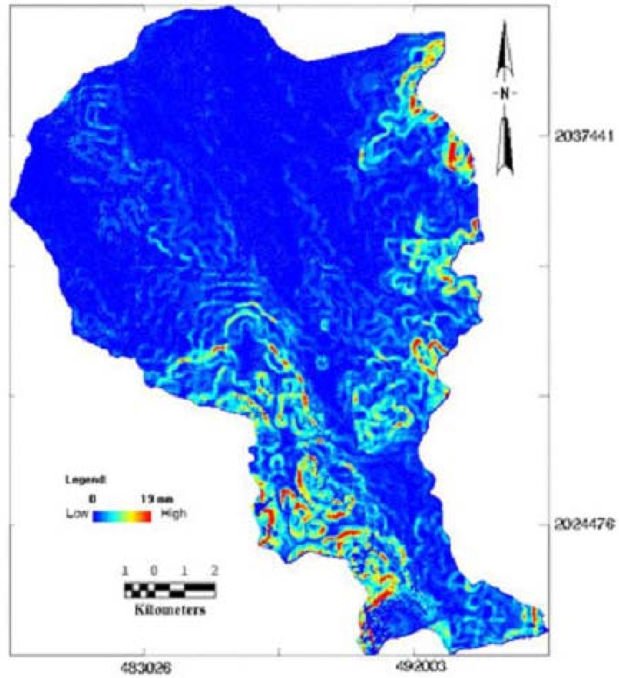

Figure 4. Soil erosion map showing average annual rate of erosion in 1994.

Table 1. Farm performance.

Economic indicators	1992		1996	
	Without external cost	With external cost	Without external cost	With external cost
Net farm income	38,675,712	53,820,874	62,740,702	50,956,127
Family income	98,481,713	82,488,718	174,781,536	162,996,961

Cost of soil erosion

The amount of Organic Carbon content (%), available Phosphorus (ppm) and exchangeable Potassium (meq/ 100 gm of soil) were derived for each soil mapping unit, using an existing soil map to calculate equivalent amount of Nitrogen, Phosphorus and Potassium. Using the market price of the respective fertilizers, the cost of soil erosion in 1992 was estimated to be 16,010,244 Baht, of which 6,963,792 Baht was attributed to the loss of Nitrogen, 3,383,553 Baht to loss of Phosphorus and 5,662,899 Baht to loss of Potassium. In 1996, the cost for Nitrogen, Phosphorus and Potassium loss was estimated to be 5,069,302 Baht, 2,696,012 Baht and 4,034,464 Baht, respectively for a total of 11,799,960 Baht. Thus, there was a reduction in external cost of soil erosion of 4,210,284 Baht from 1992 to 1996.

Economic impact of soil erosion

Gross farm income increased from 87,058,804 Baht in 1992 to 111,191,081 Baht in 1996. This implies that the overall production scenario improved by 27% during this period of time in the watershed area. Table 1 shows that the net farm income in the study area increased from 38,262,654 Baht in 1992 to 62,740,702 Baht in 1996. However, the net farm income was reduced to 22,645,290 Baht in 1992 and 50,956,127 Baht in 1996, if the external cost of soil erosion is taken into account. A similar trend was also observed in the case of family income. The external cost of farming should be seen as a part of farm income. As long as the external cost of farming shares a major portion of farm income, the economic performance of farming systems will remain poor.

CONCLUSION

The overall estimated soil erosion rate in the study area decreased from 1.24 mm to 0.91 mm over the time span of four years. Changes in agricultural pattern from traditional agriculture to orchard cultivation along with the conservation activities taken up in the Mae Ao project area showed a positive impact on soil erosion, leading towards sustainable farming system. However, the rate of soil erosion (0.91 mm/year) after four years of implementation of the project is still high and more erosion control practices are required in vulnerable areas of the Mae Ao watershed on a priority basis to make the farming system sustainable in a true sense.

REFERENCES

Dixon, J.A., L.F. Scura, R.A. Carpenter and P.B. Sherman. 1994. Economic Analysis of Environmental Impacts. 2nd ed. Earthscan Publications Ltd., London.

Honda, K. 1993. Evaluation of Vegetation Change in the Asio Copper Mine Using Remote Sensing and its application to Forest Conservation Works, D.Eng. diss. University of Tokyo, Tokyo, Japan.

Honda, K., L. Samarakoon, A. Ishibashi, Y. Mabuchi and S. Miyajima. 1996. p. B21-B26. Remote Sensing and GIS technologies for denudation estimation in Siwalik watershed of Nepal. Proc. 17th Asian Conference on Remote Sensing, Colombo, Sri Lanka. 4-8 November, 1996.

Honda, K., L. Samarakoon and A. Ishibashi. 1998. Erosion control engineering and geoinformatics: river planform change and sediment yield estimation in a watershed of Siwalik, Nepal. p. 63-70. In R.B. Singh et al. (ed) Space Informatics for sustainable development. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.