CHAPTER 4

SPATIAL AND TEMPORAL DISTRIBUTION OF OPEN BURNED RICE FIELD RESIDUE AND EMISSIONS FROM OPEN BURNING

4.1 Introduction

Open burning of rice residue is the common method generally found in Thailand because it is the cheapest and quickest method for clearing an area. Although the burning of rice residue is the cost-effective and ecologically method [Hansen, D.G. and Carlson, J.E., 2004], it can also cause GHG emissions as carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), non-methane volatile organic compounds (NMVOC) and nitrogen as N_2O and NO_x species [Levine, J., 2000] due to incomplete combustion of the fuel [2006 IPCC]. Moreover, it leads to health and visibility problem [Hays, M.D., 2005]. The amount of pollutants emitted depends on the composition and moisture content of the residue, the manner in which the field is burned (heading fire, backing fire, and strip-light fire), combustion temperatures and ambient conditions, including wind speed, ambient temperature [USEPA, 2001; Jenkins B M, et al., 1996; and PCD, 2005].

Rice residue open burning has been considered an important source of pollutant and GHG emission [I. Ortiz de Za′ rate et al., 2005; Ministry of Natural Resources and Environment, 2010] that has a significant impact on global warming.

Thailand realizes this problem and has set a national master plan for open burning control since 2003 [Pollution Control Department, 2005]. To achieve the goal of open burning control, it is very important to know the situation of the problem.

The objective of this part is to assess the amount of rice residue open burned in Thailand by using the information from field survey and questionnaire survey that leads to the estimation of GHG emission as CO_2, CH_4, N_2O and pollutant as CO, NO_x, $PM_{2.5}$ based on 2006 IPCC guidelines.

4.2 Methodology

4.2.1 Amount of burned rice residue

The amount of rice residue burned in the field is estimated by subtracting the amount of residue by the amount of residue used for any purpose, and then multiplied by the fraction of burned area and combustion efficiency (see Equation 4.1). The value of factor is obtained from questionnaire survey and field survey.

$R_B = R \times (100\text{-}U) \times A_B \times CE$ --- (Equation 4.1)

Where: R_B = Residue burned in the field

R = Generated residue

U = Percentage of used residue

A_B = Amount of burned area

CE = Combustion efficiency

Residue generated (R)

The amount of stubble and straw is assessed by harvest method data, rice variety data, and relationship between weight in unit area and cutting level. Harvest method and rice variety data is obtained from questionnaire survey (see Chapter 3.3 for details). Relationship between weight in unit area and cutting level developed from field survey data (see Chapter 2.3 for details)

Percentage of residue used outside the field (U)

Percentage of residue used outside the field obtained from questionnaire survey. The information of questionnaire survey is shown in Chapter 3.3.

Amount of burned area

The amount of burned area obtained from questionnaire survey. The information of questionnaire survey is shown in Chapter 3.3.

Combustion efficiency

Combustion efficiency obtained from questionnaire survey. The information of questionnaire survey is shown in Chapter 3.3.

4.2.2 Emission from open burned rice residue

This study applied the method of biomass open burning in 2006 IPCC Guidelines to estimate emission from rice residue burning. The GHG emission and pollutant considered in this study included CO_2, CO, CH_4, N_2O, NO_x, $PM_{2.5}$, PM_{10}, and black carbon. The principal of emission estimation from open burning of biomass related to the emission factor and the amount of residue that consumed by fire. Emission factor mostly specific for open burning of rice residue is summarized as shown in Table 4.1. The amount of rice residue consumed by fire is estimated by field survey data and questionnaire survey data.

Table 4.1 Default value of emission factor

	EF (g/kg)	Source
CO_2	1,185	Kanokkanjana, K. and Garivait, S., 2010
CO	133.2	Kanokkanjana, K. and Garivait, S., 2010
CH_4	2.7	Andrea, M.O., Merlet, P., 2001
N_2O	0.07	Andrea, M.O., Merlet, P., 2001
NO_x	3.1	Kadam, K., et al., 2000
$PM_{2.5}$	27.63	Kanokkanjana, K. and Garivait, S., 2010
PM_{10}	13	Andrea, M.O., Merlet, P., 2001
Black carbon	0.69	Andrea, M.O., Merlet, P., 2001

4.3 Results and Discussion

4.3.1 Amount of residue burned in the field

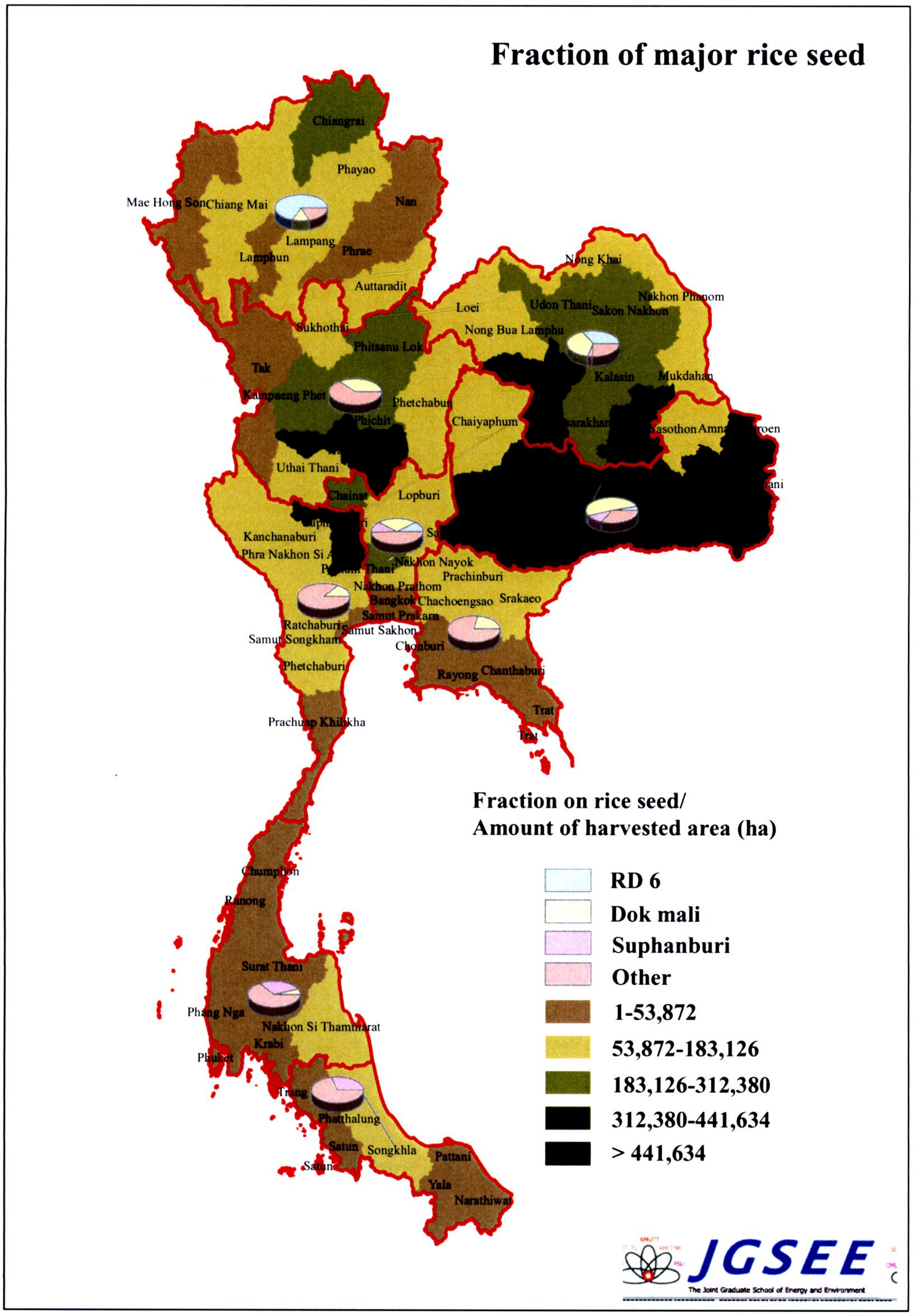
4.3.1.1 Generated residue

Based on the relationship between weight in unit area and cutting level for major rice and minor rice as shown in Equations 2.1 and 2.2 respectively, the spatial distribution of rice variety (as shown in Figure 4.1) and harvest method (as shown in Figure 4.2) found during 2007-2008, the overall amount of rice residue was about 117.7 Mt that included 42.3 Mt of major-stubble, 36.4 Mt of major-straw, 17.1 Mt of minor-stubble, and 21.9 Mt of minor-straw.

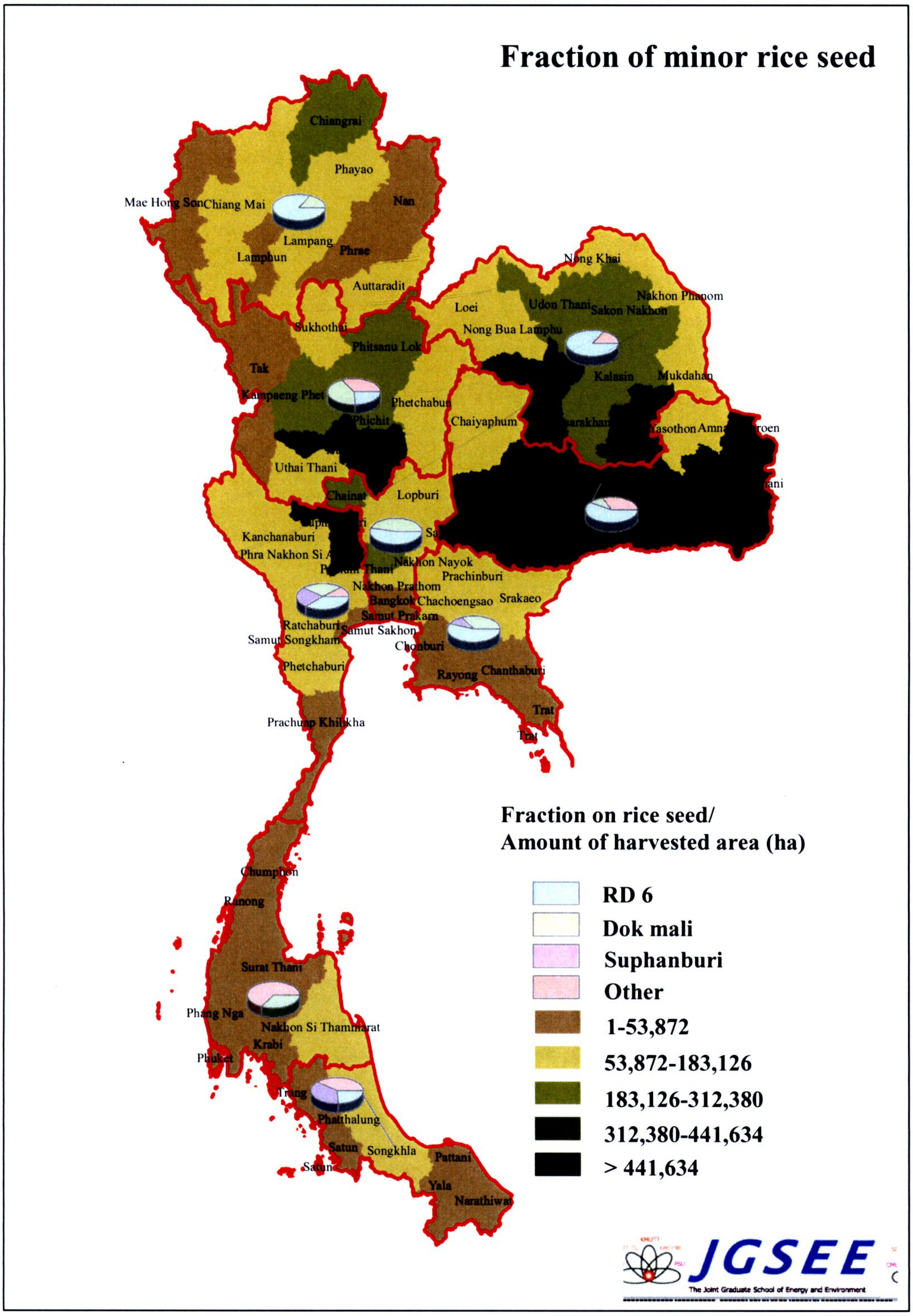
Take into account on regional level (as shown in Table 4.2) found the lower northeastern part of Thailand was the largest of producer of rice residue by produce about 21% of overall rice residue, followed by the upper northeastern (20%) and the lower northern (20%), and the central (15%). The lower northeastern was the largest residue producer because of there was a largest of rice producer which had the maximum of harvested area (25% of overall harvested area or about 2.7 Mha).

Table 4.2 Amount of rice residue by type of residue and region

Region	Major residue (M tons)		Minor residue (M tons)		Total
	Stubble	Straw	Stubble	Straw	
Eastern	1.42	2.81	0.77	1.05	6.04
Central	2.00	3.98	4.66	6.41	17.05
Western	1.17	2.33	3.21	4.41	11.13
Lower-Northern	5.86	6.06	5.22	6.42	23.57
Upper-Northern	2.70	2.79	0.90	1.10	7.49
Lower-Northeastern	14.72	9.07	0.52	0.54	24.85
Upper-Northeastern	13.10	8.07	1.36	1.43	23.96
Lower-Southern	0.85	0.81	0.32	0.33	2.31
Upper-Southern	0.47	0.46	0.18	0.19	1.31
Total	**42.29**	**36.38**	**17.15**	**21.89**	**117.71**

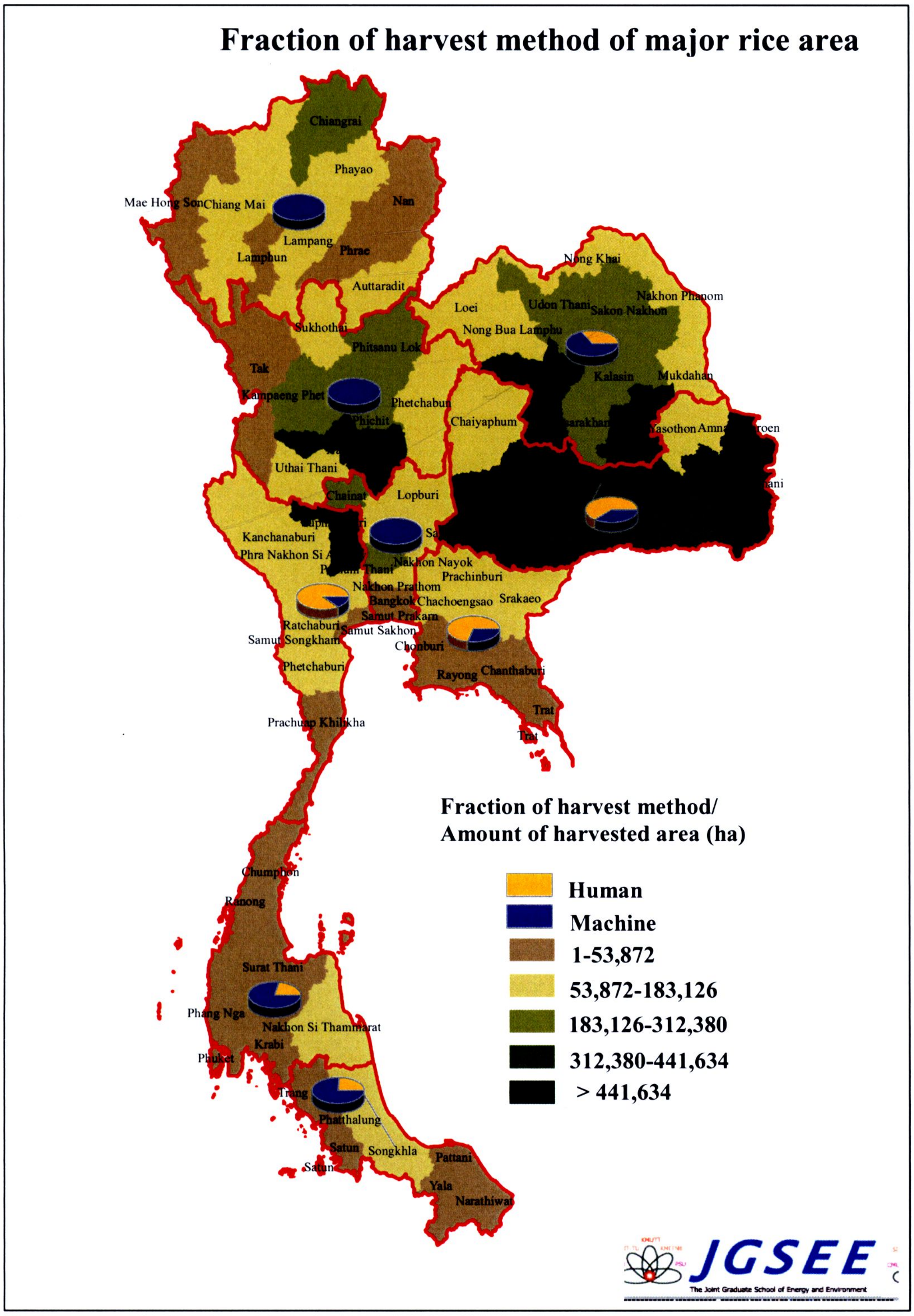


4.1 (a) Major rice seed

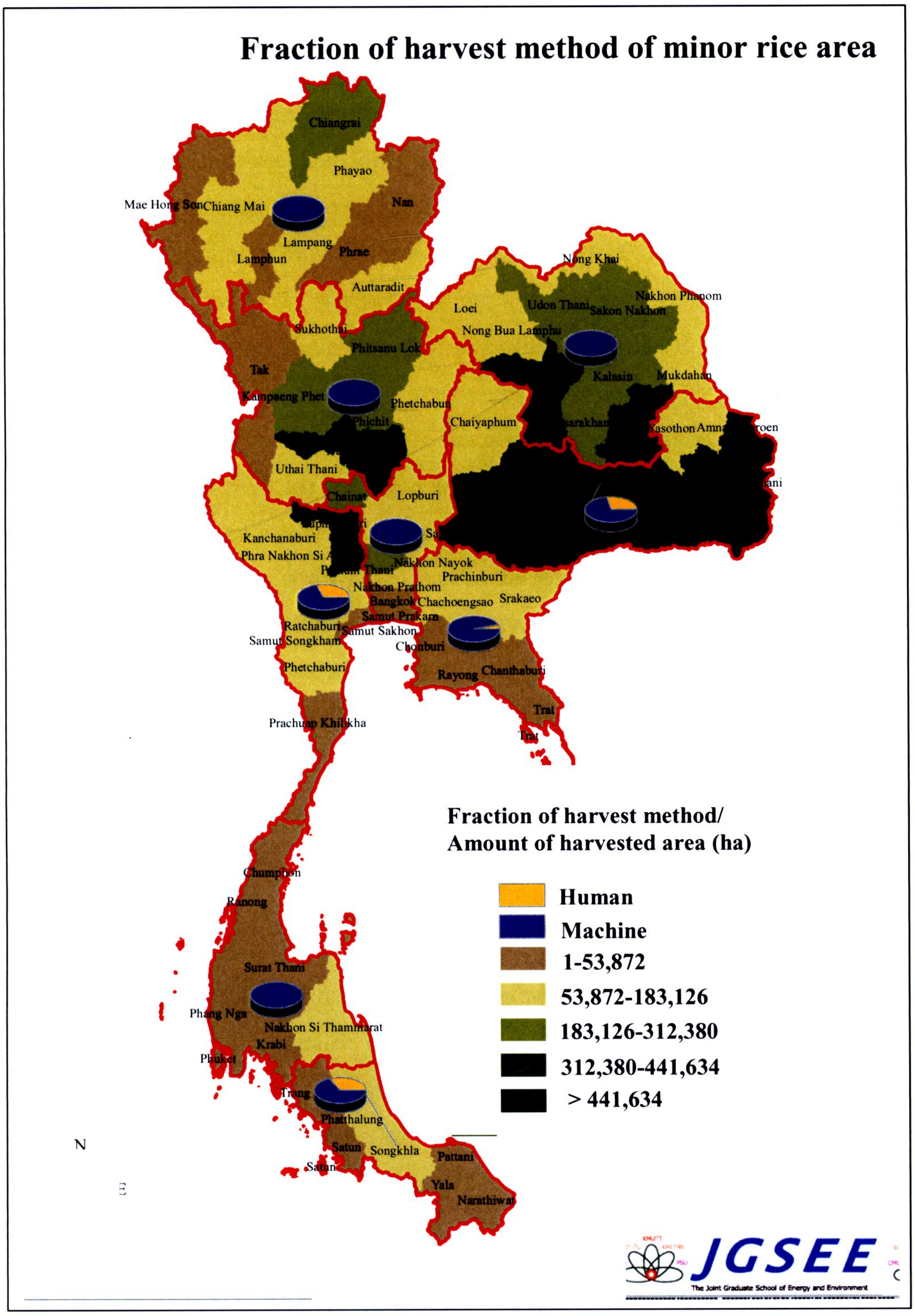


4.1 (b) Minor rice seed

Figure 4.1 Fraction of rice seed in each region



4.2 (a) Major rice area



4.2 (b) Minor rice area

Figure 4.2 Fraction of harvest method in each region

According to the amount of rice residue classified by type of residue (major-residue/minor-residue) and region found the main of major-residue was generated in the lower northeastern region by about 30% of overall major-residue. Next was generated in the upper northeastern and the lower northern regions which was about 27% and 15% respectively. For minor-residue, the maximum was in the lower-northern region by available 30% of minor-residue, followed by the central (28%) and the western regions (20%). The lower northeastern region was the main of major residue producer because there had the maximum of major rice which was about 30.2% of overall major field or about 2.6 Mha). The lower northern region was the main of minor residue producer because there had the maximum of minor rice which was about 29.8% of overall minor field or about 0.6 Mha).

According to the amount of residue classified by type of residue, the overall stubble and straw was about 59.4 Mt and 58.3 Mt respectively. The area where there was the largest stubble producer was the lower northeastern region (26.5% of stubble). The area where there was the largest straw producer was the lower northern region (21.4% of straw).

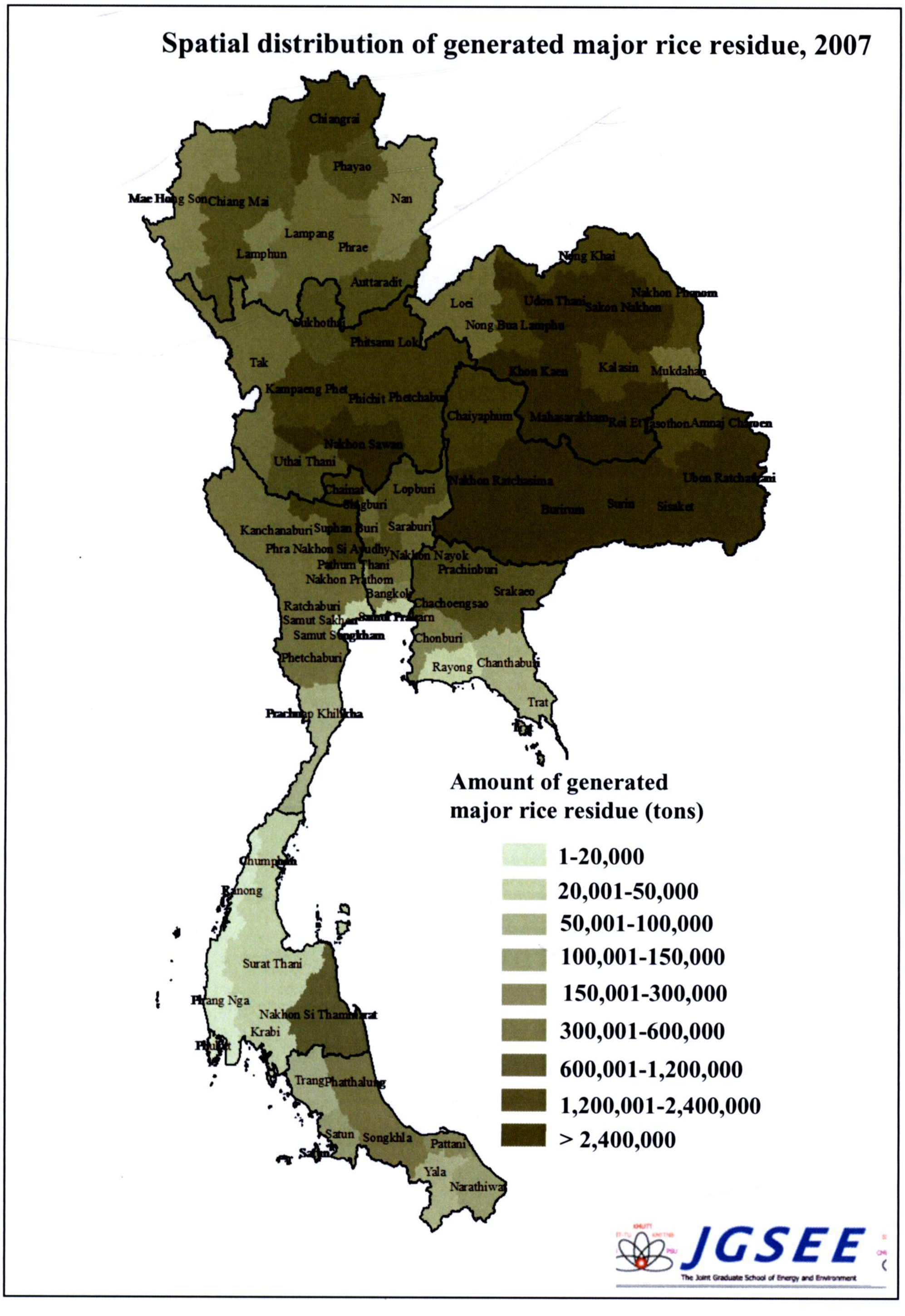
In the case of stubble, the lower northeastern region could produce the maximum of stubble because of the harvest area in the lower northeastern region was about 2.7 Mha (25% of total paddy area) included 2.6 Mha of major paddy field and 0.1 Mha of minor paddy field. About 70% of major paddy field and 4% of minor paddy field used human harvest method, the cutting level was high, the part of the rice botanical connected with the soil which called stubble also high. (The information of harvested method was represented in Chapter 3 and Table B-14.)

In the case of straw, the lower northern region could produce the maximum of straw because of the harvest area in the lower northern region was about 1.9 Mha (18% of total paddy area) included 1.3 Mha of major paddy field and 0.6 Mha of minor paddy field. About 66% of major paddy field and 100% of minor paddy field used machine harvest method, the cutting level was low, the amount of straw also short. (The information of harvested method was represented in Chapter 3 and Table B-14.)

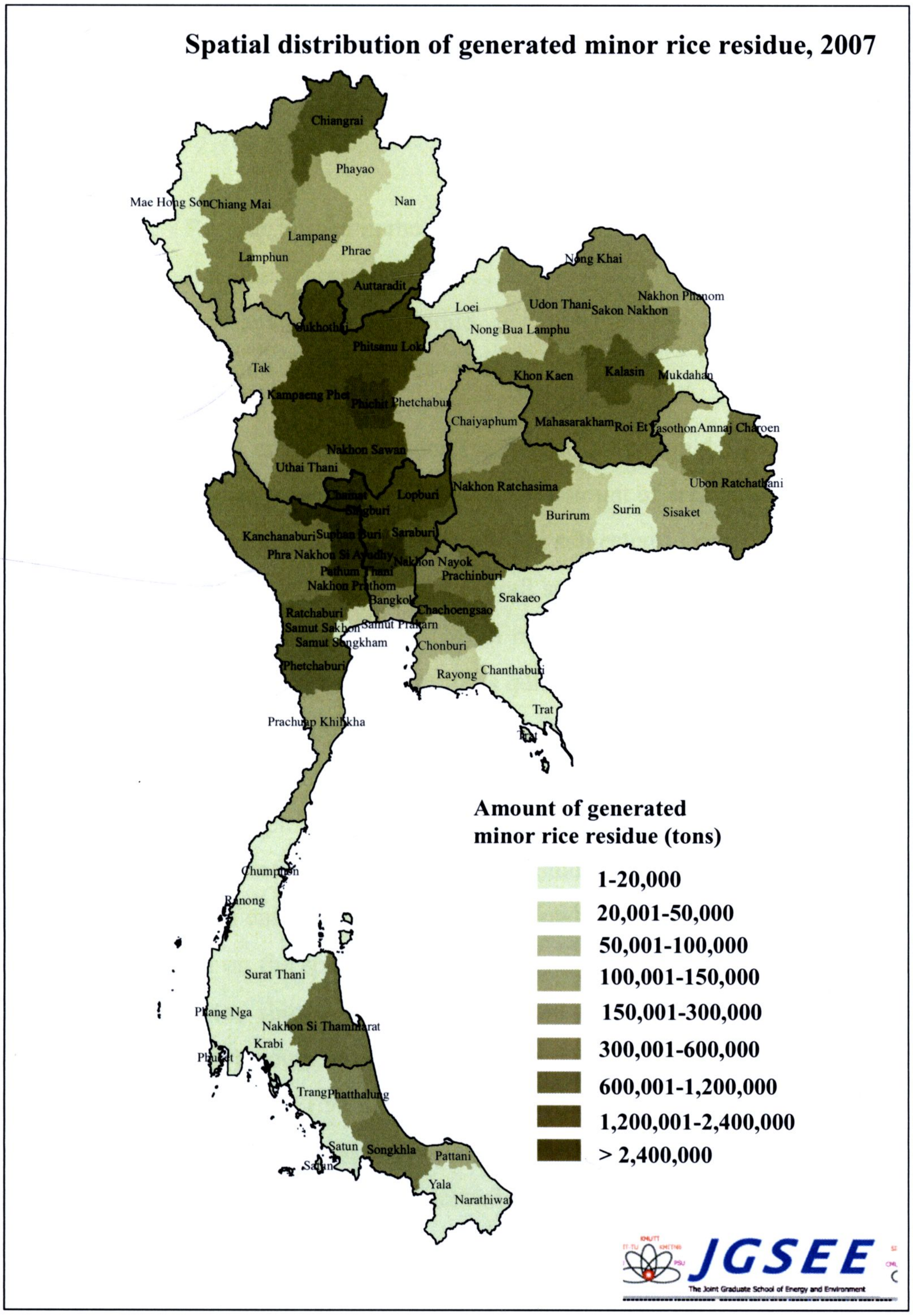
Consideration of the fraction between stubble and straw found the fraction was in the range of 0.5 to 1.6 which varied on region. The fraction was about 0.50-0.73 in the central, the western, and the eastern regions. The fraction was about 0.80-1.0 in the lower northern and the upper northern regions. The fraction was about 1.00-1.60 in the lower northeastern and the upper northeastern regions. The fraction was about 0.90-1.00 in the lower southern and the upper southern regions. These result demonstrated only in the lower northeastern and upper northeastern regions had more stubble than straw. Another factor that related to the fraction between stubble and straw was the rice variety. The fraction value of the lower northern, the upper northern, the lower southern, and the upper southern regions had the similar value and higher than the value of the central, the western, and the eastern regions due to the related height of seed that planted in the lower northern, the upper northern, the lower southern, and the upper southern regions and higher than the seed that planted in the lower southern, and the upper southern regions. The major seed and minor seed planted in the lower northern, and the upper northern regions was RD 6 (140-150 cm) for major rice and Suphanburi/Chainat (95 cm) for minor rice. The major seed and minor seed planted in the lower southern, and the upper southern regions was local seed (113-140 cm) for major rice and Chainat (83 cm) for minor rice. The major seed and minor seed planted in the central, the western, and the eastern regions were Pathumthani (133 cm) and Suphanburi (103-113 cm) for major rice and minor rice respectively. The higher of height of rice affected to the high of fraction. So, rice seed is another factor that related to the amount of stubble and straw. (The information of rice variety represented in chapter 3 and Tables B-15 and B-16.)

Figures 4.3 (a) and 4.3 (b) show the spatial distribution of major-residue and minor-residue respectively. From these figures demonstrates, the first producer of rice residue was Suphanburi (located in the central region) and Nakornsawan (located in the lower-northern region) or about 5% of overall residue. Next producer was Ubonratchathani (located in the lower-northeastern region), Nakornsritammarat (located in the lower-northeastern region), and Pichit (located in the lower-northern region) which had the similarity value or about 4% of overall residue. The value of rice residue by provincial scale is shown in Appendix C.

Based on these results, the amount of rice residue depends on the paddy area, the rice variety, and the harvest method. The proportion of straw and stubble depends on technique of harvesting. These result associates to the result of Summers, M.D. 2003 that reported the amount of straw/stubble depends on rice seed, planting method, and cutting height and also is similar to the study of K. Kadam, et al. that reported the proportion of straw depends on the technique of reaping and harvesting and condition of the field (wet or dry). The major rice plantation has higher residue than minor rice plantation because of more cultivated area and higher of rice botanical. In terms of type of residue, major rice cultivation provides higher stubble than straw whereas minor rice cultivation provides lower stubble than straw because of harvest method. In major rice plantation, especially in the northeastern region which has the most paddy field area, is mainly harvest by human that has higher of cutting level, so getting high stubble. In minor rice plantation, which mainly planting in the central and the lower northern regions is mainly harvest by machine that has lower of cutting level, so getting low stubble.



(a) The amount of generated major-residue



(b) The amount of generated minor-residue

Figure 4.3 Spatial distribution of the amount of rice residue

4.3.1.2 Rice field residue subjected to open burned

Rice field residue subjected to open burning is the unused residue that left in the field. The estimation of rice field residue subjected to open burned is calculated as follows:

$$R_B = R \times (100\text{-}U) \times A_B \qquad \text{---(Equation 4.1)}$$

Where:

R_B	= Residue burned in the field
R	= Residue generated
U	= Percentage of used residue
A_B	= Amount of burned area

Regarding to the amount of residue (as shown in Section 4.3.1.1), the percentage of used residue (as shown in Section 3.3.2.1) and the amount of area burned area (as shown in Section 3.3.2.2) found the amount of rice residue subjected to open burned in 2007-2008 was about 30.8±7.47 Mt or about 26% of overall amount of generated residue. There were 7.8±1.90 Mt of major-stubble, 3.9±0.96 Mt of major-straw, 9.0±2.18 Mt of minor-stubble, and 10±2.42 Mt of minor-straw. This result is quiet lower than the report of Department of Alternative Energy Development and Efficiency (DEDE). DEDE reported the amount of unused residue that available for energy production is about 37.7 Mt [DEDE, 2009]. The value from DEDE is higher than this study (amount of residue subjected to open burned) because of the amount of unused residue in this study is only in the burned area. It is not include the amount of unused residue in the unburned area.

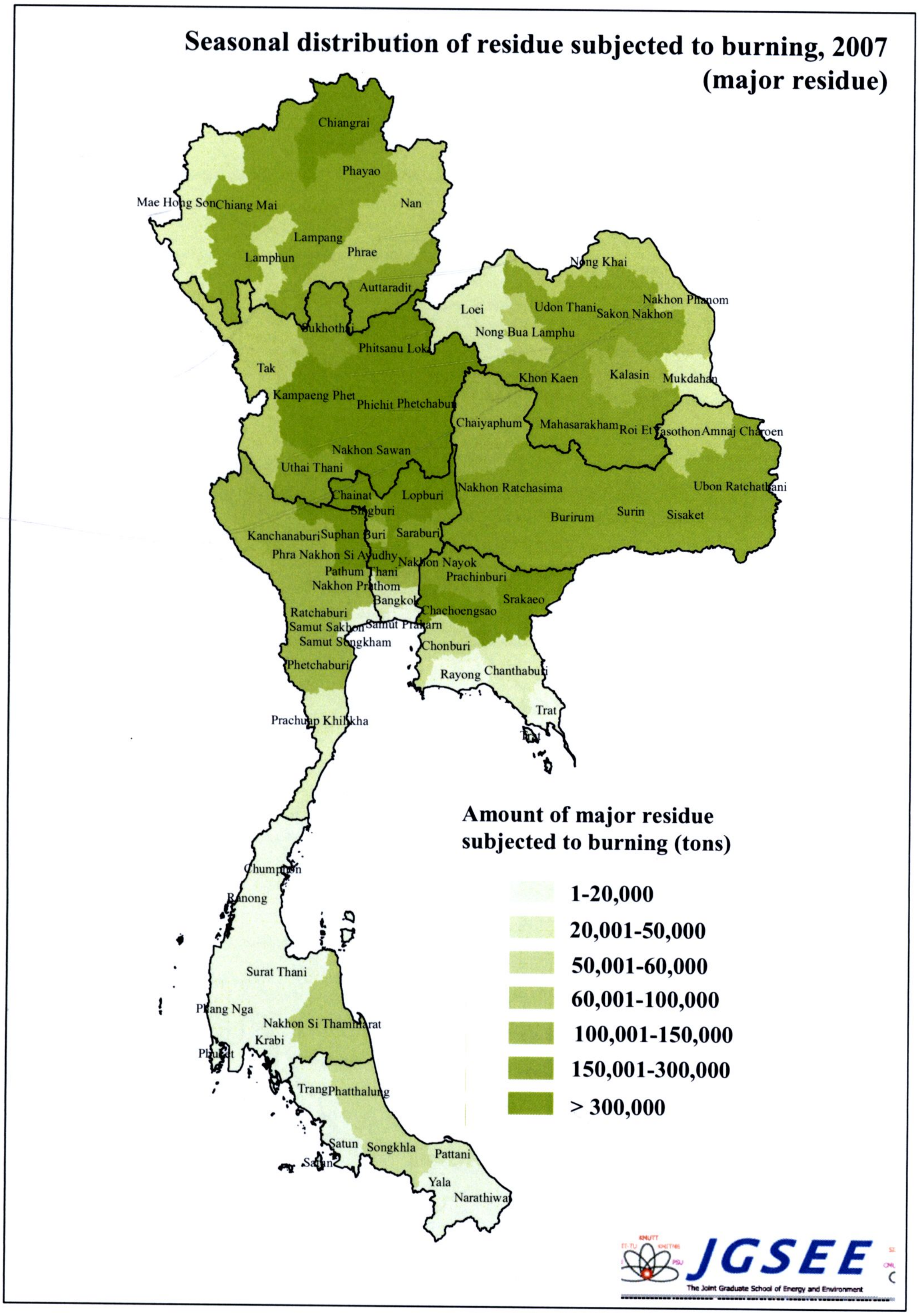
Consideration on the spatial distribution of rice residue subjected to open burned in the regional level (as shown in Table 4.3) found the central region was the area that contained the largest amount of unused residue in the field (8.8±2.07 Mt), followed by the lower northern region (7.7±1.92 Mt) and the western region (5.8±1.46 Mt). The amount of residue subjected to burn related to the frequency of plantation. The central region had the highest frequency of rice plantation which was about 5 times/2 years. (The information of frequency of rice cultivation is shown in Chapter 3 and Table B.2) In this area, the residue was removed from the field in a shortest time. The burning was a quickest method so the high amount of residue subjected to burn in this area.

Table 4.3 Amount of rice residue subjected to open burned by type of residue and region

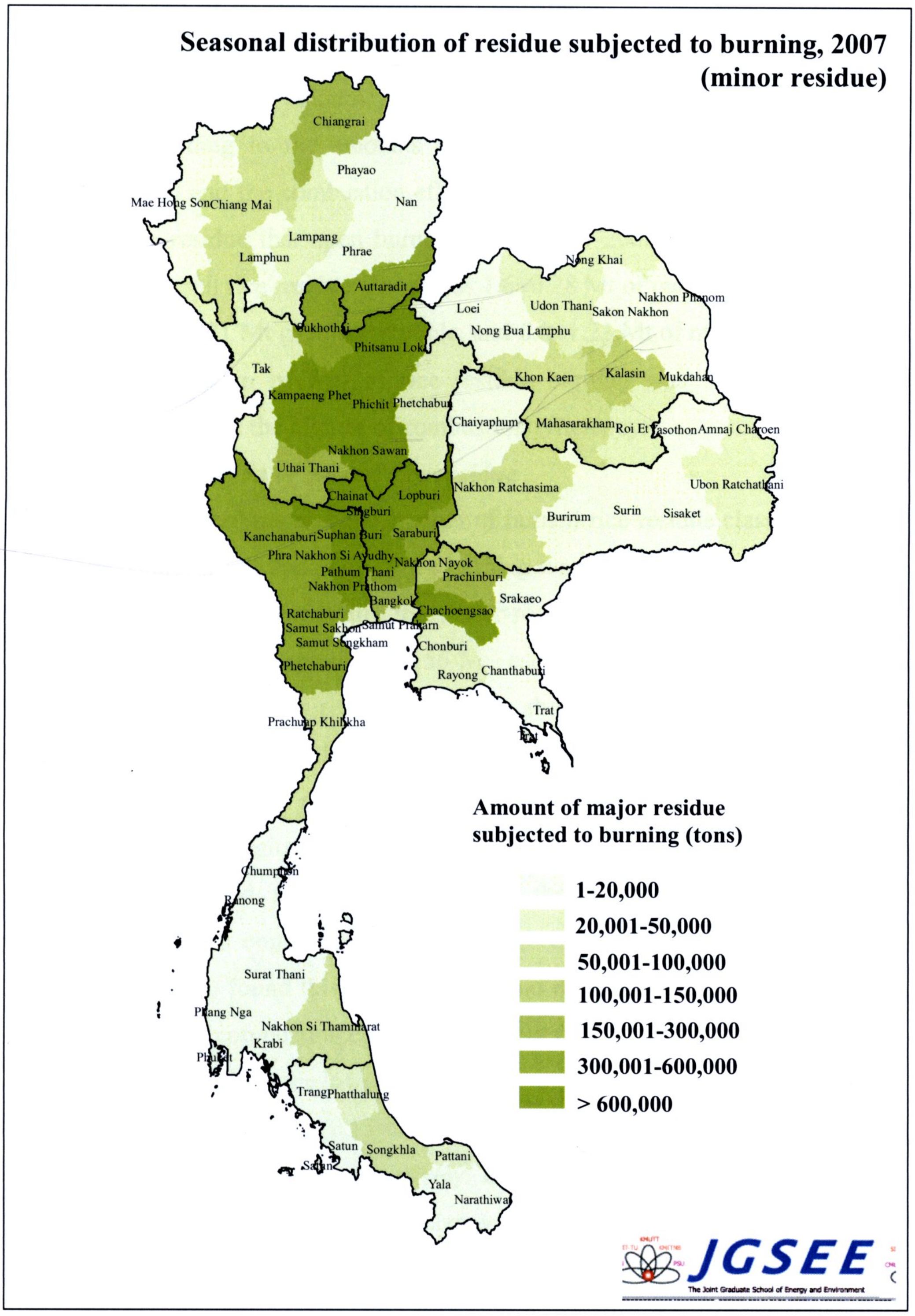
Region	Major residue burned (Mt)		Total Major residue burned (Mt)	Minor residue burned (Mt)		Total Minor residue burned (Mt)	Totally burned (Mt)
	Stubble	Straw		Stubble	Straw		
Eastern	0.61 (0.151)	0.62 (0.137)	1.23 (0.288)	0.54 (0.126)	0.62 (0.142)	1.16 (0.268)	2.38 (0.556)
Central	0.86 (0.213)	0.87 (0.227)	1.73 (0.440)	3.28 (0.761)	3.74 (0.871)	7.02 (1.632)	8.75 (2.072)
Western	0.50 (0.122)	0.51 (0.119)	1.01 (0.241)	2.26 (0.570)	2.58 (0.648)	4.84 (1.218)	5.85 (1.459)
Lower Northern	2.07 (0.533)	1.14 (0.280)	3.21 (0.813)	2.15 (0.526)	2.38 (0.581)	4.53 (1.107)	7.74 (1.920)
Upper Northern	0.95 (0.240)	0.52 (0.139)	1.48 (0.379)	0.37 (0.092)	0.41 (0.102)	0.78 (0.194)	2.25 (0.573)
Lower Northeastern	1.40 (0.300)	0.11 (0.027)	1.51 (0.327)	0.08 (0.020)	0.06 (0.014)	0.14 (0.034)	1.65 (0.361)
Upper Northeastern	1.25 (0.294)	0.10 (0.024)	1.34 (0.318)	0.22 (0.053)	0.15 (0.037)	0.36 (0.090)	1.71 (0.408)
Lower Southern	0.14 (0.036)	0.04 (0.010)	0.18 (0.046)	0.07 (0.020)	0.06 (0.016)	0.14 (0.036)	0.31 (0.082)
Upper Southern	0.08 (0.017)	0.02 (0.006)	0.10 (0.023)	0.04 (0.009)	0.04 (0.006)	0.08 (0.015)	0.18 (0.038)
Total	**7.85 (1.896)**	**3.93 (0.963)**	**11.78 (2.875)**	**9.01 (2.177)**	**10.04 (2.417)**	**19.05 (4.594)**	**30.83 (7.469)**

Consideration of the spatial distribution of rice residue subjected to open burning, classified by type of rice and region found the lower northern region was the area that had the largest amount of unused major-residue. The central region was the area that had the largest amount of unused minor-residue. The lower northern region had the highest amount of minor paddy field or about 0.6 Mha (29% of minor field) so major residue in 0.6 Mha had to be removed for preparing area during pre-cultivation season and there was subjected to burn in the field. The central region had the highest frequency of rice cultivation (5 times/2 years) so this region had the highest of minor residue subjected to burn in the field.

Figures 4.4 (a) and 4.4 (b) show the spatial distribution of major-residue and minor-residue subjected to open burning respectively. From these figures demonstrates, the area that contained the largest amount of unused residue was Suphanburi (located in the central region), by contained about 3.2 Mt. The second was Chainat and Ayuthaya which had the same amount about 1.9 Mt. The third was Nakornsawan which was about 1.8 Mt. The value of rice residue subjected to open burning by provincial scale is shown in Appendix D.



(a) The amount of major residue subjected to burned



(b) The amount of minor residue subjected to burned

Figure 4.4 Spatial distribution of the amount of rice residue subjected to open burned

4.3.1.3 Burned rice field residue

The amount of residue consumed by fire depends on the combustion efficiency of residue. Based on Equation 4.1, the amount of burned residue estimates from the production between the amounts of residue subjected to burn and the combustion efficiency. Regarding to the amounts of residue subjected to burn (as shown in the previous section) and the combustion efficiency (as shown in Section 3.3.2.2) found the amount of rice residue that open burned during 2007-2008 was about 11.3±2.19 Mt or about 15% of overall rice residue. There was 1.6±0.28 Mt of major-stubble, 2.6±0.46 Mt of major-straw, 1.1±0.21 Mt of minor-stubble, and 6.0±1.23 Mt of minor-straw. These results demonstrated the main of fuel of rice residue burning was minor straw due to the maximum quantity and the highest of combustion efficiency.

Spatial distribution of burned rice residue

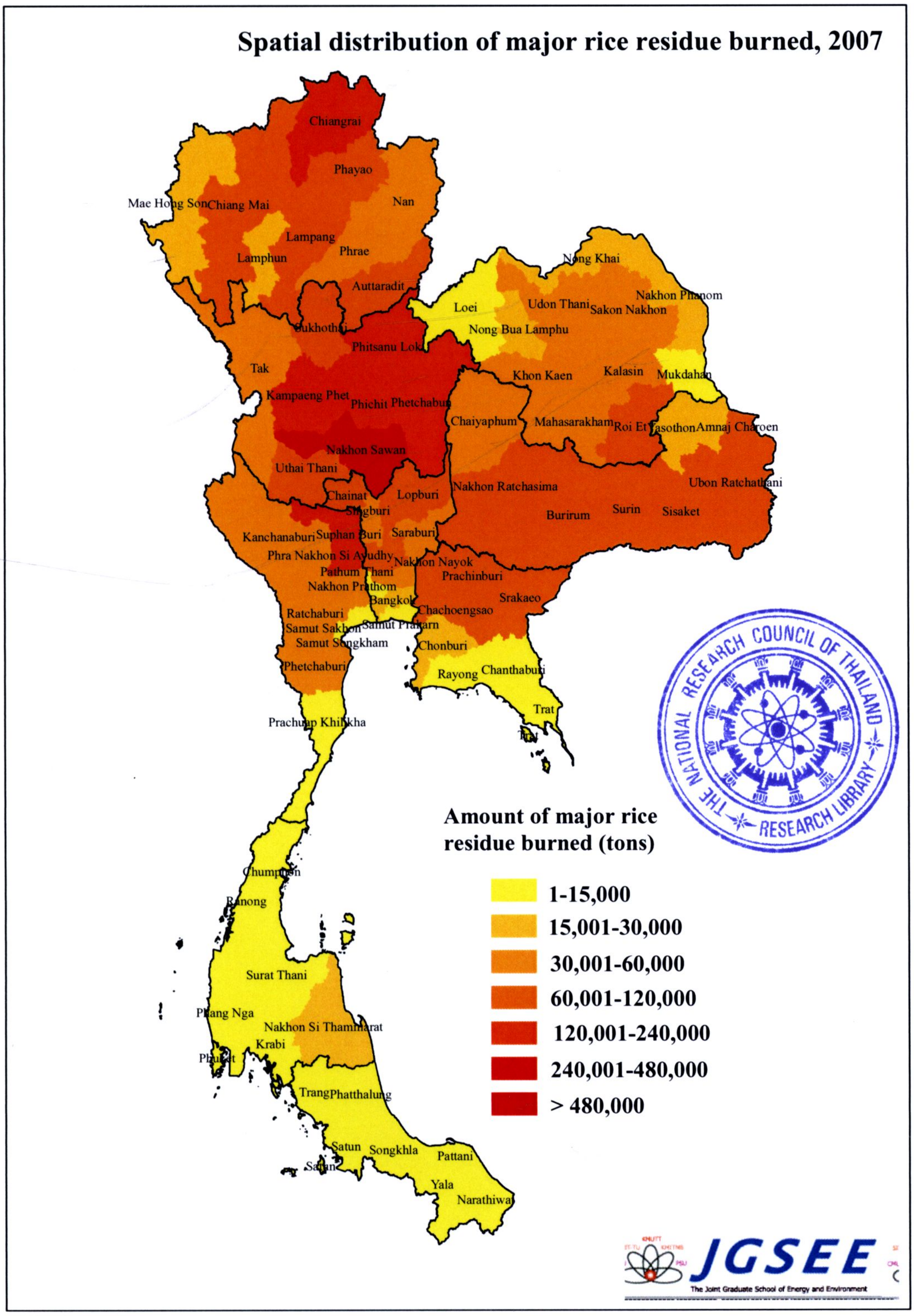
The spatial distribution of the amount of burned rice residue classified by region (as reported in Table 4.4) found majority of burning was in the lower northern region which was about 3.4±0.65 Mt, especially the minor-residue (2.1±0.41 Mt). The next was the central region which was about 2.9±0.56 Mt, especially minor-residue (2.3±0.47 Mt). It was followed by the western region which was about 1.9±0.40 Mt, mainly minor-residue (1.6±0.34 Mt). The lower northern region has the highest amount of burned residue due to this area is the second rank of amount of residue which is about 7.7 ± 1.92 Mt. (The first rank is in the central region which is about 8.7 ± 2.07 Mt; the information of the spatial distribution of unused residue is shown in the previous section.). Based on the questionnaire data on combustion efficiency (the information of questionnaire survey is shown in Chapter 3) found this area is the second rank of the combustion efficiency also which the valued of combustion efficiency is about 0.20-0.21 for stubble and 0.54-0.68 for straw. (The first rank is in the lower northeastern and the upper northeastern regions which has the value of stubble about 0.15-0.19 and 0.29-0.36 respectively and the value of straw about 0.79-0.93 and 0.71-0.93 respectively. Based on the high amount of unused residue and the high value of combustion efficiency, the lower northern region has the highest amount of burned residue.

Table 4.4 Amount of rice residue burned in the field by type of residue and region

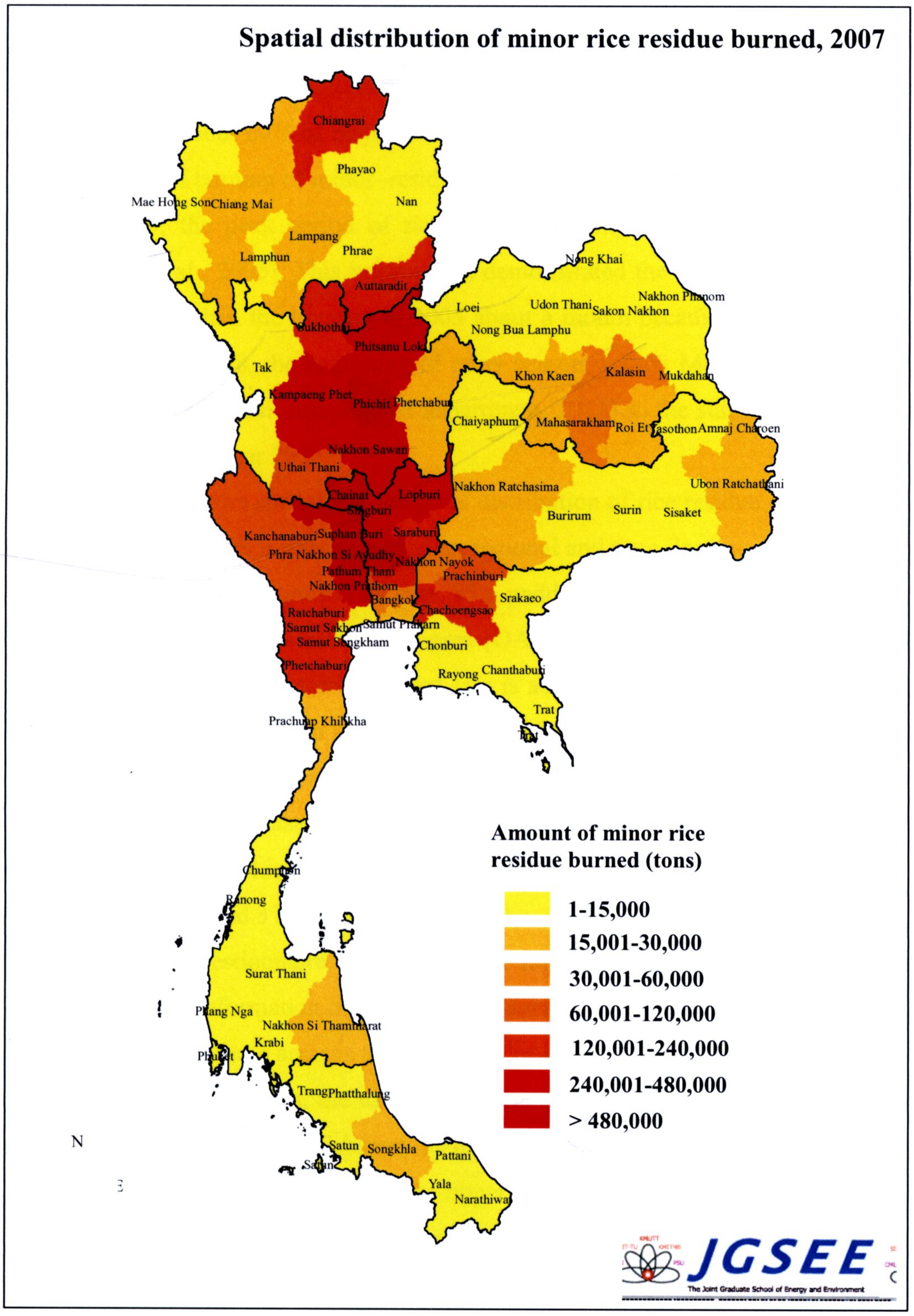
Region	Major residue burned (Mt)		Total Major residue burned (Mt)	Minor residue burned (Mt)		Total Minor residue burned (Mt)	Totally burned (Mt)
	Stubble	Straw		Stubble	Stubble		
Eastern	0.06 (0.012)	0.34 (0.067)	0.41 (0.079)	0.04 (0.009)	0.35 (0.080)	0.38 (0.089)	0.79 (0.168)
Central	0.09 (0.014)	0.49 (0.082)	0.57 (0.096)	0.23 (0.046)	2.10 (0.422)	2.33 (0.468)	2.90 (0.564)
Western	0.05 (0.009)	0.29 (0.052)	0.34 (0.061)	0.16 (0.034)	1.45 (0.306)	1.60 (0.340)	1.94 (0.401)
Lower Northern	0.50 (0.088)	0.84 (0.149)	1.34 (0.237)	0.45 (0.090)	1.62 (0.323)	2.07 (0.413)	3.41 (0.650)
Upper Northern	0.23 (0.043)	0.39 (0.073)	0.62 (0.116)	0.08 (0.017)	0.28 (0.060)	0.36 (0.077)	0.97 (0.193)
Lower Northeastern	0.36 (0.056)	0.10 (0.018)	0.46 (0.074)	0.02 (0.004)	0.04 (0.011)	0.07 (0.015)	0.53 (0.089)
Upper Northeastern	0.32 (0.053)	0.09 (0.015)	0.41 (0.068)	0.06 (0.011)	0.12 (0.021)	0.18 (0.032)	0.59 (0.100)
Lower Southern	0.01 (0.002)	0.03 (0.005)	0.04 (0.007)	0.01 (0.001)	0.04 (0.007)	0.04 (0.008)	0.08 (0.015)
Upper Southern	0.01 (0.002)	0.02 (0.003)	0.02 (0.005)	0.00 (0.000)	0.02 (0.005)	0.02 (0.005)	0.05 (0.01)
Total	**1.63 (0.279)**	**2.58 (0.464)**	**4.21 (0.743)**	**1.05 (0.212)**	**6.00 (1.235)**	**7.06 (1.447)**	**11.27 (2.190)**

The spatial distribution of the fraction of residue burned to the generated residue found that the highest of residue burned was in the western region which was about 17.4% of residue in the western region. The next was in the central region which was about 17.0% of residue in the central region and followed by the lower-northern region which was about 14.5% of residue in the lower northern region. These results related to the study of Garivait, et al. which reported the area that had the high of burned area included Pathumthani, Ayuthaya, Nakornpathom, Chainat, Angthong, Suphanburi, and Nakornsawan. These areas located in the central, the western, and the lower northern regions.

Figures 4.5 (a) and 4.5 (b) show the spatial distribution of burning of major-residue and minor-residue respectively. From these figures demonstrates, the burning of rice residue was mainly occurred in Suphanburi, covered 1.1 Mt of burned residue, next was Nakornsawan and Pichit, about 0.8 Mt and 0.7 Mt respectively. The value of rice residue burned in the field by provincial scale is shown in Appendix E.



(a) The amount of burned major residue



(b) The amount of burned minor residue

Figure 4.5 Spatial distribution of the amount of rice residue burned in the field

Temporal distribution of burned rice residue

The burning of rice residue varies on month as shown in Figure 4.6. There are 2 peaks of burning; during December to January and during April to May. Considering on each peak of burning found the burning in December-January is the period of burning of major–residue. About 60% of major-residue was burned at this period. During April-May, it is the period of burning of minor–residue, about 54% of minor residue was burned at that time. In 2005, the peak period of rice residue burning was during January to March [Garivait, S. et al., 2005]. This information demonstrated the burning of rice residue was occurred quicker than the burning in 2005 about a month because of the changing of the rainy season. In 2008, the beginning of rainy season was on May, 5 which quicker than 2005 about a week [Thai metrological department, 2011] so the starting of rice cultivation was earlier than the year 2005.

Figure 4.7 shows spatial and temporal distribution of rice residue. From these figures found the burning of rice residue varied on regional and time. In the central, and the lower northern, the burning is occurred all year. 85% paddy field in the central and 54% of paddy field in the lower northern is irrigated area [OAE, 2007]. From the questionnaire survey found the frequency of plantation in that area is about 5 times per 2 years (information of questionnaire survey is shown in Chapter 3). So, the burning is occurred all year. The main cause of burning in these areas is to decreased time of preparing area.

In the lower northeastern and the upper northeastern, the burning is occurred mainly during April to May which is the pre-cultivation period. About 37% of paddy field in the lower northeastern and 37% of paddy field in the upper northeastern is rain fed area [OAE 2007]. From the questionnaire survey found the frequency of plantation in that area is only 1 round per year (information of questionnaire survey is shown in Chapter 3). So, the main cause of burning in these areas is to remove major-residue and weed from the field.

In the upper northern, the eastern, and the western regions, the burning is occurred mainly during December to February of the following year which is the post-harvesting period. About 54% of paddy field in the upper northern region, 85% of paddy field in the eastern region, and 85% of paddy field in the western region is irrigated area [OAE, 2007]. The fraction between major paddy field and minor paddy field is about 0.2, 0.2, and 1.0 for the upper northern, the eastern, and the western regions respectively [OAE, 2007]. The upper-northern and the eastern regions are the main of producer of garlic, bean, shallot, onion, and so on (group of vegetables) which are planted switching with rice. So, the main cause of burning in these areas is to clear areas for the other crop. The cause of the burning in the western region is to clear area for rice cultivation (same as in the central and the lower northern regions).

In the lower southern and the upper southern regions, the burning is mainly occurred during February to April. About 66% of paddy field in the lower southern and 66% of paddy field in the upper southern are irrigated area. The fraction between major paddy field and minor paddy field is about 0.18 and 0.19 for the lower southern and the upper southern regions respectively so the plantation in these areas is major rice. The cause of the burning in these areas is to remove major-residue from the field

The results from this study demonstrate the burning period in each region depends on the frequency of cultivation in each area. The cause of burning included (1) to decrease preparing area period for rice cultivation or other crop cultivation and (2) to clear area which is not related to time.

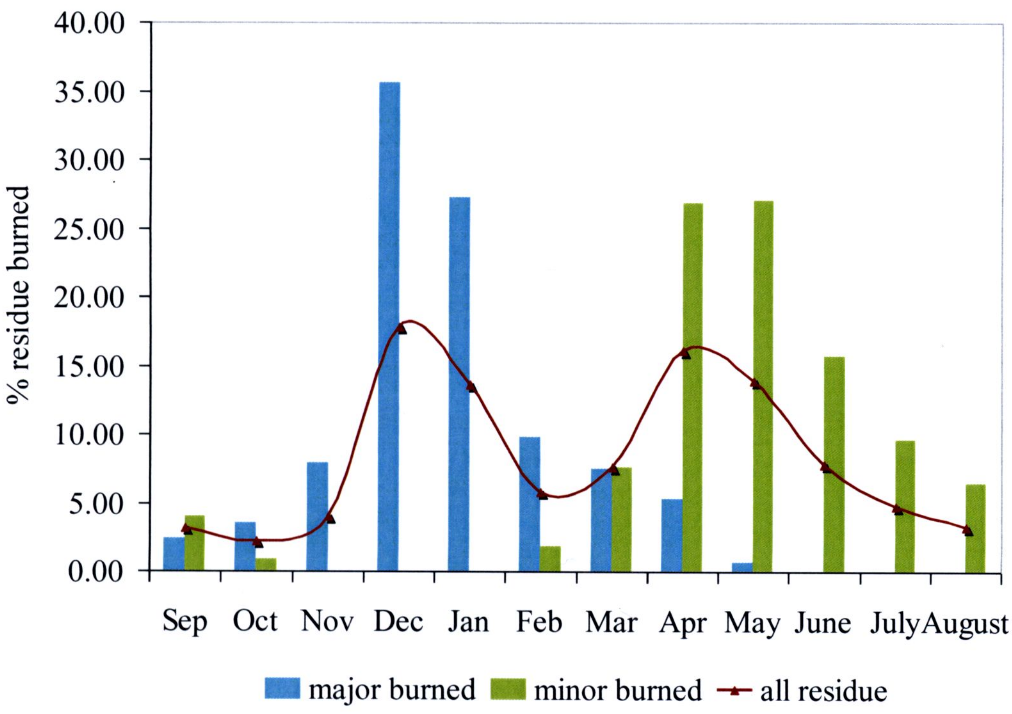
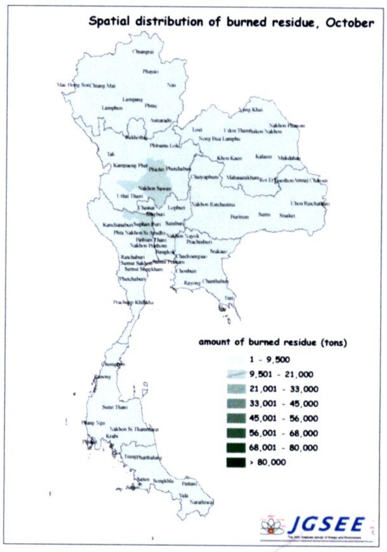
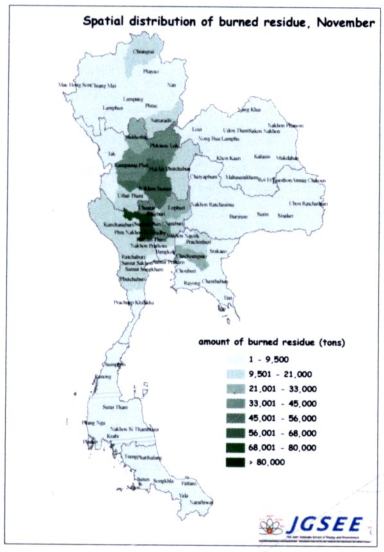


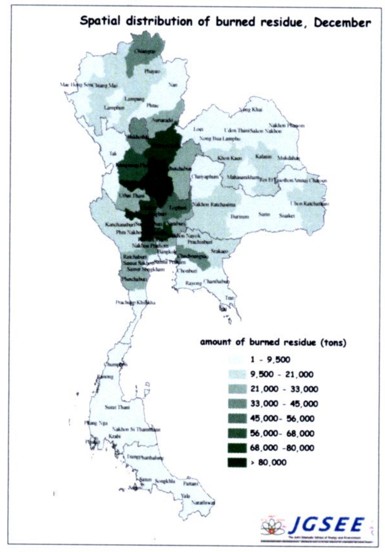
Figure 4.6 Temporal distribution of burning of rice residue



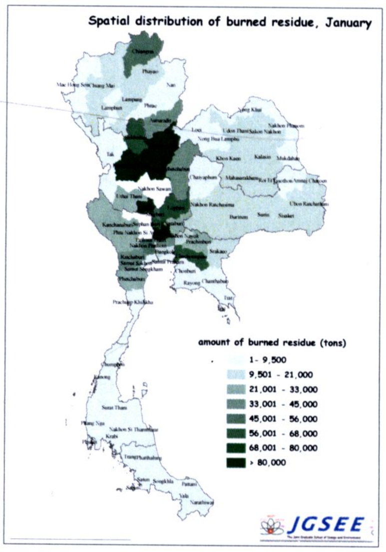
(a) RFR Burning in Oct 07



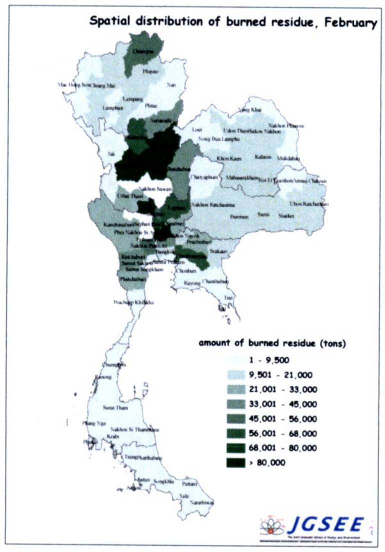
(b) RFR Burning in Nov 07



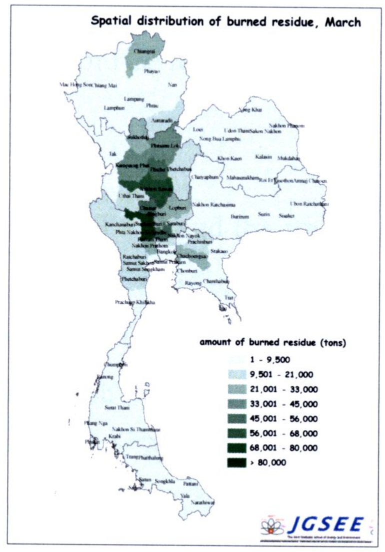
(c) RFR Burning in Dec 07



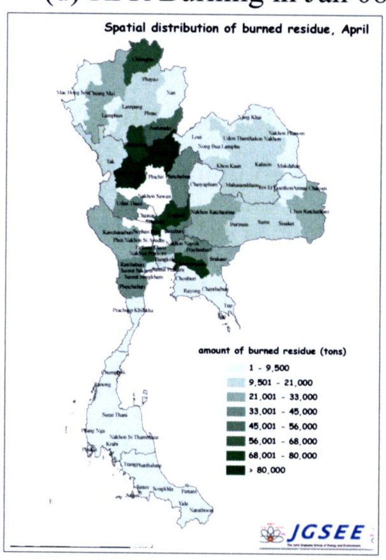
(d) RFR Burning in Jan 08



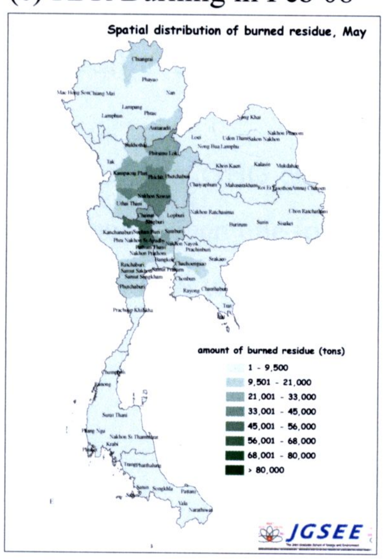
(e) RFR Burning in Feb 08



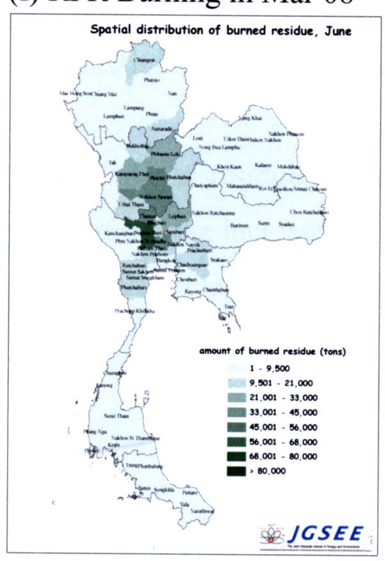
(f) RFR Burning in Mar 08



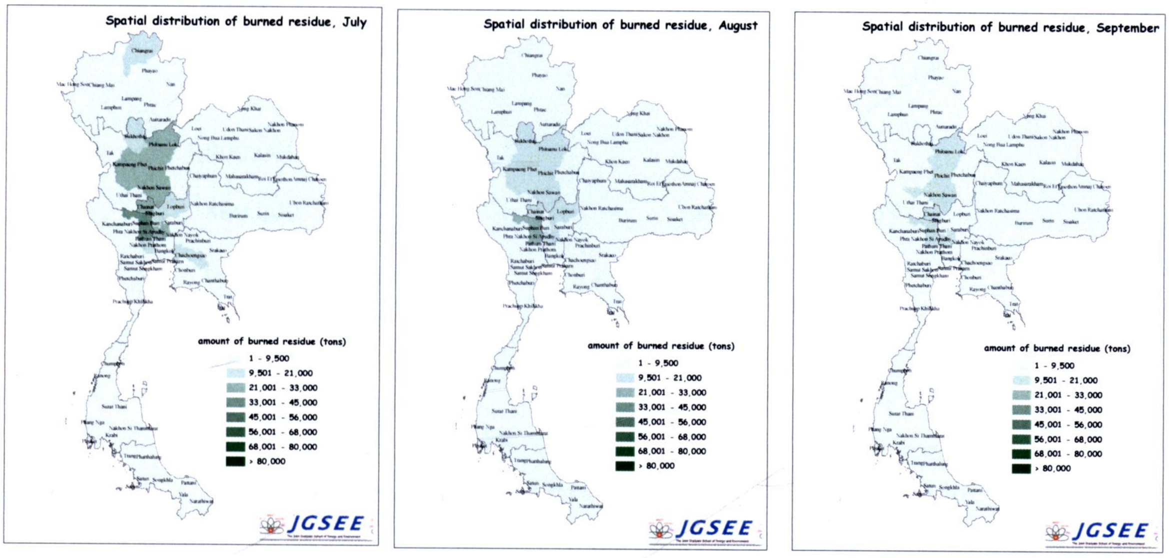
(g) RFR Burning in Apr 08



(h) RFR Burning in May 08



(i) RFR Burning in Jun 08



(j) RFR Burning in Jul 08 (k) RFR Burning in Aug 08 (l) RFR Burning in Sep 08

Figure 4.7 Spatial and temporal distribution of burning of rice residue

4.3.2 Emissions from rice residue open burning

Based on the amount of rice residue burned in the field (Section 4.3.1.3) and the emission factor (Table 4.1) found the burning of 11.3±2.19 Mt of rice residue contributes 14.24±2.638 Mt of CO_{2eq} (included 13.35±2.595 Mt of CO_2, 0.003±0.0006 Mt of CH_4 at GWP = 21, and 0.0008±0.0001 Mt of N_2O at GWP = 310) which was about 6.21% of GHG emission contributed from Thailand activity in 2000 [ONEP, 2010] or 27.4% of GHG emission contributed from Thailand agricultural activity in 2000 [ONEP, 2010]. There also emitted 1.5±0.29 Mt of CO, 0.035±0.0007 Mt of NO_x, 0.31±0.060 Mt of $PM_{2.5}$, 0.15±0.028 Mt of PM_{10}, and 0.008±0.0015 Mt of black carbon. Take into account on flux of emission (emission in unit area) found the average of emission flux was about 3.08±0.442 tonCO_{2eq}/ha.

From the study on the relationship between GHG emissions and amount of residue burned in the field (as seen in Figure 4.8) found when one ton of burning of residue increased, the GHG emission in term of equivalent of CO_2 will be increased 1.26 tons (include CO_2).

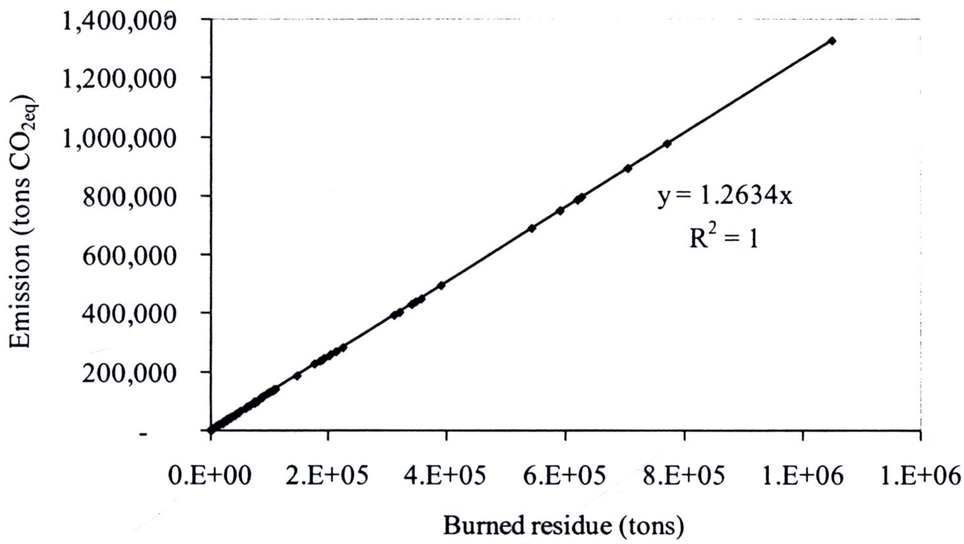


Figure 4.8 Relationship between burned residue and GHG emission

4.3.2.1 Spatial distribution of emission from burning of rice residue

The GHG and pollutants from burning of rice residue, classified by type of emissions and region are presented in Tables 4.5 and 4.6 respectively. The lower northern region was the largest contributor of emissions from burning of rice residue, which emitted nearly 30% of overall emissions from rice residue burning, followed by the central (26%) and the western regions (17%). The lower northern region was the largest contributor of emissions from burning because this area has the highest amount of residue consumed by fire.

The flux of emissions, the top three of flux was in the western, the central, and the lower northern which has the similar value as 4.77±0.062 $MgCO_{2eq}$/ha, 4.61±0.056 $MgCO_{2eq}$/ha, and 4.43±0.053 $MgCO_{2eq}$/ha respectively. Take into consideration on the fraction between burned area and overall harvested area found the western has the highest of this fraction which is about 0.5 for major paddy field and 0.89 for minor paddy field (from the questionnaire survey as shown in Chapter 3.3.2.2) whereas the total burned area in the western is lower than the lower northern. Although the emissions in the western region are lower than the lower northern region, the flux of emission in the western region is higher than the lower northern region.

Table4.5 Amount of GHG from burning of rice residue in the field by type of GHG and region

	Emission (Tg)				Flux
	CO_{2eq} [a]	CO_2	CH_4	N_2O	($MgCO_{2eq}$/ha) [a]
Eastern	1.00	0.93	2E-03	6E-05	3.18
Central	3.66	3.44	8E-03	2E-04	4.61
Western	2.45	2.30	5E-03	1E-04	4.77
Lower Northern	4.31	4.04	9E-03	2E-04	4.43
Upper Northern	1.23	1.15	0.003	7E-05	3.55
Lower Northeastern	0.67	0.63	1E-03	4E-05	1.46
Upper Northeastern	0.75	0.70	2E-03	4E-05	1.73
Lower Southern	0.11	0.10	2E-04	6E-06	1.97
Upper Southern	0.06	0.06	1E-04	3E-06	1.99
Total	**14.24**	**13.35**	**0.03**	**8E-04**	**3.08**

Remark: a include CO_2 and GWP of CH_4 = 21 and GWP of N_2O = 310

Table4.6 Amount of pollutant from burning of rice residue in the field by type of pollutant and region

	Emission (Tg)				
	CO	NO_x	$PM_{2.5}$	PM_{10}	BC
Eastern	0.11	2E-03	0.02	1.E-02	5.E-04
Central	0.39	0.01	0.08	4.E-02	2.E-03
Western	0.26	0.01	0.05	3.E-02	1.E-03
Lower Northern	0.45	0.01	0.09	4.E-02	2.E-03
Upper Northern	0.13	3E-03	0.03	1.E-02	7.E-04
Lower Northeastern	0.07	2E-03	0.01	7.E-03	4.E-04
Upper Northeastern	0.08	2E-03	0.02	8.E-03	4.E-04
Lower Southern	0.01	3E-04	2E-03	1.E-03	6.E-05
Upper Southern	0.01	1E-04	1E-03	7.E-04	3.E-05
Total	**1.50**	**0.03**	**0.31**	**1.E-01**	**8.E-03**

Figure 4.9 shows the spatial distribution of emission from burning of rice residue in provincial scale. This figure shows that Suphanburi was the main contributor of emissions, which emitted about 9% of emission from rice residue burning, followed by Nakornsawan and Pichit which had the similar value or about 6% of emission. The value of emission from burning rice residue in the field by provincial scale is shown in Appendix F.

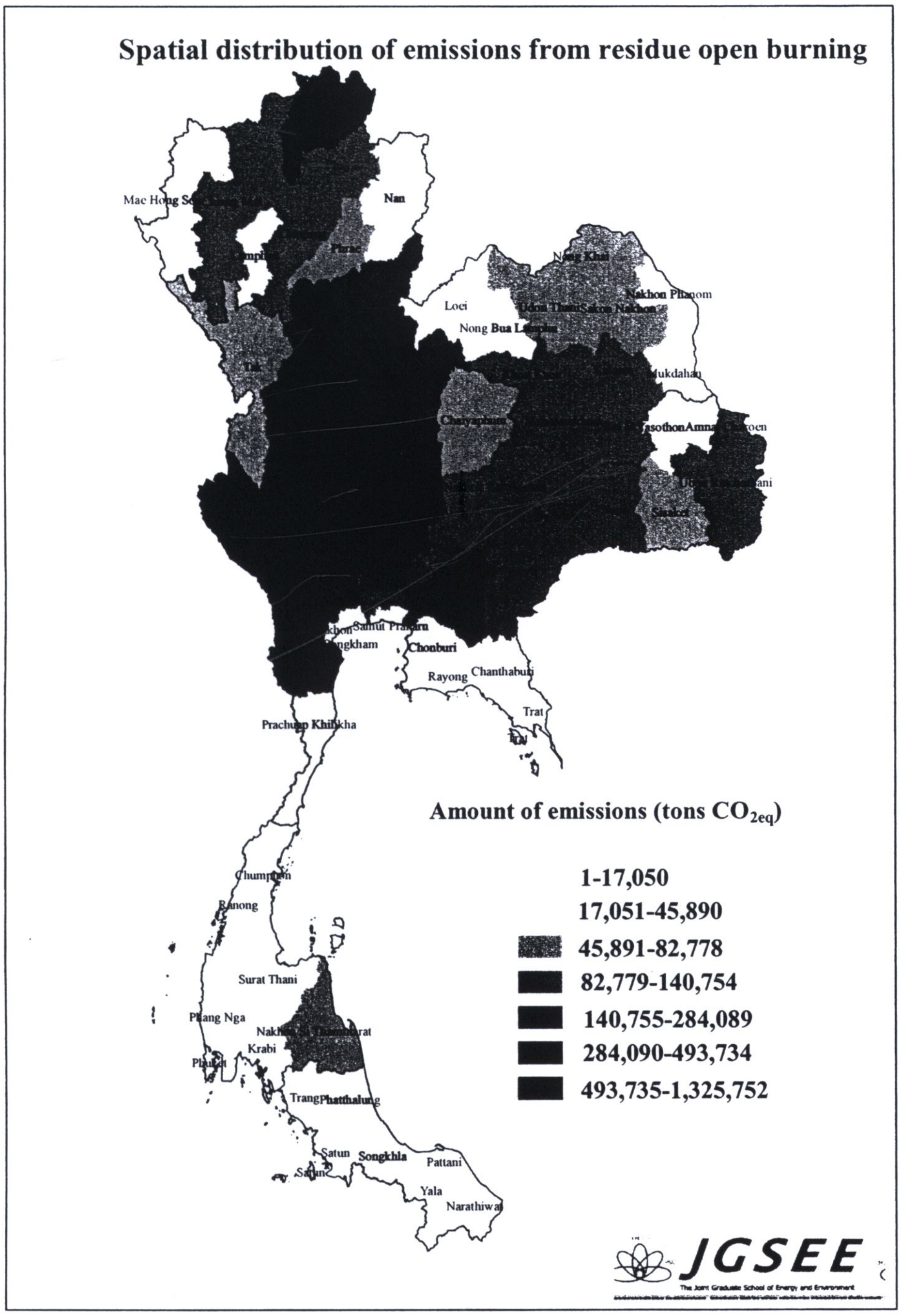


Figure 4.9 Spatial distribution of the amount of emission from rice residue open burning

Flux of emissions for each province varies on 1.13-4.87 $MgCO_{2eq}$/ha. The province which had the highest amount of emission as Suphanburi province, the flux of emission was about 4.72 $MgCO_{2eq}$/ha. Comparing between flux of emission and amount of emission found the area where had high of flux of emission but had low of the amount of emission. For example, the flux of emission in Samutsongkram was about 4.87 $MgCO_{2eq}$/ha, the overall amount of emission was only about 1,655 $MgCO_{2eq}$ because of Samutsongkram had the high amount of unused residue and the high value of combustion efficiency. From this result, it demonstrates, there is no relationship between flux of emission and amount of emission. The amount of emissions depends on the amount of unused residue and combustion efficiency.

4.3.2.3 Temporal distribution of emission from burning of rice residue

The amount of GHG emissions (in term of CO_{2eq}) due to the burning of rice residue in the field in each month is shown in Figure 4.10. The total of 14.2 $MtCO_{2eq}$ emitted between January and December. The peak period of emission is during December to January (31% of GHG emission of residue burning) and April to May (30% of GHG emission of residue burning).

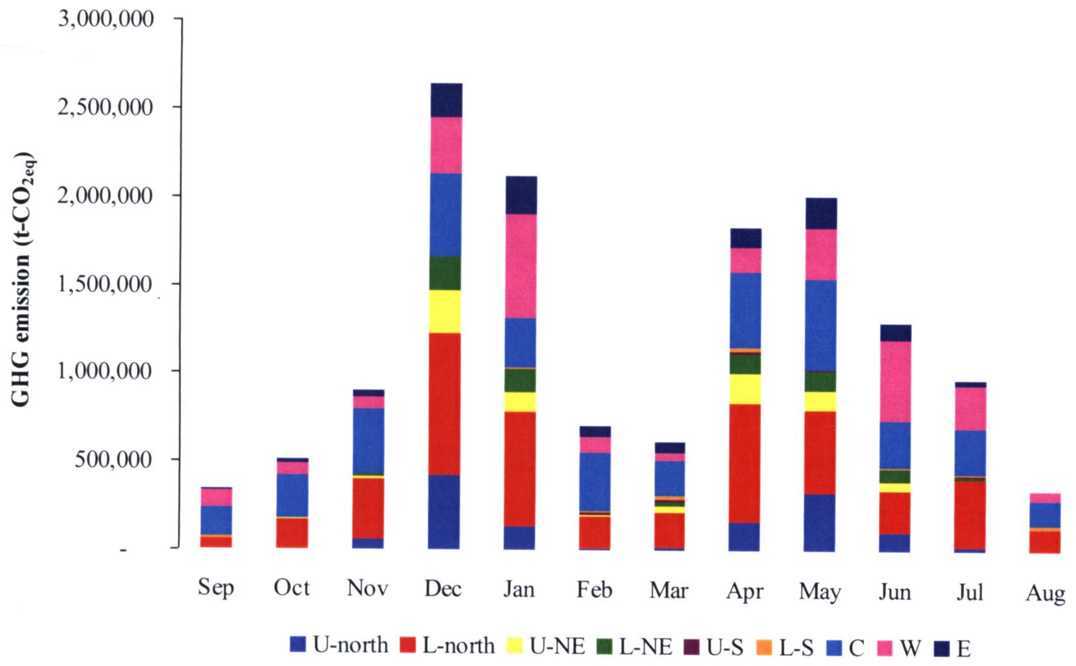


Figure 4.10 Spatial and temporal distribution of the amount of GHG emissions from residue open burning

4.4 Conclusions

This part assessed the spatial and temporal distribution of rice field residue burning in the field and emission from that burning. The assessment of the spatial and temporal distribution of burned residue used field survey data and questionnaire survey data to quantify the amount of residue subjected to open burn and the amount of residue consumed by fire. The estimation of air pollutants (CO, NO_x, $PM_{2.5}$, PM_{10}, and black carbon), and GHG emissions (CO_2, CH_4, and N_2O) from rice field residues burning based on 2006 IPCC guidelines which derived from the emission factor that mostly specific for rice residue open burning in Thailand and the amount of residue that burned in the field.

This study found rice residue includes straw and stubble. The amount of rice straw/stubble that actually combusted is given by the amount of straw/stubble, the amount of straw/stubble used for some purpose, the amount of burned area, and the combustion efficiency.

The amount of straw/stubble depends on rice seed, planting method, and cutting height. Although RPR is widely used to estimate the amount of residue, it cannot estimate the actual amount of rice stubble and rice straw. This study applies the relationship between weight and height of botanical rice to estimate the amount of rice straw/stubble. The type of rice seed and harvest method for each area is used with the relationship to get the amount of straw and stubble in each area. The analysis is found that the overall amount of rice residue is about 117.7 Mt, included 42.3 Mt of major-stubble, 36.4 Mt of major-straw, 17.1 Mt of minor-stubble, and 21.9 Mt of minor-straw. The amount and type of residue (straw/stubble) varies by region which depends on paddy field area (size of major area or minor area), rice seed, and harvest method (manual or mechanical). The proportion of straw/stubble depends on technique of harvesting. The amount of straw/stubble used for some purpose is in the term of percentage of rice residue that currently used. Based on questionnaire survey data found the current uses of rice residue is about 40% that classified by type of rice and residue as 27% of major-stubble, 70% of major-straw, 25% of minor-stubble, and 38% minor-straw. The fraction of utilization varies on region which depends on frequency of plantation.

The amount of burned area is in terms of percentage of burned area obtained from the questionnaire survey. Based on questionnaire survey data is found 36% of paddy field is burned that classified by type of rice as 36% of major area and 65% of minor area. The percentage of burned area varies on region which also depends on frequency of plantation.

The combustion efficiency is a measure of the proportion of the residue that is actually combusted. Combustion efficiency obtained from questionnaire survey. The questionnaire survey data showed that the average combustion efficiency was about 0.18 for major-stubble, 0.72 for major-straw, 0.17 for minor-stubble, and 0.65 for minor-straw.

The combustion efficiency of residue varies by region which depends on moisture content of residue and humidity in the area.

The residue subjected to burning is the unused residue that is left in the field. The amount of residue subjected to burn derives on the amount of straw/stubble, the amount of straw/stubble used for some purpose, and the amount of burned area. The estimation found 26% of overall residue (30.8±7.47 Mt) is subjected to burn in the field. There are 7.8±1.90 Mt of major-stubble, 3.9±0.96 Mt of major-straw, 9.0±2.18 Mt of minor-stubble, and 10.0±2.42 Mt of minor-straw. The amount of residue subjected to burn is strongly related to the frequency of plantation which varies on region.

In the estimation of the amount of residue that is burned in the field found the actual amount of residue burned in the field is about 15% of overall rice residue (11.3±2.19 Mt). There are 1.6±0.28 Mt of major-stubble, 2.6±0.46 Mt of major-straw, 1.1±0.21 Mt of minor-stubble, and 6.0±1.23 Mt of minor-straw. This result is in the range of the study of Tritib Suramaythangkoor and Shabbir H. Gheewala that reported about 8.5-14.3 Mt of rice residue is burned annually.

The western, the central, and the lower northern regions are the top-three areas that have the maximum of fraction of residue burned in the field. Rice residue open burning mainly occurres after harvest period and preparing area period from December to January and during April to May respectively. During December to January, the fuel is major-residue, mainly in the area that has access to water (irrigated area) as the western, the central, and the lower northern regions whereas during April to May, the fuel is major-residue, minor-residue and weed as well, that occurs for all areas.

Based on 2006 IPCC guidelines, the burning of 11.3±2.19 Mt of rice residue contributes 14.24±2.638 Mt of CO_{2eq} (included 13.35±2.595 Mt of CO_2, 0.003±0.0006 Mt of CH_4 at GWP = 21, and 0.0008±0.0001 Mt of N_2O at GWP = 310) which about 6.21% of GHG emissions contributed from Thailand activity in 2000 [ONEP, 2010] or 27.4% of GHG emissions contributed from Thailand agricultural activity in 2000 [ONEP, 2010] and pollutants as 1.5±0.29 Mt of CO, 0.035±0.0007 Mt of NO_x, and 0.31±0.060 Mt of $PM_{2.5}$, 0.15±0.028 Mt of PM_{10}, and 0.008±0.0015 Mt of black carbon. Amount of burned residue strongly affect to the GHG emissions, when one ton of burning of residue increased, the GHG emission increased 1.26 tons CO_{2eq} (include CO_2).

The amount of emission varies by region and time. The main source of emissions from open burning is the western, the central, and the lower northern regions especially during December to January and during April to May. During that time, it is the period of harvesting and the period of preparing areas for the next cultivation.