Assessment and Monitoring of Land Use/Land Cover Change in Continental Southeast Asia

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Abstract

Land use/land cover change particularly that of tropical deforestation and forest degradation have been occurring at an unprecedented rate and scale in Southeast Asia. The rapid rate of economic development, demographics and poverty are believed to be the underlying forces responsible for the change. Accurate and up-to-date information to support the above statement is however, not available. The available data, if any, are outdated and are not comparable for various technical reasons. Time series analysis of land cover changes and identification of driving forces responsible for such changes are needed for the sustainable management of natural resources and also for projecting future land cover trajectories. We analyzed the multi-temporal and multi-seasonal NOAA AVHRR satellite data of 1985/86, and 1992/93 and SPOT VEGETATION data of 1999/2000 to (1) prepare historical land cover maps and (2) to identify areas undergoing major land cover transformations (called “hot spots”). The identified “hot spot” areas were investigated using high-resolution satellite data such as Landsat and SPOT supplemented by intensive field survey. Shifting cultivation, intensification of agricultural activities and change of cropping patterns, and conversion of forest to agricultural land were found to be the principal reasons for land use land cover change in Oudomxay province of Lao P.D.R, Mekong Delta of Vietnam and Loei province of Thailand respectively. Moreover, land use/land cover dynamics of the region and a typical land use/land cover change patterns of the ‘hot spot’ areas were also examined. We also developed a field-based methodology for land use/land cover change analysis at the national level with the help of national remote sensing institutions.

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1. BACKGROUND

Land use/land cover change, particularly that of tropical deforestation and forest degradation have been occurring at an unprecedented rate and scale in Southeast Asia (Lebel and Steffen, 1998, Giri et al. (2000) and Stibig et al. 2001). Years of high population growth, rapid economic development and poverty are believed to be important factors responsible for the change, threatening all major ecosystems of the region. Recently, the increased awareness of on-going and emerging environmental issues and the need to strive for sustainable management of natural resources have focused attention of the scientific community and international organizations to map and monitor such changes on a regular basis.

The available vegetation and ecosystem datasets (Mathews, 1983; Olson et al; 1983) compiled from ground surveys or various national sources are outdated and are not suitable for regional and national applications. It is also necessary to understand national and regional issues and priorities at appropriate scale so as to help address global environmental change issues. Having realized the necessity of this information need, UNEP GRID-Bangkok (United Nations Environment Programme, Global Resources Information Database-Bangkok) started land cover assessment and monitoring project in South and Southeast Asia in 1991. This paper presents a synopsis of this project.

2. OBJECTIVE

The overall goal of the project was to (1) assess and monitor the major land cover types, (2) identify areas undergoing major land cover transformation (called “hot spots”), (3) investigate identified ‘hot spot’ areas in detail and (4) build the capacity of sub-regional/national institutions. Specific objectives were:

1. Prepare cloud free and georeferenced mosaics of Southeast Asia using NOAA (National Oceanic and Atmospheric Adminstration) AVHRR (Advanced Very High Resolution Radiometer) satellite data;
2. Prepare time-series land cover maps of selected countries in South and Southeast Asia;
3. Identify ‘hot spot’ areas and investigate in detail using high resolution satellite data and ground survey;
4. Develop methodological guidelines and land cover classification system suitable for the project;
5. Training and hardware/software support to national institutions;
6. Regional aggregation and analysis and serve as a regional data gateway to transfer data from global to regional, national and sub-national level and vice-versa.

3. Study Area
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The study area covers countries in continental Southeast Asia including Myanmar, Thailand, Lao P.D.R, Cambodia, and Vietnam (Fig. 1).

![Location Map of Continental Southeast Asia](image)

**Fig. 1. Location Map of Continental Southeast Asia**

4. **METHODOLOGY**

4.1 **Data acquisition**

NOAA AVHRR HRPT (High Resolution Picture Transmission) and LAC (Local Area Coverage) data acquired at Thailand Meteorological Department (Thailand), National Research Council of Thailand (Thailand), EROS Data Center (USA), State Meteorological Administration/Satellite Meteorology Center (China) and National Oceanic and Administrative Administration/National Environmental Satellite Data Information Service (NOAA/NESDIS) was used for preparing the mosaic and land cover map of 1985/86 and 1992/93. SPOT VEGETATION data was used for 1999/2000 analyses.

4.2 **Pre-processing**
The AVHRR data were preprocessed for data extraction, noise removal, radiometric calibration, geometric correction, and cloud masking. The HRPT Level-IB data were received in packed format that was converted from BIL (Band-Interleaved-by-Line) to BSQ (Band-sequential) using in-house program. The original radiometric resolution of 10-bit pixel value was maintained by using two bytes for each pixel for all five channels. The bad/noisy lines were identified by visual inspection of each channel. All such bad/noisy lines were marked as being areas of 'no data' by assigning zero values.

Radiometric calibration was performed using the procedures described by European Space Agency (ESA, 1991) Handbook on ‘SHARP LEVEL-2: Development Procedures and Format Specifications' and by NOAA Technical Memorandum NESS 107 (NOAA/NESDIS, 1988) on 'Data Extraction and Calibration of TIROS-N NOAA Radiometers'.

Due to the lack of atmospheric data, atmospheric correction was not performed. To reduce the bidirectional reflectance effect caused by the viewing geometry and surface angular anisotropy affects of AVHRR channels 1 and 2 (Gutman 1991), images taken at large view angles (off-nadir views) which fall at the extreme of the scan line was excluded for the analysis.

A two-step procedure was used for the geometric correction of AVHRR images. The images were first resampled to a reference map projection based on locational data generated by orbital model navigation. They were then further corrected by a linear first order rectification based on ground control points.

An interactive visual cloud masking procedure was used to identify the threshold value for clouds. Use of such procedure proved to be highly effective in removing clouds without losing useful data. An average of only 6 per cent of transparent and mixed clouds (mixels) remained in the images after cloud removal.

Finally, country masks were generated by rasterizing the vector boundaries of the study area. Digital vector boundaries were obtained from the World Data Bank II (WDB II, 1990).

4.3 Classification

Unsupervised classification was performed followed by interacting labeling (Fig. 2). Both summer season and harvest season data were used to capture the seasonality information. Secondary information such as old land use maps, forest cover maps etc. were used during the analysis supplemented by ground survey in selected areas.

5. Results and Discussion

5.1 AVHRR Mosaic

AVHRR mosaics were prepared and distributed in both hard-copy and digital format. The first mosaic was prepared using AVHRR data of 1990/1991 covering Southeast Asia (Fig. 3) and the second mosaic was prepared using 1998/99 AVHRR data covering whole continent of Asia. The mosaics were prepared with a geometric accuracy of ± 1 pixel (approximately ± 1 KM). Both spatial and spectral enhancements were performed to improve visual appearance.

These mosaics were found to be useful for visual and digital interpretation to derive information for land use/land cover mapping, forest cover mapping, and environmental
assessement and monitoring. The mosaic was particularly useful for a comprehensive overview of land cover at a regional scale (Defourny et al., 1994). The hardcopy map became very popular among policy/decision makers across the region. The digital and/or printed version of the cloud free mosaic is available on request from GRID-Bangkok.

Fig. 3. AVHRR Mosaic of Southeast Asia

5.2 Land Cover Classification Scheme

Both harvest season and summer season data were used to capture seasonal phonological differences of vegetation. In defining land cover classes both user’s requirements and sensor’s capabilities were considered.
The proposed classification scheme (Fig. 4) does not necessarily yield results with high classification accuracies in all the countries. Thus, country specific modifications were made to suit local terrain conditions. This classification scheme is based largely on the experience gained from the nine South and South East Asian countries (Nepal, Bangladesh, Thailand, Myanmar, Lao P.D.R., Cambodia, Vietnam, Philippines, Malaysia).

### 5.3 Land Cover Maps

The land cover maps of 1985/86 and 1992/93 were prepared for Myanmar, Vietnam, Thailand, Lao P.D.R and Cambodia. The digital data and country report are available at [www.rrcap.unep.org](http://www.rrcap.unep.org) or is available on request from GIRID Bangkok. Major land cover types discerned were forest, crop land, grass land, marshes, barren land, shrub land, savannas, snow & Ice and waterbodies. Forest have been further subdivided into evergreen, deciduous and mangrove forest. Country specific variations in selecting the classes and details were noted to be of practical use. These classes were regrouped into 7 classes for regional aggregation and manipulation.
Major findings of land cover analysis are presented below.

1. Cloud-free 1985/86 data of Lao P.D.R. was not available and hence was not included in the present analysis.
2. Persistent cloud cover in many parts of Southeast Asia is a major problem working with optical remote sensing.
3. NOAA AVHRR data are available in the region but systematic archive of these dataset are unavailable. EDC and NOAA/NESDIS are two important data sources for historical datasets.
4. Pre-processing of NOAA AVHRR is time consuming and tedious. One encouraging sign is that many commercial software packages are now accommodating AVHRR pre-processing at various degrees.
5. Both harvest season and summer season data was used for the analysis which provides complimentary information to each other. Forest and non-forest areas can be distinguished more easily during the harvest season when agricultural crops, predominantly rice, is harvested. However, discrimination of evergreen and deciduous forest is not possible at this season. To solve this problem, summer season data were used when deciduous trees shed their leaves. By combining these results, improvements in the land cover classification were achieved. This clearly demonstrated the usefulness of multi-temporal satellite data. One should be careful in selecting the season as it varies slightly among countries.
6. Mangrove forest possesses a distinct signature due to which even small patches of mangrove forests in Myanmar, Thailand, Cambodia and Vietnam were discriminated easily.
7. Plantation forest areas less than the resolution of AVHRR sensor and beach forests occurring in a narrow strip along the coastlines were not able to discriminated.
8. Mosaic of forests and shifting cultivation in Northern Laos and Northern Vietnam was difficult to discern with AVHRR data resulting overestimation of forest areas in these countries.
9. A clear demarcation of national political boundaries between Laos/Cambodia and Thailand is evident from the satellite image.

10. NOAA AVHRR satellite data and the methodology adopted was found to be useful for the assessment and monitoring of land cover status and dynamics at a wider scale.

11. AVHRR images acquired during the dry season provided vital information on wild-fires in Cambodia. Dry deciduous forests exhibited large burnt area followed by crop lands and the moist mixed deciduous forests.

12. In the case of Myanmar, shifting cultivation, logging and forest fire play a dominant role in forest degradation and forest type conversion. Increasing proportion of open woodlands and shrub lands and conversion of evergreen/semi-evergreen forest to dry deciduous forest were noticed in many parts of country.

13. Even with the multi-temporal satellite data, it was not possible to discriminate evergreen and deciduous forest with reasonable accuracy particularly in North-western part of Thailand, where a complex mosaic of evergreen and deciduous forests exits. Conversion of forests to agricultural land was found to be significant in many parts of the country. Shifting cultivation was found to be an important factor in forest type conversion and forest degradation in high-lands. Due to persistent cloud cover in Peninsular Thailand, it was not possible to acquire cloud free imageries of this region.

14. Forest areas are shrinking mainly in the Northern region and central plateau of Vietnam. Major land cover transformation is also going on in the Mekong Delta.

15. Lao. P.D.R follows the common nature of land cover transformation with other countries in Southeast Asia. Shifting cultivation was found be major reason for forest type conversion and forest degradation in Northern part of the country.

5.4 Change Detection

Land cover change has been attributed by various reasons and those reasons are site specific. Shifting cultivation has been identified as a major cause of forest destruction, which is prominent in case of Laos. Conversion of forest to agricultural land was noticed in many countries including the Loei Province of Thailand and southern part of Burma. Conversion of swamp forest to other land uses was noticed in the Mekong Delta in Vietnam.

Land cover conversion pattern varies from place to place. The following diagram (Fig. 5) shows a typical conversion pattern in continental Southeast Asia. As can be seen from the diagram, a very strong linkage exists between forestry and agricultural sector. This is mainly because agriculture is a mainstay of economy for these Southeast Asian countries and a majority of people lives in rural areas.
Fig. 5. Major Change pattern showing strong linkages between forest and crop land

5.5 Hot Spot Areas Investigation

By overlaying land cover maps of 1985/86 and 1992/93, “hot spot” were identified. Three identified ‘hot spot’ areas were investigated in detail using high resolution satellite data supplemented by field survey. High resolution satellite data such as Landsat, SPOT and ERS were used for the analyses. Major findings of these analyses are presented below.

A. Oudomxay Province, Lao P.D.R.

An area with an approximate size of 60 km x 60 km was in Oudomxay province of Northern Laos was investigated using SPOT data acquired on 26 March, 1992. Major land use/land cover types and their areal extent are presented below (Table 2.).
Table 2. Areal extent of distribution of the classified land use/land cover categories (in hectare).

<table>
<thead>
<tr>
<th>Land use/land cover Categories</th>
<th>Area (hectare)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense Forest</td>
<td>117398.1</td>
<td>32.61</td>
</tr>
<tr>
<td>Disturbed Forest</td>
<td>71298.8</td>
<td>19.81</td>
</tr>
<tr>
<td>Scrubland</td>
<td>104345.0</td>
<td>28.99</td>
</tr>
<tr>
<td>Shifting cultivation-burnt surface</td>
<td>5021.6</td>
<td>1.40</td>
</tr>
<tr>
<td>Shifting cultivation- exposed soil</td>
<td>13161.2</td>
<td>3.66</td>
</tr>
<tr>
<td>Shifting cultivation-short fellow</td>
<td>9330.8</td>
<td>2.59</td>
</tr>
<tr>
<td>Shifting cultivation-long fellow</td>
<td>20551.8</td>
<td>5.71</td>
</tr>
<tr>
<td>Paddy fields</td>
<td>921.2</td>
<td>0.26</td>
</tr>
<tr>
<td>Water bodies</td>
<td>285.5</td>
<td>0.08</td>
</tr>
<tr>
<td>No Data</td>
<td>17655.1</td>
<td>4.90</td>
</tr>
</tbody>
</table>

Various stages of shifting cultivation practices from land preparation (burnt and exposed soil) to short and long fellow covered by thick bushes were identified both in satellite image and on the ground. Shifting cultivation plot size ranges from 2 to 650 ha. mainly associated with the family size of shifting cultivators. The shifting cultivation areas are distributed in upper watershed of two major river system: Nam Tha and Nam Beng.

The remaining forest areas are located in steep slopes and paddy cultivation can be found in river valleys. The intensity, distribution and large plot size of shifting cultivation areas suggest high pressure on remaining forest areas. This is attributed by increasing population of shifting cultivators and in-migration from other provinces. Informal interviews with local villagers revealed gradual decline of forestry and agricultural productivity in the area.

B. Loei Province, Thailand

An area of 60 km x 60 km was investigated in detail using multi-spectral SPOT data acquired on 21 March, 1996. Landsat MSS data acquired on 19 December, 1985 was used to compare changes in land/use land cover types. Major land use/land cover types and their areal extent are presented in Table 2.
Table 3. Land Use/land Cover Types of the Study Area

<table>
<thead>
<tr>
<th>Land Use/Land Cover Classes</th>
<th>Area (in ha.)</th>
<th>% Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>7592.72</td>
<td>1.99</td>
</tr>
<tr>
<td>Hill Forest</td>
<td>118658.64</td>
<td>31.23</td>
</tr>
<tr>
<td>Degraded Forest</td>
<td>77385.48</td>
<td>20.35</td>
</tr>
<tr>
<td>Soybean</td>
<td>10802.72</td>
<td>2.84</td>
</tr>
<tr>
<td>Paddy Field</td>
<td>21752.28</td>
<td>5.72</td>
</tr>
<tr>
<td>Eucalyptus Plantation</td>
<td>460.84</td>
<td>0.12</td>
</tr>
<tr>
<td>Rubber Plantation</td>
<td>3881.84</td>
<td>1.02</td>
</tr>
<tr>
<td>Cassava</td>
<td>1997.4</td>
<td>0.52</td>
</tr>
<tr>
<td>Other Crops</td>
<td>5873.2</td>
<td>1.54</td>
</tr>
<tr>
<td>Barren Land</td>
<td>57398.76</td>
<td>15.09</td>
</tr>
<tr>
<td>Scrubland</td>
<td>24005.04</td>
<td>6.31</td>
</tr>
<tr>
<td>Sand</td>
<td>1257.88</td>
<td>0.33</td>
</tr>
<tr>
<td>Waterbodies</td>
<td>1625.44</td>
<td>0.42</td>
</tr>
<tr>
<td>Other Classes</td>
<td>47595.72</td>
<td>12.52</td>
</tr>
</tbody>
</table>

The Loei province is characterized by one of the most forest rich province of Thailand consisting of more than 50% of forest areas with 20 forest reserve areas and five national parks and wildlife sanctuary. Paddy field and soybean cultivation can be found in the river basins and valleys. Cassava and forest plantation can be found in uplands.

The conversion of forest to other land uses primarily to agriculture and forest plantation was found to be the major causes of land use/land cover change in the area. Forest fire and illegal logging is also contributing for the change. Migration from other provinces to this relatively less populated province has created additional stress on the already fragile natural resources of the province.

C. Mekong Delta, Vietnam

An area of the size of 60 km by 60 km in the Mekong delta of Vietnam was investigated using SPOT XS data acquired on 4 March, 1995. The satellite data interpretation was supported by existing maps and intensive field survey.

The Mekong delta is characterized by one of the most productive rice growing area of Vietnam. Coincidently, this is also a highest population density and major ‘economic development region’ of the country. Much of the forest areas were destroyed during the famous Vietnam war and economic reconciliation after the war. Few degraded Malaleuca and Mangroves are left in patches. Major land use/land cover types and their areal distribution are presented in Table 4.
Table 4. Land Use/Land Cover Types of the study area

<table>
<thead>
<tr>
<th>Land Use/Land Cover</th>
<th>Area (hac.)</th>
<th>% area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice-1</td>
<td>9858.76</td>
<td>2.62</td>
</tr>
<tr>
<td>Rice-2</td>
<td>9214.52</td>
<td>2.45</td>
</tr>
<tr>
<td>Rice-3</td>
<td>63644.12</td>
<td>16.93</td>
</tr>
<tr>
<td>Mixed Orchard</td>
<td>71602.52</td>
<td>19.04</td>
</tr>
<tr>
<td>Mixed Coconut</td>
<td>70446.55</td>
<td>18.74</td>
</tr>
<tr>
<td>Mangrove/Malaleuca</td>
<td>4632.80</td>
<td>1.23</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>5552.84</td>
<td>1.48</td>
</tr>
<tr>
<td>Built-up Areas</td>
<td>6158.32</td>
<td>6.96</td>
</tr>
<tr>
<td>Cloud</td>
<td>531.64</td>
<td>0.14</td>
</tr>
<tr>
<td>Cloud Shadows</td>
<td>4898.96</td>
<td>1.30</td>
</tr>
<tr>
<td>Muds</td>
<td>6416.80</td>
<td>1.71</td>
</tr>
<tr>
<td>Waterbodies</td>
<td>103051.04</td>
<td>27.41</td>
</tr>
</tbody>
</table>

Human induced land use/land cover change include, changes in agricultural practices, destruction of Mangrove and Malaleuca forests and conversion of land to built-up areas. Agricultural practices are changing in terms of their intensities and management regimes attributed by change in cropping patterns (mainly from rice to cash crops such as sugar cane, aquaculture, coconut plantation etc.) and change in cropping patterns (from monocrop to multiple crops per year). With artificial reclamation, agricultural production has increased but at the expense of aquatic animals and Mangrove forest. Few efforts are in place to conserve environmental base but a holistic approach to manage complex and interwoven environmental problem in the delta is lacking.

6. Global Land Cover - 2000 for Continental Southeast Asia

Global Vegetation Monitoring unit of Joint Research Center (Italy) is coordinating and implementing the Global Land Cover 2000 project (GLC 2000) in collaboration with a network of partners around the world, the main purpose of which is to prepare a harmonized land cover database of the world for the year 2000 (http://www.gvm.sai.jrc.it/glcl2000/defaultGLC2000.htm). Center for International Earth Science Information Network (CIESIN) of Columbia University is implementing the project for continental Southeast Asia.

VEGA 2000 dataset which is a dataset of 14 months of pre-processed daily global data acquired by the VEGETATION instrument on board SPOT-4 satellite will be used for the analysis. This 1 km spatial resolution satellite data was provided through a sponsorship from members of the VEGETATION programme (http://vegetation.cnes.fr).

Land cover classification system (LCCS) developed by FAO (Food and Agriculture Organization of the United Nations) will be used together with the minimum required classifiers for mapping vegetation cover recommended by the participants of GLC 2000.
legend workshop held in Ispar (Italy) from 28 to 29 March, 2001. The results are expected to be available early next year.

7. Conclusions

Based on the project experience, it is concluded that:

• A number of data sources for acquiring and distributing AVHRR data both within and outside the region were identified. It was noticed that a systematic archive of these datasets in the region is lacking. It is also noted that acquisition of satellite data should be done carefully considering phenology and structure of vegetation and cropping patterns of agricultural crops.

• The AVHRR mosaic provides a very interesting overview of the whole of Southeast Asia that is being used for various applications.

• A simple classification system and methodology was developed with an active involvement of sub-regional and national partners of the region.

• Pre-processing of AVHRR data is time consuming and tedious. Appropriate standardized means and techniques needs to be developed.

• AVHRR satellite data and the methodology adopted were found to be very useful for the assessment and monitoring of land cover status and dynamics at macro scales. The availability and accessibility of ancillary data and active involvement of local experts plays an important role in AVHRR data interpretation.

• AVHRR data analysis was found to be useful for providing an overview of major land cover transformations (‘hot spot’ areas) occurring in the region. Detail investigation is necessary to identify driving forces responsible for the change.

• High resolution satellite data e.g. SPOT and Landsat proved to be an important source of data for ‘hot spot’ areas analysis. Driving forces responsible for the change were identified using satellite data interpretation supplemented by ground survey.

• Land cover maps of 1985/86 and 1992/93 and their associated attribute information were prepared and are available for free distribution. Major land cover change areas were also identified.

• Hardware/software and training support were provided to relevant sub-regional and national government agencies in the countries.

• Shifting cultivation, conversion of forest to other land uses and intensification of agricultural practices were found to be driving forces responsible for the change in Oudomxay province of Lao P.D.R, Loei Province of Thailand and Mekong Delta of Vietnam respectively.

• Regional aggregation and manipulation was performed and the output was used for state of the environment reporting at sub-regional, regional and global levels.

Acknowledgements:

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Reference:


WORLD DATA BANK 11, 1990, A *circular letter*, USGS, Eros Data Center, Sioux Falls, USA.