# Quantifying Land Use Changes for Greenhouse Gas Inventory Purpose in Thailand between 2000 and 2007

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**Abstract:** This study quantifies the magnitude of land use change in Thailand during 2000-2007. Land use categories classified by the Land Development Department (LDD) were re-arranged to be consistent with the land use categories defined by the IPCC's in its 2006 Guidelines for National Greenhouse Gas Inventories. During this period, there were the net losses of forest and cropland areas of 9,441.77 $km^2$ (from 172,013 to 162,571 $km^2$ or a decrease of 5.5%), and 8,461.85 $km^2$ (from 285,811 to 277,349 $km^2$ or a decrease of 3.3%), respectively. On the other hand, there were the net increases in the areas of grassland (1,705 $km^2$ or 13%), wetland (4,823 $km^2$, or 34%) and settlement (11,523 $km^2$ or 45%). The loss of forest land was mainly through the conversion to cropland, and the loss of cropland was through conversion to settlements and forest. The conversion of forest land was mainly found in the northern region while cropland loss occurred mainly in central, east and southern regions. Conversion of land into settlement was found to increase in all regions of the country.

**Keywords:** Land use, Land use change, 2006 IPCC Guidelines, Greenhouse gas inventory, Thailand.

## 1. Introduction

The adverse impacts of global warming and climate change that are induced by greenhouse gases in the atmosphere have been the important issues threatening social and economic developments. Human activities in excessive utilization of natural resources have resulted in increase of the greenhouse gas (GHGs) concentrations in the atmosphere since the beginning of industrial revolution [1]. Among greenhouse gases, $CO_2$ contributes most to the current warming. Its concentrations in the atmosphere have increased from a pre-industrial time of approximately 280 ppmv to 383 ppmv in 2007 [1]. Its concentrations continue to increase at approximately 1% per year, and are expected to double in the coming century. The main anthropogenic sources of $CO_2$ are fossil fuel combustion and deforestation, and other activities related to land use change.

To avoid the adverse impacts of climate change, greenhouse gas emissions need to be mitigated. Effective mitigation requires accurate and comprehensive quantification of the emissions from all major sources. In addition, mitigation cooperation among emitters worldwide is the important element to achieve emission reduction target sufficient for slowing down the global warming. As one of the cooperation actions that serve as greenhouse gas emission mitigation worldwide, the signatories to the United Nations Framework Convention on Climate (UNFCCC) have agreed to the periodic submission of greenhouse gas inventory report to the UNFCCC Secretariat. To accommodate this, UNFCCC has endorsed the use of the greenhouse gas inventory methodology developed by the Intergovernmental Panel on Climate Change (IPCC).

Several guidelines for national greenhouse gas inventories were released by IPCC. For Thailand, the 1996 revised Guidelines were used for its national greenhouse gas inventory submissions in 2000 and 2011 [2-3]. However, recently IPCC has released the new guidelines (2006 Guidelines, [4]) and UNFCCC has encouraged the countries to incorporate this into the national greenhouse gas inventory system. This new guidelines differs in many aspects when compared with the previous ones. Compared to the Guidelines and Good Practice Guidance (i.e. the 1996 IPCC Revised Guidelines, GPG 2000, and GPG on LULUCF 2003), the 2006 Guidelines has advanced the estimate methodology and covered many details of GHG inventory. Countries are suggested to employ these Guidelines as the way to standardize the methodology used for GHG inventory among UNFCCC signatories, and thus provide the platform for comparison among parties.

Land use data in Thailand relevant to the application of the 2006 IPCC Guidelines for greenhouse gas inventory so far has not been available. Although there have been many studies on land use and land use change aspects in the Thailand [5-7], none of these has relevant details sufficiently for greenhouse gas inventory purpose. In Thailand various land use categories exist and these are not consistent with those classified in the 2006 IPCC Guidelines. In addition, land conversion from one to other categories has not yet quantified countrywide. Accordingly, in this study we quantified the magnitude of land use changes and conversion of lands among IPCC land use categories in Thailand during 2000-2007. The objective of the study is to primarily evaluate the scale of land use change that could serve as the basis for national greenhouse gas inventory.

## 2. Experimental

### 2.1 Datasets

In order to estimate the land use change, at least two points in time of the data are needed. This study selected the land use data in 2000 and in 2007. For 2000, the GIS database of Land Development Department (thereafter called LDD2000) developed from Landsat-7 satellite and field verification was used. This was available at the spatial resolution of 30×30 m. For 2007 (thereafter called LDD2007), the GIS database of LDD from Spot-5 satellite image at the spatial resolution of 2.5×2.5 m was used. There are some limitations in using these data sets for land use and land use change study. Due to different spatial resolution, the province and land use boundaries in the LDD2000 database sometimes differed from that were used in the LDD2007 database, and for some areas in southern Thailand the GIS database were missing. The LDD2007 database has many overlapped areas following the boundary lines and these have to be corrected before use. In addition, the GIS data in LDD2007 is rather large in size due to high spatial resolution, so make them difficult to utilize. However, LDD2007 has the

advantage of giving more details of land use. To correct these defects and when applicable, LDD GIS data associated with Google Earth and local maps were used.

To cope with the boundary issue, merging the land use data in each province was performed by using merge (management) function in ArcGIS programme. Overlap areas were removed by using Thiessen polygon approach available in the ArcGIS software and the boundary was overlaid by using union function of the software.

### 2.2 Land use category and land use change estimate

The LDD database categorizes land use into several levels; higher levels imply higher spatial details and resolution of land use. The LDD land use classification is based upon the function and the actual purpose for which the land is currently being used. Thus, a land use can be defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one, or more than one piece of land, and several land uses may occur on the same piece of land. Inventorying land by such classification provides a quantitative measure of land in relation of the economic and environmental outcomes/impacts of various human activities and natural events for precise and quantitative analysis and future planning (Table 1). For such purpose, LDD level 1 classifies land use into 5 main categories; Urban and Built-up land (U), Agricultural land (A), Forest land (F), Water body (W) and Miscellaneous land (M). In level 2 and 3, each of these categories is subdivided into more disaggregated land use types. For example Agricultural land for level 2 is subdivided into paddy fields (A1), field crop (A2), perennial crop (A3), and so on. For level 3, A1 is subdivided further into A100: abandoned paddy field, A101: rice paddy, A102: sown rice paddy, and so on. The information used for these land use classification is generally based on mapping of land area using techniques like aerial photography, cadastral surveys, supported by ground checking [8].

The 2006 IPCC Guidelines classifies land use into 6 categories; forest, cropland, grassland, wetlands, settlements, and other lands. Each land-use category is further subdivided into land remaining in that category (e.g. forest land remaining forest land) and land converted from one category to another (e.g. forest land converted to cropland) [4].

Sine there are differences in land use categories defined by IPCC for the national greenhouse gas inventory purpose and by LDD for planning purposes, land use under LDD system needs to be re-arranged to be consistent with those classified by IPCC in its 2006 Guidelines. For each land use layer, level 3 information of the LDD land use database was used because of more details. Therefore this study uses those data to classify them by mainly considering each land use definition. Land use categories from LDD were organized into groups following IPCC land use category (forest land, cropland, grassland, wetlands, settlements, and other land), by using ArcGIS program.

Once the IPCC land use categories were assigned, calculating the area change was carried out by overlaying the data derived from the 2000 and 2007 database using intersect (analysis) function of the software. They were subdivided into land remaining in the same category and land converted from one category to another.

**Table 1.** Land use levels and land use types according to LDD land use classification.

| Land use classification Level 1 | Land use classification Level 2 | | Land use classification Level 3 | |
|---|---|---|---|---|
| | Code | Description | Code | Description |
| **U:** Urban and Built-up land | U1 | City, Town , Commercial | U100 | City, Town , Commercial |
| | U2 | Village | U200 | Abandon Village |
| | | | U201 | Village |
| | | | U202 | Hill tribe village |
| | | | U203 | Land, Housing project |
| | U4 | Transportation , Communication and Utility | U401 | Airport |
| | | | U402 | Railway station |
| | | | U403 | Bus station |
| | | | U404 | Harbour |
| | | | U405 | Road |
| A: Agricultural land | A1 | Paddy field | A100 | Abandoned paddy field |
| | | | A101 | Rice paddy |
| | | | A102 | Sown rice paddy |
| | A2 | Field crop | A200 | Abandoned field crop |
| | | | A201 | Mixed field crop |
| | | | A202 | Corn |
| | | | A208 | Mungbean |
| | | | A209 | Soybean |
| | A3 | Perennial | A300 | Abandoned mixed perennial |
| | | | A301 | Mixed perennial |
| | | | A302 | Para rubber |
| **F:** Forest land | **F1** | Evergreen forest | F100 | Disturbed evergreen forest |
| | | | F101 | Dense evergreen forest |
| | | | F102 | Dry evergreen forest |
| W: Water Body | **W1** | Natural water body | W101 | River, Canal |
| | | | W102 | Lake |
| | **W2** | Reservoir (Built-up) | W201 | Reservoir |
| | | | W202 | Farm pond |
| | | | W203 | Irrigation canal |
| **M:** Miscellaneous land | **M1** | **Rangeland** | M100 | Rangeland |
| | | | M101 | Grass |
| | | | M102 | Scrub |
| | | | M103 | Bamboo |
| | **M2** | **Marsh and Swamp** | M200 | Marsh, Swamp |
| | **M3** | **Mine, pit** | M300 | Abandoned mine, pit |
| | | | M403 | Rock out crop |
| | | | M404 | Garbage dump |
| | | | M405 | Landfill |

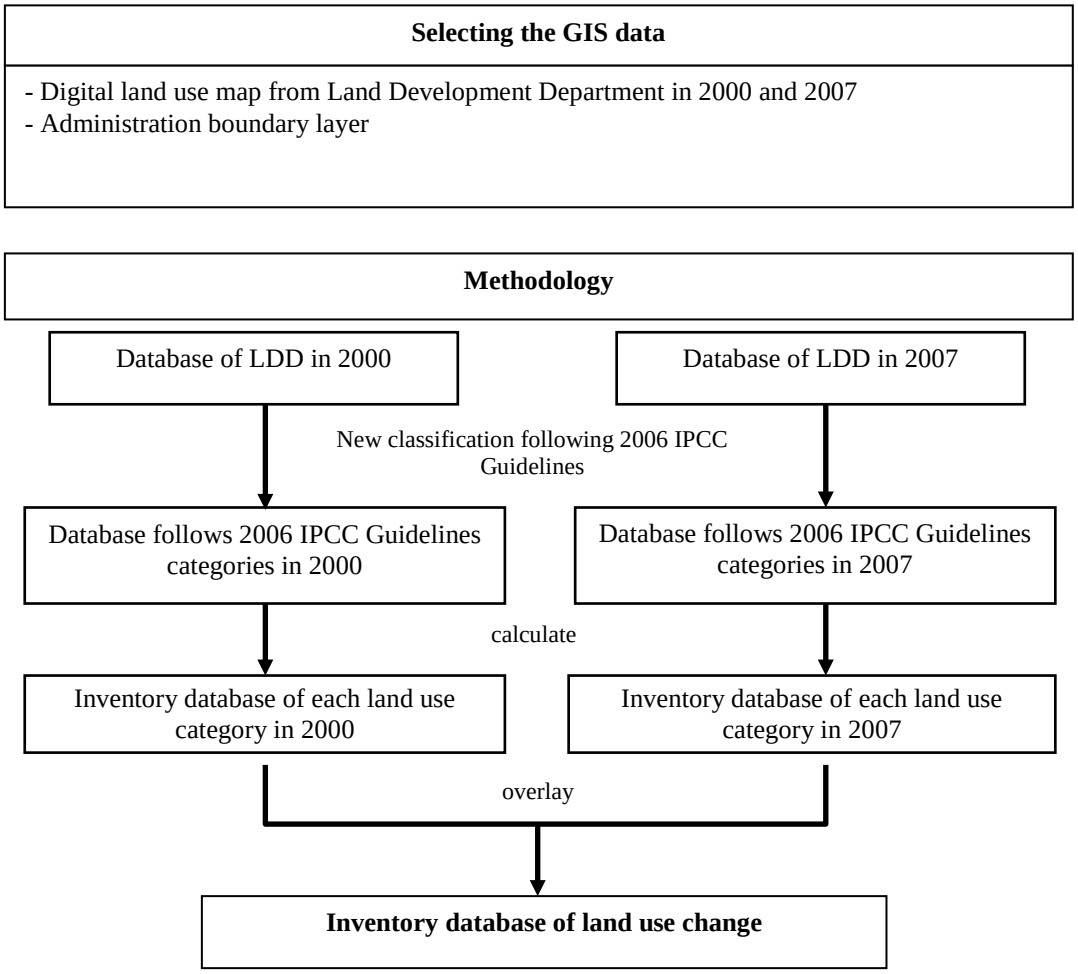


**Figure 1.** Procedures of analysis land use and land use change data.

**Table 2** Re-arrangements of LDD land use categories into IPCC land use categories.

| IPCC land use | LDD Level 3 land use code | LDD Land use types |
|---|---|---|
| Forest land | F100, F101, F102, F200, F201, F300,F301, F400, F401<br>F500, F501, F0, M103 | Disturbed evergreen forest, Dense evergreen forest, Dry evergreen forest, Disturbed deciduous forest<br>Dense deciduous forest, Disturbed mangrove forest<br>Dense mangrove forest, Disturbed swamp forest<br>Dense swamp forest, Disturbed forest Plantation<br>Dense forest plantation, Disturbed forest, Bamboo |
| Cropland | A1,A2,A3,A4, A5, A6, A702, A703, A704, A0, F6 | Paddy field, Field crop, Perennial, Orchard, Horticulture, Swidden cultivation, Cattle farm house, Poultry farm house, Swine farm house<br>Integrated farm/ Diversified farm, Agro – forestry |
| Grassland | A701, M100, M101, M102 | Pasture, Rangeland, Grass, Scrub |
| Wetlands | A8, A9, W1, W2, M200 | Aquatic plant, Aqua cultural land, Natural water body, Reservoir (Built-up), Marsh, Swamp |
| Settlements | U1, U2, U3, U4, U5, U6 | City, Town , Commercial, Village, Institutional land, Transportation, Communication and Utility,<br>Industrial land, Other |
| Other land | U200, U300, U500, U600, A100, A200, A300, A400, A500, A700, M3, M4 | Abandon village, Abandoned institutional land<br>Abandon factory, Abandoned area, Abandoned paddy field, Abandoned field crop, Abandoned mixed perennial, Abandoned orchard, Abandoned factory, Abandoned farm house, Mine pit, Other |

## 3. Results and Discussion

### 3.1 Re-arranging the LDD land use categories to be consistent with that of the IPCC's

Most of the land use category defined by LDD can be readily merged into those by the IPCC land use category (Table 2). For forest land, the bamboo (M103) was moved from miscellaneous lands under LDD to forest land under IPCC. For cropland, LDD agro-forestry (F6) was moved from forest and added into cropland category. In the LDD system, grassland is not separated from agricultural land and in the re-arrangement, those were identified as pasture, rangeland, grass and scrub were re-classified as grassland of the IPCC's. Wetland was mainly those under water body land under LDD system. In addition, land classified as aquatic plant, aquaculture and swamp were also included in the IPCC wetland category. All urban land uses of LDD system were identified under settlements category of the IPCC's. Finally, since there are lacks of details of actual land use activity, all land uses identified as abandoned land under LDD were put in the "other land" of the IPCC's. Doing this

could fit most of the land uses of the LDD's into those of the IPCC's. The exception was "other land" category but this occupied only 2,737.5 km$^2$ in 2000 and 2,589.2 km$^2$ in 2007 (about 0.5% of the total land area), therefore would not affect significantly the overall land use inventory.

### 3.2 Land use characteristics in Thailand in 2000 and 2007

Based on the land classification re-arrangement mentioned above, land use and land use change between 2000 and 2007 were investigated. Cropland (with total area of 285,811.0 km$^2$ and 277,349.1 km$^2$ in 2000 and 2007, respectively) and forest land (with total area of 172,013.0 km$^2$ and 162,571.3 km$^2$ in 2000 and 2007, respectively) were the main land use categories in Thailand (Fig. 2). Both land categories combined occupied approximately 86-89% of total land area in Thailand (513,114.95 km$^2$). Comparing land use category in these two years, it is obvious that settlements were increased significantly. Between 2000 and 2007, the areas classified as settlements increased from 25,398.9 km$^2$ to 36,922.1 km$^2$, or an increase of 45%. Urbanization and increase in population have been suggested as the driving force for such increase [5-6, 9]. For wetland, although in terms of magnitude of changes (an increase of 4,823.28 km$^2$) was small, wetlands that are classified here as land use for aquatic plant, aquaculture land, natural water body, reservoir (Built-up), marsh and swamp were also significantly increased. Other significant changes countrywide were the net loss of the forest land (-5.5%) and cropland (3.3%), with the loss areas of 9,441.77 km$^2$ and 8,461.85 km$^2$, respectively (Table 3).

Since no estimate of land use change in Thailand for all of these categories is readily available for comparison, it is difficult to estimate the error associated with the current calculations. However, for some land use categories such as forest land, The Royal Forestry Department [10] has maintained the database that can be used to compare with the results obtained from the current study. Countrywide, there is only a slight difference in the forest area estimated between our study and those from the Royal Forest Department (Table 4). The overall averaged difference between these two studies was 1.12%. However, this difference varied among regions in Thailand. The highest difference (8.86%) was found in the Southern regions, presumably caused by the issues such as data missing/exclusion and area overlapped as mentioned in Section 2.2.

### 3.3 Land use changes in Thailand between 2000 and 2007

#### 3.3.1 Overview of land use change

Fig. 3 presents the land use area for those lands remaining in that category and those were converted from the initial land use category in 2000 to other land use categories in 2007. Table 5 is the summarized matrix of land conversion to and from each land category. It is obvious that conversion of land occurred in all land categories. During these two time points, 31,002.81 km$^2$ of forest land was lost, mainly converted to cropland (23,169.49 km$^2$, or about 75% of all forest land area converted). On the other hand, there were 21,561.04 km$^2$ of land area that were converted to forest land. Among these, conversion of cropland to forest land was the predominant one (15,847.7 km$^2$ or 74% of all land areas converted to forest land). Thus, overall land forest area change was a net loss of 9,441.77 km$^2$ as

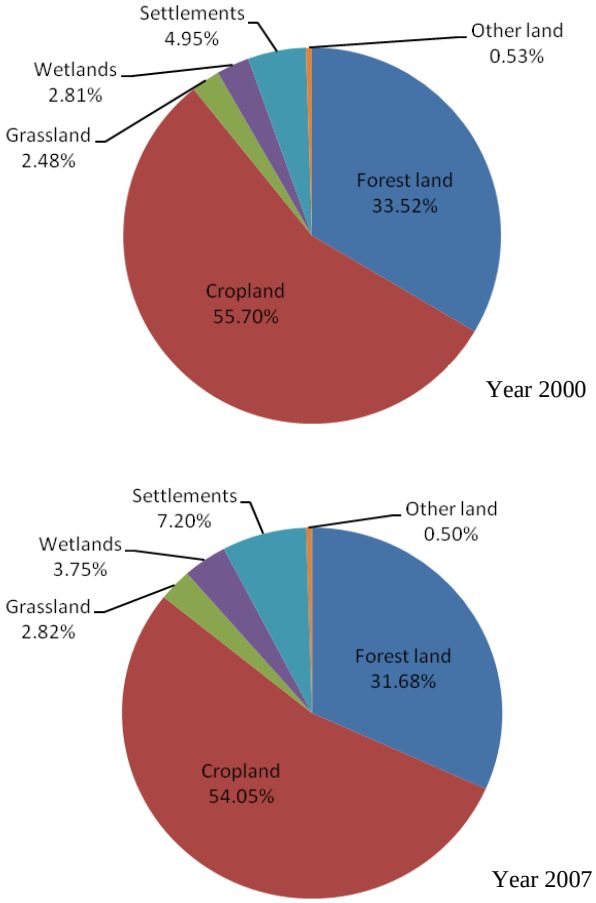


**Figure 2.** Proportion of land use in Thailand in 2000 and 2007.

**Table 3.** Land use and land use change between 2000 and 2007 in Thailand. Negative values indicate the area decrease in 2007 compared to 2000.

| Land use category | Land use area in 2000 (km$^2$) | Land use area in 2007 (km$^2$) | Net area change (km$^2$) | % change in 2007 compared to 2000 |
|---|---|---|---|---|
| Forest land | 172013.0 | 162571.3 | -9,441.77 | -5.5 |
| Cropland | 285811.0 | 277349.1 | - 8,461.85 | -3.0 |
| Grassland | 12740.5 | 14445.9 | 1,705.38 | 13.4 |
| Wetlands | 14414.1 | 19237.4 | 4,823.28 | 33.5 |
| Settlements | 25398.9 | 36922.1 | 11,523.27 | 45.4 |
| Other land | 2737.5 | 2589.2 | -148.31 | -5.4 |

**Table 4.** Comparison of forest land area in 2000 between those given by Royal Forest Department [10] and by this research study.

| Regions | Forest land from this study (km$^2$) | Forest area from Royal Forest department (km$^2$) | % Difference |
|---|---|---|---|
| North | 95,459.50 | 96,270.28 | -0.8 |
| Northeast | 27,036.48 | 26,526.94 | 1.92 |
| Central | 21,798.50 | 21,461.85 | 1.57 |
| East | 8,763.10 | 8,438.28 | 3.85 |
| South | 18,955.47 | 17,413.43 | 8.86 |
| Total | 172,013.04 | 170,110.78 | 1.12 |

mentioned earlier. This was equal to 0.78% per year area loss relative to the forest area in 2000, assuming that the loss rate is the same during these 7 years interval. Cropland also shows a significant change during this period. The cropland area loss was 50,839.88 km$^2$ and the area gained was 42,378.02 km$^2$. The main cropland area loss was the conversion to settlements (38% of all cropland area loss), and to forest land (31% of all cropland area loss). Most of the new cropland gained were the conversion from forestland (55%). During 2000-2007, there were 24,302.76 km$^2$ of settlement area increase while the settlement land loss (mainly converted to cropland) was 12,799.49 km$^2$. Out of the total settlement area increased, 19,283.26 km$^2$ (79%) were converted from cropland. In sum, it can be said that the dominant mode of land use change in Thailand during 2000-2007 was the loss of forest land and cropland, and the significant increase in the settlement areas. The top-three in terms of area size for land conversion were forest land converted to cropland, cropland converted to settlements, and cropland converted to forest land. Out of total land subject to conversion of 112,485.48 km$^2$ during 2000-2007, these top-three modes of land conversion accounted for 52% of all land conversion. Other modes with less but significance in terms of areas (conversion area between 5,000- 9,000 km$^2$ during 2000-2007) were the conversion of cropland to grassland (6,856.13 km$^2$), and to wetlands (7,693.46 km$^2$), the conversion of grassland to cropland (5,283.61 km$^2$), and the conversion of settlements to cropland (9,316.13 km$^2$).

### 3.3.2 Regional distribution of land use change

To locate the active land use change spot during these years, we investigated land use change in different regions of Thailand. It was found that forest land was decreased, and wetlands and settlements were increased in all regions (Fig. 4). Among regions, forest land in the North was reduced the most both in terms of the net area (5,915.70 km$^2$, Fig. 4a) and the percentage relative to the region total area (3.49%, Fig. 4b). The loss of cropland relative to the regional land area, on the other hand, mainly occurred in the central, eastern and southern regions. Cropland in central region was reduced by 4,558.49 km$^2$ (6.76%), the highest reduction among regions. For wetland, increases were found in all regions but the highest increase in terms of area was in the central region (1,786.75 km$^2$ or 2.65%), followed by the northern region (1,145.85 km$^2$ or 0.68% of total regional area). Settlement land was also increased in all regions; 3,682.31 km$^2$ (2.17%), 3,175.61 km$^2$ (4.71%), 1,644 km$^2$ (0.97%),

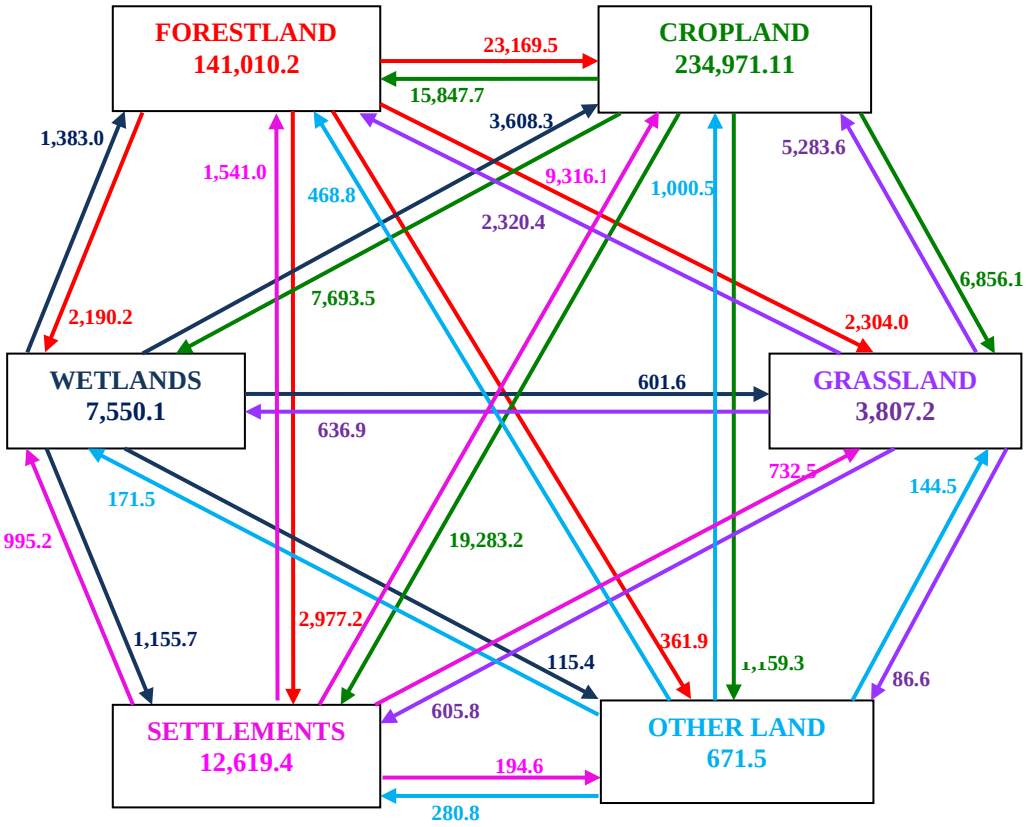


**Figure 3.** Land use changes in Thailand during 2000-2007. The values within the boxes indicate the area of land remaining in that category (e.g. the forest land remaining forest land in 2007 as compared to 2000 was 14,456.36 km$^2$). The arrow direction and value associated with it indicate the land conversion and the converted land area size in km$^2$.

**Table 5.** Land use change associated with land conversion from one to other land use categories in Thailand during 2000-2007.

| IPCC land category | Land converted to Forestland | Land converged to Cropland | Land converted to Grassland | Land converted to Wetlands | Land converted to Settlements | Land converted To Other land | Total area Converted to land category |
|---|---|---|---|---|---|---|---|
| Forest land | - | 23,169.49 | 2,304.01 | 2,190.20 | 2,977.24 | 361.87 | 31,002.81 |
| Cropland | 15,847.70 | - | 6,856.13 | 7,693.46 | 19,283.26 | 1,159.33 | 50,839.88 |
| Grassland | 2,320.41 | 5,283.61 | - | 636.9 | 605.81 | 86.58 | 8,933.31 |
| Wetlands | 1,383.08 | 3,608.31 | 601.55 | - | 1,155.68 | 115.35 | 6,863.97 |
| Settlements | 1,541.09 | 9,316.13 | 732.47 | 995.21 | - | 194.59 | 12,779.49 |
| Other land | 468.76 | 1,000.48 | 144.53 | 171.48 | 280.77 | - | 2,066.02 |
| Total area converted from land category | 21,561.04 | 42,378.02 | 10,638.69 | 11,687.25 | 24,302.76 | 1,917.72 | - |

1,577.06 km$^2$ (2.23%) and 1,444.29 km$^2$ (3.96%) in northern, central, northeastern, southern and eastern regions, respectively.

Within each region, there were some differences in mode of land conversion. In the North, the main mode of change was the conversion of forest to cropland (8,596.04 km$^2$, or 63% of all lands converted cropland, Table 6). However, there was relatively small net change in the area of cropland. This was due to the fact that total area of lands converted to cropland (13,565.63 km$^2$) was similar to the total area of cropland converted to other land categories (13,433.19 km$^2$, Table 6). Settlement land in the North was also significantly increased, mainly converted from cropland. Similar patterns of land conversion for forest, cropland and settlements were also found for the Northeast, East and South. In the central region, the conversion of cropland to settlements dominated the land use change patterns during this period.

There have been various studies carried out to improve our understanding of the cause of land use change. Generally, it has been suggested that the factors such as population growth, increase food and habitat demand along socio-economic developments are the main drivers of land use change [11-12]. In Thailand, the modernization of farming systems and commercialization of crop production were reported as the main cause of land use change, especially forest conversion to cropland [6, 13]. Migration has also been reported as one of the important drivers for land use change in Northeast Thailand [14].

### 3.4 Uncertainty associated with land use change estimate

There are various sources of uncertainty associated with estimating land use change in this study. These include the differences in satellite image resolution between LDD2000 and LDD2007 data. LDD2000 database was developed based on the Landsat satellite but in 2007 Spot satellite interpretation was used. Thus, some spatial data in 2007 cannot be compared and accounted for in 2000 due to different spatial resolution. Although this has been corrected but some degrees of uncertainty still remain.

**Table 6.** Land use change associated with land conversion from one to other IPCC's land use categories in Thailand during 2000-2007.

| Region | IPCC land category | Land converted to Forestland | Land converted to Cropland | Land converted to Grassland | Land converted to Wetlands | Land converted to Settlements | Land converted to Other land | Total area converted to land category |
|---|---|---|---|---|---|---|---|---|
| North | Forest land | - | 8,596.04 | 923.56 | 694.01 | 1,802.19 | 141.92 | 12,157.72 |
| | Cropland | 4,127.73 | - | 1,723.63 | 1560.57 | 5,828.98 | 192.28 | 13,433.19 |
| | Grassland | 914.20 | 978.21 | - | 83.2 | 190.45 | 10.61 | 2,176.67 |
| | Wetlands | 456.90 | 677.58 | 51.57 | - | 328.54 | 4.08 | 1,518.67 |
| | Settlements | 715.60 | 3,220.30 | 196.07 | 323.83 | - | 39.23 | 4,495.03 |
| | Other land | 27.59 | 93.50 | 3.8 | 2.85 | 27.18 | - | 154.92 |
| | Total area converted from land category | 6,242.02 | 13,565.63 | 2,898.63 | 2,664.46 | 8,177.34 | 388.12 | - |
| Northeast | Forest land | - | 7,897.07 | 871.54 | 410.8 | 536.89 | 98.43 | 9,814.73 |
| | Cropland | 6644.37 | - | 1948.42 | 2086.06 | 5335.62 | 81.39 | 16,095.86 |
| | Grassland | 841.23 | 2610.09 | - | 334.27 | 147.62 | 7.43 | 3,940.64 |
| | Wetlands | 289.68 | 1429.92 | 318.29 | - | 207.25 | 9.68 | 2,254.82 |
| | Settlements | 401.28 | 3667.89 | 250.1 | 260.29 | - | 5.89 | 4,585.45 |
| | Other land | 44.98 | 20.57 | 0.73 | 1.76 | 27.18 | - | 95.22 |
| | Total area converted from land category | 8,221.54 | 15,625.54 | 3,389.08 | 3,093.18 | 6,254.56 | 202.82 | - |
| Central | Forest land | - | 1,705.57 | 197.04 | 202.18 | 319.89 | 46.96 | 2,471.64 |
| | Cropland | 980.52 | - | 1046.33 | 2190.39 | 4056.12 | 275.57 | 8,548.93 |
| | Grassland | 313.02 | 1046.33 | - | 125.15 | 112.87 | 28.72 | 1,626.09 |
| | Wetlands | 177.35 | 432.52 | 53.31 | - | 352.96 | 50.7 | 1,066.84 |
| | Settlements | 306.88 | 1017.37 | 134.1 | 255.95 | - | 46.69 | 1,760.99 |
| | Other land | 41.41 | 81.53 | 19.67 | 79.94 | 94.75 | - | 317.30 |
| | Total area converted from land category | 1,819.18 | 4,283.32 | 1,450.45 | 2,853.61 | 4,936.59 | 448.64 | - |
| East | Forest land | - | 1,559.80 | 127.05 | 157.52 | 180.74 | 34.48 | 2,059.59 |
| | Cropland | 907.67 | - | 881.65 | 1030.98 | 1938.1 | 381.47 | 5,139.87 |
| | Grassland | 110.78 | 379.44 | - | 50.8 | 74.73 | 18.24 | 633.99 |
| | Wetlands | 125.03 | 402.7 | 54.28 | - | 137.81 | 43.79 | 763.61 |
| | Settlements | 51.74 | 731.84 | 78.86 | 93.69 | - | 44.77 | 1,000.90 |
| | Other land | 273.7 | 663.53 | 92.28 | 60.71 | 113.8 | - | 1,204.02 |
| | Total area converted from land category | 1,468.92 | 3,737.31 | 1,234.12 | 1,393.70 | 2,445.18 | 522.75 | - |
| South | Forest land | - | 3,411.01 | 184.82 | 725.69 | 137.53 | 40.08 | 4,499.13 |
| | Cropland | 3187.41 | - | 1256.1 | 825.48 | 2124.43 | 228.62 | 7,622.04 |
| | Grassland | 141.17 | 562.44 | - | 43.48 | 80.13 | 21.58 | 848.80 |
| | Wetlands | 334.11 | 665.6 | 124.1 | - | 129.12 | 7.11 | 1,260.04 |
| | Settlements | 65.58 | 678.64 | 73.33 | 61.46 | - | 58.01 | 937.02 |
| | Other land | 81.07 | 141.34 | 28.05 | 26.22 | 42.87 | - | 319.55 |
| | Total area converted from land category | 3,809.34 | 5,459.03 | 1,666.40 | 1,682.33 | 2,514.08 | 355.40 | - |

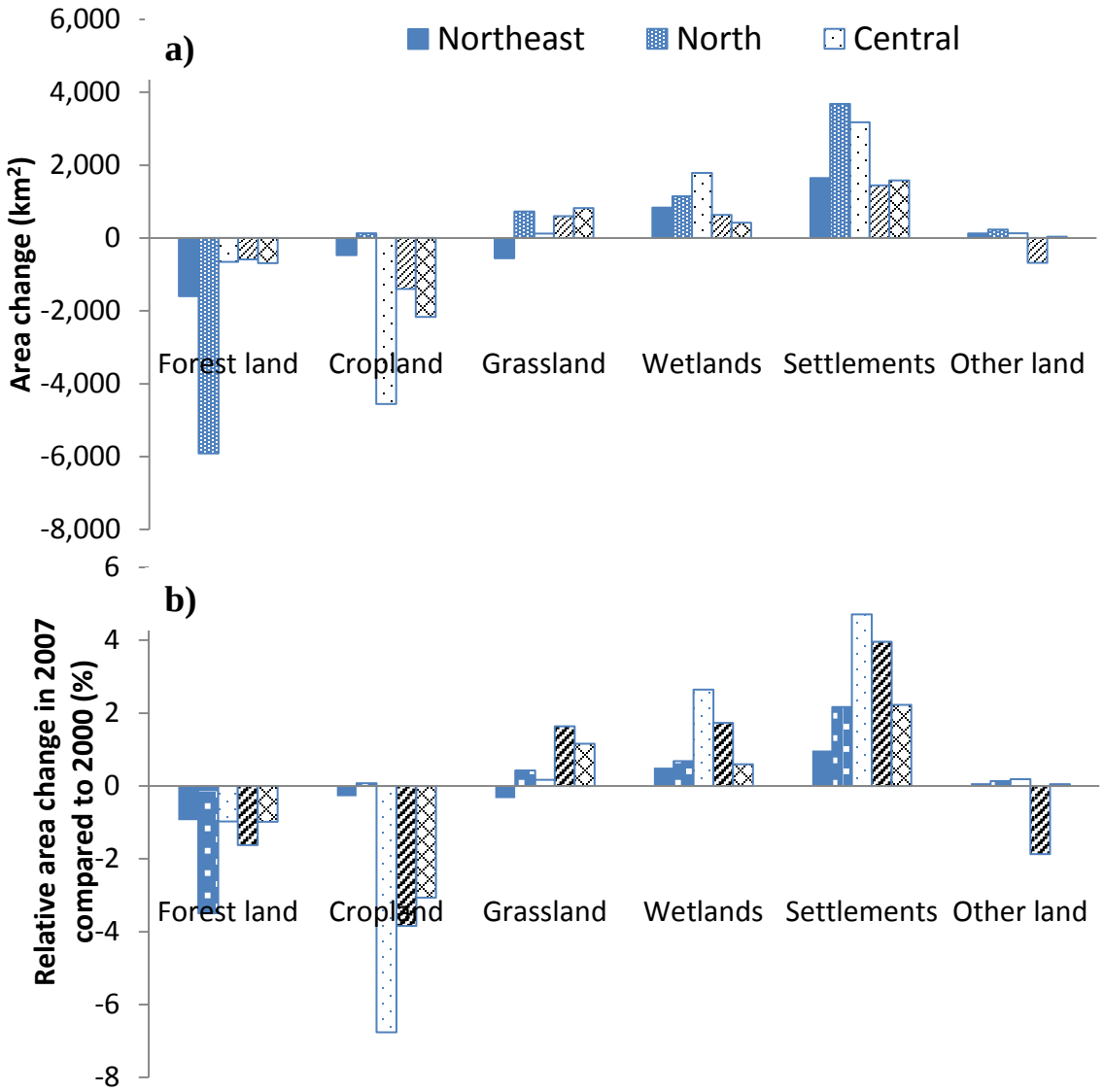


**Figure 4.** Land use change magnitudes during 2000-2007 distributed in different Thai regions; a) actual land areas change and b) magnitude of changes in 2007 compared to that in 2000.

There were also data missing. This happened mainly in the southern region where some data such as sea and lake areas are missing in the database. In addition, there are many isles and shorelines so the errors in Phang Nga, Krabi (Fig. 5), Phatthalung, and Song Khla boundaries may be occurred. In this case, the maps were cross-checked with the Google Earth. The example of such errors is illustrated in Figure 5 when the land areas in Krabi province from Spot satellite in 2007 were overlaid with that from Landsat satellite in 2000. The land use boundary is marked by the black color. It is clear that some areas in 2007 (shown as the blank-white area) were excluded from current inventory, otherwise the land use change could not be estimated. Overall, about 5% of southern land uses have been applied with this crosscheck methodology. There were also many overlapped areas in the LDD2007 database. These need to be revised in future study in order to avoid double counting. Most overlapped areas are in boundary of provinces. We have corrected these by using Thiessen polygons technique as mentioned earlier. However, it could not be ruled out that corrections were complete and thus certain degrees of uncertainty still remain. There were also the issues of different definition of land category given by LDD classification and IPCC's. For example, LDD does not clearly define the land use subcategory "agro-forestry (F6 code)"while IPCC suggests this should be classified as cropland. LDD Land use subcategory A8 (Aquatic plant) and A9 (Aqua cultural land) were classified as cropland (agriculture) but they are classified as wetlands in the IPCC guidelines, following Ramsar that identifies human-made wetlands such as fish and shrimp ponds, reservoirs, sewage farms, irrigated agricultural land into wetlands category. These are some examples of difference between country specific land use category and IPCC category. Re-classification of these categories and subcategories and cross-check with other databases may help improve the accuracy of land use change and future greenhouse gas inventory. Lastly, to capture the dynamic of land use and land use change, it is better to use more time points and more frequent time intervals. In the current study, only the net land use change in 2007 compared to 2000 was estimated but annual land conversion which is required for national greenhouse gas inventory could not be accurately quantified.

## 4. Conclusions

The current study evaluates the magnitude of land use change in Thailand between 2000 and 2007 using the existing land use databases of LDD. Land use categories of LDD database were re-arranged to be consistent with those categorized by IPCC in its 2006 Guidelines for National Greenhouse Gas

Inventories. Higher levels of details provided by LDD database have made this re-arrangement possible. Cropland and forest land were the main land use categories in Thailand, occupying approximately 54-57% and 32-34% of total country land area. These two land categories were also subject to most land conversion activity. Forest lands were mainly converted to cropland (75% of forest land conversion), while majority of croplands were converted to settlements (38%) and to forest (31%). Thus, increases in the settlement areas and decreases in forest and cropland areas were the main patterns of land use changes in Thailand during 2000-2007. Land use change in other categories such as wetland, grassland and other land were also found but less significant. Regionally, there were some differences. Forest loss was found mainly in northern region while cropland loss was in central, eastern and southern regions. Wetlands and settlements were found to increase in all regions. It can be said that the results from our study have fulfilled the basic requirement of data for greenhouse gas inventories for AFOLU sector (Agriculture, forest and other land use sector) of the 2006 IPCC Guidelines, that the magnitude of land use change must be quantified. However, in order to be able to estimate greenhouse gas emission and removal, the data on carbon content for above and belowground (soil and biomass) together with the amount of biomass content for each land use category or subcategory are needed. This should be one of the priorities for further research.

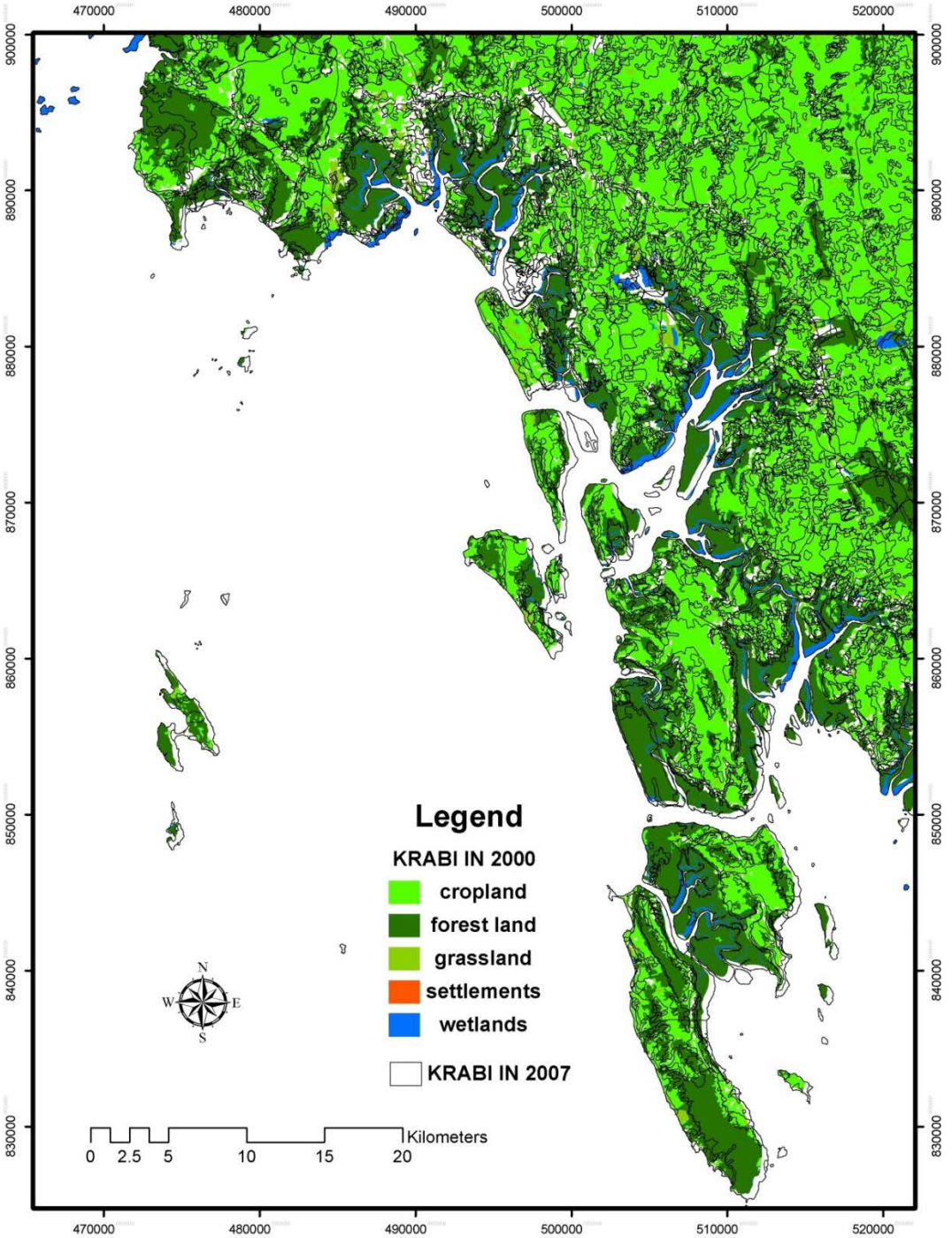


**Figure 5.** An example of the potential bias in estimating land use change (in Krabi province) that is arisen from the differences in satellite image resolution between 2000 (Landsat) and 2007 (Spot).

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