LAND USE AND LAND COVER CHANGE IN SOUTHEAST ASIA: A SYNTHESIS REPORT

ASIA PACIFIC NETWORK FOR
GLOBAL CHANGE RESEARCH (APN)
NO: 2001-13

Asia-Pacific Network for Global Change Research

NASA

START
IHDP • IGBP • WCRP

SEARRIN
SOUTHEAST ASIA REGIONAL RESEARCH & INFORMATION NETWORK

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Contents

FOREWORD

The contract between Asia Pacific Network for Global Change Research (APN) and UKM provide funds for the study of Land Use and Land Cover Change in Southeast Asia. The study was conducted from April 2000 to March 2002. The seven participating countries taking part in the research were Malaysia, Indonesia, Philippines, Thailand, Cambodia, Vietnam and Laos. The final activity for this contract is report that a summarised and synthesized results from seven country reports. Overall, the study detected land use changes over specified period of time. It took an interdisciplinary approach to explain the driving forces of land use and land cover change in the selected study sites. The study also developed a common protocol for methods and data sets, aimed at providing a framework for inter-country comparisons.

The synthesis report aims to improve scientific understanding of the role of Southeast Asia in term of global change through its influence on the global change cycle and the role of human dimensions in causing land use changes. It is hoped that, the findings will contribute towards policy formulation in the region.

This APN funded research has successfully developed a solid network of scientists in the region through capacity building and development of data management system. The APN researchers network, now known as Southeast Asia Regional Research and Information Network (SEARRIN) has been established specifically to undertake future global Change Research programme in the region.

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1.0 BACKGROUND

1.1 Introduction

Asia Pacific Network for Global Change Research (APN) is an intergovernmental network whose purposes are to foster global environmental change research in the Asia Pacific Region, increase developing country participation in that research and to strengthen links between the science community and policy makers. It promotes, encourages and supports research activities on long term global changes in climate, ocean and terrestrial systems, and on related physical, chemical, biological and socio-economic processes (APN 2001).

APN promotes the following objectives:

- Supporting regional cooperation in global change research on issues that are particularly relevant to the region;
- Standardization, collection, and exchange of scientific data relating to global change research;
- Improvement of scientific and technical capabilities and research infrastructure of nations in the region;
- Cooperation with research networks in other regions;
- Providing scientific knowledge to the public, and input to policy decision-making; and
- Development of appropriate mechanisms for transfer of know-how and technology

The current Land Use and Land Cover Change (LUCC) research undertaken by the Southeast Asia network fulfils most of the objectives mentioned above.

1.2 APN Relationship with START-SARCS

APN activities are based on existing research programmes established by large scientific unions such as the International Geosphere and Biosphere Programme (IGBP), International Human Dimensions Global Environmental Change Programme (IHDP) and World Climate Research Programme (WCRP). All these programmes have initiated an international collaborative programme through the Global Change System for Analysis, Research and Training (START). START works through regional committee in the APN region, which include Southeast Asia Regional Committees for START or SARCS. The current research is coordinated by SARCS.

1.3 Project Relationship to Global Change Research Programme

The land use and land cover change (LUCC) research project initially commenced in 1994 as a project of IGBP. The fund was provided by Global Environment Facility (GEF) through United Nations Operation Project Services (UNOPS) in New York. The initial project was labelled as LUCC phase 1 for easy reference and incorporated 4 participating countries namely Malaysia, Philippines, Thailand and Indonesia. LUCC phase 1 research focused on applying remote sensing and GIS technologies and socio-economic data to explain land use and land cover changes. It emphasized basic data sets, developed common protocols and variables and initiated inter-comparative analysis. Socio-economic data were used to explain anthropogenic forces of land use and land cover changes using multiple regression analysis. With the completion of this project the SARCS-LUCC interdisciplinary team was in place and the regional research network formed.

LUCC Phase 2 which was sponsored by NASA and SARCS proceeded with multidate analysis and expanded the socio-economic modelling to include various models not implemented in the first phase. Among the activities implemented in Phase 2 of the project were:

- Developing case studies to determine deforestation dynamics i.e. determining the importance of secondary growth, the annual dynamics of land use change and the land use transition probabilities.
- Determining whether annual rates of deforestation have been significantly different from the decadal mean rate over the selected study areas.
- Developing diagnostic models of the deforestation process to better understand and quantify the differential controls on rates of deforestation and abandonment.

LUCC phase 3 was funded by APN in the year 2000 to 2001. The activities implemented were:

- Expanding the network within the region to include Vietnam, Laos and Cambodia. The new entries require assistance in acquiring the capacity to conduct research in global change. The present team members assisted in the training of relevant LUCC methodologies.
- Regional implications of the LUCC results.
- Applications of socio-econometric and LTM modelling of the control rates of deforestation.
- Application and interface of LUCC to GOFC-SEA project.

1.4 Regional Collaborators

A total of eight APN member countries were involved in this project. Appendix 1 gives the name of the implementing agencies, team members and resource persons and their institutions. The United States provided leading resource persons in the advance-training workshop. All implementing agencies in each country contributed in kind such as their laboratories and equipment use, technical and administrative assistance.

1.5 The Establishment of SEARRIN Network.

The implementation of the LUCC phase 3 under the APN funding saw the establishment of a cohesive research network in SEA. It is made up of diverse academic and professional expertise such as geography, forestry, economics, sociology, ecology and others. At APN, Manila Workshop in November 2000, this network was officially launched under the name of Southeast Asia Regional Research Information Network or SEARRIN. It is a regional science network dedicated to Earth Observation Science in a global context. SEARRIN conducts research on land cover and land use change in an integrated science framework that includes remote sensing and GIS technology, econometric and system models and field work. SEARRIN Science agenda include capacity building, modelling the human dimensions of land use and land cover change, impact of deforestation on biodiversity, global change and sustainable development.

1.6 The Content of the Synthesis Report

This report summarizes and synthesizes all the seven LUCC country reports. The report covers four important aspects. They are as follows:

(i) Common methodology adopted in the
  - Collection and processing of biophysical data
  - Collection and processing of socio-economic data
  - Collection and processing of the remote sensing and GIS data
  - Modelling techniques adopted in LUCC

(ii) The summary of land use and land cover change in the selected study sites.
(iii) The similarities and differences in the types of driving forces underlying the LUCC.
(iv) The LUCC impact on policy.
(v) Comparison of results from other tropical regions.

2.0 DATA ACQUISITION

2.1 Background of Site Selection

In May 1999 a workshop was held in Kuala Lumpur to discuss the common methods and data collection protocols for LUCC-SEA research. The items discussed and agreed upon include the following:

- Selection of case study sites based on data availability and accessibility
- Watersheds should be given priority as it is regarded as critical areas that are covered with forestland
- Identification of data sets
- Strategy for data acquisition
- Methods of image analysis/GIS
- LUCC classification systems
- Protocols for collaboration
- Specification schedule for general work

2.2 Sites Selected in LUCC-SEA

Table 1 gives the list of sites selected for the LUCC-SEA. Figure 1 shows their distribution in the region.

Table 1: Sites Selected for LUCC in Southeast Asia.

Country	Name of Site	Latitude	Longitude	Area (km^2)
1. Malaysia	(i) Klang-Langat Watershed	2° 40' - 3° 16'	101° 17' - 101° 53'	24.4
	(ii) Batang Kayan-Sempadi	1° 25' - 1° 45'	109° 40' - 110° 15'	34
2. Indonesia	(i) Citarum Watershed	6° 40' - 7° 14'	107° 15' – 107° 60'	26
	(ii) Mahakam Watershed	1° 0' - 1° 50'	117° 30' – 117° 50'	32
	(iii) Batang Hari Watershed	1° 10' - 1° 40'	103° 50' - 104° 00'	36
3. Thailand	(i) Mea Chaem	18° 15' – 18° 30'	98° 15'– 98° 30'	7.84
	(ii) Lin Thin	14° 30' - 14° 45'	98° 45' - 99° 00'	15.32
	(iii) Phusithan	16° 46' – 16° 29'	104° 13'- 104° 31'	0.31
	(iv) Eastern Sea Board	13° 00' – 13° 15'	101° 44' - 102° 01'	9.20
	(v) Ao Sawi Area	10° 15' – 10° 30'	99° 05' - 99° 20'	962.55
4. Philippines	(i) Magat Watershed	16° 07' – 17° 01'	120° 51' - 121° 27'	22.91
	(ii) Puerto Princesa	9° 30' - 10° 15'	118° 25' - 119° 05'	25.40

5.	Vietnam	(i) Tamdao National Park	21° 21' – 21° 42'	105° 23'– 105° 44'	3.60
6.	Cambodia	(i) West Kampung Cham	10°-15°	102° – 108°	1810.35
7.	Laos	(i) Nam Thuen Watershed	18° 32' – 18° 50'	104° 30' - 104° 50'	15

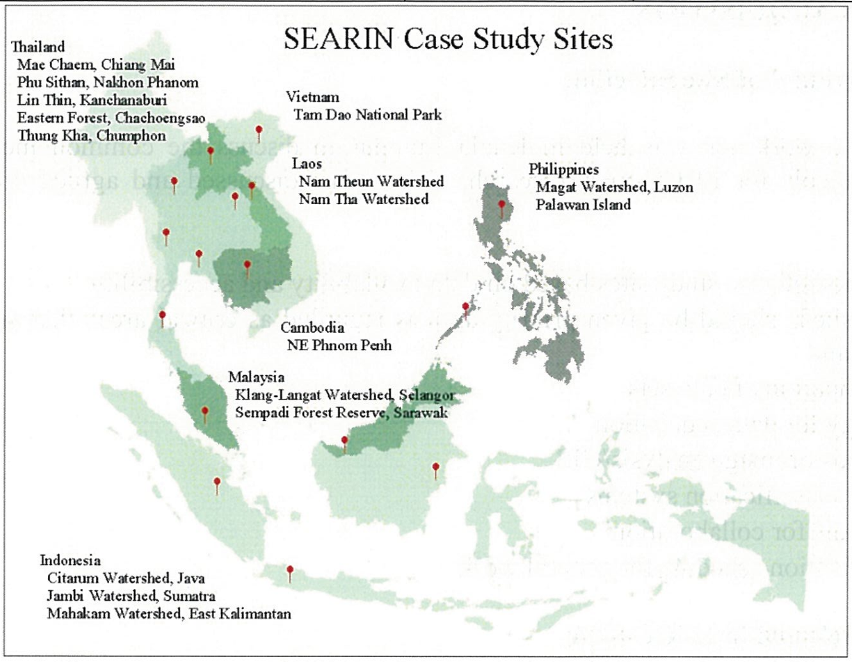


Figure 1: LUCC Case Study Sites in Southeast Asia

2.3 Data Acquisition

The selected sites chosen for the LUCC-SEA were sent to Basic Science and Remote Sensing Centre at the Department of Geography, Michigan State University, East Lansing for Landsat TM data acquisition. Request for yearly data imageries for all the sites selected was not possible as some of the imageries are cloud covered. The final Landsat TM data acquisition for the sites is given in Table 2.

However, Laos has only 2 dates to work on. Furthermore the dates are also close together making the detection of land use changes less significant. Attempts to acquire new dates in the late 1990's failed due to unavailability of the data.

METHODOLOGY

The research methodology is divided into 4 sections. They are collection and processing of biophysical data, collection and processing of socio-economic data, remote sensing and GIS data processing and modelling of land use and land cover change. The summary of the data collection is given below.

3.1 Collection and Processing of Biophysical Data

Biophysical data are important in explaining the land use changes taking place in the study area. Most of these data are derived from published maps and reports. Some of the data are updated via satellite imageries and field investigations to make them relevant to this study. Table 3 identifies these data set and they are mostly processed using GIS or remote sensing methods.

Table 2: Landsat TM Data Acquisition for LUCC-SEA

Country / Sites	Date of Acquisition												
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Malaysia													
Klang-Langat		✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	
Batang- Kayan Sempadi	✓	✓	✓	-	✓			✓	✓		✓		
Indonesia													
Citarum Watershed		✓	✓	✓	✓	✓	✓	✓	✓	✓			
Mahakum Watershed			✓	✓	✓	✓				✓			
Batang Hari Watershed		✓			✓	✓							
Thailand													
Mea Chaem			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Lin Thin			✓				✓						✓
Phusithan			✓					✓					✓
Eastern Sea Board		✓						✓					✓
Ao Sawi Area		✓				✓							✓
Philippines													
Magat Watershed	✓		✓		✓	✓	✓		✓	✓	✓		
Puerto Princesa			✓								✓		
Vietnam													
Tamdoa National Park	1975 MSS				✓							✓ ETM +	
Cambodia													
West Kampong Cham	84/85 MSS			✓	✓						✓		
Laos													
Nam Thuen Watershed		✓			✓								

Table 3: Biophysical Data Used in the LUCC – SEA Project

Data	Malaysia	Thailand	Indonesia	Philippines	Vietnam	Cambodia	Laos
Soil (class/suitability)	✓	✓	✓		✓	✓	✓
Soil erosion risk Climate	✓	✓		✓			
-Rainfall	✓	✓		✓	✓		
- Temperature	✓	✓		✓			
Geology	✓	✓		✓			
- Drainage network	✓	✓	✓	✓			
Topography	✓	✓		✓			
- Contour	✓	✓		✓			
- Elevation	✓	✓	✓	✓	✓		
- Slope aspect	✓	✓	✓	✓	✓		
- Digital Elevation Model		✓		✓			
Administrative boundary	✓	✓	✓	✓	✓	✓	✓
Road network	✓	✓	✓	✓	✓	✓	✓
Watershed Boundary	✓	✓	✓	✓	✓	✓	✓
Population size	✓	✓	✓	✓	✓	✓	✓
Population density	✓	✓	✓	✓	✓		
Land use/land cover (according to individual sites)	1989-1999 1989-1999	1990-1999	1989-1997 1989-1992 1990-1997	1988-1998 1990-1998	1995-1999	1992-1997	1989-1992

3.2 Collection and Processing of Socio-Economic Data

The LUCC – SEA study had successfully executed the identification of the various socio-economic variables that could shed light to understanding the LUCC in their respective countries. Where possible, similarity in the variables used was to be observed for comparative purposes like those shown in Table 4. Nonetheless, several uncommon variables had also been utilized in cases where their presence was crucial as explanatory factors in certain countries.

Table 4: Common Variables Used for Cross Country Comparison

Variables	Details of Variables
Demographic factors	Population size density growth rate migration
Economic Factors	Employment income (GDP/GNP)
Social factors	Educational level literacy rate
Policy	Land development subsidy

Summary of variables used in this study for all the 7 countries is given in Table 5. Most of the variables are from secondary sources. Attempts were made to correspond the data dates with that of the Landsat TM dates.

However, this is not always easy and some extrapolation is required. Besides socio-economic variables, the spatial coverage of the study area was determined based on the availability of data and of manageable scale. Thus participating countries chose spatial scale that varies from sub-district (Thailand) and Kacamatan (Indonesia) to large administrative unit of either municipality (Philippines) or district (Malaysia).

Table 5: Socio-economic Variables Used in the LUCC-SEA Study

Country	Variable	
Indonesia	Population density, annual growth Age, sex structure Migration Education level and literacy rate Location of city/town Distance from major town Distance from highway	• Road density • Land tenure • Prices of goods • Crop yield/ha • Input prices • Policy variable
Malaysia	Population dynamics • Size • Density • Growth • Net migration • Urbanization Socio-economic status: • Income • Educational attainment • Selected indicators of affluence; % owning car, % having telephone	Locational factors: • Distance from major town • Distance from toll-highway • Distance from trunk road • Road density per ha Policy-driven development • Crisis-motivated development • Agricultural subsidy • Land scheme
Philippines	Enhancement with new data sets of socio-economic variables used in Phase 1: Population: • Size • Density Technology: Fuel used for cooking • Energy used for lighting • Use of fertilizer and pesticide Socio-economic status: • Literacy rate • Number (aged 20+) completed secondary education • Dependency ratio • Possession of household appliances	

Country	Variables
Thailand	Socio -economic data to be imputed into socio-economic modelling (pixel approach). Population • Size • Density • Number aged 15 – 65 yrs • Number completed secondary education Socio-economic status: • Number of agricultural area (in Rai) in sub-districts • Number of households having small tractors • Number of households having electricity • Number of households having television. Locational factors: • Distance (km) of hard surface roads • Distance (km) of soft surface roads
Vietnam	Population • Size • Density Socio-economic status: • Labour force Locational Factor • Road density
Cambodia	Population • Size • Density Socio-economic status: • Labour force Locational Factor • Road density
Laos	Population • Size • Density Socio-economic status: • Labour force Locational Factor • Road density

The time period used by each case study varied and followed the dates of the Landsat TM imageries available as given in Table 2.

3.3 Remote Sensing and GIS Data Processing

At Kuala Lumpur workshop in May 1999, it was agreed that the remote sensing data processing sequence followed the details as given in Figure 2.

In remote sensing data processing it was necessary to apply radiometric correction on satellite data in order to remove data errors caused by sensor as well as distorting effects of atmospheric properties. Geometric correction was carried out to ensure the data are co-registered with conventional map and co-registered with each other as more than one set of remote sensed data were used. Topographic map was used for this purpose.

The classification used for this study was hybrid with application of both supervised and unsupervised classification. This is to ensure that maximum information was obtained from the data source. For supervised classification approach maximum likelihood classifier had been adopted as it was found to be most suitable to the number of land use change that were to be expected for this study. Post classification was carried out to the data classes derived so as to further improve the results.

The results of land use changes were also tested and validated using reference data as well as field verification with the use of GPS. This is to ensure the reliability of the land use classification derived. The results were generated in digital form, land copy as well as statistic as required in the research. Multidate or overlays produced coincidence matrix.

Table 6 shows the details of the change detection adopted by individual country in terms of resample pixel size, band combination, classification methodology and accuracy assessments.

The GIS was used to convert analogue map into digital format and to analyse the result of LUCC and other thematic overlays generating statistical data for land cover. In designing the database the study area boundary was determined for the topographic map as well as for land use and land cover map produced from the Department of Agriculture. Creation of typology is necessary to make the spatial data usable. Errors were edited which include arc, label, move and intersect. The typology was constructed by using CLEAN and Build commands. The typology was reconstructed when errors were found. The attributes data were input into ARC/INFO. Data filenames were assigned to all the files created while JOINTITEM command was used to link attributes from data file with the related coverage. In managing the data base all coverage from digitiser unit were converted to real world coordinates using UTM system.

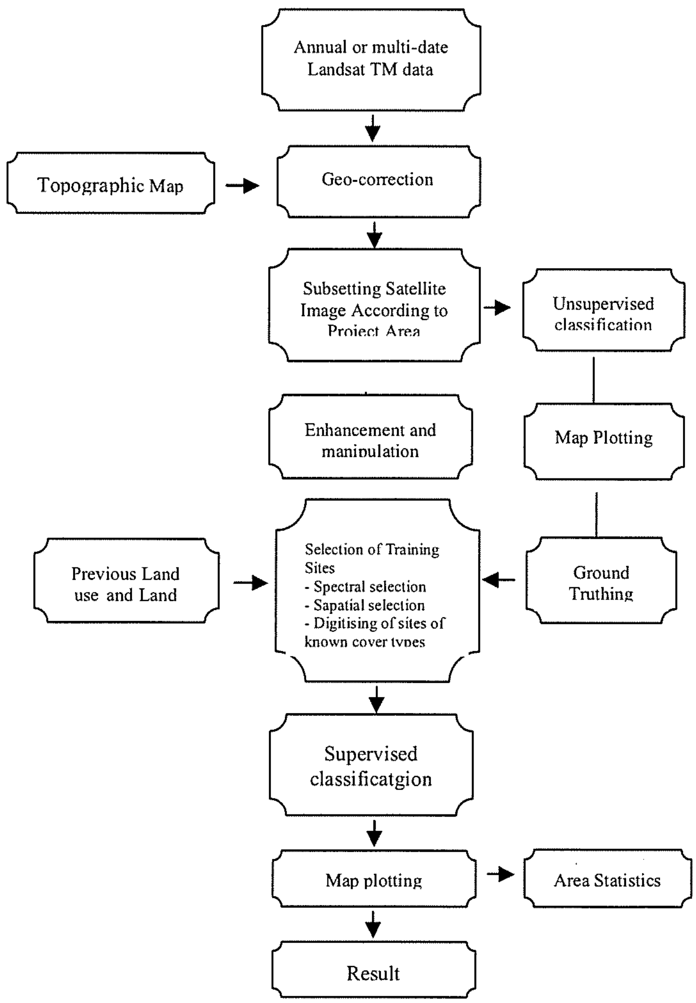


Figure 2: Land Use and Land Cover Data Procedures Using Image Analysis

Table 6: Details of Remote Sensing Data Processing

Item	Malaysia	Indonesia	Philippines	Thailand	Cambodia	Vietnam	Laos
Data Source: - Landsat MSS	-				1985-1985	1975	
- Landsat TM	1989-1999 1988-1998	1989-1997 1990-1997 1989-1993	1988-1998 1990-1998	1990-1999 1990-1999 1990-1999 1990-1999 1990-1999	1991-1998	1992	1989-1992
- Landsat ETM+						1999	
Band Combination	453			345			432, 321
Classification Method	Hybrid Post Classification	Supervised and Post Classification	Supervised and Unsupervised with ISODATA	Hybrid	Hybrid	Hybrid	Hybrid
Accuracy Assessment	Field verification with GPS	Field verification with GPS	Field verification with GPS	Field verifi-cation with GPS	Field verifi-cation with GPS	Field verifi-cation with GPS	Field verifi-cation with GPS

Table 7 explains further the GIS activities carried out by individual country in term of type of data entry, GIS hardware and software's used, overlay analysis, and output generated.

Table 7: The GIS Activities

Country	Data Entry/Input	Data Processing	DBMS* Used	Overlay Analysis	Output Generation
Indonesia	Digitising	PC-Arc/Info	PC Info	Overlay/TIN	Digital Data & Hard Copy
Malaysia	Digitising	Unix-Arc/Info	WS Info	Overlay	Digital Data & Hard Copy
Philippines	Digitising	PC-Arc/Info	PC/WS Info & PC dBaseIII	Overlay/TIN	Digital Data & Hard Copy
Thailand	Digitising	PC-Arc/Info & PCI	PC Info	Overlay/TIN	Digital Data & Hard Copy
Vietnam	Digitising	PC-Arc/Info	PC Info	Overlay	Digital Data & Hard Copy
Laos	Digitising	PC-Arc View	-	Overlay	Digital Data & Hard Copy
Cambodia	Digitising	PC-Arc View	-	Overlay	Digital Data & Hard Copy

3.4 Modelling of Land Use and Land Cover Change

All team members started with the basic understanding that there exist several significant causal factors that are responsible for land use and land cover change. In its most general form, the relationship between LUCC and the causal factors can be written as:

LUCC = f (population dynamics, economy, technology, political and economic institution, culture).

All country teams appeared to have adopted the causal factors in building their general model. The next steps involved empirical estimation of the above model. All teams utilized multivariate Ordinary Least Squares regression technique for this purpose. The empirical model estimated is as follows:

$$LUCCi = a+b_1.$$

Where LUCC is some measure of land use and land cover charge, a is the intercept, X_1, X_2 … X_n are the causal factors, b_1, b_2 … b_n are regression parameters and e_i is the error term. Implicit in this modelling is that the current land use status of any plot represents its long run equilibrium state. In other words, given a the land's relevant socio-economic input, climate and soil attributes the current land use is chosen because it yields the highest socio-economic return.

4.0 LAND USE AND LAND COVER CHANGE: RESULTS

The following section briefly reviews the results of the 7 country case studies. This is followed by socio-economic assessment of the broader implication of this study from the human dimension perspective.

The overall result is given in Table 8 and Figures 3, 4, 5 and 6. The results showed successful application of RS/GIS techniques to detect land use and land cover change in the selected sites for a chosen time period. The county teams also used statistical modelling in order to understand the human driving forces that cause the land use and land cover to change in the manner described in the results.

Table 8. Land Use and Land Cover Change for Forest and Agriculture in Southeast Asia.

COUNTRY (Study sites)	FOREST (Km^2)	AGRICULTURE (Km^2)	BUILT UP AREA (Km^2)
Malaysia			
i. Klang-langat (1989-1999)	846.9-758.5 (-10.4%)	1916.9-1559.4 (-18.6)	-
ii. Kayan-Sempadi (1988-1998)	613.15-438.18 (-28.54%)	407.04-595.86 (+46.39%)	9.13-19.21 (110.8%)
Indonesia			
i. Citarum (1984-1996)	985.26-779.84 (-20.8%)	923.87-521.86 (-43.51%)	-
ii. Mahakam (1992-1997)	667.81-532.37 (-20.85%)	-	-
	414.98-570.85 (+37.56%)	-	27.91-37.90 (+35.79%)
iii. Jambi (1992-1998)	1921.23-1625.83 (-15.38%)	444.13-502.52 (+13.15%)	1.51-1.84 (+21.85%)
Philippines			
i. Magat (1989-1998)	521.65-571.33 (+9.52%)	233.91-152.89 (-34.64%)	3.36-20.12 (+498%)
ii. Puerto Princesa (1990-2000)	1434.99-1431.52 (-0.002%)	45.39-46.61 (+2.69%)	4.47-5.88 (+31.15%)
Thailand			
i. Mae Chaem (1990-1999)	742.7-728.6 (-1.98%)	30.4-50.4 (+65.78%)	0.92-1.37 (+48.91%)
ii. Lin Thin (1989-2000)	805.56-786.36 (-2.38%)	140.66-161.70 (+14.95%)	0.39-0.48 (+13.07%)
iii. Phusithan (1990-2000)	684.52-725.27 (+5.95%)	270.32-229.50 (-15.10%)	40.5-48.6 (+20%)
iv. Eastern Forest (1989-2000)	700.76-713.03 (+1.75%)	255.67-231.42 (-9.48%)	0.29-0.67 (+230%)
v. Ao Sawi (1989-2000)	64.52-49.13 (-23.85%)	332.40-344.84 (+3.74%)	11.34-16.81 (+48.24%)
Vietnam			
i. Tamdao (1975-1999)	246.01-152.31 (-38.08%)	16.24-16.33 (+0.55%)	-
Cambodia			
i. Kg. Cham (1984-1997)	1529.44-1134.20 (-25.84%)	1903.12-2552.81 (+34.14%)	49.54-36.06 (+27.2%)
Laos			
i. Nam Thuen (1989-1992)	11099.56-8936.20 (-19.49%)	216.25-2472.29 (+1043.28%)	-

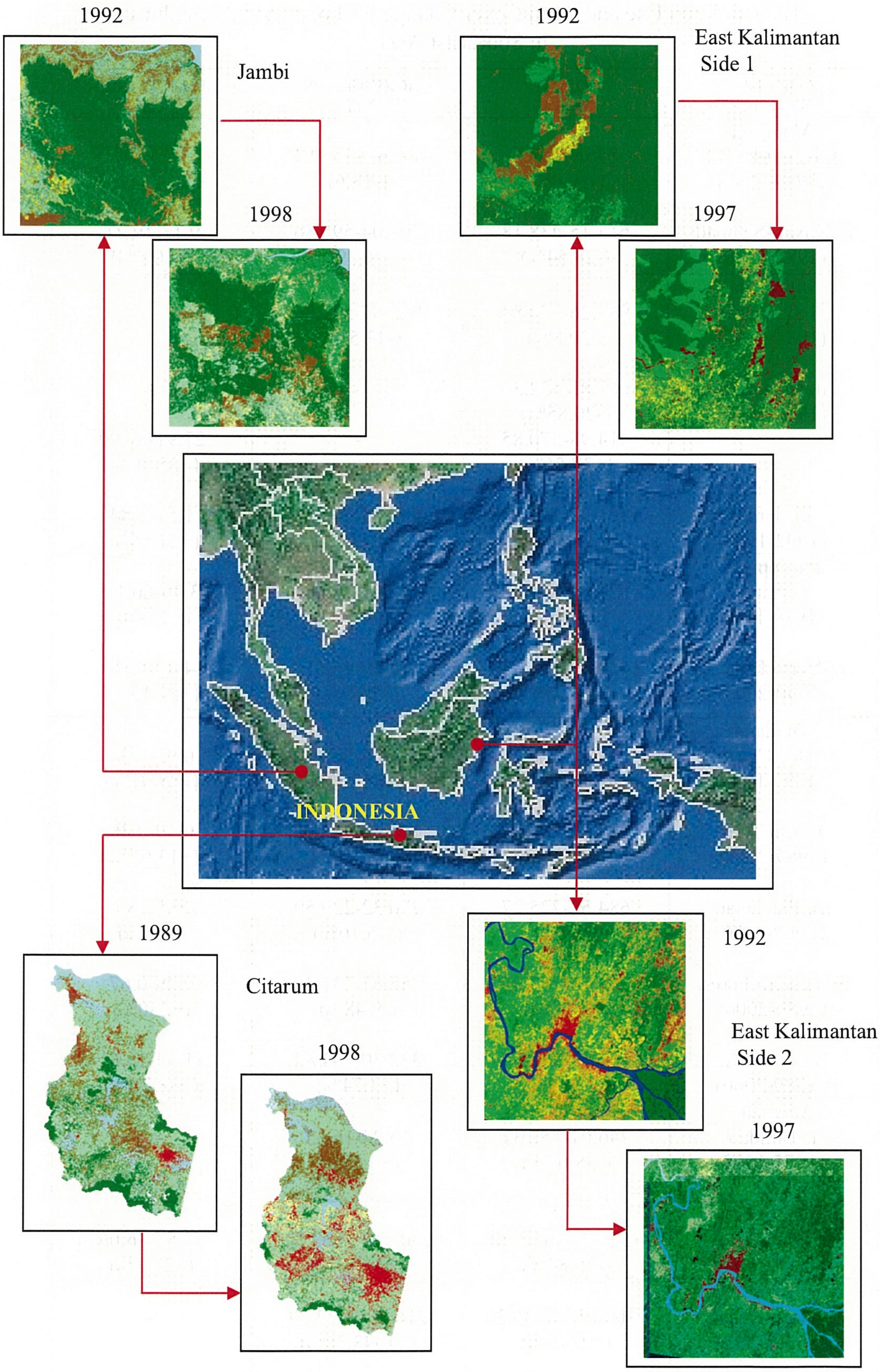


Figure 3: Land Use and Land Cover Change For SEA - Study sites in Indonesia

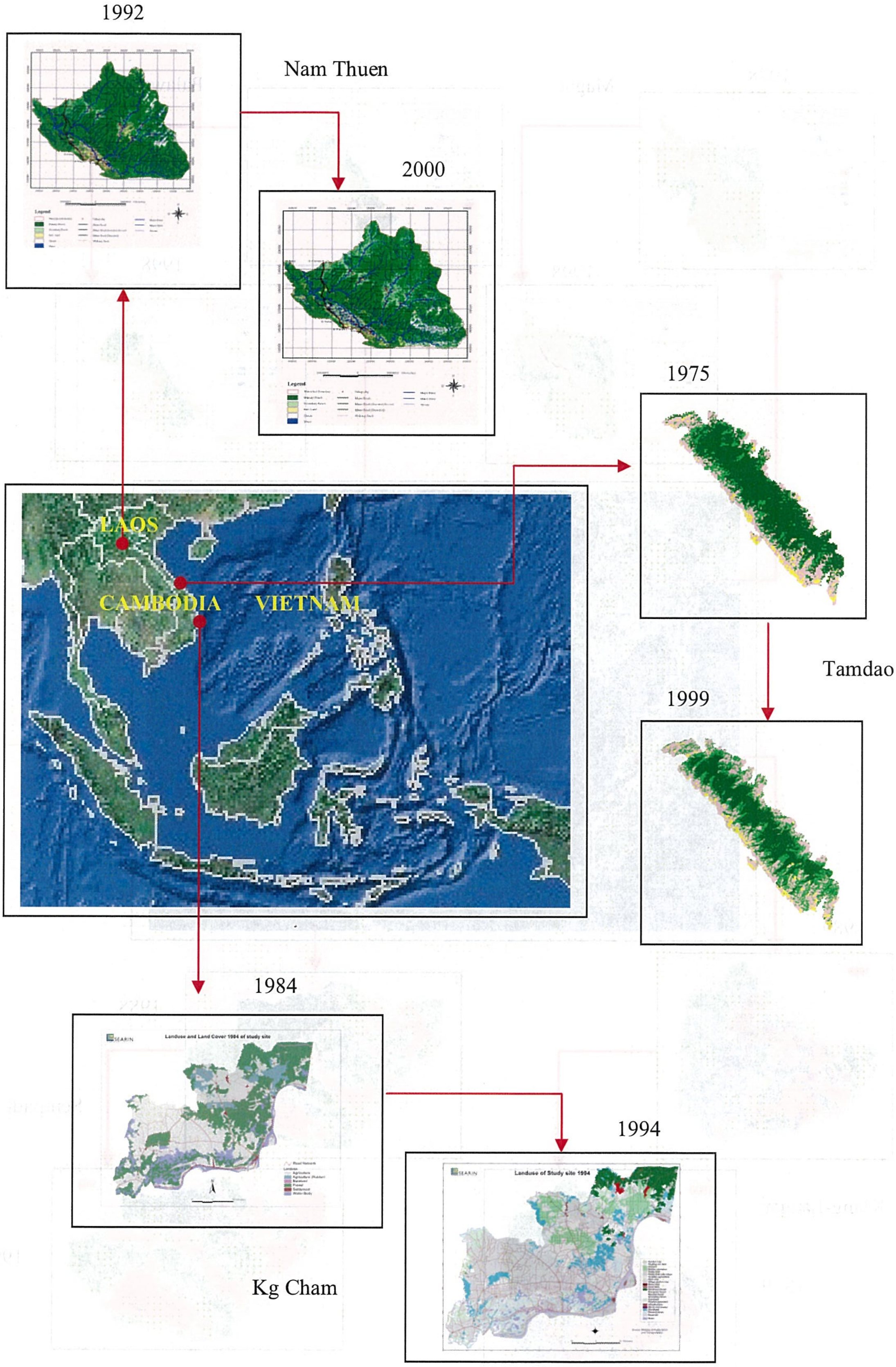


Figure 4: Land Use and Land Cover Change For SEA - Study sites in Cambodia, Laos and Vietnam

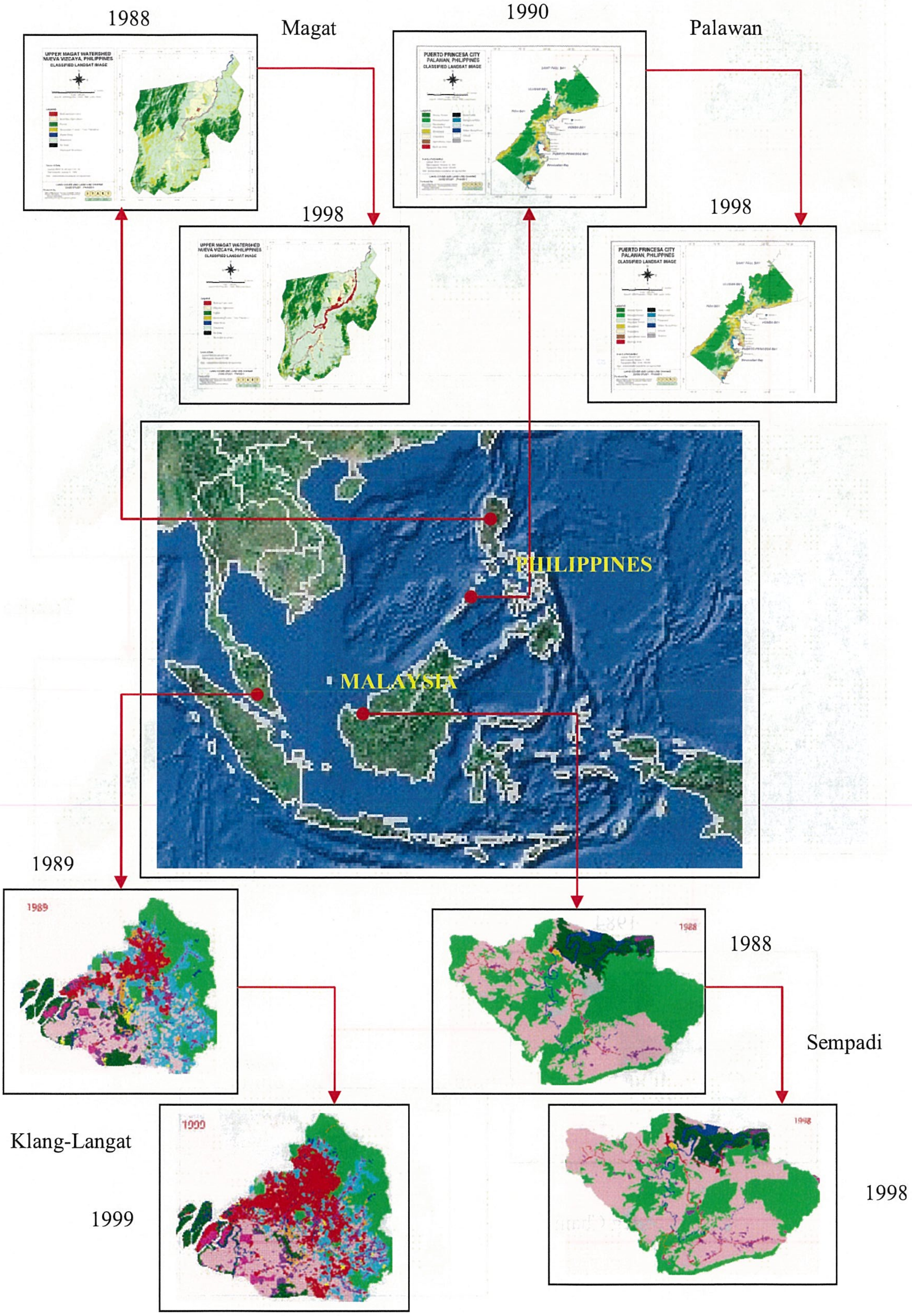


Figure 5: Land Use and Land Cover Change For SEA - Study sites in Malaysia and Philippines

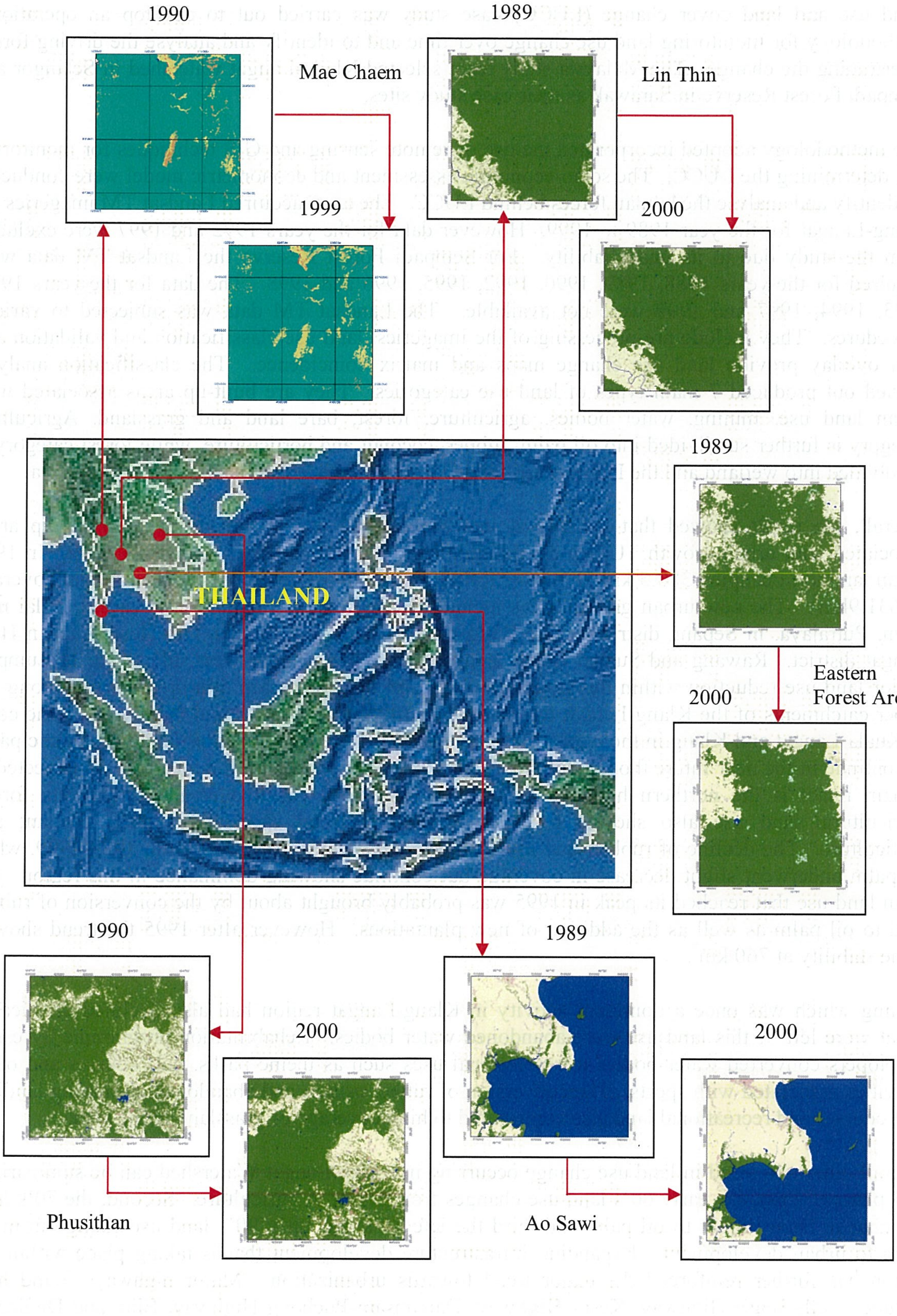


Figure 6: Land Use and Land Cover Change For SEA - Study sites in Thailand

4.1 Malaysia

Land use and land cover change (LUCC) case study was carried out to develop an operational methodology for monitoring land use change over time and to identify and analyse the driving forces determining the change. The Malaysia study team selected Klang-Langat watershed in Selangor and Sempadi Forest Reserve in Sarawak as their case study sites.

The methodology adopted incorporated the use of remote sensing and GIS techniques for monitoring and determining the LUCC. The socio-economic assessment and econometric model were conducted to identify and analyse the human forces behind LUCC. The team acquired Landsat TM imageries for Klang-Langat for the year 1989 to 1999. However data for the years 1992 and 1997 were excluded from the study due to its unavailability. For Sempadi Forest Reserve the Landsat TM data were acquired for the years 1988, 1989, 1990, 1992, 1995, 1996 and 1998. The data for the years 1991, 1993, 1994, 1997 and 1999 were not available. The Landsat TM data was subjected to various procedures. They include pre-processing of the imageries, land use classification and validation and data overlay provide land use change maps and matrix coincidence. The classification analysis carried out produced 7 main types of land use categories. They are built-up areas associated with urban land use, mining, water bodies, agriculture, forest, bare land and grassland. Agriculture category is further subdivided into oil palm, rubber, coconut and horticulture, while forest category is subdivided into wetland and the Dipterocarp forest located on the Western side of the study area.

Overall, the result showed that the largest increase in land use was recorded for built up areas associated with urban growth. Urban expansion of up to 150% occurred from 1989-1999. In 1989 urban land use occupied 380.5 km^2, however the area was almost double in 1996 with total coverage of 631.9km^2. The new urban growth areas include Kuala Lumpur International Airport, Nilai new town, Putrajaya, in Sepang districts while Bandar Baru Bangi and Bandar Tun Husin Onn in Hulu Langat district. Rawang and Sungai Buluh areas are expanding in the west side of Kuala Lumpur. Major land use reduction within this time period is tropical Dipterocarp rainforest located along the upper catchments of the Klang-Langat Rivers and the mangrove forest found mainly along the coast of Kuala Langat and Klang in the west. The 11% decline in the trend of forestland use is anticipated to continue in the near future though not drastically. The only section of the forest that is expected to remain intact is the northern highland portion that has been gazetted as the catchments forest. Agricultural land use also showed a steady decline in trend especially rubber, coconut and horticulture. The decline of rubber land use for up to 27% was experienced from 1989-1999, while oil palm underwent slight decrease in coverage but continue showing dominance in this region. Oil palm land use that reached its peak in 1995 was probably brought about by the conversion of rubber land to oil palm as well as the addition of new plantations. However after 1995 the trend showed some stability at 760 km^2.

Mining which was once a dominant activity in Klang-Langat region had also declined drastically. What were left of this land use were abandoned water bodies. Rehabilitation programme by estate developers converted water bodies to recreational uses such as theme parks, golf courses and other activities associated with sports. The conversion of rubber estates and abandoned ex-mining lands to golf courses and recreational land also contributed to high coverage of grassland in the area.

Overall, the main trend in land use change occurring in Klang-Langat Watershed can be summarized in 3 phases. First, the early 60's land use changes from forest to agriculture. Second, the 70's land use change from rubber to oil palm and third the late 80's and early 90's land use change from oil palm to urban development. Expanding infrastructure development that is taking place within the region has further reinforced the major trend towards urbanization. Major highways found here include North-South Highway, Kesas Highway, Damansara-Puchong Highway, Elite and Dedicated Highways. Highway corridors being linear features and 30-60 m wide are easily discernable in the satellite imagery of the latter years. Their networks are known to cause the fragmentation of the forest in this area.

In Batang-Kayan Sempadi watershed change detection from satellite imageries between 1988-98 showed that a total of 399.8 km^2 or 33.9 per cent of the area had undergone changes. Generally the changes are from vegetated area to less or non-vegetated land use either from forest to oil palm or to horticulture or urban land use. Substantial changes involving increase in area of more than 1,000 ha each were recorded for oil palm, followed by urban land use and horticulture.

4.2 Philippines

The study of land cover and land use change employed remote sensing and geographic information system (GIS) technique. The study sites included Magat Watershed which is within the province of Nueve Viscaya and Puerto Princesa located in the province of Palawan

For Magat Watershed, an analysis using annual LANDSAT data from 1988-98 excluding 1989 and 1995 was performed to quantify rates of land cover change. The Landsat data were classified into the following land cover classes: forest, secondary forest/tree plantation, grassland, openland/bareland, non-tree agriculture and water body. Ground-truth data were collected during a series of fieldwork trips for calibrating the interpretation of the Landsat data and to perform a statistical validation of the results. Overall results indicate that grassland covered the largest area while water body had the least coverage. Forest cover showed a declining trend from 1988 to 1996, with the decrease rates of clearing in that later part of the decade. Forest data for 1988-1998 showed that the area covered by forest had increased. The decadal mean gives a constant rate of change of forest cover area which is 496.76 ha, whereas the inter-annual rate of change varies. The decreased in forest occurred in 1990,1992,1994,1995,1996,1997,1998 while the increase was observed in 1993, 1996 and 1997.

For Puerto Princesa classified Landsat imageries from 1990-1998 showed change in forest particularly mangrove/nipah and residual forest. The mangrove forest was mainly converted to fishpond during the period 1990-1998. Large-scale deforestation also occurred in some residual (or secondary) forest. From an area of 23,178.06 ha in 1990 the secondary forest decreased to 22,964.76 ha. Mostly converted to grassland. Agricultural area in 1980 was 4539.15 ha but was reduced to only 3870.36 ha as of 1998 because of conversion to other land use types such as built up area, grassland fishpond and bare land. But built up area in Puerto Princesa grew in size from 1980 to 1990. The growth is expected because of the status of Puerto Princesa as a only of the Palawan Island. There was minimal change in the extent of water bodies throughout the years. Agricultural area in 1980 was 4539.15 ha but was reduced to only 3870.36 ha as of 1998 because of conversion to other land use types such as built up area, grassland, fishpond and bare land.

The prominent land cover changes during the period studied were conversion of grassland to secondary forest, forest to grassland, and grassland to agriculture. These changes were attributed to both anthropogenic and natural factors, including extreme climate events, population growth, changes in the economy, occurrence of landslides due to earthquake, cropping trends, indigenous agricultural practices, innovations of new technologies and implementation of government policies, etc. Each of these factors contribute with varying degrees to the observed land cover and land use change dynamics of the area. A contributory factor may be applicable in one area but not in another. It is therefore important to determine which factor contributes significantly in a specific area.

The study also focused on developing models that capture the effects of anthropogenic activities, such as land use change, by relating spatially explicit socio-economic data with the satellite base land cover and land use change data. This modelling was done within a Geographical Information System (GIS) and was used for projection of future land use changes and their impacts on land cover in the Upper Magat Watershed.

4.3 Indonesia

A case study of land use and land cover change analysis was carried out in the Citarum watershed area of West Java Province as part of regional projects. The case study employs remote sensing and Geographic Information System (GIS) techniques to analyse land cover and land use between the years of 1984 to 1996.

Results of this long-term study indicate that forest cover in the Citarum watershed declined from 985 km^2 in 1984 to 779.8 km^2 in 1996, or a 20.8 percent of forest cover loss. In East Kalimantan forest declined 20.8% from 1992 to 1997 while in Jambi the decline (from 1992-1998) was about 15%. Agriculture also decreased drastically in Citarum watershed (-43.5%) due to increased urbanization process. However in Jambi agriculture rose 13% and this was mainly due to favourable demand in plantation agriculture. Urban land use in Jambi increased by 21.85%. Future increase in trend is expected. Further change analysis using matrix coincidence on the remote sensing data, coupled with multiple regression analysis between the changes and population statistics, suggests that rapid increase in industrial activity was responsible for the rapid decrease in forest and vegetation covers. Overall, the study confirmed the argument that the economic development policy to develop the watershed as a multiple-use economic zone with the construction of three large multi-purposes dams does have environmental consequences, especially the alteration of land cover mosaic. Initial calculation of the decadal carbon dioxide (CO_2) budget as the impact of the land cover and land use change indicate that the net carbon flux is 606,040.43 gCO_2/yr, making the watershed a net emitter spatial unit. The study provides a strong baseline data for determining policy directions both for science and research, and for operational land use decision-making

4.4 Thailand

The study area focuses on the linkages between human activities that affect land use and land cover change and development of spatial/analytical model to describe the phenomena. The areas are located in the 5-different regions namely:

- Northern region (Mae Chaem District, Chiang Mai)
- Western region (Lin Thin Watershed area, Kanchanaburi)
- North-eastern region (Phusithan area, Sakol Nakorn-Nakorn Phanom)
- Eastern region (The Eastern Sea Board)
- Southern region (The Ao Sawi Area)

Determining whether annual rates of deforestation are significantly different from the decadal mean rate was also conducted over the study area in Mae Chaem District, Chiang Mai, Northern Thailand covering an area of about 784 km^2. The topography of the site is mainly mountainous area. General land use and land cover classes are forest, agriculture, open land/bare land, water bodies and urban areas.

Using overlay technique, land use and land cover change analysis between 1990 to 1994, 1995 to 1999, 1990-1995-1999 and inter-annual from 1995 to 1999 were performed from the classification results of LANDSAT TM data during 1990-1999. The results show that in Mae Chaem area forest declined slightly from 742.7 km^2 to 728.6 km^2 (-1.98%). Agriculture and built up area rose significantly to 65.8% and 48.9% respectively. In Lin Thin area forest declined 2.38%, agriculture rose 15% and built up area rose 23 %. In Phusithan, the 15 % decline in agriculture is gained by urban areas (20%). Forest gained about 6%. In Eastern Forest, forest land cover gained slightly and agriculture declined to 90%. The largest loss in forest cover occurred in Ao Sawi (-23%). There was a net gain of 3% in agriculture. Urban growth account for 48%.

Overall, the inter-annual change was not significant. Encroachment and deforestation rates over forest area declined steadily since the beginning of the last period. Agricultural land became permanent while open land was also changed to agriculture and forest. The population had decreased during 1992-1996 in Mae Chaem and this is seen to be a paradox, compared to the increasing agricultural land.

The explanation for the land use and land cover change phenomena in Mae Chaem area can be discussed as follows: Thailand declared log concession in 1989. Since then many policies for forestland protection were issued. There are also many new development projects emerging in the study area. This explains the declined rate of deforestation and increased rate of reforestation and afforestation. Inter-annual variation of land use and land cover change could be affected by biophysical factors such as local climate as well as by socio-economic factors such as marketing policy and price.

4.5 Vietnam

Land use and land cover is closely related to human dimensions and global climate change. The study was conducted to determine deforestation dynamics, including the total amount of deforestation from 1975 to 1999 and the rate of deforestation over that time period for the Tamdao study area. The study also attempts to quantify and explain the driving forces behind the observed changes in land use and land cover. Remote sensing data and GIS techniques are used to map land use and land cover and highlight the changes.

Landsat imagery of three dates (MSS 1975, TM 1992 and ETM+ 1999) were classified (unsupervised and supervised) using ERDAS IMAGINE 8.4 based on ground truth. Socio-economical factors such as administration boundary, population, population density, infrastructure and related policies, as well as biophysical data (soil, slope, etc) of the study area were collected for linkage with land use and land cover change. All data collected were converted into GIS format to create layers. The maps were then overlaid to generate statistical data for the land cover to facilitate modelling of driving forces of land use and land cover change.

The results of the case study reveal that during the study period from 1975 to 1999 the area under forest (including both old natural forest and secondary forest) had decreased by 9.5% (representing an 38.1% decrease in old natural forest and 89.9% increase in secondary forest areas). The area under open/ bare land had increased by 30.5% while the agricultural land remained almost unchanged (had increased by 0.5% only) during this period.

However, the year 1992 – one year before the national park was established in 1993 – was some kind of turning point in the dynamics of a land use pattern in the study area. It can be clearly seen in the table above, while in the period from 1975 to 1992 natural forest had decreased by 16.3%, it had increased in the next period from 1992 to 1999 by 8.1% thanks to significant increase in secondary forest (totally by 98.5%). In terms of open / bare land and agricultural land, we can observe a significant increase in the sub-period from 1975 to 1992 (by 379% and 88.0% respectively) and decrease in the next one (by 5.4% and 46.5% respectively) having led to overall less significant increase in these landuses for whole study period from 1975 to 1999.

The study team has integrated these results with spatially explicit socio-economic and biophysical data in a GIS framework to model the driving forces of these changes. Changes are most likely to be changes in management policies and legislation that have been recently introduced in Vietnam. Amongst these are the Land Law (1993), Code on Forest Protection and Development (1991), and Forest Lands Allocation Policy. On the other hand, during the same period parts of the study area had lost some forest cover due activities directly related to the human activities, mainly illegal logging and firewood collecting. This approach of linking remote sensing based estimates of land cover change with socio-economic and biophysical data is critical for judicious natural resource management and long-term planning in Vietnam.

4.6 Cambodia

The study site in Cambodia is located to the west of Kampong Cham province, with about 26% forest cover in 1992/93. The site covers a total area of 402,382 ha. This area historically contained large areas of intact forest, but in the last few decades had experienced significant forest loss. The land cover and land use changes were assessed by analysing Landsat TM data from years 1984 to 1991. In addition, biophysical and socio-economic data were also acquired and used to model land use and land cover change.

Analysis of this region revealed dynamic land cover changes. The results show that loss in forest cover (71183 ha) was larger than the conversion of agricultural land to bare lands (34192 ha and 1156 ha respectively) to forest land during the 5- year study period from 1984 to 1991. The results indicate that there have been an extensive change in land cover due to changes in land use, including clearing of forests for supporting economical and commercial activities, wood fuel harvesting, agriculture land, and hunting.

4.7 Laos

Nam Thuen Watershed, located in the central part of Laos, is one of the country's critical watersheds and has an important role in both conservation and development functions. Nam Thuen was declared as a National Biodiversity Conservation Area and is a candidate development area for a hydroelectric power plant. Land use changes in this watershed area will not only affect the flora and fauna, but also the potential and success of hydropower production. The dominant land use in the uplands of this area is shifting cultivation. This study relies on using remote sensing and GIS, that is two powerful tools for providing scientific information in support of decision-making process for natural resources management.

Landsat TM satellite images, acquired in 1989 and 1992, were classified using maximum likelihood classifier and post-classification change detection to quantify the extent and spatial patterns of land cover changes. The analysis was focused on classifying the extent and quantifying the changes in forest cover, agricultural lands, bare lands, and grasslands. The results show both the extent and rates of land cover change and also land use practices causing the observed land cover changes. Large areas of change were documented during this 4-year period. These changes were then related to spatially explicit socio-economic data in order to assess and model the driving forces behind these changes. The magnitude and widespread changes of the land cover indicate the urgent need for studies on land-use planning and management process in the watershed areas to ensure their sustainable development.

4.8 Land Use and Land Cover Change: An Overview

The results obtained from the 16 sites showed that forest cover incurred the highest loss in hectarage. Eleven sites recorded forest loss of various extent as shown in Figure 7. Tamdao site in Vietnam recorded 38% reduction in forest land cover followed by Kayan Sempadi (28%), Ao Sawi (24%), East Kalimantan (21%), Citarum (20.8%), Nam Thuen (19%), Jambi (15%), Klang-Langat (10%), Lin Thin (2%), Mae Chaem (1.9%) and Puerto Princesa (<1%). All the analysis projected continued forest loss as long as there is no effective enforcement in areas where forest protection law already existed. In some areas government policy favoured easy conversion of forest land to other uses and thus cause forest area to diminish further. There are attempts in Thailand, Malaysia and Indonesia to encourage plantation forest but such initiative are very small in extent. The sites with increase forest area are far from urban influence and therefore are less prone to pressure of conversion.

The deforestation in these seven countries are recorded over different time period. Tam Dao in Vietnam recorded highest loss of forest land use as compared to others but cover a long term time period of 24 years. Table 9 and Figure 8 showed per year forest loss for each country.

Figure 9 showed comparison between annual percent change in forest cover for study sites as compared to the national average using data provided by WRI (1998/99). The percent change reflect decrease in forest cover and overall Nam Theun in Laos recorded highest percentage loss while Puerto Princesa in Philippines recorded the lowest. The study sites in Indonesia, Vietnam, Cambodia and Laos, all recorded much higher percentage loss in forest than their national average record. However sites in Philippines and Thailand recorded much less forest loss than their national average. More recent FAO data (2001), as shown in Figure 10 gives much less percentage loss of forest in all the seven countries. When this national average is compared with data from study sites it showed that the except for three sites in Thailand and one in Malaysia. The results therefore varied according to the source of the data. Forest data are known to differ according to sources and such comparison are always difficult.

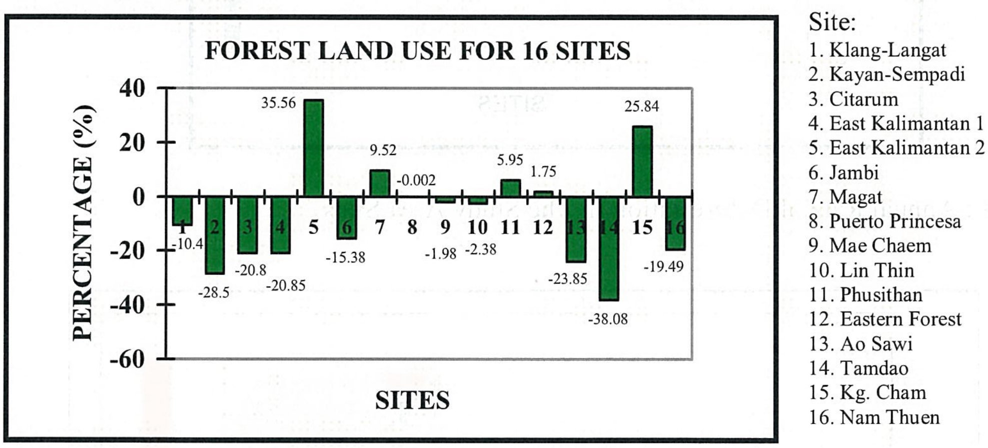


Figure 7: Forest Land Use For 16 Sites

Table 9 : Rate of Deforestation in the Study Sites

Country	Study Sites	Monitoring Period (yrs)	Total % Change	Annual % Change
Malaysia	1.Klang Langat	89 – 99 (10)	- 10.4	-1.04
	2. Kayan-Sempadi	88 – 98 (10)	- 28.54	-2.85
Indonesia	3. Citarum	84 – 96 (12)	- 20.8	-1.73
	4. Mahakam	92 – 97 (5)	- 20.85	-4.17
	5. -	-	-	-
	6.Jambi	92 – 98 (6)	- 15.38	-2.56
Philippines	7. Magat	89 – 98 (9)	+ 9.52	+1.06
	8. Puerto Princesa	90 – 00 (10)	- 0.002	-0.002
Thailand	9. Mae Chaem	90 – 99 (9)	- 1.98	-0.22
	10. Lin Thin	89 – 00 (11)	- 2.38	-0.22
	11. Phusithan	90 – 00 (10)	+ 5.95	+0.6
	12. Eastern Forest	89 – 00 (11)	+ 1.75	+0.16
	13. Ao Sawi	89 – 00 (11)	- 23.85	-2.17
Vietnam	14. Tam Dao	75 - 99 (24)	- 38.08	-1.59
Cambodia	15. Kg. Cham	84 – 97 (13)	- 25.84	-1.99
Laos	16. Nam Theun	89 – 92 (3)	- 19.49	-6.49

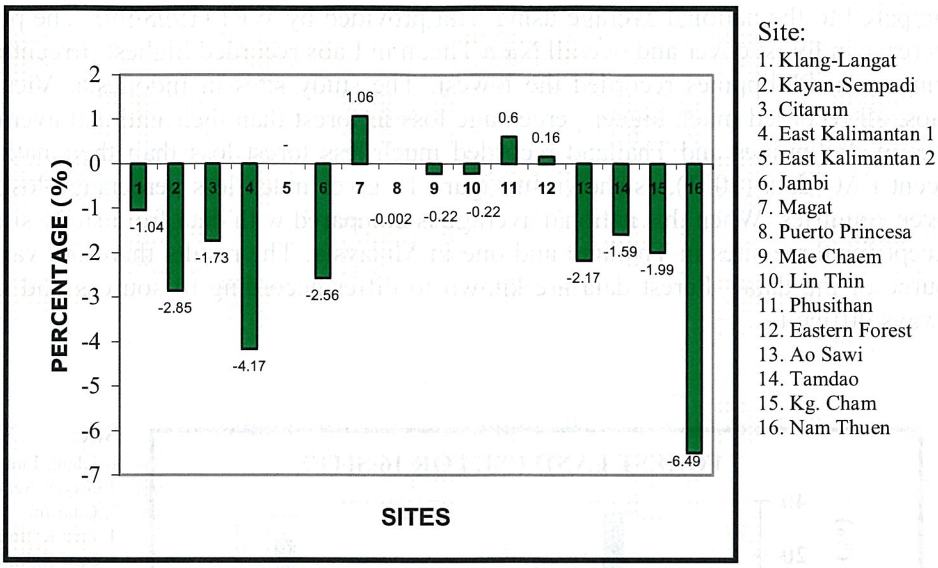


Figure 8 : Annual Rate of Deforestation In The Study Area Sites

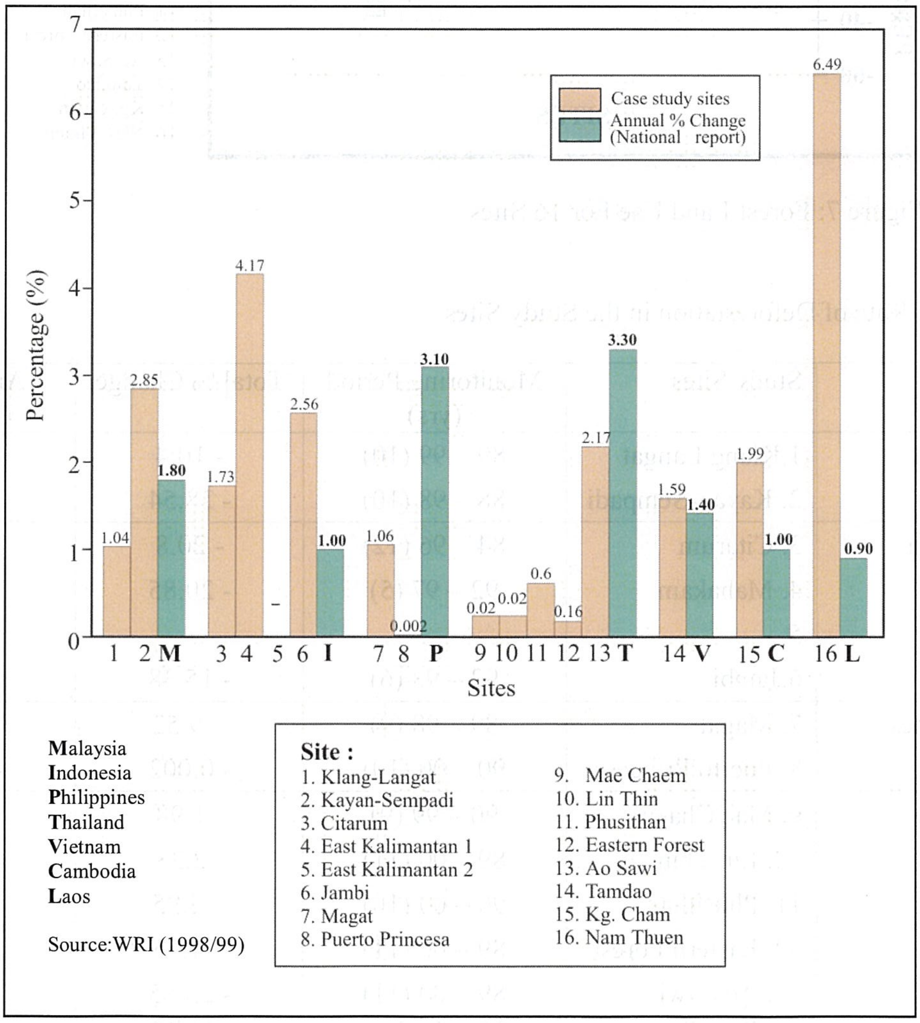


Figure 9 : Annual Percent Change in Forest Cover for Study Sites as Compared to National Average (WRI 98/99)

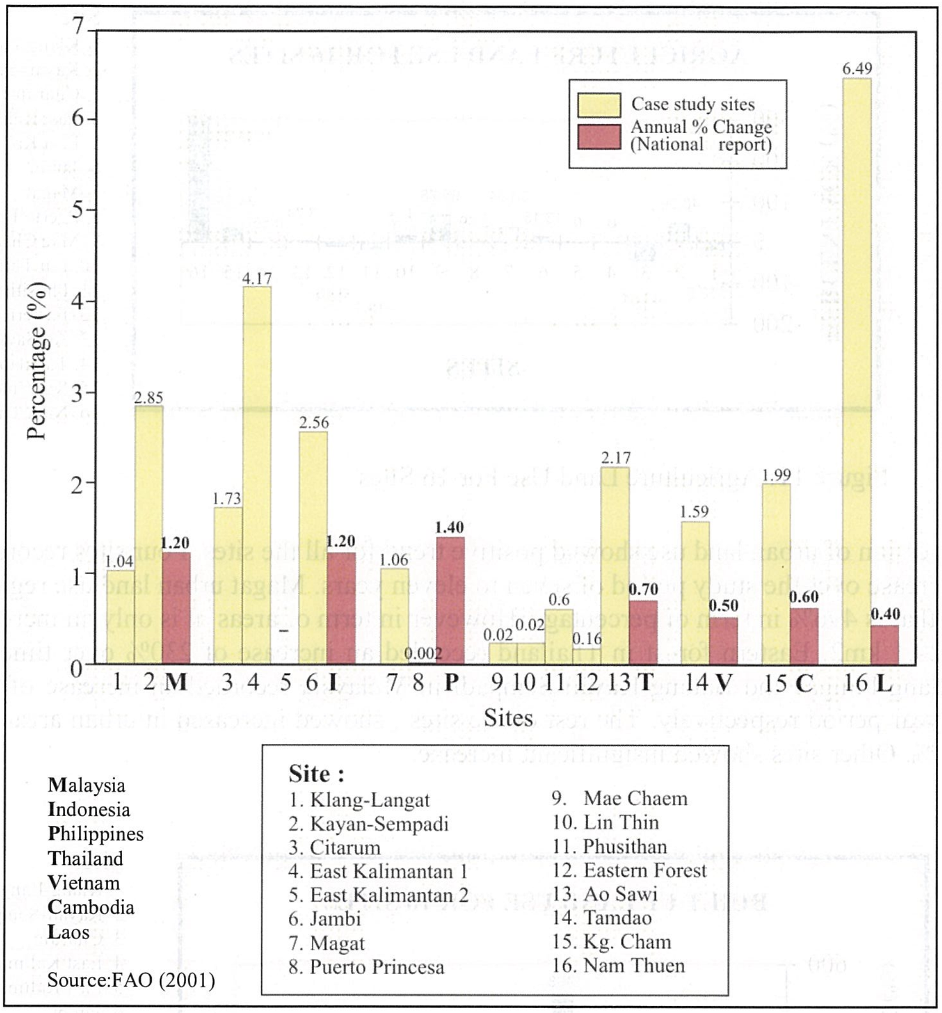
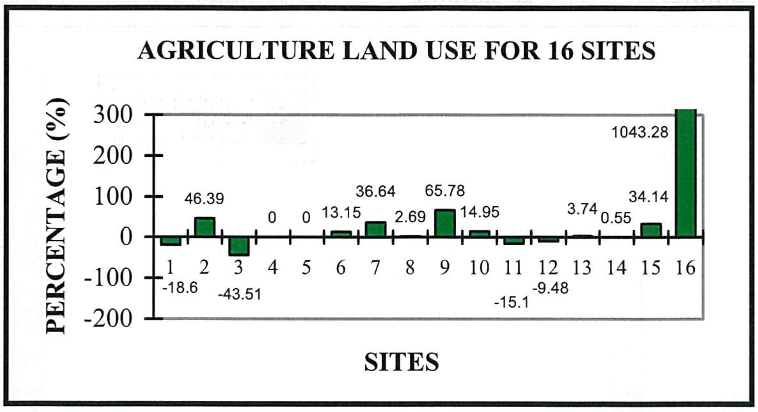


Figure 10 : Annual Percent Change in Forest Cover for Study Sites as Compared to National Average (FAO 2001)

As for agriculture land use 9 sites recorded increase in areas as shown in Figure 11. The single largest increase in the size of the agriculture land cover over four years is Nam Thuen in Laos, which recorded an increase of 1043%. This is followed by Mae Chaem (66%), Kayan Sempadi (46%), Kg. Chaem (34%), Lin Thin (15%), Jambi (13%), Ao Sawi (4%), Puerto Princesa (3%) and Tamdao (1%). There are no agriculture land uses recorded in the two East Kalimantan sites, as both are located in the tropical rainforest area.

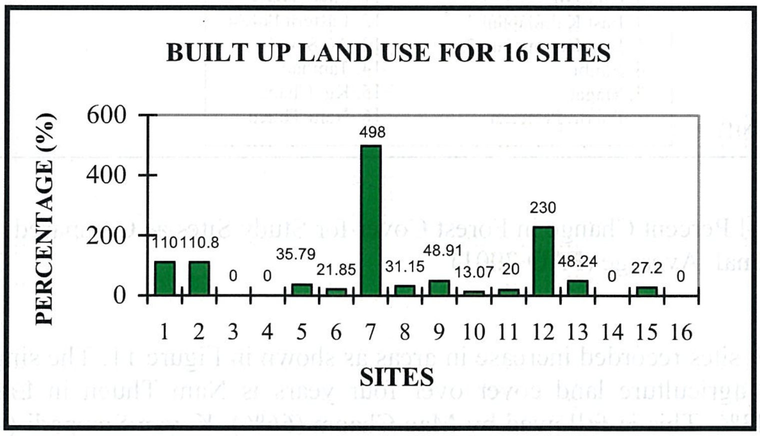
Altogether five sites registered decrease in agriculture land Citarum and Magat incurred a decrease in agriculture land by 44% and 35% respectively. In Citarum urban land use gained from agriculture land while in Magat it gained by grassland. Other sites recorded decrease in agriculture land over a decade include Klang-Langat (19%), Phusithan (15%) and the Eastern Forest (9%).



Site:
1. Klang-Langat
2. Kayan-Sempadi
3. Citarum
4. East Kalimantan 1
5. East Kalimantan 2
6. Jambi
7. Magat
8. Puerto Princesa
9. Mae Chaem
10. Lin Thin
11. Phusithan
12. Eastern Forest
13. Ao Sawi
14. Tamdao
15. Kg. Cham
16. Nam Thuen

Figure 11: Agriculture Land Use For 16 Sites

The conversion of urban land use showed positive trend for all the sites. Four sites recorded more than 400% increase over the study period of seven to eleven years. Magat urban land use registered highest increase that is 496% in term of percentage. However in term of areas it is only an increase from 3.36 km2 to 20.1 km2. Eastern forest in Thailand recorded an increase of 230% over time period of 11 years. Klang-Langat and Batang Kayan Sempadi in Malaysia recorded an increase of 110% and --- over 10 year period respectively. The rest of the sites , showed increased in urban areas varying from 10 to 50 %. Other sites showed insignificant increase.



Site:
1. Klang-Langat
2. Kayan-Sempadi
3. Citarum
4. East Kalimantan 1
5. East Kalimantan 2
6. Jambi
7. Magat
8. Puerto Princesa
9. Mae Chaem
10. Lin Thin
11. Phusithan
12. Eastern Forest
13. Ao Sawi
14. Tamdao
15. Kg. Cham
16. Nam Thuen

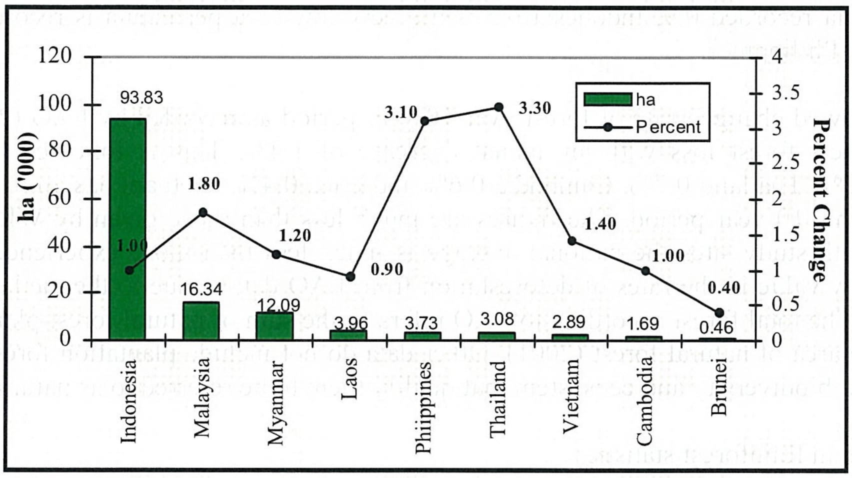
Figure 12: Built Up Land Use For 16 Sites

5.0 LAND USE AND LAND COVER CHANGE : COMPARISON OF RESULTS FROM OTHER TROPICAL REGION

Reliable statistics on the extent of the rainforests in Southeast Asia is difficult to find. Some of the best statistics are those released by the United Nations Food and Agriculture Organisation (FAO), World Resources Institute (WRI), and United Nations Environment Programme (UNEP).

World Resources Institute (WRI) Data

WRI (1999) estimates of rainforest cover in nine countries in South East Asia are given in Figure 13 below. Indonesia with the largest land area of 181.16 million ha, recorded 94 million ha of rainforest cover and subjected to 1% annual change rate from 1981-1990. Malaysia has 16 million ha of rainforest but recorded higher change rate of 1.8%. Philippines and Thailand recorded highest annual change rate of 3.1% and 3.3% respectively. For the other countries the annual change rate of forest range from 0.4% to 1.4%.



Source: WRI (1998/99)

Figure 13: Rainforest Cover and Annual Percent Change in Southeast Asia

5.2 Data from Skole (1998)

For continental Southeast Asia, Skole (1988) gives statistics that were based on two dates (1973 & 1985) satellite data analysis. The result is shown in Table 10. This is the first analysis that reports forest areas and rates of forest loss for the entire region using a single consistent method from satellite data which completely covers the region.

The rate of deforestation from the mid 1970s to mid 1980s was 1.4x106 ha yr-1, which is a rate close to that reported for the much larger Brazalian Amazon during the same period (Skole and Tucker 1993). The rate of deforestation occurs in Thailand at 0.49 x 10^6 ha yr^{-1}, representing approximately 35% of the total for the region. It also has the highest percentage loss rate in the region. Most of the deforestation in Thailand took place in the northern mountainous region and along the Cambodian boarder. Other countries have percentage loss rate that range from 0.11% to 0.32%.

These region wide results are higher than that reported by the World Resource Institute (0.25 x 106 ha yr-1) for closed forests for a letter period, 1985-1988 and approximately comparable to those reported by FAO for the later period 1981-1990.

5.3 FAO Data

The Global Forest Assessment 2000 (FRA 2000) provide the most recent information on the state and Change of forest cover globally (FAO 2001). Forests cover about 3870 million ha or 30% of the earth land area. Tropical and sub-tropical forest comprise 50% of the world forest, while temperate and boreal forest account for 44%. Forest plantations made up only 5% of all forest while the rest are natural forest. FRA 2000 reveal that the estimated net annual change in forest area world-wide in the 1990's was –9.4 million ha, representing the difference between the estimated annual rate of deforeststion of 14.6 million ha and the estimated annual rate of forest area increase of 5.2 million ha. The ASEAN countries account for 6% of the world total forest area. Forest in ASEAN region are of global significance in term of its biological diversity and conservation

Table 11 showed recent data published by FAO (2001) for forest resources in the 7 countries. Four countries showed that more that half of their land areas are still covered by forest. These countries are Malaysia, Indonesia, Cambodia and Laos. A third of Vietnam is covered by forest while it is 29% in Thailand; and Philippines has only 19%. When the data is converted to area per capita Indonesia, Thailand and Philippines has new low values, as these countries are all associated with high population densities. Laos with population density of 23 persons per km^2 has a value of 2.4. Malaysia and Cambodia recorded 0.9, Indonesia 0.5 while very low area per capita is recorded for Thailand, Vietnam and Philippines.

Table --- showed changed rate of forest over 10 year period as recorded by FAO (2001). Philippines has the highest forest loss with an annual decrease of 1.4%. This is followed by Indonesia and Malaysia 1.2%, Thailand 0.7%, Cambodia 0.6% and Laos 0.4%. Vietnam has an overall increased of forest over this 10 year period. The figures are much less than those given by WRI data. and when compared with study sites the national average is much less than those experienced by most study sites. The low value in the rates of deforestation from FAO data is due to the methods of calculating total forest. The total forest according to FAO refers to the sum of natural forest plantation and losses and gain the area of natural forest (2001). Other data do not include plantation forests as these forest do not have a biodiversity and ecosystem that qualify them to be referred to as natural forest.

5.4 Problems in Rainforest statistics

There are problems documenting rainforest statistics. Different countries often quote different forest statistics. United Nation bodies also derive their data from government statistics which in many cases register larger areas of forest. There is obviously a lack of geographically reference data at high spatial resolution and derived from a single consistent method for the whole of Southeast Asia. Other areas of data difficulties include distinguishing rates of new deforestation, abandonment and regrowth. Currently, the best method in solving them is via the use of satellite remote sensing method as it can resolve discrepancies in data output and spatial variations in rainforest cover statistics.

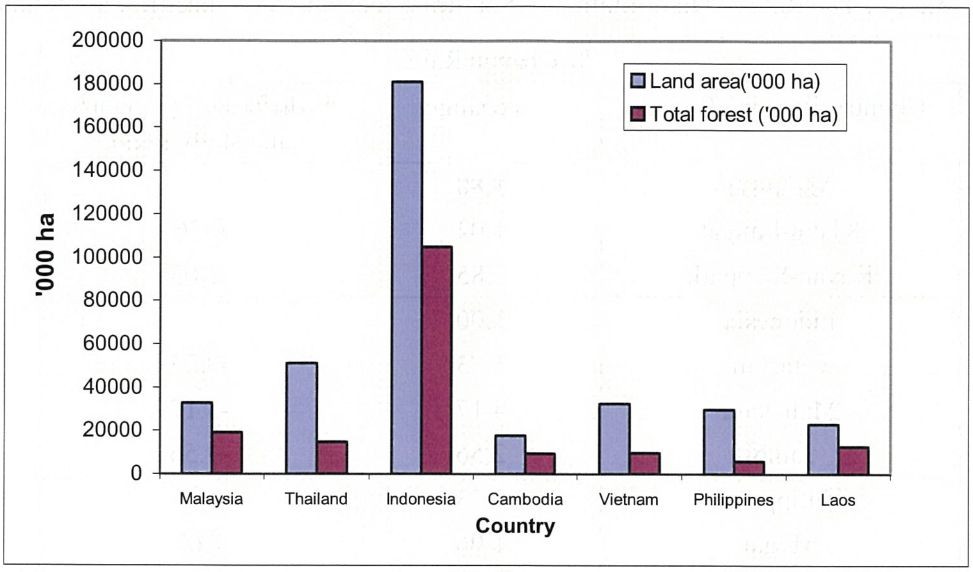


Figure 14 :

Table 10: Summary of Results from Satellite Data Analysis of Forest Areas and Their Rate of Change in Continental Southeast Asia. (Units are 10^6 h a or 10^6 per year)

Country	Forest Area in 1973	Forest Area in 1985	Forest Area Change	%Change	Deforestation Rate Per Year
Cambodia	5.25	3.98	1.27	24	0.11
Laos	18.28	16.52	1.76	10	0.15
Thailand	22.56	16.74	5.81	26	0.49
Vietnam	19.92	16.15	3.77	19	0.31
Myanmar	48.71	44.82	3.88	8	0.32
Total	114.70	98.21	16.49	14	1.37

Source: Skole (1998)

The above results gave the rate of deforestation for countries in Southeast Asia. These national rates data are compared to the site specific case studies data in Southeast Asia and the result is shown in table 11.

Table 11 : The Rate of Deforestation in Southeast Asia and Site Specific Case Studies

% Change Rate		
Country /case study sites	% change	% difference (country and study sites)
Malaysia	1.80	
Klang-Langat	1.04	0.76
Kayan-Sempadi	2.85	-1.05
Indonesia	1.00	
Citarum	1.73	-0.73
Mahakam	4.17	-3.17
Jambi	2.56	-1.56
Philippines	3.73	
Magat	1.06	2.67
Puerto Princesa	-0.0002	3.7298
Thailand	3.08	
Mae Chaem	-0.22	2.86
Lin Thin	-0.22	2.86
Phusithan	0.6	2.48
Eastern Forest	0.16	2.92
Ao Sawi	-2.17	0.91
Vietnam	2.89	
Tam Dao	-1.59	1.3
Cambodia	1.69	
Kg. Cham	-1.99	-0.3
Laos	3.96	
Nam Theun	-6.49	-2.53

6.0 OVERVIEW OF SOCIO-ECONOMIC MODELLING AND FORECASTING

6.1 Introduction

There are many socio-economic factors that could cause land use and land cover change (Turner and Meyer, 1994). These factors, also termed 'human driving forces', could be classified into population dynamics, economy, technology, political and economic institutions, and culture. Based on our understanding of these causal factors, a model could in theory be built to explain the change in land use/land cover. In addition, assuming that variations in land use/land cover and at least some of the causal factors could be appropriately identified and quantified, it is then possible to use econometric techniques to empirically estimate a model that explains land use/land cover change.

Model building and estimation are useful for at least two reasons. First, they provide a framework for testing the significance of some of the factors that have been hypothesized to be responsible for change. Second, it also enables forecasting of future land use/land cover changes to be made.

This report is intended to provide a description and a synthesis of the methods that were adopted and results obtained by various country teams in modelling land use/land cover changes in their respective countries. To the extent that different country teams have progressed at varying rates during the study period depending on their research circumstances, this chapter also allows for some evaluation of the relative achievements for different teams from the socio-economic modelling perspective.

The socio-economic modelling and forecasting section is organized as follows. The first section describes the general framework for socio-economic modelling of land use/land cover change. Subsequent, a section is devoted to individual country's modelling strategy and results. A synthesis is provided in the final section.

6.2 Socio-economic Modelling of Land Use/Land Cover Change

The ultimate goal of the socio-economic modelling effort is to construct a statistical model of land use/land cover change that is spatial in nature. A spatial model is not only capable of predicting structural changes in the relative composition of different land uses/land covers of the area under consideration but also in determining the locations of change. A model that only allows for predicting changes in the relative composition of different land uses/land covers is called a structural model. By nature, a spatial model is also a structural model but not vice versa.

Both modelling approaches are predicated upon the basic premise that there exist several significant causal factors (such as those proposed by Turner and Meyer, 1994) that are responsible for land use/land cover change. In its most general form, the relationship between land use/land cover change (LUCC) and the causal factors can be written as:
LUCC = f (population dynamics, economy, technology, political and economic institutions, culture,....)

Such general relationship is quite obviously has not yet lend itself to empirical estimation until some explicit functional form is assumed to represent the relationship between the variables. The most common and perhaps the easiest, functional form to work with is the linear function. The model in its assumed linear form can then be stated as:

$$LUCC_i = a + b_1X_{1i} + b_2X_{2i} + b_3X_{3i} + b_4X_{4i} + \ldots + b_nX_{ni} + e_i$$

Where LUCC is some measure of land use/land cover change, 'a' is a constant, X_1, $X_2 \ldots X_n$ are the causal factors, b_1, $b_2 \ldots b_n$ are the impact factors and e_i is the error term. Implicit in this modelling technique is that the current land use status of any plot represents its long run equilibrium state.

In other words, given a plot's relevant socio-economic, weather and soil attributes, its current land use is chosen because it yields the highest socio-economic return. Other functional forms (such as log-linear and double log specifications) may also be used. As a general guide, the functional form that provides the best fit to the data set is usually selected as the chosen function.

The next step involves empirical estimation of the above model[1]. Multivariate Ordinary Least Squares (OLS) regression technique is usually chosen for this purpose (see Mirer, 1995 or similar introductory texts for an overview). Alternatively the neural network algorithm can also be used for the purpose of estimating the relationship. Estimating the model requires measurements of both the dependent (LUCC) and the independent variables (causal factors). The problem that is quite common in this kind of study is that the causal factors may not lend themselves to direct measurements. In many cases suitable proxies are needed to represent some of the elements in the causal factors. It is also possible that because of data limitations, measures of some of the causal factors were simply not available.

The method that has thus far been described suffers from a very serious drawback in that it is not spatial in nature. Since land use/land cover of a plot of land is a categorical variable, the dependent variable employed in the empirical estimation procedure would have to be measured in terms of relative proportions of various land uses/land covers to allow for logical variations in the variable. However, by doing so the model renders itself incapable of making spatial predictions. In other words, such method only allows the estimation of a structural model. Predictions can be made but only in terms of proportions (and hence changes) accounted for by the various land uses/land covers and not the spatial characteristics of change. Fortunately, a probabilistic model can be estimated to overcome this problem. Estimating a probit, logit or multinomial logit model can serve this purpose. A logit model, for example, is specified below:

$$Log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} \ldots\ldots + \beta_3 X_{n,i}$$

Where P_i is the probability of a plot being a particular type of land use/land cover and the X's are the causal factors.

6.3 Summary of Various Country Models and Estimation Techniques

Teams from all countries have generally taken a very similar modelling approach[2]. They started with the basic premise that there exist several significant causal factors (such as those proposed by Turner and Meyer, 1994) that are responsible for land use/land cover change. Different country teams, however, do differ albeit slightly in their land use/land cover classifications and the causal factors adopted to explain land use/land cover change. A summary of the various country models, estimation techniques and results are given below.

a) Malaysia

The Klang-Langat river basin was selected as the study area. It is located between longitude 101° 17′ and 101°53′W and latitude 2° 40′ and 3°16′N. It spans the boundary of the states of Selangor and Negeri Sembilan and contains eight administrative districts. These districts are Gombak, Kuala Lumpur, Ulu Kelang, Sepang, Petaling, Kelang, Kuala Langat in the state of Selangor and Seremban in the state of Negeri Sembilan. In total, it covers an area of 3.809 million hectares. The watershed represents the most urbanized region in Malaysia. Kuala Lumpur, the capital city of about 1.37 million people in 1999, is located at the confluence of Klang and Gombak rivers. Combined with

Kuala Lumpur, Klang-Langat region has a population of 4.18 million (1999), which accounts for 20% of the country's total population. The importance of this region is reflected by its dominant position in the Malaysian economy contributing about 28% of the GDP with the area occupying only 1.3% of the total area of Peninsular Malaysia.

The modelling effort was directed towards determining the causal factors for change from forest to non-forest use. Observations were made at the 'pixel' level. A pixel is a square plot of land measuring 30 meters on each side. There are of course millions of pixels from which a random selection can be made for model estimation. However, in this study, 598 pixels at more or less equidistant from one another were manually selected. This selection method is adopted in order to maximize the distance between selected pixels to attenuate the problem associated with spatial auto-correlation. A value 1 is assigned to a non-forest pixel and 0 otherwise.

Various physical as well as socio-economic causal factors were considered in this study. Table 12 below provides a list of factors along with their operational definitions.

Table 12: Definitions of Causal Factors

Factors	Definitions
DIS2ROAD	The distance measured in km from the middle of a pixel to the nearest road.
DIS2TOWN	The distance in km from the middle of a pixel to the boundary of the nearest urban center.
LANDCLASS	Classified according to the Geological Department set criteria. Value=1 if land not suitable for agriculture and 0 otherwise
DENSITY	Corresponding district population density (Population in thousand per square km).
AGRIEMP	Agricultural employment as a percentage of district total employment
FOR_RES	Value=1 if located outside reserve area and 0 otherwise

Transport accessibility (DIS2ROAD) is measured by the shortest distance in km from a pixel to the nearest road. Measuring the distance requires overlaying a road network on a digitised satellite image of the area. A measure of a pixel proximity to the nearest urban center (DIS2TOWN) is also included in order to capture the impact of access to product markets on land use. The LANDCLASS variable measures the suitability of land to agricultural production. The probability of forest in a plot being cleared should be positively related to its suitability for agricultural production. This was found to be particularly relevant for forest clearing in Peninsular Malaysia (Brookfield *et al.*, 1990). Population density (DENSITY) is intended to capture the impact of population pressures on deforestation. It is measured by the number of people in thousands per square kilometre. Agricultural employment (AGRIEMP) is also included as an explanatory variable since agricultural activities tend to be relatively land intensive and variations in the percentage of agricultural employment to total employment across districts should explain differences in land use change including deforestation. Finally, a variable (FOR_RES) representing the impact of legal restriction on land use on deforestation is added to allow for an assessment of the effectiveness of the law and the relevant enforcement agency in preserving administratively designated forest reserve.

Results of the logistic regression are given in Table 13 below. Five variables were found to be significant at the 5% level, namely DIS2ROAD, LANDCLASS, DENSITY, AGRIEMP and FOR_RES. Only one variable (DIST2TOWN) was not significant and had the wrong sign. In the case of DIS2ROAD, a kilometre increase in the distance of a pixel from a road network reduces the odds of forest clearing by a factor of 0.6823. Conversely, this result says that access to a road network increases the probability of land being cleared for other uses. In addition, this finding implies that a carefully drafted policy on road construction can be a potent tool in influencing land use changes in general and deforestation in particular. It also tells us that a poorly planned road provision may result in unintended consequences. For example, providing a road link that passes through a forest area is likely to result in eventual conversion of land into other uses. This is true despite the fact that it was originally intended only to facilitate travels between two points. Conversely, it could be argued that providing road access to a previously undeveloped forest area can be a very attractive development policy instrument. The rapid rate of development along some stretches of the previously underdeveloped corridor of the North-South Highway's serves as an illustration of the impact of road access on land development.

The coefficient for the LANDCLASS variable indicates that the odds that a plot of land classified as 'unsuitable for agriculture' being non-forest falls by a factor of 0.2310 compared to a similar plot having 'suitable for agriculture' designation. Population density is the other factor that significantly affects the probability of forest clearing. The odds of a pixel being non-forest increases by a factor of 4.0170 for a unit increase in population density. The economic dependency of the local population on agriculture also influences the likelihood of forest clearing. The result indicates that the odds of a pixel being non-forest is increased by a factor of 1.27 for every one percent increase in agricultural employment of the district. The administrative designation of forest areas as reserves also appears to reduce the likelihood of forest clearing. The odds of a pixel located in a forest reserve maintaining a forest status is increased by a factor of 71.41.

The classification table given in Table 14 shows that the estimated model has good predictive power. Overall, the model correctly assigns 92.63% of the pixels although it does a slightly better job in predicting the non-forest ones.

Having empirically determined the significant causal factors, the study team is currently working on making forecast for future land use (forest/nonforest) changes and incorporating other types of land uses/land covers in the analysis.

Table 13: Logistic Regression Results

	Beta	**Wald**	**Sig.**	**Exp(B)**
DIS2ROAD	-0.3823	4.6011	0.0320	0.6823
DIS2TOWN	0.0304	0.3352	0.5626	1.0309
LANDCLASS	-1.4654	14.2219	0.0002	0.2310
DENSITY	1.3905	8.3956	0.0038	40.0170
AGRIEMP	0.2415	10.4513	0.0012	1.2732
FOR_RES	4.2685	1098345	0.0000	71.4122
Constant	-2.7802	10.3495	0.0013	

Table 14: Classification Table

Observed	**Predicted**		**Percentage Correct**
	Forest	Non Forest	
Forest	149	26	85.14
Non Forest	18	404	95.73

Overall Percentage	92.63

b) Indonesia

The Upper-Citarum Watershed was chosen as the study area. It is located in the Province of Bandung and is administratively managed by the Kotamadya Bandung Authority.

The modelling effort was directed towards determining the causal factors for changes that occurred between 1986 to 1995 for three types of land uses, namely urban/industrial, agriculture and forest. Observations were made at the sub-district level and because of constraints on data quality and consistency at and across many sub-districts, data from only 20 sub-districts were eventually used in the analysis.

The study team concentrated in determining only the socio-economic causal factors (Table 15) in their subsequent regression analysis.

Table 15: Socio-economic Causal Factors

Population growth
Change in population density
Population dependency ratio
Rate of growth in the number of school-going children
Change in the total number of school-going children (absolute change)
Growth in the number of households
The number of industrial establishment

Results of the OLS regression are presented in Table 16 above. Three variables were found to be significant at the 5% level, namely the rate of growth in the number of school children, the change in the total number of school children (absolute) and the number of industrial establishments in explaining changes in the size of urban/industrial land. Only one variable (the number of industrial establishments) was significant in explaining the change the size of agricultural land.

Table 16: Logistic Regression Results

Independent variables	**Dependent Variables**		
	Change in size of urban or industrial land	**Change in the size of agriculture land**	**Change in the size of forest land**
Population growth	213.622	-231.930	-214.480
Change in population density	5.779	16.760	10.440
Population dependency ratio	20.878	12.240	-37.129
Rate of growth in the number of school-going children	-301.541*	-207.520	560.967*
Change in the total number of school-going children (absolute change)	33.541*	2.108	-48.519*
Growth in the number of households	75.791	285.277	-452.470
The number of industrial establishment	3.682*	-6.062*	0.549

* Significant at the 5% level

In the third regression equation, only two variables (the rate of growth in the number of school children and the change in the total number of school children) were significant in predicting changes in the size of forest land. The signs of the coefficients were as expected. For example, the sign of the coefficient for the number of industrial establishment variable is positive for urban/industrial regression indicating that an increase in the number of establishment leads to a larger size of land devoted to urban/industrial use.

The model estimated by the Indonesian team is not spatial in nature and is therefore not capable in predicting the location of change for the various types of land uses. Efforts are, however, being made to estimate a socio-economic model that is capable not only in determining the significant driving forces of land use/land cover change but also in predicting the spatial aspect of change.

c) Philippines

Socio-economic modelling was conducted to explain the changes that took place in the size of forest cover in the Upper Magat Watershed in Nueva Viscaya between 1990 and 1992. Observation was made at the municipality level and thirteen municipalities were eventually included in the analysis out of fourteen that were initially considered.

Ten socio-economic factors were included in the econometric models as shown in Table 17. Four (4) multivariate statistical techniques were used to formulate models to explain the dynamics of forest cover change in the Upper Magat watershed with respect to a number of socio-economic parameters, namely: (a) Non-spatial regression analysis using Ordinary Least Squares (OLS) method; (b) Principal Component Analysis (PCA); (c) Cluster Analysis; and (d) Spatial data analysis using iterative approach on Maximum Likelihood estimation. Forest cover change (i.e., 1990 data –1992 data) served as the dependent variable of the models.

Using the OLS regression analysis, the results using backward elimination procedure are provided in Table 16. Although the analysis started with ten independent variables, only seven variables were found to be significant at the 5% level. With stepwise elimination approach, only "literacy rate" was found to be significant.

Table 17: Socio-economic Causal Factors

Number of households using *charcoal* as fuel for cooking
Size of farm
Size of irrigated area
Literacy rate
Size of area planted with permanent crop
Rural population
Size of area planted with temporary crop
Urban population
Size of woodland and forest in farm area
Number of household using *wood* as fuel for cooking

The regression coefficients along with the model standard error of 16,078.06 were used as inputs to spatial regression analysis employing the maximum likelihood approach. The parameter estimate β converged at values presented in Table 18 while the parameter estimates σ^2 and ρ converged at the values 65,998.54 and 0.05, respectively.

The value of ρ indicates the degree of spatial influence of one municipality on adjacent municipalities. Results indicate a very low influence of neighbouring municipalities on forest cover changes. Other proximity measures need to be examined as they may display a contradicting result compared to the outcome generated by the maximum likelihood approach. This model was developed to explore relationship of spatial patterns for use in spatial classification or discrimination rather than predicting location of forest cover change.

Table 18: OLS Regression Results

Independent Variables	Regression coefficients, β
Number of household using charcoal as fuel for cooking	-1.151*
Number of household using wood as fuel for cooking	0.421*
Farm areas	-0.237*
Literacy rate	-30.450*
Area planted with permanent crop	1.603*
Rural population	-0.05939*
Area planted with temporary crop	-0.086*
Woodland and forest in farm area	-0.963*

Table 19: Convergence Values of Coefficients

Parameters	Regression coefficients β	Std.Error
No. of HH Using Charcoal as Fuel for Cooking	-2.112427	5.461E-11
No. of HH Using Wood as Fuel for Cooking	0.6773429	3.424E-12
Area Planted with Temporary Crops	-0.135519	7.91E-13
Area Planted with Permanent Crops	1.7306479	7.129E-11
Area of Woodland Forest in Farm Area	-59.269203	2.784E-8
Rural Population	0.0951748	1.83E
Farm Area	-0.369218	9.685E-12
Literacy Rate	-11.215926	

Table 20 presents the results of the Principal Component Analysis which are the loadings of the original variables on the first three (3) principal components only. The table shows that virtually all agriculture-based variables loaded positively on the first principal component. These variables include " area of farms", "woodland and forest in farm area", "area planted with temporary crops", "area planted with permanent crops" and "irrigated area". This component differentiates agriculture-based from non-agriculture-based communities as indicated by the loadings. The second principal component has high positive loadings for "literacy rate" and "urban population" but high negative loadings for "forest cover change". This component broadly indicates the environmental awareness of the community. The component's negative loading for "forest change" suggests that high "literacy rate" and "urban population" contribute to the increase in forest cover. On the other hand, the third component has high positive loading for variables " number of households using wood as fuel for cooking", number of households using charcoal as fuel for cooking" and "rural population". These variables are associated with people in rural areas.

Lastly, results of the clustering technique was compared with those of the PCA to test the 'robustness' of its grouping. Results indicate no significant difference between the grouping based on the PCA scores and that using clustering technique. Thus, the grouping or classification of municipalities by either PCA or clustering technique is reasonably "robust". A confusion or error matrix shows that the overall accuracy of the clustering procedure using the different sets of data is about 93 percent or thirteen (13) out of the fourteen (14) municipalities have similar groupings regardless of the dissimilarity of the inputs.

Table 20: Rotated component matrix extracted using PCA

	Component		
	1	2	3
FARMAREA	.955	.145	6.727E-02
WFFARM	.834	.125	2.370E-02
PERMCRP	.757	-.249	-.238
TERMCRP	.753	.182	.302
IRRIGARE	.677	.524	.370
FORESTCH	-.276	-.854	.131
URBANPOP	-.221	.822	.191
LITERACY	8.484E-02	.817	.176
WOOD4CK	.281	-1.07E-02	.896
CHAR4CK	-.370	.128	.830
RURALPOP	.459	.497	.558

Extraction Method: Principal Component Analysis
Rotation Method: Equamax with Kaiser
Normalization
[a]. Rotation converged in 5 iterations.

d) Thailand

The Thai study team chose five sites for the purpose of their study. These sites were Mae Chaem (Chiang Mai), Lin Thin Watershed (Karnchanaburi), Phusithan (Nakarnphanom), Easter Forest (Eastern Seaboard) and Thung Kha (Chumporn). These sites were carefully selected to capture a wide and varying range of land uses/land cover. Socio-economic modelling was conducted to explain the changes that took place in the size of the various types of land uses from 1992 to 1996. Unlike the Malaysian, Indonesian and Filipino studies described earlier, the Thai team resorted to the descriptive method of explaining change. As a result no concrete links were established between the various types of land use changes and the socio-economic driving forces. Efforts are, however, currently underway to construct a quantitative model of land use/land cover change for the study area.

e) Vietnam, Cambodia and Laos

The Tamdao National Park and West Kampong Cham Province were selected by the Vietnam and Cambodia study teams. All study teams have not progressed much by way of socio-economic modelling mainly because of the fact that they began research work later than the first four country teams whose work had been described earlier. The teams had however managed to 1) identify several socio-economic driving forces that are potentially useful in explaining change, and 2) collect some baseline socio-economic data for future analysis. In the case of Vietnam, some descriptive assessments had also been done to link land use changes to the driving forces.

To summarize, all the study teams from the seven countries have made some significant progress towards a comprehensive modelling of socio-economic driving forces of land use/land cover change. The study teams for Malaysia, Indonesia, Philippines and Thailand are however, significantly more advanced than Vietnam, Cambodia and Laos in their progress towards the final goal. This is mainly due to the fact that the second group of countries (Vietnam, Cambodia and Laos) came into the research scene at a later stage (Phase 2) compared to the first group. Consequently, they did not have the advantage of building upon past research findings (from Phase I) for the purpose of developing a socio-economic model of land use/land cover change (Phase II).

Although data collection activities were conducted with the view of constructing a spatial model, only the Malaysian (and to a lesser extent the Filipino) teams had made some attempt in that direction. For the rest of the study teams, the determination of the significant driving forces had been undertaken within the context of a structural model. Despite this limitation, the modelling efforts conducted thus far have been quite successful in enhancing our understanding of the socio-economic driving forces responsible for land use/land cover change.

6.4 Summary Of Causal Factors: An Overview

In explaining the causal factors behind the deforestation process participating (Vietnam, Cambodia & Laos) qualitative assessments in linking land use changes to the driving forces. Malaysia, Philippines, Thailand and Indonesia have generally taken a very similar modelling approach. Their assumption is that there exist several significant causal factors that are responsible for land use and cover change. Multivariate ordinary Least Squares regression is the technique chosen for their analysis. The result of the variables that are significant at 5% level is given in Table 21 below.

Table 21 : The Significant Socio-economic Variables in Explaining Tropical Deforestation in the Study Sites

Country	Variable
Malaysia	• road distance from forest area • land classes suitability • population diversity • agricultural employment • forest reserve and non reserve area
Indonesia	• rate growth in the member of school going children • change in the total member of school going children • member of industrial establishment
Philippines	• number of household using charcoal as fuel • number of household using wood as fuel • farm areas • literacy rates • area planted with permanent crop • rural population • areas planted with temporary crops • woodland and forest in farm areas
Thailand	• population structure • population age • number of household with pick up truck • number of shops • number of rice mills • number of household practising agriculture

The result shows that population dynamic variables explain 54.5% of the land use change in the four countries, combined agriculture and economic variables explain 18.2% while economic variables explain 13.6%. Other significant variables are policy 9.1% and road network 4.5%. Philippines case study has the most population dynamic variables as significant variables. Empirical findings of LUCC research show that there are no single variable that can explain causes of deforestation. The factors are few and most frequently interrelated. The results show that for this study the combination factors are population dynamics, road, agriculture and economics. They are all driven by policy, institutional and cultural factors combined. Forest loss is the most significant land use change in most sites.

7.0 THE CAUSAL FACTORS OF LAND USE AND LAND COVER CHANGE : COMPARISON OF RESULTS FROM OTHER STUDIES.

Understanding the drivers of land use and land cover change is a complex issue. The causes attributed to LUCC are multivariate in nature are multivariate in nature, interrelated and differ at local, national as well as regional scale. Some of the data are not readily available while some have to be generated. To achieve the research objectives one has to reduce the complexity of the driving factors by resorting to single and few factors causation rather than the realistic multiple, simultaneously and synergistically related factors. The drivers of tropical deforestation can be summed up as complex socio-economic processes that are impossible to isolate a single cause. Mc Neill (1994) refers to the driving forces as a theoretically informed set of choices and distinction, designed specifically for the purposes of capturing the most consequential human and environmental causes of land use change. Lambin (2001) explain the underlying forces of deforestation as fundamental forces that underpin the more obvious or proximate causes of tropical deforestation. They can be seen as a complex of social, political, economic, technological and cultural variables that constitute initial conditions in the human-environmental relations that are structural (or systematic) in nature. In terms of spatial scale, underlying drivers may operate directly at local level or indirectly from the national or global level.

Many literatures broadly group the driving forces into various categories (Turner 1989, Stern 1992, Geist 1999, NRC 1999, Sharifah Mastura *et al* 2000). Lambin and Geist (2001) compile the most detail grouping of the drivers of tropical deforestation. These are a complex set of actions and factors involved in deforestation. They are given in three clusters as follow:

(i)	Proximate causes:	Agricultural expansion Wood extraction Expansion of infrastructure
(ii)	Underlying causes:	Demographic Economic Technological Policy/ institutional Cultural or socio- political factors
(iii)	Other factors (land characteristics, biophysical drivers, and social trigger events)	Land characteristics Biophysical environment War Health and economic crisis Government policy failures

Population Pressures

Rising population in Southeast Asia is often cited as the most important cause of deforestation. This is due to the increase number of rural families seeking land to cultivate, fuel wood and timber. There are also expected demand for agricultural and forest products. Population increased also induced technological or institutional change.

Mayers (1980) notes, with that kind of population increase and per capita crop land decrease forest farmers would convert more tropical moist forest for crop cultivation. Meyers attributes 82% of the global conversion rate of tropical moist forest to logger and forest farmer's interaction i.e. loggers log the forest and then leave, while the farmers follow logging roads to new accessible forest areas for cultivation. The extensive use of forest environments does not encourage regrowth and regeneration of new forests. As such the activities result in permanent conversion of land use from forest to agriculture or marginalization or degradation of forestland.

However, it is interesting to note that in explaining deforestation factors, human population dynamics it is only the fifth most important among five directly underlying driving forces considered. Lambin (2001) notes that many causes of deforestation could be related to human population dynamics. For example, demographic factors especially in-migration and expansion of cropped land and pasture explained 47% of deforestation. Mathers *et al* (1998) summarises it as " approximately half in statistical terms are explained by variation in population. Allen and Barnes (1985) conclude that population growth alone as the primary cause of deforestation can be rejected against empirical evidence from other more important underlying driving forces.

Demographic factors are deemed to be important drivers only when they are related or combined with other underlying causes. Lambin and Geist (2001) show the indirect effects of population variables. Cheap abundant production factors (including labour) accounted for 6% and special cost condition (mainly low labour costs) for 7% of all causes of deforestation. Demand for wood products explains deforestation by 32% than demand for agricultural products, which is 18%. Given causes where both demand (labour and forest products) overlap a total of 41% of the causes explained deforestation. Meanwhile demographic factors that underline technological/policy changes further explain up to 13%. Generally from many studies population dynamics do not operate as a single and direct causative factor. However, it becomes crucial when these factors are related to other underlying causes.

Applying the result from LUCC case study sites, four countries showed that population dynamic variable explain 54.5% of LUCC. This is much higher than finding from other region.

Improved Infrastructure And Utilities Network

In the past, many countries in Southeast Asia have been successful in maintaining high growth rate for several years. To sustain this high growth it is essential to have a well-developed and integrated infrastructure and utilities network. The provisions in this network include transportation, telecommunication, postal, electricity, water supply, sewerage and gas pipeline. It is also very necessary for the governments to expand the infrastructure network into rural areas to allow progress into these areas. In fulfilling such a need for excellent road network requirement, extensive corridors need to be provided far up to 400m. In most cases their road alignments transact through tropical forests that have been allowed to be converted.

Analyses of land use and road maps in the Philippines and Malaysia show that the closer the forest to the road the higher the rate of deforestation (Lin *et al* 1992 Sharifah Mastura 2000). 78% of the 2.1 million ha of forest within 1.5 km from the roads in 1934 was removed by 1988. On the other hand only 39.5% of forest between 15.0 and 16.5 km from the road were lost. In Malaysia, LUCC study showed that a kilometre increase in the distance of a pixel from a road network reduces the odds of forest clearing by a factor of 0.68. This means that access to road network increases the probability of land being cleared for other uses. Lambin and Giest (2001) show that extension of infrastructure in combination with other proximate causes explain 110 out of 152 cases of deforestation (72%).

Other Causal Factors

Besides the above factors there are many other driving forces of LUCC. Case study examples showed significant variables which can be mainly categories into population dynamic, agricultural and infrastructural expansion and economic variables. They are mainly proximate causes while the underlying variables are not considered in detail due to lack of data and information. Other factors that cause land use and land cover change include Land settlement scheme, large scale commercial agriculture, commercial logging, powerty and hydrolute dam (Sharifah Mastura 2001).

8.0 IMPACT OF LAND USE AND LAND COVER CHANGE

Land use and land cover change, especially the conversion of forest to other uses, have been associated with environmental degradation issues that have directly increased the real cost of development. In Southeast Asia policies in favour of economic growth over environment protection are common. The Southeast Asian government are aware of the long term policy option that the countries have to bear as a result of the rapid land use changes. Malaysia, Indonesia, Philippines are a head in the development of environment policies while Vietnam, Cambodia and Laos are actively formulation theirs. The most important impacts caused by rapid paced land use configuration affects distribution, abundance of plant and animal population. Comprehensive records potential loss of biodiversity has been estimated at between 15,000 and 50,000 species per year deforestation (Manakaran, 1993).

Table 22 below shows natural habitat loss in Southeast Asia. Most countries showed high percentage loss that without policy intervention would lead to invaluable social cost to society as these loss are irreversible.

Table 22: Natural Habitat Loss in Southeast Asia

Country	Original Wildlife Habitat (km^2)	Amount Remaining	Habitat Loss (%)
Indonesia	1,446,433	746,861	49
Cambodia	180,879	43,411	76
Laos	236,746	68,656	71
Malaysia	356,254	210,190	41
Philippines	308,211	64,724	79
Thailand	507,267	130,039	74
Vietnam	332,116	66,423	80

Source: IUCN/UNEP (1986)

Species loss has serious implication on human society as a whole. These species provide an enormous potential in the field of medicine, agriculture and other industries. At present 25% of the world's pharmaceutical products are derived from tropical plants.

(i) Soil erosion and sedimentation

Under natural conditions, tropical forest intercepts 21-36% of the annual rainforest while forest litter and almost absence of bare ground minimize surface erosion. Forest also protects the highly weathered material that is a product of deep weathering in tropical climate. However modification of these conditions due to land use changes often results in an accelerated soil loss and substantial increase in river sediment loads and siltation. Table 23 below shows some of the selected soil erosion studies conducted under various conditions and methods in forest areas. The rates vary from place to place and under different land cover conditions. In forest area soil erosion is minimal. However, examples from bare ground give very high rates of erosion.

Table 23: Selected Soil Erosion Studies Conducted under Various Conditions and Methods in Forests Areas.

Source	Location	Soil Erosion Under Forest	Soil Erosion Under Specified Land Uses
Baharuddin, *et al.* (1995)	Tekam Forest Reserve , Malaysia	453.7 kg ha^{-1} yr^{-1}	-
Hatch (1981)	Semangkok Forest Reserve, Malaysia	0.5 t ha^{-1} yr^{-1}	-
Malmer (1996)	Mendalong Sabah, Malaysia	38 kg ha^{-1} yr^{-1}	-
Wiersum (1985)	Jawa, Indonesia	0.03 kg m^{-2} yr^{-1}	1.59 kg m^{-2} yr^{-1} (bare ground)
Hatch (1983)	Sarawak, Malaysia	4-14 t km^{-2} yr^{-1}	5321-13, 912 t km^{-2} yr^{-1} (cultivated paper)
Sharifah Mastura (1992)	Bangi Forest Reserve, Malaysia	0.3-0.49 t ha^{-1} yr^{-1}	3600 t ha^{-1} yr^{-1} (bare ground)
Sabri Al Toum (1996)	Tekala River Forest Reserve, Malaysia	0.85 t ha^{-1} yr^{-1}	-
Ng and Teck (1992)	Niah Forest Reserve, Malaysia	8.3-31 t km^{-2} yr^{-1}	-
Petch (1985)	Forest	10-23 t km^{-2} yr^{-1}	8100to 9000 t km^{-1} yr^{-1} (paper cultivation)
Suki & Jaafar (1990)	-	-	200 t km^{-2} yr^{-1} (disturbed forest and mixed land use)

Another effects of deforestation due to land cover change is the carbon cycle. Forest absorbed carbon dioxide but deforestation adds considerable quantities of carbon dioxide to the atmosphere. It is stated that deforestation contributes between one 25% to 50% of the five billion tons released from burning of fossil fuel. Systematic measurement of atmospheric carbon dioxide was made in the late 1950's and the carbon dioxide concentration has steadily increased. This is due to two sources i.e. land cover change mainly due to deforestation and combination of fuels (Skole 1998). Human driving forces have caused the land transformation from forest areas to agriculture, and long term process of about 300 years has released continuous carbon to the atmosphere. The release of carbon attributed to land cover conversion is a major biogenic source of carbon in Southeast Asia. The current net flux of carbon from land cover conversion in the tropics is expected to rise if deforestation issues are not abated.

The Greenhouse effect due to increase in the loading of carbon dioxide in the atmosphere would lead to global warming. The negative consequences of global warming are catastrophic. These include increase in droughts and desertification, crop failures and coastal flooding. Current study by Eswaran *et al* (2001) indicates land areas in Southeast Asian countries which are prone to desertification. Countries with distinct dry period seasons are vulnerable. Philippines, Thailand, part of Indonesia and Myanmar are the most affected countries with process to desertification by more than 10% forest destruction areas in these countries are the prone areas.

9.0 IMPACT OF POLICIES

The seven participating countries have put forward various policy and institutional option in minimizing the negative impacts of tropical deforestation as mentioned earlier and sustaining forest for the future. The following are summaries of the policy options given according to each country.

a) Malaysia

The pertinent question to ask is why Malaysia converts is land use and land cover especially forest at such an alarming rate that it may threaten their functions. The main reasons are attributed to relevant national policies that have direct impact of land use change. The most important policy being the land policies. Land policies are mainly covered under two major legistrations. These are the National Land Code 1965 and Land Conservation Act 1960 for Peninsular Malaysia, Sarawak Land Ordinance 1948 and The Sabah Land Ordinance 1930. These legistrations provide detailed framework governing the administration and alienation of land. The major concern regarding land policies is the liberal attitude towards land alienation. This is normally linked to a strong commitment to eradicate poverty and providing land to the landless.

The other important legistration related to land use and land cover change is The EQA 1974, particularly the amendment of 1987, that introduced the Environmental Impact Assessment report. Under EIA Order 1987 major land use changer can take place from forest cover to other uses such as agriculture settlement and industrial areas. This has been critiqued by many agencies and public sector that we sensitive to environmental issues. It is suggested that all projects involving forested land should be removed from list of prescribed activities required an EIA. Instead, all forest areas in Malaysia should be defined for various functions after detail investigation. Those forest with important functions should be classified as Permanent Estate under the National Forestry Act 1984. The designated Permanent Forest Estate is formally gazetted and cannot be touched for any development purposes.

Land Acquisition Act of 1960 allows all state government to acquire land for economic purposes. Thus under such laws, extensive land areas in the state which include forest are being change to other commercial land uses. There are extensive environmental damages and long-term impacts of such conversion as well as cases of abuse. The 1996 land acquisition via this Act had been suspended until amendment to the Act is carried out in the near future.

Policies on infrastructure and utilities network also affects land use and land cover change. To sustain high growth up to 8%, it is essential for Malaysia to have a well-developed and integrated infrastructure and utilities network. In fulfilling the need for excellent road network requirement, extensive corridors need to be provided for up to 400m. In most cases their road alignments transect through developers and agriculture land that has been acquired by developers and subsequently converted to road corridors. All the above policies in Malaysia explain why forest land can be easily converted to other land uses. Only forest that are declared as Permanent Forest Estate will remain as forest as it is protected under the National Forestry Act of 1984.

b) Philippines

Forest regeneration was detected in the municipalities of Diadi, Aritao and Solano by visual interpretation and comparison of the classified Landsat images from 1996 to 1998. This regeneration was due to Integrated Social Forestry Programme Conducted from 1979 to 1996. Moreover on January 16, 1990, a logging moratorium was issued prohibiting the exploitation of forest resources within the watershed area. Some of the forest occupants are aware of these policies and others have even approved the reforestation programmes of the government.

No Timber Licensee Agreement (TLA) has been executed in Magat Watershed since its declaration as forest reserve in 1969. TLA is a privilege granted by the state to a person to utilize forest resources in any forest land without any right of occupation and possession over the same to the exclusion of others, or establish and operate a wood processing plant, or conduct any activity involving the utilization of any forest resources.

In Puerto Princesa, commercial logging has been totally banned since the enactment of Republic Act 7611, otherwise known as the Strategic Environmental Plan (SEP), on June 12, 1992 and the issuance of the Administrative Order No. 45 dated October 21, 1992. Because of this development, large-scale deforestation is prohibited and gathering of forest products is limited to minor forest products on a regulated production. The minimal decrease of about 0.24% in the area of forest in Puerto Princesa City from 1990 to 1998 can be attributed to this development.

Given the policies and programmes of the government for Magat Watershed and Puerto Princesa City, their deforestation cannot be attributed to commercial or large-scale logging but to small-scale forest clearing activities for fuelwood and timber for household consumption or for other purposes.

c) Thailand

In Thailand logging concession ceased in 1989. Since then many policies for forestland protection were issued. Forest reserve title does not ensure that the area is truly protected. In 1990-1995 a total of 539.4 and 2588 hectare of forest in the forest reserve area were converted to other land uses mainly agriculture. In non-reserve area the conversion of forest area is much less only 45.6 hectare. In 1995-1999 a further 497.88 and 264.49 hectare were converted to other uses where in non-reserve area the figure is only 64 hectare.

Increased in forest cover for other land use is mixed only 81 hectare for 1990-1995 and 263.2 hectare in 1999. Therefore forest loss is so much higher than forest gain. The conservation and reserve forest area do not ensure sustainability of the forest land use.The commitment and will power in enforcing the law is obviously lacking. The above result is also true for about 50% decreased in forest land use occurred in forest reserve and conservation area. In Phusithan the loss of forest area in the reserve and conservation area is the highest during 1990 to 1995. About 70% of forest land cover change in the reserve area. However, for 1990-2000 there was a high increase in forest area for other land uses (7730 ha). This is attributed to the declaration of the area as wildlife sanctuary. Enforcement of the conservation and reservation of forest area fully enforced and successful.

d) Vietnam

In Vietnam the drivers of land use and land cover change are shifting cultivation, shrimp farming, illegal logging and agriculture intensification. So ensure that the forest are being protected from further depletion, the country has introduced various measures under the decree no 58-LCT dated 12-08-1991.

Article 18 stated that people's committee of all levels in their functions, duties and rights as well as foresters have to manage and protect the existing forest system, prevent forest-damaged action, carry out method of protection and development of forest-plant and animal, protect water resources, land and against erosion. Articles 9 to 25 of the code also requested what should be done to conserve and develop the forest. Local authorities have tried their best to implement the law on forest protection and management. The legal basis of this code has provided the authority with the intent to take action on those who violate the law. As a result deforestation, forest damage and forest fire have reduced considerably since the implementation of the code.

In 1994, the government introduced circular no. 02-CP providing forest land to organization, household, individuals for stable and long term use of forest. The circular covers various articles from using the land profitably to regulation on rewards and penalty as well as protect the land. This circular designate people to the responsibility of the forest management. Thus irresponsible deforestation, forest fire etc become less when people are given such a responsibility over the forest.

Bare land and damaged forest are also required to be replaced responsibility. As such the standard thing for people who manage forest properly also increased. The Vietnam government has also step up its efforts in further providing the education on sustainability of the forest to the people.

e) Cambodia

Cambodia's Protected areas was under the Royal Decree on Creation and Designation of Protected areas in November 1993. This was follow in 1996 by the enactment of the law on Environmental Protection and National Resources Management which reaffirmed the Ministry's mandate on protected areas and other aspects of Environmental Management. Other instruments (Sub-Decrees, Regulations, Prakas) are needed to cover the operational aspects of protected areas, including the process of designating, gazetting, preparing and implementing management plans. Environmental Impact Assessment Regulations was also introduce to conserve biodiversity.

The MoE, under the Royal Decree establishing a Protected Areas system, is responsible for managing protected areas. And, also The Ministry of Agriculture, Forestry and Fisheries has the mandate forests outside protected areas, including inundated forests, mangroves, primary and secondary forests and wildlife. Timber and another forest products should continue to play an important role in economic development. However, to ensure sustainable use of forest resources, policies and regulations need to be update and the management capacity of the forest department strengthened. The department has already begun to define the government's role in the sector by form formulating a six-part strategy for sustainable development of forestry and wildlife.

The strategy identifies six areas of concern and action, including strengthening the institutional frame work (i.e. legislative reforms and organizational responsibilities); developing human resources and managing forests and wildlife (including land classifications and inventories); use of forests and wildlife (managing concessions and developing forest industries); establishing and foresting plantations; and strengthening international cooperation (working with neighbouring countries on enforcing forest laws and with donor countries on a coordinating assistance.

However, the enforcement of the environmental regulations are not strongly adhered to. Lack of political will to enforce the regulation has caused the forest to deplete further. Enforcing this regulation in term of monitoring their compliance and sanction violation has been hampered by shortage of qualified staff, equipments and vehicles.

10.0 CONCLUSION

LUCC case studies have successfully developed an operational methodology for monitoring LUCC overtime. The annual changes of LUCC and multidate for some countries detected the rapid rate of change especially in the forest sector. In some countries intensification of agriculture has shown to exert pressure to other land uses. The causal factors of LUCC were also identified and analysed. Land use and land cover changes were monitored from time series data between the 1980's and 1990's. The primary tools used for the analysis of the satellite imagery were remote sensing and GIS techniques. Study sites covering a reasonable size area for micro-scale analysis were mostly selected in the watershed area.

Results of the studies focused on two areas. First, improved scientific understanding of the role of Southeast Asia in terms of global change through its influence on the global carbon cycle and the role of human dimensions causing LUCC. Second, the development of a solid network of scientists in the region through capacity building and development of data management systems. The case studies show significant results. The land use and land cover changes in the forest area has been shown to be an important component in the global carbon budget. Overtime forest have been converted to agricultural lands, urban and settlement areas, water bodies and recreational areas and other land use categories. Human activities are the dominant underlying forces of these changes. The studies indicate that population dynamics variables play an important roles in explaining LUCC. Others include combined factors of agriculture and economic variables. However in some countries policy driven parameters and infrastructure expansion are important in making the conversion of forest easier and faster.

Some case studies elaborated on the usefulness of a logistic regression model in explaining the change while three new participating countries chose qualitative approach in explaining change. The regression models could be expanded into dynamic models for LUCC to predict future trend of change. There are currently various models being studied within the network such as the Land Transformation model and the CLUE model. Both models have been successfully applied to Klang-Langat site. The use of dynamic models to other sites are being planned for the future.

The LUCC mapping adopted in this research only detected the dominant features for each category. It does not indicate multiple landuse which is sometime common in tropical areas. Forests for example are mapped as discrete class without further indication of their denseness and matureness, which are important input to the study of sustainability science. To further improve on the value of the information system the research network has already initiated selected sites within the region to carry out a fractional forest cover mapping. The project is also funded by APN. Fractional forest cover mapped an image pixel as a continuous field variable that characterised how much of the pixel is actually forest. In the field this derived estimates can be validated by measuring the canopy closures. Thus fractional forest cover mapping improves further the quality of LUCC data. Such data can be linked to forest biophysical parameters which are vital input to forest resource management.

There are few recommendations that can be put forward for future work in LUCC research. The case study approach should be upscale to a multi-date wall to wall coverage for the whole country and Southeast Asia region. Full scale coverage would certainly be very useful to the decision makers as the information provided would significantly strengthen each country national capacity to assess their national resources systematically as well as to monitor environmental change arising from land use change. The knowledge and experienced acquired allowed the Southeast Asian countries to participate effectively in international agreement and conventions.

The LUCC classification system adopted in this study has been developed independently within the network. It is not a universal land classification system but has been devised to suit the region's requirement. In the future, adopting the standard system such as the Land Cover Classification System (LCCS) formulated by the UN-FAO would have an advantage for comparison purposes.

The successful completion of the project has allowed the researchers to participate actively in several important international programmes. The more significant ones are the development of the Global Observation of Forest Cover (GOFC-GOLD) programme, which is a collaboration of the space agencies, IGBP and other participants in the Global Observing Systems. The other important international programme is the Millennium Ecosystem Assessment that is developed to improve the management of the world's natural and managed ecosystems. This is achieved by meeting the needs of decision makers and the public for policy-relevant scientific information on the condition of ecosystems, consequences of ecosystems change and option for response. Another interrelated programme in the region is the UN-FAO project on Asia Cover. The main objectives of the projects is to develop landuse map, digital database and statistics based on existing landcover information to facilitate regional cooperation for food security, sustainability and environmentally sound agriculture in Southeast Asia.

The researchers in this LUCC project team has established the Southeast Asia Regional Research Information Network or SEARRIN. The network is now ready to take up the challenge of the above new projects as well as other integrated science work within the framework of global change.

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APPENDIX 1

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