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Estimation of Carbon Stocks from Land-use Change due to Tourism in Phuket Island, Thailand

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According to the National Statistical Office (NSO) and the Phuket Provincial Statistical Office (PPSO), Phuket Island records a high growth rate for tourism, indicating the importance in local and national economic development. The tourism industry created noticeable effect on economic, social and also on the environmental systems. The growth of the tourism industry in Phuket has resulted in significant changes to the island, especially in the urban structure, causing problems for local citizen such as serious traffic congestion, cost-of-living increases, and loss of original forest area. The tourism industry is also a major contributor to the generation of greenhouse gases whilst it is accepted that global warming may bring tsunami. Phuket is a high-risk area for tsunami events. This has become more evident since the 2004 Indian Ocean tsunami devastated many coastal areas on the island and this is now a major concern to many citizens. Deforestation is an obvious cause of global warming due to the release of carbon from this pool. As a starting point to find the solution for these stated problems, the study aims to explore the consequence of land-use change on soil carbon stocks in Phuket province from 2000 to 2009, applying geographical information system (GIS). This exploration can help to provide information for Phuket urban planning and initiation of the forest landscape restoration so as to be a part in assisting Phuket's tourism industry to develop sustainably.

1. Introduction

International tourism is a major source of income for Thailand and a forceful developmental drive to circulate money from domestic tourists within the country (MTS, 2015). Phuket is one of the most popular tourist destinations in Thailand. A major source of income for Phuket citizen is tourism. The number of visitors in Phuket in 2013 was around 11.3 M, and income from tourism industry was around 6,912 M USD or approximately 2 % of gross domestic product (GDP) for that year. According to the National Economics and Social Development Board, the province's per capita GPP was at around 7,170 USD. Phuket GPP is the highest among all provinces in the southern region of Thailand, and it holds the 10th position in all of Thailand (PPSO, 2015). The 4th national economic and social development plan (1972-1977) was the key turning point that transformed Phuket from a city with a strategic focus on the mining industry into a focus on the tourism industry. The Phuket provincial development strategy (2015-2019) is currently in use for strengthening the tourism industry by enhancing its international competitiveness (DOT, 2015). There have been significant developments in infrastructure aiming at Phuket's growth (PRED9, 2015). This development has resulted in noticeable changes in land use as that land use is put at the service of the growing demand in the context of global change (DOT, 2015). It is suspected that natural and agricultural areas have been vastly replaced with new buildings and infrastructures such as restaurants, hotels, recreation areas, department stores, sport clubs and roads to reduce traffic congestion.

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Changes in land use is a crucial factor impacting on the greenhouse gas balance (USEPA, 2016). It can result in changes to the amount of carbon storage in soil that can be converted to CO_2 in the air (Erb, 2004), which varies according to geographic factors such as the type of existing vegetation (IPCC, 2006). In the case of either forest or cultivation, if plants have been in existence in the same area, it can be assumed that the carbon stock change in the landscape is zero. If a new type of crop has been replanted in the same area, carbon stock can be increased or decreased (Gnanavelrajah et al., 2008). In response to the changes and conditions stated above, the purpose of this study is to track and analyze land-use changes in Phuket province from 2000 to 2009 by using GIS, and to estimate their impact on soil carbon stocks. This investigation is beneficial to provide visualized information in urban planning and initiation of activities that help reduce risks of climate change such as rehabilitation and restoration of degraded forests (Stanturf et al., 2014). Since the tourism industry is one of the activities resulting in the generation of primary gasses causing climate change (Huang and Tang, 2016); a balance between economic, societal and environmental dimensions for sustainable development must be achieved (Thomé and Scavarda, 2015). This research project aims to make a contribution in supporting effective decision-making to expand Phuket's tourism for socioeconomic growth and to preserve natural areas simultaneously and sustainably.

2. Methodology

2.1 GIS map creation

The secondary land use data were obtained from the Land Development Department, Ministry of Agriculture and Cooperatives of Thailand. Land use and land cover maps in GIS shapefile format of the year 2000 (LU2000) and 2009 (LU2009) were used in the analysis of landscape changes. The land use defined in the maps was classified into three levels corresponding to the Land Development Department. The first level consists of five major types, named Urban and Built-up land, Agricultural land, Forest land, Water Body and Miscellaneous land. There are 60 different types of land use that can be specified in the study area. However, only 11 types of land use were re-grouped and presented to gain a clearer understanding in accordance with the study objectives; they are as follows: U502 (factory), U602 (golf course), U (other urban and built-up land), A1 (paddy field), A (other agricultural land), F1 (evergreen forest), F (other forest), W2 (reservoir 'built-up'), W (other water body), M (miscellaneous land) and NA (non-classify).

Since the LU2000 map was generated based on Indian 1975 datum, it requires coordinate reference system transformation to match with the LU2009 map, which is in the World Geodetic System 1984 (WGS 84) reference. Therefore, the boundary of the study area (the Phuket Island and all small island around it) does not match the same coordinates exactly. The overlap of vector features (polygons) caused by the process of constructing LU2000 map which used the outdated GIS technology and low-resolution satellite images, and the LU2009 were not generated on top of the old LU2000 data. In order to make land-use change analysis more accurate, the LU2000 data required coordinate shifting. The extra pre-processing step was achieved by manually selecting 200 pairs of coordinates around the boundary of Phuket Island that have the same shape (angle or arc) to be the ground reference points from both maps. The different value of latitude and longitude of each pair of selected points were averaged and used as a shifting value for every coordinate of all features in the LU2000 data. This process was done using R program and the coordinate of the polygon features in text format as the input data in order to ensure that the boundary of all vector features from both maps mostly overlay on each other. However, there is some area of polygon (~3 % of all area) around the boundary of the islands that still overlap and this produces the area of non-classify (NA) in the land use change analysis process. Both land use data were converted from vector to raster with 100 by 100 meter grid resolution using maximum combined area algorithm. Grid analysis was then used to analysis and extract change of LU2000 and LU2009 using QGIS software.

2.2 Estimation of carbon storage in the soil

This study uses standard guidelines (IPCC, 2006) with local data to estimate how much carbon is stored and emitted to the atmosphere from the changes in land use in Phuket. The change of carbon storage can be estimated using the following equation:

$$SOC = SOCREF \times FLU \times FM_G \times FI \times A \times 100 \quad (1)$$

The term SOC is soil carbon stock in managed land (unit: T C); SOCREF is the reference carbon stock (unit: T C hectare^{-1}), FLU is stock change factor for land-use systems (dimensionless), FM_G is stock change factor for management regime (dimensionless), FI is stock change factor for input of organic matter (dimensionless), and A is land area (unit: hectare). The calculation unit for the estimation of carbon storage in soil for each type of forest located in Phuket area are shown in Table 1. It can be assumed that urban areas such as factories, airports, villages, buildings, and roads, have no carbon stored in their surface soil (Dorendorf, 2014). That is the reason why there are only 5 land categories, i.e., paddy field, other agricultural land, evergreen forest (tropical rain forest), dense deciduous forest and mangrove forest) presented in Table 1.

Table 1: Estimation of aboveground carbon stock per hectare for each type of forest in tropical wet

Land categories	Reference carbon stock	Stock change factor for			Carbon stock per hectare	Reference
		land-use systems	management regime	input of organic matter		
Paddy field	60	1.1	1.22	1.11	89.38	IPCC, 2006
Other agricultural land	60	1	1.22	1.11	81.25	IPCC, 2006
Evergreen forest: tropical rain forest	-	-	-	-	125.5	THAI-GLOB, 2011
Dense deciduous forest	-	-	-	-	40.5	THAI-GLOB, 2011
Mangrove forest	-	-	-	-	82.6 (primary) 35.2 (secondary)	THAI-GLOB, 2011

3. Results and discussion

3.1 Land-use change and categories

Phuket has an area of 542.7 km^2. Its shape and land utilizations in 2000 and 2009 were illustrated in Figure 1. Land-use change matrices for Phuket, Thailand between 2000 and 2009 were constructed for a simplified set of 11 land-use categories as presented in Table 2. According to the inventory in 2000, other agricultural land, evergreen forest, and other urban & built-up land were the main areas of land use for a total of 292.9, 96.6, and 80.4 km^2 while that in 2009, other agricultural land, other urban & built-up land, and evergreen forest were the main areas of land use at 228.8, 119.6, and 92.4 km^2, respectively. These numbers show the substantial increase of city area and decrease of farmland during that 10 year periods, mainly in the southern part of the island as demonstrated in Figure 1.

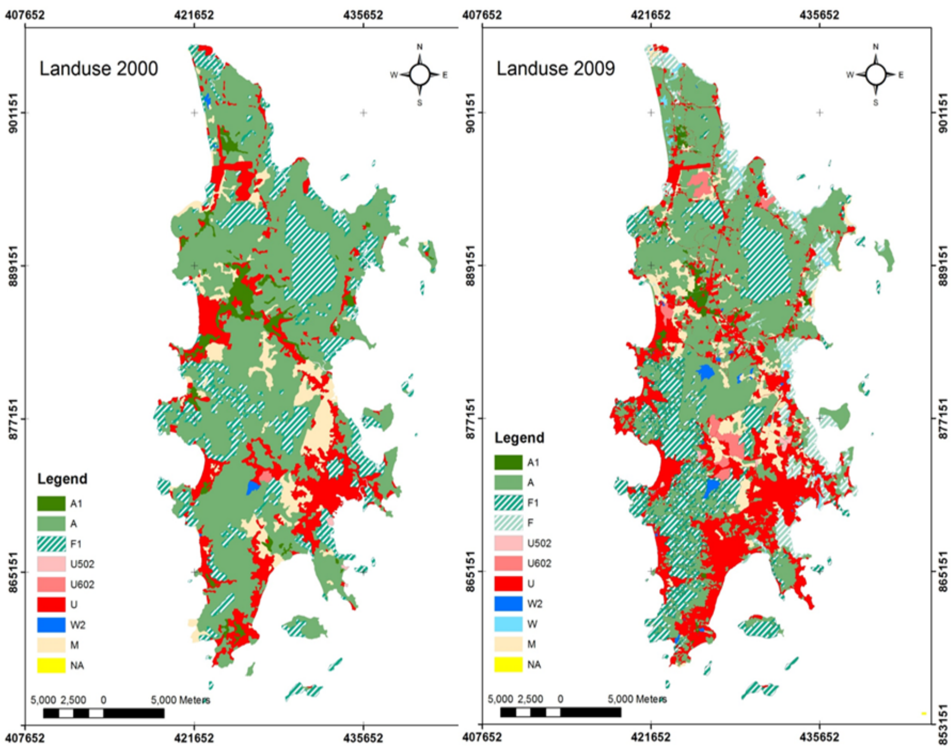

Figure 1: Phuket's land use 2000 (left) and 2009 (right)

The amount of factory area increased by 1.6 km^2, raising from 0.5 to 2.1 km^2, while factories were all moved to new locations. To serve the tourists' demand, golf courses in Phuket area increased by more than 13 times from 0.7 to 9.5 km^2 (located on the area of other agricultural land and other urban & built-up land in 2000). Rice fields decreased almost 3 times and most of them have become other urban & built-up land. The amount of other agricultural land decreased from 292.9 to 228.75 km^2 while that of other urban & built-up land increased from 80.4 to 119.6 km^2. These numbers imply a change in the social structure going from agricultural human activity to urban city human activity.

Nevertheless, the amount of evergreen forest area decreased only ~4 km^2, falling from 96.5 in 2000 to 92.4 km^2 in 2009, while other forest area had an area of 35.5 km^2 in 2009. The reason behind the increase of total forest area, even almost 30 km^2 of forestland in 2000 changed to nonforest in 2009, was due to the largest transformation of area (~42 km^2), from other agricultural land into evergreen forest. Most of this transformed area were located in the land-reform area. Thai government initiated the land-reform scheme, in 1975, in order to distribute degraded forest areas to poor farmers under the condition for temporary land tenure, so-called S.P.K.4-01 (Sor Por Kor 4-01). The landowners and inheritors holding this certificate could utilize the land for only agricultural propose (Wannasai and Shrestha, 2008). However, in practice, not all of the distributed lands were used for agriculture because a considerable part of them were not worth and suitable for cultivation (e.g., too steep, difficult to access). Thus, some areas remained uncultivated and turned naturally into dense forest under local owners' responsibility to protect and safeguard the areas from invasions for any usages inconsistent with the original purpose of the land-reform program. Regarding type of forest in Phuket, apart from evergreen forest, other forest area consisted of dense mangrove forest, disturbed mangrove forest, and dense deciduous forest which were estimated to be around 28, 2 and 5 km^2, respectively. Actually, a large part of other forest area in 2009 (22.2 km^2) were evergreen forest in 2000 but it was not specifically categorized in the LU2000 data. Reservoir 'built-up' increased approximately 3 times. This indicates awareness of high water consumption and good planning urbanization during 10 years from 2000 to 2009.

Table 2: Land-use change matrix for Phuket between 2000 and 2009 (unit: km^2); U502: factory, U602: golf course, U: other urban & built-up land, A1: paddy field, A: other agricultural land, F1: evergreen forest, F: other forest, W2: reservoir 'built-up', W: other water body, M: miscellaneous land and NA: non-classify (same abbreviation and full term for Figure 1)

Land use 2000	Land use 2009											
	U502	U602	U	A1	A	F1	F	W2	W	M	NA	Total
U502	0	0	0.43	0	0.02	0	0.03	0.0	0	0	0.01	0.49
U602	0	0.63	0	0	0	0.09	0	0	0	0	0.00	0.72
U	0.53	3.08	57.59	0.79	9.29	1.09	1.45	0.48	0.44	5.11	0.55	80.40
A1	0.10	0	6.58	5.26	2.98	0.03	0.04	0.07	0.01	3.72	0	18.79
A	0.75	5.40	32.36	0.65	190.31	42.49	6.75	1.54	0.28	10.47	1.91	292.91
F1	0	0.37	6.07	0.01	17.48	45.90	22.21	0.04	0.60	2.18	1.69	96.55
W2	0	0	0.03	0	0.25	0.10	0	0.50	0.26	0	0	1.14
M	0.73	0.05	13.13	0.03	7.17	1.96	1.29	0.60	0.41	13.80	0.73	39.90
NA	0	0	3.44	0	1.25	0.77	3.68	0.0	1.33	1.3	0	11.80
Total	2.11	9.53	119.63	6.74	228.75	92.43	35.45	3.24	3.33	36.60	4.89	542.70

3.2 Carbon storage and its change from 2000 to 2009

Using the information from Table 1 and 2, carbon stocks from land-use change in Phuket is estimated and presented in Table 3. There are 2 columns for carbon stock in 2009. One (2009A) is for the fair comparison with carbon stock in 2000 by using the same forest categories since dense deciduous forest and mangrove forest were still identified as 'evergreen forest' in the LU2000 data. The other one (2009B) is for giving more accurate values of carbon stock according to the updated data. Though using the values of carbon stock in 2009A give the higher values of that in 2009B, overall, losses of carbon were found for both cases compared to 2000. The losses in carbon stocks in 2009A and 2009B compared to 2000 were 242 and 307 T carbon, approximately. In conclusion, changing the land-use from agricultural area to other land-use categories is a major cause of carbon release from the soil surface for this study area.

Table 3: Carbon stock in soil: 2000, 2009A and 2009B (unit: T)

Land categories	Carbon stock			Carbon stock change	
	2000	2009A	2009B	A*	B**
Paddy field	167.9	60.2	60.2	-107.7	-107.7
Other agricultural land	2379.9	1858.6	1858.6	-521.3	-521.3
Evergreen forest	1211.7	1599.2***	1160.0	387.5	-51.7
Dense deciduous forest	0	0	20.3	0	20.3
Mangrove forest	0	0	353.4	0	353.4
Others	0	0	0	0	0
Total	3759.5	3518.1	3452.5	-241.5	-307.1

*Carbon stock change A = carbon stock in year 2009A - carbon stock in 2000
**Carbon stock change A = carbon stock in year 2009B - carbon stock in 2000
***dense deciduous forest and mangrove forest were calculated by using the same factor as evergreen forest

4. Conclusions

This study uses the implementation of GIS integrated with the technique for estimating carbon storage in the soil. GIS data is applied for the investigation of land use for years 2000 through 2009 in Phuket Island, a popular destination for both Thai and foreign travellers. The results illustrate the changes in land use due to the national development plan focusing on tourism. This, in turn, resulted in changes to the social structure from agrarian society to urban society. The GIS data and findings from the literature indicate that there has been an effort to secure green areas in Phuket at the same time that it has been transformed into a major tourism hub. Even the amount of forest areas in 2009 was larger than that in 2000, the results show that effort alone is not enough to maintain the quantity of carbon stock in the soil to ensure effective action against global warming. This is due to the significant transformation of agricultural areas into other urban categories as a result of citizen's adaptation along with the promotion of tourism. Moreover, according to the current provincial development strategy (DOT, 2015), there is not only a decrease of agricultural area, but it is a difficult and challenging task to avoid a decrease of forest area due to the expansion of the tourism industry in the near future. As explained above, this degradation of the natural and agricultural environment can have negative effects including climate change, a possible cause of tsunami (Kain et al., 2015). Consequently, a revision of development strategy or effective mitigation plans must be urgently triggered not only to retain but also to ensure an increase of green areas at the provincial and national levels.

Further research with an aim for finding a comprehensive solution to support decision-making process for sustainability of Phuket's tourism including socioeconomic dimension is necessary. The next step will be the application of the latest GIS data integration with satellite imagery for obtaining the most updated land-use situation. Not only to estimate the amount of carbon stored in and emitted from surface soil, GIS can also be applied as a tool to evaluate hotspots of emissions that are produced from human activities such as transport, industry and so on (Asdrubali et al., 2013). Developing emissions inventory and finding air pollution hotspots in Phuket area by using GIS for helping decision makers in choosing the proper management strategies (Pozza et al., 2015) and any available techniques that can reduce GHG emissions (Ishak et al., 2015) has been started and ongoing.

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Reference

Asdrubali F., Presciutti A., Scrucca F., 2013, Development of a greenhouse gas accounting GIS-based tool to support local policy making-application to an Italian municipality. Energy Policy, 61, 587-594, DOI: 10.1016/j.enpol.2013.05.116.

Dorendorf J., 2014, Urbanization and the Terrestrial Carbon Cycle: Pools, Processes and Implications for Ecosystem Services in the City of Hamburg, Fakultät für Mathematik, Informatik und Naturwissenschaften, Universität Hamburg, Germany <ediss.sub.uni-hamburg.de/volltexte/2015/7149/pdf/Dissertation.pdf> accessed 10.10.2016.

DOT (Department of Tourism), 2015, Tourism statistics (in Thai) <newdot.2samartmultimedia.com/home/listcontent/276/221/11> accessed 14.07.2016.

Erb K-H., 2004, Land use-related changes in aboveground carbon stocks of Austria's terrestrial ecosystems, Ecosystems, 7(5), 563-572, DOI: 10.1007/s10021-004-0234-4.

Gnanavelrajah N., Shrestha R.P., Schmidt-Vogt D., Samarakoon L., 2008, Carbon stock assessment and soil carbon management in agricultural land-uses in Thailand, Land Degradation and Development, 19(3), 242-256, DOI: 10.1002/ldr.838.

Huang H., Tang L., 2016, Calculation analysis of tourism carbon emissions amount – a case study. Chemical Engineering Transactions, 51, 1165-1170, DOI: 10.3303/CET1651195.

IPCC (Intergovernmental Panel on Climate Change), 2006, Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use, Eds. Apps M., Plume H., Schlamadinger B., Appadu S.N.S., IGES, Kanagawa, Japan <www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html> accessed 14.07.2016.

Ishak S.A., Hashim H., Muis Z.A., 2015, Optimal low carbon cement production cost via co-processing and carbon capture and storage, Chemical Engineering Transactions, 45, 295-300, DOI: 10.3303/CET1545050.

Kain C.L., Gomez C., Hart D.E., Chagué-Goff C., Goff J., 2015, Analysis of environmental controls on tsunami deposit texture, Marine Geology, 368, 1-14, DOI: 10.1016/j.margeo.2015.06.011.

MTS (Ministry of Tourism and Sports), 2015, Strategy for Thai Tourism (2015-2017) (in Thai) <www.mots.go.th/ewt_dl_link.php?nid=7114> accessed 14.10.2016.

Pozza S.A., Penteado C.S.G., Criscuolo V.G., 2015, A greenhouse gas inventory in the municipal landfill of the city of Limeira, Brazil, Chemical Engineering Transactions, 43, 2083-2088, DOI: 10.3303/CET1543348.

PRED9 (Phuket Real Estate Development 9), 2015, The development of road and transport Infrastructure in Phuket <phuket9.com/property-blog/blog/development-of-road-and-transport-infrastructure-in-phuket> accessed 14.07.2016.

PPSO (Phuket Provincial Statistical Office), 2015, Information about Phuket province (in Thai) <phuket.nso.go.th/images/new/interest_stat/phuketdata1_10-58.pdf> accessed 14.10.2016.

Stanturf J.A., Palik B.J., Dumroese R.K., 2014, Contemporary forest restoration: A review emphasizing function, Forest Ecology and Management, 331, 292-323, DOI: 10.1016/j.foreco.2014.07.029.

THAI-GLOB (Thailand Reserach Fund's Reserearch and Development and Co-ordination Center for Global Warming and Climate Change), 2011, IPCC & TARC report: knowledge of Thailand and global climate change (in Thai), The Thailand Research Fund, Bangkok, Thailand.

Thomé A.M.T., Scavarda A., 2015, A systematic literature review of design-manufacturing integration for sustainable products, Chemical Engineering Transactions, 45, 691-696, DOI: 10.3303/CET1545116.

USEPA (United States Environmental Protection Agency), 2016, Causes of climate change <www.epa.gov/climate-change-science/causes-climate-change> accessed 01.11.2016.

Wannasai N., Shrestha R.P., 2008, Role of land tenure security and farm household characteristics on land use change in the Prasae Watershed, Thailand, Land Use Policy, 25(2), 214-224, DOI: 10.1016/j.landusepol.2007.07.003.