EMISSION OF CO_2 RESULTED FROM CONVERSION OF FORESTS TO AGRICULTURAL LANDUSE IN MALAYSIA

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ABSTRACT

Increasing human population and the rapid grows of Malaysia's economy are often associated with various environmental disturbances which have been contributing to depletion of natural resources and climate change. The need for more spaces for numerous land development activities has made the existing forests suffer deforestation. The study was carried out in Pahang, which is the largest state in Peninsular Malaysia currently has about 2.2 million ha of forest cover. The forests have declined between years 2000 and 2015 due to conversion of forests to other land uses. The causes of deforestation have been identified and the amount of carbon dioxide (CO_2) emitted into the atmosphere has been determined in this study. Satellite images over the years 2000, 2005, 2010 and 2015 were used to determine forest cover changes and identify drivers of deforestation in the study area. Information on landuse that has been extracted from satellite images classification were used to determine rate of deforestation and types of landuse conversion that occurred within the periods. The CO_2 emission resulted from conversions of forests to agricultural lands were estimated by using stock changes method. Agriculture activities that contributed to the CO_2 emission were comprised mainly oil palm plantation, rubber plantation and other agricultural crops. The study found that the total CO_2 emission from these conversions was about 127 million Mg CO_2 from years 2000 to 2015, which encompassed about 61% out of the total CO_2 emission from various landuse conversions.

Key words: Deforestation, Agriculture Crops, Carbon Loss, Climate Change.

Introduction

Forests play an important role as a substantial coastal carbon sink. It is interesting to note that plant biomass in the ocean and coastal areas comprise of only 0.05% of the total plant biomass on land, get it cycles a comparable amount of carbon each year. Forests account for a large percentage of carbon fixing of about 80% of plant biomass carbon and 40% of the soil carbon (Dixon 1994). Carbon sequestration results from the difference between photosynthetic carbon fixation and ecosystem respiration in the forest ecosystem (Gong et al. 2012) and overall it results in the determination of the net ecosystem carbon exchange (Valentini et al. 2000). However being a developing nations with increasing human population and the growing economy is often associated with various environmental disturbances which have been altering the natural earth ecosystem. The need for more spaces for numerous land development activities has made the existing forests suffer deforestations.

The largest single source of greenhouse gases (GHG) emission in recorded history is from conversion of forest to other landuse types (Agus et al. 2014). This conversion has direct on-site effects resulting in degradation of vegetation, loss of biodiversity, destruction of property and occasional loss of life, while off-site impacts include carbon emissions and thus global warming and climate change. Deforestation in tropical region is considered as the second largest source of anthropogenic greenhouse gas emissions (IPCC 2007) and is expected to remain a major emission source for the foreseeable future. Deforestation is defined as the felling of trees without subsequent replanting or regeneration, i.e. the conversion of previously forested land to agricultural, urban or other land uses, which do not have a substantial tree canopy cover <10% (FAO 2010). Statistically, about 1 to 2 billion Mg of carbon per year which is equivalent to 15 - 25% of annual global greenhouse gases (GHG) emissions arises from tropical deforestation and forest degradation (Houghton 2005, Gibbs et al. 2007).

In general, deforestation is often associated with various environmental disturbances caused by human activities that alter the natural earth ecosystem. Most disturbances occur due to the demands for an improved quality of life along with the increasing human population. Deforestation is caused by multiple drivers and pressures, including conversion for agricultural uses, infrastructure development, wood extraction, agricultural product prices, and a complex set of additional institutional and location-specific factors (UNFCCC 2011), which can be extremely important in certain localities. Most importantly, the specific characteristics and magnitude of (in particular) the socioeconomic drivers behind deforestation vary widely across continents, regions and countries. Avoiding deforestations are difficult as they contribute to the nation's economy. Nevertheless it is possible to minimize deforestation while sustaining economic growth of the country through a proper mechanism.

In Malaysia the conversion of existing forest to non-forest areas has increased the GHG emissions where could lead to the global climate change. Land degradation and loss of Malaysia's original forest have resulted from rapid clearing and conversion of land for agricultural purposes, and the forest had decreased by 1.2 million hectare by 1990 (FAO 2010). Half of the forests in the Peninsular Malaysia was cleared in the late 1980s (Gillis and Repetto 1988), which decreased the total forest area to 57% of the original area by 2002 (Langner et al. 2007). This has resulted in a serious land cover challenge in the Peninsular Malaysia (Brookfield and Byron 1990). The rapid expansion of oil palm over the two decades has led to the transformation of large areas of forest and plantation landscapes throughout Southeast Asia and is believed to be one of the major sources of greenhouse gas (GHG) emissions linked to land use in the region (Ekadinata and Dewi 2011, Wicke et al. 2011). Demand for palm oil continues to grow and the sector continues to invest in expanded production through multiple strategies, including by increasing yield and avoiding waste, but also expanding the area under cultivation. The ongoing and future expansion of oil palm plantation may or may not result in future emissions of CO_2, the most significant GHG linked to land use, depending on the type of land cover that is converted for new plantations. For example, if expansion occurs on forest landscapes with high above and below-ground stocks, then net emissions linked to the sector will be proportionally large. In contrast, if the source of land for new plantations has low carbon stock value, such as shrub land or agroforest, then future expansion could be considered carbon neutral. In some cases, expansion might actually be carbon positive if the initial carbon stock is less than that of oil palm as the case with grassland and most types of annual crops.

Malaysia is now committed to the program of reducing emissions from deforestation and degradation, and forest conservation (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC). The main aim of the program is to stabilize the GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. However the amount of deforestation and forest degradation and emission from these activities are yet to account. Given the current gap in knowledge and understanding of emission at national level, the research presented in this paper aims at providing methodology for estimating emission from deforestation with special reference to the activities related to the agriculture. While national data on carbon emission have commonly not been available in the past, this research will generate new information for the country in-line with the REDD+ requirements. The study was conducted in Pahang, Peninsular Malaysia. The period covered was between 2000 and 2015, where variations of drivers of deforestation were quantified spatially and temporally. Rate of deforestation and changes of carbon stock over the past 15 years is also elaborated in this paper. Finally, the net emission of CO_2 as a result from the conversions was estimated in yearly basis based on carbon stock change method. Benefits from the study not only help the country to reduce carbon emissions but potentially gain credits under the current REDD+ initiative. It is also to ensure that activities under the REDD+ will be able to provide advantages to the communities as well as the government.

Materials and Method

There are some basic procedures for estimating CO_2 emission that have been published by the IPCC which have already undergone peer reviews for technical soundness. IPCC (2006a) in particular, include Volume 4 dealing with Agriculture, Forestry and Other Land Use (AFOLU), and IPCC Good Practice Guidance for Land Use Change and Forestry. These two guides contain very specific information about the methods, equations, and tools. The procedures have been adopted in this study, which can be summarized into three major steps, which are (i) forest cover change analysis, (ii) carbon stock assessment, and (iii) estimation of carbon emission. The first step involved mainly data from satellite images, which is Landsat. It was used because it is the only satellite system that offer consistent data over the last more than 30 years. The Landsat archive provides a lengthy and uninterrupted time series of Earth observation data, a crucial element in the development of our understanding of the linkages between anthropogenic activities and ecological outcomes (Carpenter et al. 2006). Other important advantages of Landsat include cost effectiveness, easy access, free data policy and web-based data distribution (Wulder et al. 2012). The combination of all these factors makes Landsat a viable, cost effective, non-destructive and practical tool that could potentially provide a vital source of information for the planning and management of forested lands.

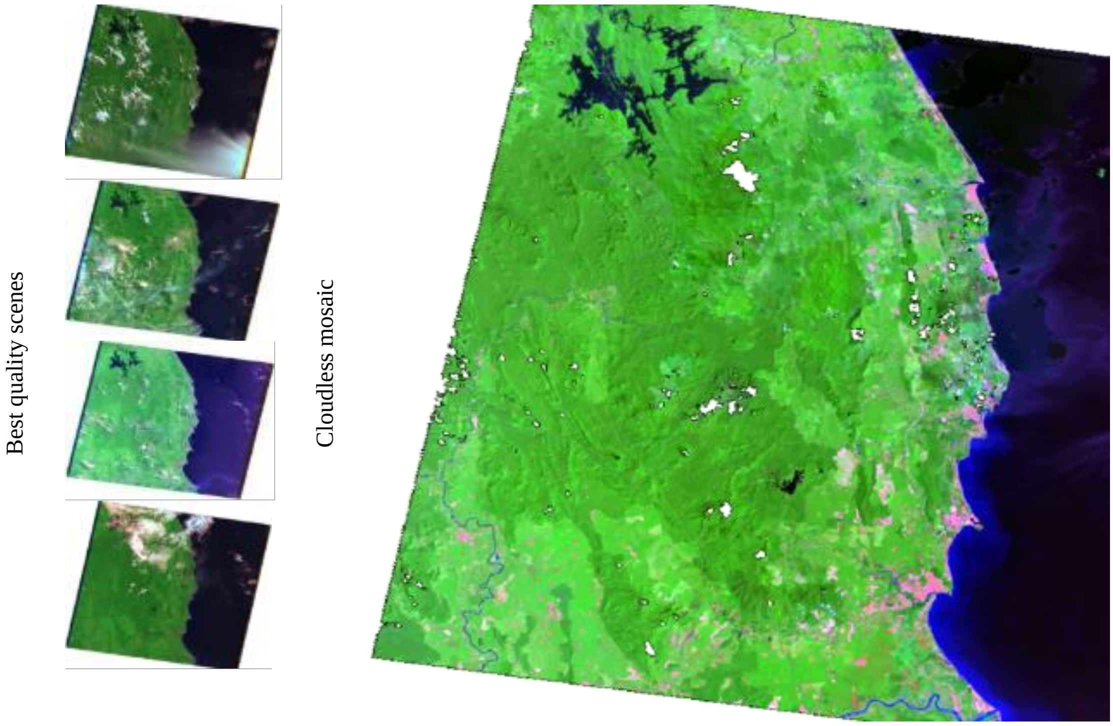
Forest cover change analysis

The forest area is defined as land under natural stands has at least with 30% crown cover, with the minimum area spanning 0.5 ha and the minimum stands height of 5 m at maturity. Changes of forest area is referred to as deforestation, which is human induced permanent conversion of forest land to non- forest, as all of the forest is cut and the land is cleared and used for other purposes. Temporary change in forests, like one rotation tree crop (up to 25 years) within forest reserves are not considered as deforestation and it falls under sustainable management of forests. Forest cover changes analysis has been conducted to determine the areas that have been converted from forest to other land uses especially to agriculture crops and commercial plantations.

The landuse classes in the entire Pahang have been produced from the Landsat-TM, ETM+ and OLI satellite images over the years 2000 – 2005, 2010 and 2015, respectively. The images were the major input for mapping forest cover and change over time. This data was downloaded from US Geological Survey National Centre for Earth Resources Observation and Science via the GLOVIS data portal (http://glovis.usgs.gov/) with relatively cloud cover less than 30%. At least four individual scene of Landsat images are required to cover the entire Pahang for a year and the path/row numbers for the scenes are 126/057, 126/058, 127/057 and 127/058. Therefore, at least 16 scenes were acquired to complete the years of 2000-2015.

The methodologies were based on two main approaches; (i) images classification for land use and (ii) post-classification changes detection. Cloud cover on Landsat images was removed for each individual scene and was then combined to produce a mosaic images of the study area (Figure 1). Images for each year were classified to determine forested areas that have been existed in Pahang. The classified images were then converted to vector format (.shp) to perform post-classification change detection. Changes have been determined from this process for each pairing interval of 2000-2005, 2005-2010, and 2010-2015. Rate of deforestation was quantified within each interval.

Figure 1: Cloudless mosaic of Landsat images after cloud removal process from a number of best quality scenes



The landuse classes were generalized into 10 classes that consisted of forest area, oil palm plantation, rubber plantation, urban area, agriculture (other than oil palm and rubber plantations), water body, mine and quarry, grassland, animal husbandry areas and cleared land for the purpose of simplification. From-to changes analysis has been conducted for each interval and the extents of forests that have been converted to other land uses have been determined. In addition to this analysis, a ground truthing activity has been conducted at several locations to conform the current landuse on the ground.

Carbon stock assessment

Carbon stock in the remaining forests have been assessed before carbon emission due to deforestation can be estimated. To complete this exercise, carbon stock in all forest types (i.e. inland, peat swamp and mangrove forests) in Pahang have been surveyed on the ground at a number of sample sites. The sampling design in this study was a modified sampling design according to the standard operating procedure (SOP) that has been developed by Winrock International (Walker et al. 2012), which follows the IPCC standards (IPCC 2006b). A cluster comprises four (4) subplots and the design is shown in Figure 2. The subplot was designed in circular with smaller nests inside. The biggest nest measures 20 m in radius, followed by the smaller nests measuring 12 and 4 m. The sizes of trees were measured according to the nest sizes, which is summarized in Table 1. Depending on the nest size, it indicates that not all stands were measured in a single subplot. In additional to these nests, there is another small nest measuring 2 m in radius, which is used to count saplings (i.e. trees measuring < 10 cm in diameter at breast height (dbh) and > 1.3 m in height). Clustering of subplots at each sampling unit is recommended for natural forest areas and areas that have been selectively logged. The sampling system is design in a way to make the data collection processes easier, faster but reliable and representative for a particular forest stratum.

A forest ecosystem normally has five terrestrial carbon pools, which are; (i) aboveground living biomass, (ii) belowground living biomass, (iii) deadwood, (iv) non-tree vegetation and litters, and (v) soil. However, one of the most significant carbon pools is aboveground biomass as it the easiest and the most practical pool to assess, while representative to an ecosystem. Aboveground biomass (AGB) comprises all the living aboveground vegetation, including stems, branches, twigs and leaves, deadwood, non-tree vegetation and litters. Allometric functions is the best way that above ground biomass can be estimated. In this study, regional allometric functions that are found in the literature (Table 2) were used to estimate the biomass of living trees in the inland, peat swamp and mangrove forests. A default factor of 0.47 was used to convert the biomass into carbon.

Figure 2: Layout of the sampling plot and sampling design of a cluster of sample

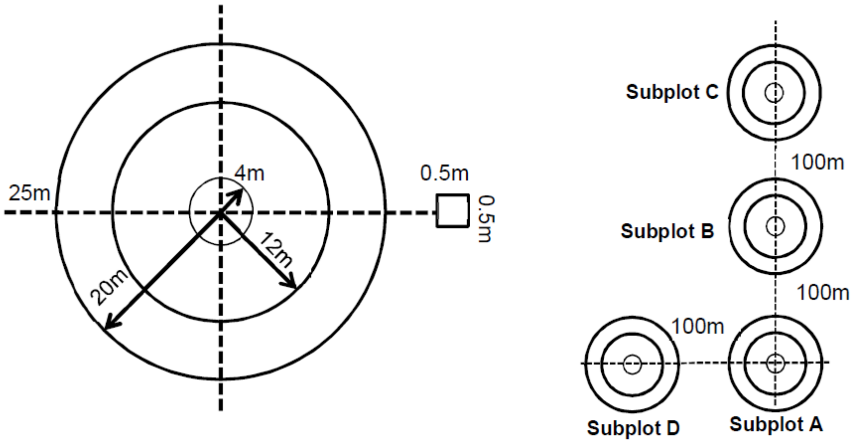


Table 1: Summary living trees measurement in a subplot

Nest radius (m)	Size	Tree size, dbh (cm)
4	Small	≥ 10
12	Medium	≥ 20
20	Large	≥ 40

Table 2: Allometric functions that have been used for AGB estimations

Forest type	Allometric function	Source
Inland forest	AGB = [exp (-1.803 – 0.976E+0.976 ln(ρ) + 2.673 ln(D) – 0.0299 [ln(D)]^2]	Chave et al. (2014)
Peat swamp forest	AGB = 0.65*exp(-1.239 + 1.98*ln(D)+ 0.207* ln(D)^2 - 0.0281*ln(D)^2	Chave et al. (2005)
Mangrove forest	AGB= 0.251ρD$^{2.46}$	Komiyama et al. (2007)

AGB denotes aboveground biomass (kg/tree), E represents bioclimatic variable (average value of -0.099 for Pahang), ρ is wood specific gravity/ wood density, and D is dbh.

Estimation of carbon emission

There are two methods that can be used to estimate emission, which are the stock-difference method and the gain-loss method. Stock-difference requires two measurements in two different time periods. The estimated carbon stocks between the two periods divided by the time difference between the two time periods is the estimated carbon stock change per unit area. This method is better suited for deforestation. The gain-loss method, on the other hands, does not require two measurements; instead it simply measures the rate of carbon change in a given period, i.e. mean annual increment of carbon. Hence, this method is better suited for forest degradation where the stock change can be measured in two time periods through the expected change in carbon stock. Once the areal extents of deforestation is known, emission factor (EF) is then required. Emission factor is a measure of carbon loss that is caused by conversion of forest to other land uses. The carbon stock in forested areas was measured on the ground while carbon stock in the other landuse categories were adopted from literature to obtain the EF, as summarized in Table 3. Net emission from land use and land use changes can be estimated based on equations provided by (IPCC 2006a), which can be expressed as

$$\Delta\ C = \frac{(Ct2-Ct1)}{(t2-t1)} \qquad (1)$$

where ΔC is annual carbon stock change (Mg C yr^{-1}), C_{t1} and C_{t2} is carbon stock at time t_1 and t_2 (Mg C) respectively. However, whenever activity data (i.e. deforestation information) is available from changes analysis that has been conducted prior to the estimation of carbon emission, the following equation can be used,

$$Ct = \sum (AD \times EF) \qquad (2)$$

where Ct is the carbon stock in time t, AD is the activity data or the area undergoing a specific type of land use change that emits carbon (measured in ha), and EF is emission factor, which is the total loss of the carbon stock per unit land area during the specific type of land use change (measured in Mg C ha^{-1}). Carbon emission can be expressed in terms of C loss or can be converted to CO_2 by multiplying with a factor of 3.67 which is the molecular weight of CO_2 per unit atomic weight of C.

Table 3: Emission factor for different types of land conversion
(Summarized from Agus et al. 2014)

Landuse classes	Carbon stock (Mg C ha^{-1})	Conversion of forest to	Emission factor (Mg C ha^{-1})
Forest	186	Forest	0
Oil palm	36	Oil palm	150
Rubber	58	Rubber	128
Urban area	7	Urban area	179
Agriculture	54	Agriculture	132
Water body	0	Water body	186
Mine and quarry	0	Mine and quarry	186
Grassland	3	Grassland	183
Animal husbandry	3	Animal husbandry	183
Cleared land	0	Cleared land	186

Results and Discussion

Deforestation in Pahang

The total land area in Pahang is estimated at about 3.56 million ha with an overall forest area at 2.2 million ha in the year 2015. Changes of forest area in Pahang between 2000 and 2015, as resulted from deforestation are reported in Table 4. Factors of this deforestation is summarized in Table 5. The total deforested area was found at 326,449 ha for the years 2000 to 2015, which was accounted for deforestation at the rate of 21,763 ha yr^{-1}. Large piece of forest area in Pahang have been converted to oil palm and rubber at commercial scales. Furthermore, the forest area has been replaced by urban area in terms of development, high density of human structures such as houses, commercial buildings, roads, and highways. Similarly, agricultural land is the share of the forests area that is converted to arable under permanent crops. This arable land includes land defined by the FAO (2006) as land under temporary crops, land under market or kitchen gardens, and land temporarily fallow. The forest area were also converted to quarry and mine sites from which bauxite, dimension stone, rock, construction aggregate, riprap, sand, gravel, or slate have been excavated from the ground. These activities result to open-pit mine from which minerals are extracted. Certain area of the forest are left idle that is they are not cut, burned, cropped, heavily grazed, cultivated, or otherwise disturbed. Other part of the forest are converted to animal husbandry and farms domestic supplies. The ground truthing confirmed that most of the cleared lands that appear on the landuse maps were spaces that have been prepared for oil palm plantations. Small patches of the clear land were also identified as scars of forest fires that occurred in the past.

Table 4: Forest cover in Pahang from 2000 to 2015

Year	Forest area (ha)
2000	2,519,545
2005	2,440,596
2010	2,286,367
2015	2,193,096

Table 5: Loss of forest in Pahang due to land conversion (ha)

From forest to	2000-2005	2005-2010	2010-2015	Total
Oil palm	57,572	51,177	44,982	153,731
Rubber	22,156	17,505	15,386	55,046
Urban area	7,746	4,288	3,769	15,802
Agriculture	15,763	9,361	8,228	33,352
Water body	1,575	2,942	2,586	7,103
Mine and quarry	2,114	1,250	1,098	4,461
Grassland	13,853	15,704	13,803	43,360
Animal husbandry	453	438	385	1,275
Cleared land	5,832	3,453	3,035	12,320
Total	127,062	106,116	93,271	326,449

The assessed carbon stock

The assessment of carbon stock have been done in all major forest types found in Pahang. However, the calculation of EF used an average value of carbon stock from inland and peat swamp forests only. Mangrove forest was excluded from the estimation because its extent was found too small and if included in the estimation, will produce serious underestimate of carbon stock for all forests in entire Pahang. The average carbon stock of these forests was estimated at 186.46 Mg C ha^{-1}. Table 6 summarizes the assessed carbon stock for all forest types in different pools of aboveground carbon. Table 3 that was shown earlier used this average value as a basis to calculate the EF.

The loss of carbon was estimated by multiplying the extents of deforested areas (Table 5) with the emission factors for each corresponding landuse category. Table 7 shows the estimated loss of carbon within each interval for the entire Pahang. It is obvious that the major contribution to the loss of carbon in Pahang was from the expansion of oil palm and rubber plantations.

Table 6: The estimated aboveground carbon stock in different forest types

Forest type	Average carbon stock (Mg C ha^{-1})			
	Aboveground living	Deadwood	Non-tree vegetation and litters	Total carbon stock
Inland	174.49	4.92	1.29	180.70
Peat swamp	168.63	21.40	2.19	192.22
Mangrove	135.45	22.12	3.88	161.45

Table 7: Loss of C (Mg C)

From forest to	2000-2005	2005-2010	2010-2015	Total
Oil palm	8,635,800	7,676,550	6,747,328	23,059,678
Rubber	2,835,904	2,240,576	1,969,361	7,045,841
Urban area	1,386,445	767,463	674,564	2,828,471
Agriculture	2,080,716	1,235,652	1,086,080	4,402,448
Water Body	292,950	547,212	480,974	1,321,136
Mine and quarry	393,111	232,407	204,275	829,793
Grassland	2,535,099	2,873,832	2,525,964	7,934,895
Animal husbandry	82,808	80,063	70,371	233,241
Cleared Land	1,084,752	642,258	564,515	2,291,525
Total	19,327,584	16,296,012	14,323,432	49,947,028

The estimated carbon emission

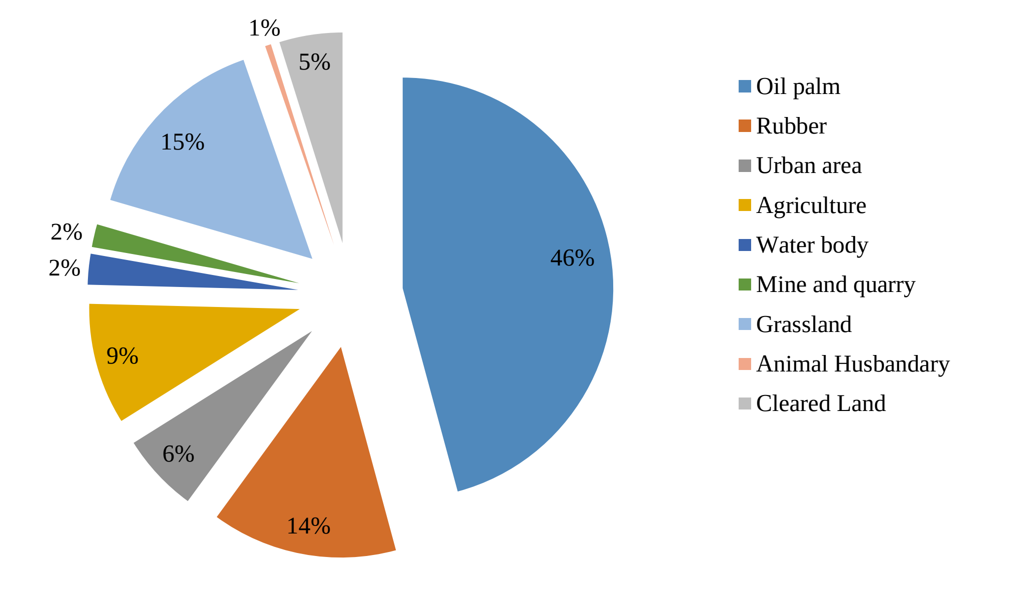
The emission resulted from conversion of forest to other types of land uses were estimated by using stock-changes method. Table 8 summarizes carbon emission that occurred in Pahang. Normally the rate of net emission is reported in yearly basis, but it also can be estimated in cumulative between two periods. The study found that the net CO_2 emission from deforestation in Pahang was at 183.3 million Mg of CO_2 from year 2000 to 2015. Agriculture activities contributed about 69% of the total CO_2 emission (i.e. 110.5 million Mg CO_2), which comprised oil palm (46%), rubber (14%) and other agricultural crops (9%). The results indicated that the emission from permanent crops alone, which are oil palm and rubber contributed 60% of the net CO_2 emission occurred in Pahang from 2000 to 2015 as depicted in Figure 3.

Table 8: Summary of carbon emission in years 2000 – 2015

Year	Carbon loss (Mg C)	Rate of Carbon loss (Mg C yr^{-1})	Rate of carbon emission (Mg CO_2 yr^{-1})
2000-2005	19,327,584	3,865,517	14,302,412
2005-2010	16,296,012	3,259,202	12,059,049
2010-2015	14,323,432	2,864,686	10,599,340

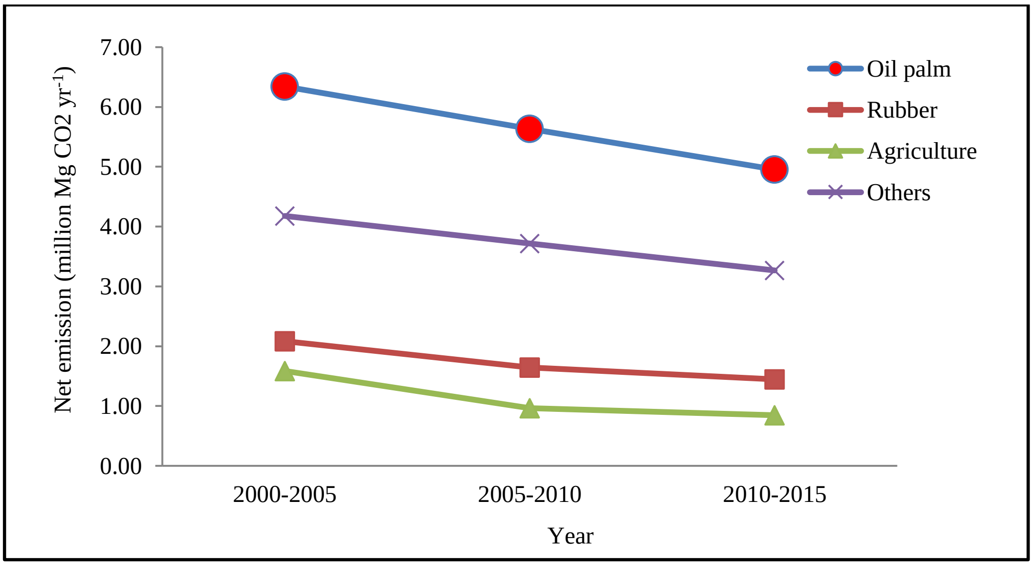
The results can also be used to develop reference emission levels (REL) to identify which one of conversion activities that contributed significantly to the carbon emission. Since the study focuses only to the agricultural sector, especially the oil palm, rubber and agricultural activities other than these crops, therefore the emission level highlights only these three classes. The other conversions is merged into a single class namely 'others', which includes urban areas, water body, mine and quarry, grassland, animal husbandry areas and cleared land. Figure 4 shows the levels of CO_2 emission in Pahang. It was anticipated that the oil palm plantation was always contributing to the highest emission, followed by others. The conversion of forests to others mainly involved settlements, development of industrial areas and mining activities. These kind of conversions have caused the highest emission because any amount of carbon stock in the forests will turn into zero (0) when converted. Rubber plantation was identified as the third contributor. The observation indicated that the rubber plantation has plummeted between years 2000 and 2005. In contrast, there was considerable increase in oil palm plantation in the same period. It shows that there was a huge change in Malaysia's economy during that period, where oil palm started to be the main commodity and play major roles in the export industry as compared to rubber. This pattern was found consistent through years 2005 until year 2010. After that, more lands were required to support the industry and rubber plantation again suffered from the change economic condition and consequently became less attractive due to the decrease in demand.

Figure 3: The total carbon emission due to conversion of forests to other land uses from 2000 to 2015



Net carbon emission from agricultural crops other than oil palm and rubbers plantations was consistent throughout the years 2000 to 2015. Only certain areas, which are the districts of Cameron Highlands and Pekan that experience conversion from forests to agriculture, especially for vegetable and fruits cultivations for domestic supplies. These changes is depicted in Figure 5, which shows locations of deforestation that occurred in Pahang since year 2000 to 2015. The expansion of oil palm plantations can be seen concentrating in the east part of Pahang, which covers the districts of Kuantan, Maran, Pekan and Rompin.

Figure 4: Net emission of CO_2 from agricultural sector in Pahang from years 2000 to 2015



Conclusion

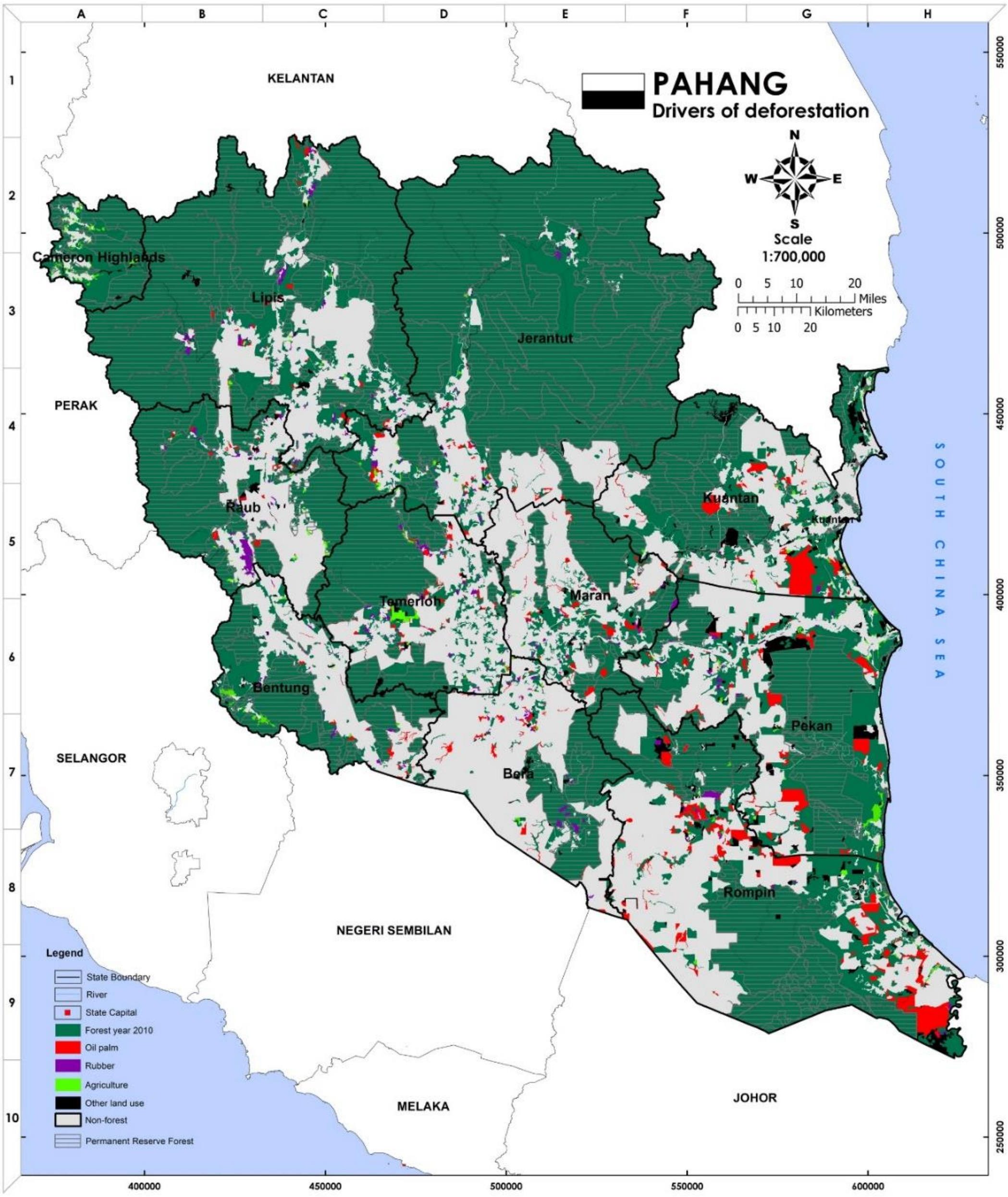
The study has provided methodology for estimating emission from deforestation with special reference to the activities related to the agriculture. The total deforested area was found at 326,449 ha for the years 2000 to 2015, which was accounted for deforestation at the rate of 21,763 ha yr^{-1}. The study found that the net CO_2 emission from deforestation in Pahang was at 183.3 million Mg of CO_2 from year 2000 to 2015 at an average of 12.2 million Mg CO_2 yr^{-1}. Agriculture activities contributed about

69% of the total emission. The study indicated that the emission from permanent crops alone, which are oil palm and rubber contributed 60% of the net CO_2 emission occurred in Pahang from 2000 to 2015.

This has proven that the palm oil and rubber plantations were the main factor of the deforestation in Pahang. This factor is very common in Peninsular Malaysia (Saiful and Nobukazu, 2008) and also in Malay Borneo (i.e. Sabah and Sarawak) since year 1990. (McMorrow and Mustapa, 2001). It is also occurred to some extents in the South East Asia region (Wicke et al. 2011). It was demonstrated that the integration of multi temporal datasets from land use maps was capable in identifying factors of the deforestation. The findings of this study will be an important indicator in assessing forest status and the trend of agricultural crops expansions in the country. It is also essential in providing activity data for carbon emission studies to make the REDD+ a reality. The information produced from this study is valuable for the policy makers to balance between development and environmental amenity. Although agricultural expansion has been determined as the key factor of deforestation in Pahang, the factors are actually vary regionally and change over time.

The sampling design adapted for assessing carbon pools was appropriate to represent forests in Pahang. While national data on carbon assessment have commonly not been available in the past, this research has generated new information for the country in-line with the REDD+ requirements. Based on carbon stocks in different landuse types in Pahang; these values can be used to calculate CO_2 emission factors due to landuse change. However, some limitations have been identified from the study, which can be summarized as (i) generalization of net CO_2 emission from conversion, regardless the CO_2 intake during the growth of the agriculture crops, and (ii) the forest ecosystem was considered as one single stratum, regardless the variations of the status and management practices. Above all, to identify cost effective policies that will effectively reduce emission from agriculture expansions in Malaysia, REDD+ mechanism should depends on capacity to implement measures for effectively controlling deforestation and practicing good agriculture practices.

Figure 5: Deforestation in Pahang between years 2000 and 2015



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