Application of Digital Image Processing Integration with Satellite Remote Sensing and GIS in Land Use Land Cover Change and Soil Erosion

Kyaw Zaya Htun, Dr. Lal Samarakoon*

Remote Sensing Department, Mandalay Technological University, Myanmar
** Director, Geoinformatics Center, Asian Institute of Technology, Thailand*
kyawzaya.htun@gmail.com

Abstract

The relationship between land use land cover changes and soil erosion is investigated using digital image processing integrated with Remote Sensing (RS) and Geographic Information System (GIS) in Tonle Sap Watershed, Cambodia. The Universal Soil Loss Equation (USLE –Wischmeier and Smith, 1978) was applied to build a model to estimate the annual soil loss from the watershed in 1976 and 2002. The analysis process on land use land cover change is based on geo-processing of GIS utilizing the raster and vector analysis. The analysis result of land use land cover change between 1976 and 2002 show that the agriculture land was expanded and the forest area was decreased in the study area. A grid based and polygon based GIS were used to comparatively calculated soil loss map. The result shows that grid based method also enables the meaningful use of pixel based remotely sensed land cover information for modeling soil erosion. The result also shows that increasde soil erosion in the agriculture land and suggests that mitigation measure should be taken for prevention of further degradation. High resolution satellite images are very effective tool for not only monitoring the land use land cover change but also estimating soil erosion in the watershed. Similarly, GIS is also an effective tool in analyzing by overlaying various vector maps related to factors affecting in soil erosion. C++ programs were also developed for digital image processing such as solving LS factor and converting raw Digital Number (DN) value to reflectance valves. The main data used in this study are Landsat ETM satellite images.

1. Introduction

Soil erosion is a very complex process monitored or determined by mutual interaction of numerous factors. To assess the spatial extent and severity of environmental risk of this process, extensive data sets related land cover and soil are necessary. The hardware and software facilities, as well as the new methodological approaches, integrated into digital image processing with Remote Sensing & Geographical Information Systems (RS_GIS) allow to model soil erosion at different land cover and analyze the change detection.

Geographic Information Systems are becoming a popular tool when seeking solutions to issues of these kinds, which are spread over large spatial extents and require a study of many alternatives. Most common method for soil erosion assessment is the use of Universal Soil Loss Equation (USLE). Many have proposed modifications to the USLE but all are woven around the same concept where rainfall erosivity, soil erodibility, slope length, slope class, land cover and land management factors are taken as directly proportional to the rate of annual erosion (Brooks et al 1991, Renard et al 1997,Morgan 1986). Present study describes the methodology adopted to compute these factors and a comparison of results with the polygon based study done by ijesekera & Chandrasena (2001).

2. Study Area and Data

Tonle Sap Watershed is located in the northwest part of Cambodia between longitudes 102° 15' to 105° 50' E and latitudes 11° 40' to 14° 28' N covering an area of about 80 000 km^2, including Tonle Sap Lake. The Watershed consists of six provinces and it covers about 44% of the total land area of Cambodia. Population is about 5.14 million (Population Census of Cambodia. 2002) which represents nearly 43% of the total population of Cambodia (11.50 million persons). Tonle Sap Watershed is an important region for socio-economic development of Cambodia. (Dr Geoff Wright, Dr David Moffatt, Dr Jonathan Wager,2004). It consists chiefly of plains with elevations generally of less than 100 meters. Mountainous area is in north and south of study area and rise to more than 1 500 meters. 53% of the total land resources of the Watershed is covered by forest. The land use for agriculture is 2,368,059 ha or 30.92% and urban area is 12,256 ha or 0.15% of the total land use in Tonle Sap Watershed (Keskinen, 2003) (Figure 2 and 3).

3. Methodology

Detail discussion of the methodology of

each digital image processing phase and its stepwise procedures has been described in separated flow diagrams for change detection and soil erosion. Each step includes Remote Sensing (RS) section and GIS section (Figure 1 and 11).

3.1. Remote Sensing Data Classification

Raw digital number (DN) was converted to reflectance for each band of Landsat ETM satellite images of the year 1976 and 2002 using C++ program which was developed based on the formula describing in Landsat ETM Science Data Users Handbook (Irish, 2000) before image processing step because acquisition date of two satellite images changing sun illumination geometry strongly affects DN.

Firstly, DN value was converted into radiance using the following equation 1.

$$L_\lambda = (L_{\max,\lambda} - L_{\min,\lambda}) / 255 * DN + L_{\min,\lambda} \quad (1)$$

And then conversion of radiance into reflectance was carried out by using the equation 2, 3 and 4.

$$\rho_\lambda = \frac{\pi . L_\lambda . d^2}{E_\lambda . \cos\theta} \quad (2)$$

d = 1.00011 + 0.034221 cos x + 0.00128 sin x + 0.000719 cos 2x + 0.000077 sin 2x (3)

x = 2π (DOY) / 365 (4)

where, ρ_λ = unitless planetary reflectance

L_λ = spectral radiance at the sensor's aperture

d = earth- sun distance in astronomical units

E_λ = mean solar exoatmospheric irradiances

θ = solar zenith angle in degrees

The unsupervised classification image produced 40 classes through the satellite data and then using Maximum likelihood to reclassify them to seven classes according to the existing land use map of 2001 and ground control points (ground truth data) which were collected during the field survey. There was some confusion in satellite images during classification step. The wet season image and NDVI images of each year also was used as reference images during the classification step because deciduous forest, harvested paddy field, urban area and bare land were confused with the other classes or each other. Both classified images accuracies were an acceptable accuracy of 85% (Figure 4). Image Segmentation separated classified image into each layer and then each was converted into vector format.

3.2. Change Detection

Geo-processing tool and logical function was applied two satellite images to detect and quantify the land use changed in ArcGIS 9.0 software. The basic tools used in landuse/ landcover change are shown in Table 1. Detail methodology is shown in Figure 3. The result is shown in Figure 5 and the statistical data is shown in Table 2. The most significant changed was occurred in agricultural land and forest area.

3.3. DEM Generation

Digital Elevation Model (DEM) provides a digital representation of a portion of the earth's surface terrain over a two dimensional surface. We can derive much useful topographic information such as slope, aspect, stream networks and watershed boundaries. Digital elevation models may be prepared in a number of ways, but they are frequently obtained by remote sensing rather than direct survey. At present study, older methods of generating DEM is used and it involves interpolating digital contour map having 10 m interval that may have been produced by direct survey of the land surface. DEM was interpolated from elevation contours and was employed to generate the slope and LS-factor. It is a time saving and cost effective procedure to calculate the LS factor.(Panda et al.,2000) (Figure 6).

3.4. Potential of Soil Erosion Estimation

This study of estimation of soil erosion potential by water between the year 1976 and 2002 using Universal Soil Loss Equation (USLE) based on raster calculation. Preparation of USLE parameters are described in following section.

3.4.1. Rainfall Erosivity (R) Factor

According to R factor vector image (Figure 7), there is no too much different amount of rainfall among provinces in study area. The rainfall data of fourteen rainfall stations of Tonle Sap Watershed including neighboring stations were used. The annual rainfall data was calculated based on the equation used by El-swaify et al, 1985; Harper, 1987; Funnpheng et al 1993 for computation of R factor. This equation is as follow:

R=38.5 + 0.35 r (5)

where,
R = rainfall erosivity index
r = total rainfall amount in millimetre
Total rainfalls of fourteen stations of the watershed were interpolated based on location.

3.4.2. Soil Erodibility (K) Factor

As the soil information is not available in soil map (1998, 1:100,000 scale) of the Tonle Sap

Watershed, FAO Soil Map of the World book was used to match local soil name and global soil name of FAO. Assigning the soil information (organic matter, silt percent, very fine sand percent, clay percent, permeability and soil texture) was done in soil database using following equation (Figure 8).

$$K= [2.1 * 10^{-4} (12 – OM) M^{1.14} + 3.25 (s – 2) + 2.5 (P – 3)] / 100 \quad (6)$$

where,
K = soil erodibility
OM = % of organic matter (%OM= 1.724 * %OC)
OC = Organic Compound
M = particle size parameter [(%silt + % very fine sand) *100 - %clay]
s = classes for structure
(1= very fine granular, 2= fine granular, 3= medium or coarse granular, 4 = blocky, platy or massive)
p = permeability class
(1= rapid, 2 = moderate to rapid, 3= moderate, 4= slow to moderate, 5= slow, 6 = very slow)

3.4.3. Topographic (LS) Factor

In modeling erosion in GIS, it is common calculating the LS combination using a formula:

$$LS = (Flow Accumulation * Cell Size/22.13)^{0.4} * (sin slope/0.0896)^{1.3} \quad (7)$$

Where Flow Accumulation is the number of cells contributing to flow into a given cell and Cell Size is the size of the cells being used in the grid based representation of the landscape. This formula is based on the suggestion by Moore and Burch (1986a, b) that there was a physical basis to the USLE L and S factor combination. A C++ program based on above equation was also developed to calculate LS factor. This program involved four steps: removing sink, calculation of slope, slope direction (aspect) and then GRID accumulation (flow accumulation), which were calculated on centre pixel of 3*3 window (Figure 9).

3.4.4. Crop Management and Practice (C and P) Factor

The value of C factor was derived by the expert assessment of the values published by Wischmeier, Smith (1975), Morgan (1996) and Pasak et. al. C value was assigned according to land use classes of land use map 1976 and 2002. The agriculture land was covered with annual crop such as paddy, wheat, barley, maize, etc., and the C value is assigned as 0.377 to the whole agriculture land. Moreover, people have to collect wood for fuel supply. So, the woodlands were consequently opened in some part of the watershed and so equally assigned to 0.006 which is recommended by Wischmier and Smith (1978). P value is assigned 0.5 equally to all the agriculture land because of the practices of all agriculture are traditionally ploughed with contour and assigned 1 to built-up area, bare land, scrub, grass and forest which has no conservation practices (Figure 10).

3.5. Intervention Analysis Using GIS

Estimation of soil erosion by water in the study area was modelled using the USLE. USLE estimates the average annual soil loss (A) by using a functional relation of several factors expressed as A=RKLSCP where R is the rainfall erosivity, K is the soil erodibility, L & S are slope length and slope angle factors, C is the crop management factor and P is the eros ion control practice factor. Modeling in the present study used a raster based approach where a square cell of 50 meters was chosen. It was taken that this resolution would be suitable for a reasonable accuracy considering that the original data were mos tly from 1:50,000 maps. Grids of rainfall, soil land use and elevation data created using ArcGIS software were used for the computation for the USLE (Figure 11).

4. Comparison

Comparison of computed spatial distribution of erosion levels on polygon and grid based calculation method is checked for the year 2002 in Figure 12. Modeling results showed that about 3.3% of watershed could be ranked in the severe erosion level category. Investigation of the individual cell values showed that 3.3% of the area had resulted in annual soil loss values greater than 126. Both methods resulted in similar values through model calculations. Calibration of USLE values in the polygon -based method had 26 and 45 tons/ha/year as threshold values between insignificant, moderate and severe erosion classes. Though the values from both methods do not drastically differ from one another, it is prudent to be cautious of the averaging effect over spatial extents when model computations are used for planning purposes. Investigation of computations at each cell showed that in most cases such flat area represented insignificant soil erosion zones as expected in nature. This deficiency was noted in both methodologies. Percentage of extents classified at moderate level of erosion in polygon based computation shows a reduction in the raster -based approach. Comparison shows that there had been a tendency for values of polygon approach to move from the moderate category to the insignificant category when raster approach is used. This suggests that polygon -based approach may lead to an over estimation of extents that require precautionary measures. However it is noted that a careful selection of manageable polygon sizes may look after this concern. Comparison shows that both methods estimated similar annual erosion levels for approximately 70% of the watershed with a well matched spatial distribution. Estimations were quite close in the severe category indicating the greater emphasis on this category when using a weighted function for optimization (Figure 13).

5. Results and Discussion

Erosion was mostly occurred in agriculture land within 7 km along National 6 road in the year 1976 and 2002(Figure 12 and 13). It was found that soil loss had increased from 105,385 ton/ha/yr in the year 1976 to 161,035 ton/ha/yr in the year 2002 along this road. It was also clearly found that total soil erosion potential had increased more than double in Kampong Thom Province, Preah Vihear Province and Poussat Province. In former two Provinces, the percent of change from forest to agriculture was 45 % (951.15 sq km) and 13% (290.60 sq km) of total change area of forest to agriculture (2,104.67 sq km) in Tonle Sap Watershed. The reason is that the agriculture land was expanded in these sites after 26 years because of population pressure. This expansion was mostly happened in forest area around Tonle Sap Lake. In Preah Vihear Province, agriculture land was also expanded, which was occurred by clearing forest in high land area.

It can be conclude that population pressure affected the soil erosion. The population data of some provinces are shown in table3. The populations have increased almost double in some provinces over the past 26 years. In 2010, this may be increased at least 15% more in each province according to the growth rate formula (Table 3). As a result, agriculture land expanding will increase in lowland as well as upland area. In the uplands, farming is generally practiced along slopes without any soil conservation measures where the erosion potential is high. Three months after clearing, one to 1.5 cm of the topsoil is typically lost (Yang Saing Koma 1997). The exploitation of forests has also led to reduced availability of resources to local communities; increased run off and siltation from commercial logging; reduced soil fertility (Shams and Ahmed 1996; CEDAC 1997).

The average depth of the lake has decreased from 4.5 m in January 1979 to 3.5 m in January 1994 (Global Witness 1997). According to filed data, the depth of the lake has decreased to 1m in January 2004 and frequency of flood was also increased. The flood area has expanded by 43.92 km2 during this period. Changed flood patterns leading to food shortages in some parts of the country. Mottet (1997) claimed that if the present pace of deforestation remained unabated, the Tonle Sap Watershed would very soon stop producing rice and fish.

In this study, limitation of data about soil erosion cause difficult to validate. So estimated erosion rate of some classes were compared with some sites of soil loss rate which are published to evaluate the soil yield. The reference information about soil erosion rate is shown in Table 4.

6. Recommendation

The results of this study have confirmed that digital image processing with RS-GIS data integration and analysis is an efficient approach for obtaining information on spatial variability of soil erosion at regional scale. The contemporary hardware and software systems enable to process the data sets representing large territories in scale useful for regional studies but also for global. The methodology used in this study is rather simple and straightforward and alternative solutions based on similar models integrated with simulation can be also applied. In this study, land use land cover change categories only considered seven major types of land. The categories should be considered more detail as further analysis based on the classification criterion of the world. Upland planting should be established in high land area to control erosion. Long term shrub fallow should be cultivated along farm boundaries, scattered over the plot or in house compound because they contribute to control of soil erosion.

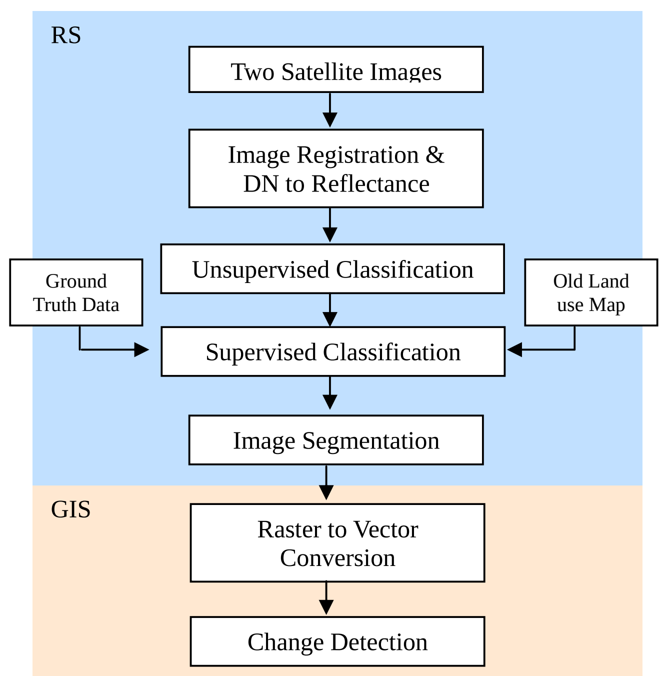


Figure. 1. Flow Chart of Change Detection

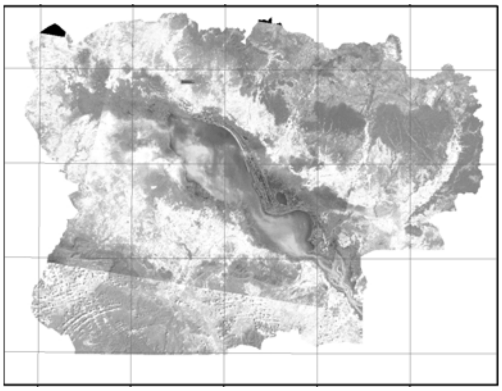


Figure. 2. Satellite Images of Study Area (Landsat_MSS _1976)

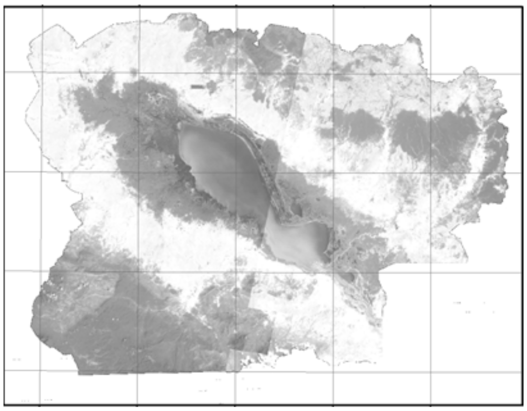
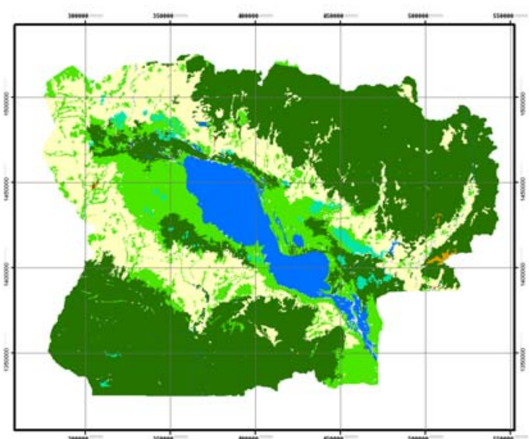
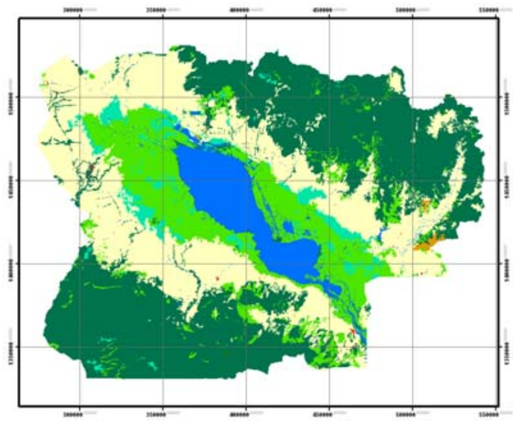


Figure. 3. Satellite Images of Study Area (Landsat_ETM_2002)



(a)



(b)

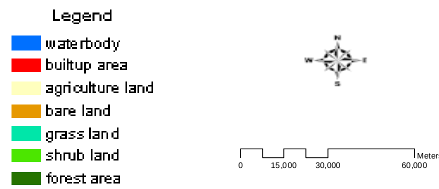
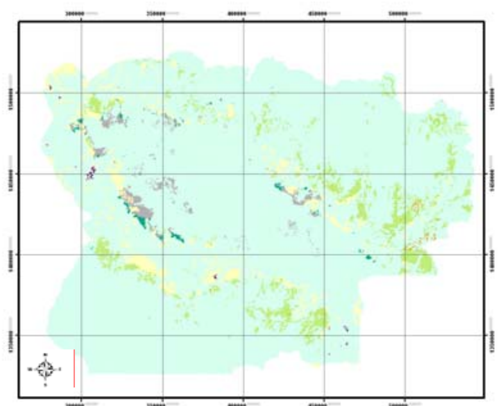


Figure. 4. Vector Images of Land Cover of Study Area : (a) 1976 and (b) 2002



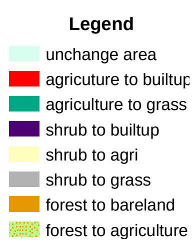


Figure. 5. Change Detection Analyses between 1976 and 2002

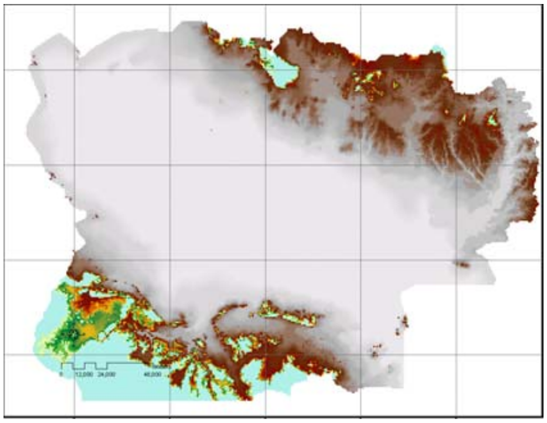


Figure. 6. DEM Raster Image

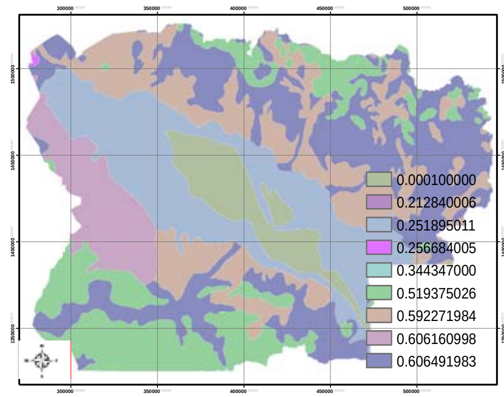
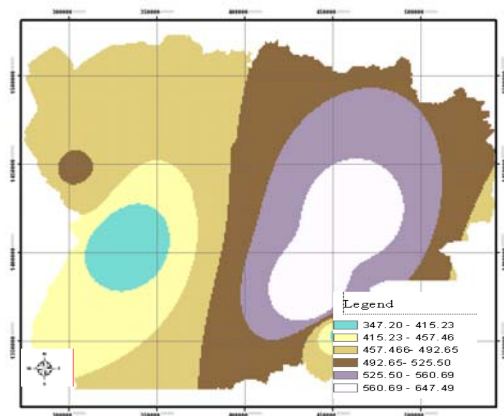


Figure. 8. Vector Image of K Factor



(a)

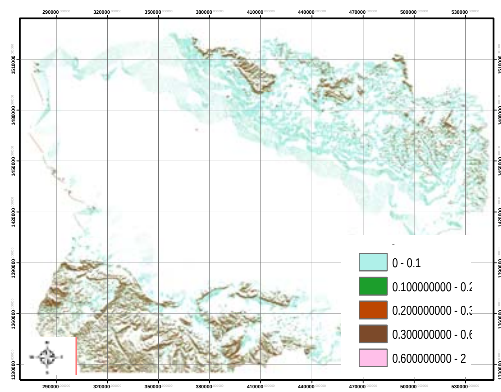
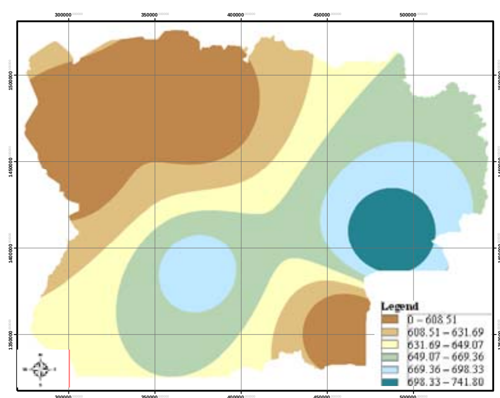
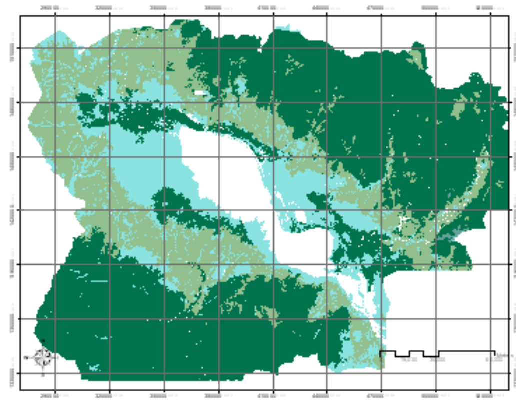


Figure. 9. Vector Image of LS Factor



(b)

Figure. 7. Vector Image of R Factor: (a) 1976 and (b) 2002



(a)

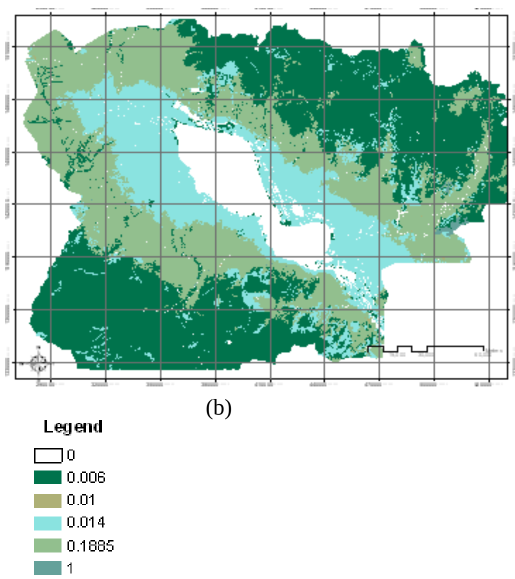


Figure. 10. Vector Image of CP Factor: (a) 1973 and (b) 2002

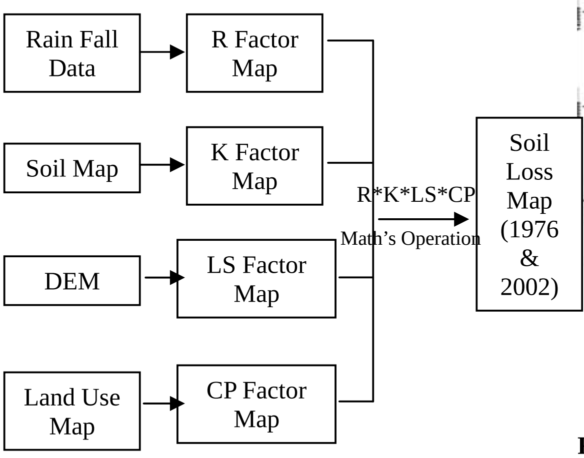


Figure. 11. Flow Chart of Soil Erosion

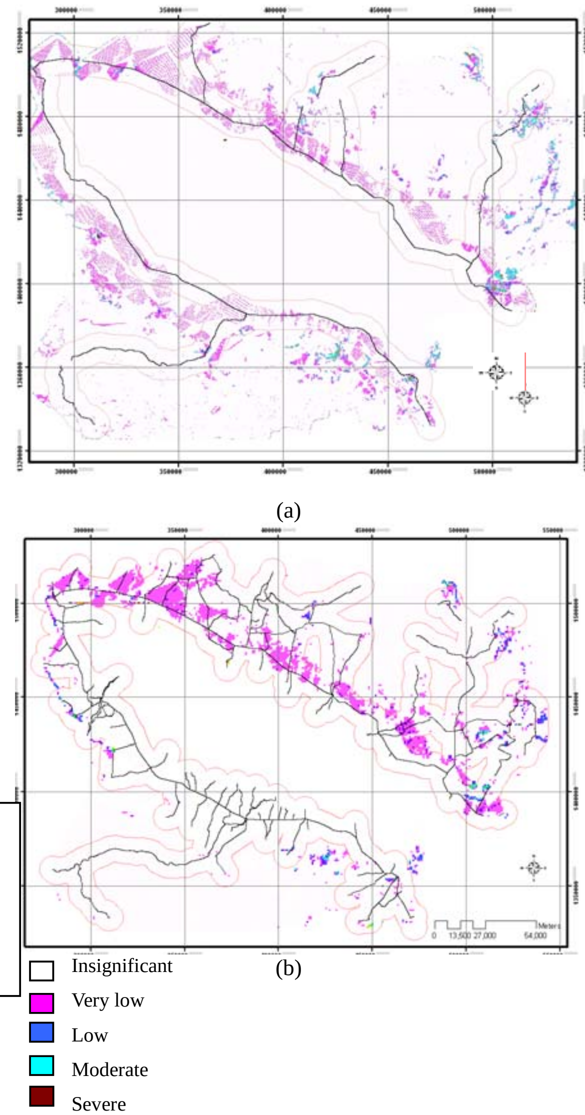


Figure. 13. Soil Loss on (a) Polygon Based Calculation (2002) (b) Grid Based Calculation (2002)

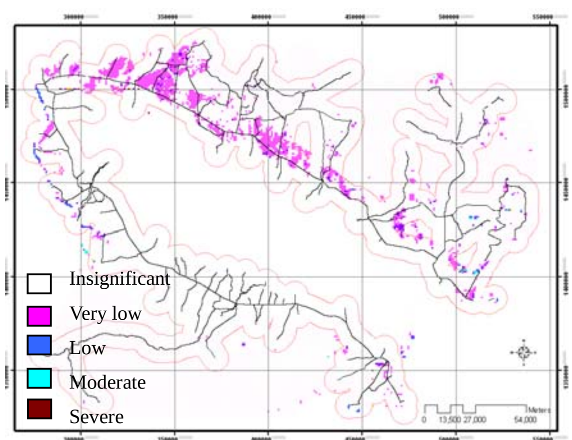


Figure. 12. Soil Loss on Grid Based Calculation: (1973)

Table 1. GIS function in land use/ land cover analysis

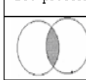
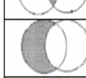
Geo-processing	GIS function	Result in land use/ land cover change
	Intersection	Unchanged area between 1976 and 2002
	Intersection and Erase	Area lost between 1976 and 2002
	Union	Not immediate interest
	Union, Intersection and Erase	Area gained at 2002

Table 2. Land Cover Change between 1976 & 2002

No.	Land Use	Land Use in 1976 (sq km)	Land Use Percent in 1976	Land Use in 2002 (sq km)	Land Use Percent in 2002	Change Percent
1	water body	3,171.73	7.89	3,216.97	7.89	0.00
2	built-up area	11.10	0.03	37.41	0.09	0.06
3	agriculture land	8,421.76	20.95	12,633.11	31.42	10.47
4	bare land	51.78	0.13	97.20	0.24	0.11
5	grass land	515.53	1.28	1,465.17	3.64	2.36
6	shrub land	6,771.20	16.84	6,556.98	16.31	-0.53
7	forest cover	21,261.67	52.88	16,241.86	40.40	-12.49
	Total	40,204.77	100.00	40,248.69	100.00	

Table 3. Population Data

SrNo.	Province	Estimated Population (1976)	Actual Population (2002)
1	Siem Reab	221,035	696,164
2	Kampong Thum	271,907	569,060
3	Kampong Cham	170,907	371,357
4	Kampong Chnang	181,272	417,693
5	Pousat	110,120	360,445
6	Bat Dambang	314,906	793,129
7	Bantaey Mean Chey	318,463	577,772
8	Kaoh Kong	-	131,912
9	Prean Vinear	60,595	119,261

Table 4. Soil Erosion in Some Sites

unit (ton/ha/yr)

Land Use Type	Mayaguez, US	Japan: Asio region (30°)	Siwalik: Far West Nepal Sandstone foothill	Tonle Sap Watershed(2002)
Grass land	-	20.27 (1mm/yr)	-	6.59
Agriculture Land	39.7	-	-	27.56
Forest	-	2.027 (0.1 mm/yr)	20.00	1.098
Bare land	339.7	-	-	139.86
reference	Smith and Abruna,1995	Honda,1993	Laban,1978	model result

Degraded forest, sandstone foot hill, Siwalik, Far West Nepal

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