Final Report

Database development for spatial and temporal distribution of biomass burning In Northern Thailand

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Ms.Praphatsorn Punsompong [a] and Asst.Prof.Dr.Somporn Chantrara [b]

[a] Ph.D. Student of Environmental Science Program, Faculty of Science, Chiang Mai University, Chiang Mai Thailand 50200,. Thailand.

[b] Environmental Science Program/Department of Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai Thailand 50200,. Thailand.

August 2013

Acknowledgements

Funding in partial support of this research was supported by ICRAF, KSC-GMS Faculty of Social Science, Chiang Mai University. I would like to grateful to *Ms. Natjan Chairat* , *Dr. Prasit Wangpakapattanawong* and *Asst.Prof.Dr.Somporn Chantrara to conduct and support this research*. I would like to thank Environmental Science Program and Environmental Chemical Research Laboratory, Faculty of Science, Chiang Mai University for chemical data supporting to determine the emission factors.

Ms.Praphatsorn Punsompong

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Introduction

Fire is widely used in the tropical countries for deforestation, slash and burn agricultural, land clearing of agricultural residues and removal of excess crop residue from fields. It has been considered an important source of atmospheric trace gases and particulate matter (Dennis et al., 2002; Garivait et al., 2004; He et al., 2011; Mieville et al., 2010). The pollutants species emitted from biomass burning such as CO_2, CO, CH_4, NO_x, NH_3, SO_2, Non Methane Volatile Organic Compounds (NMVOC) and Particulate Matter (PM). It contributes to global environmental change by affecting local, regional and global air quality and human health (Chang and Song, 2009; Heil and Goldammer, 2001; Ito and Penner, 2004; Langmann et al., 2009; Mieville et al., 2010). In the northern part of Thailand has been annually facing air pollution during the dry season (Oanh and Leelasakultum, 2011; Pengchai et al., 2009). The source apportionment of PM10 concentrations during dry season was possibly from vegetative burning such as the forest fires or agricultural waste burning (Pengchai et al., 2009).

A standard formula to estimates of emissions from biomass burning has been developed by Seiler and Crutzen (1980) and has been widely used to estimate the emission in regional and global scale and various authors have periodically provided updated estimates (Dennis et al., 2002; Ito and Penner, 2004; Langmann et al., 2009; Mieville et al., 2010; Zhang et al., 2008). The gaseous emitted from open biomass burning in Asia reported by Streets et al. (2003) showed total emission of 2002 are 900 Tg of CO_2 and 57 Tg of CO. For Thailand, the emission from forest fire and crop residue burningfor total CO_2 about 69 Tg and 4.48 Tg of CO (Garivait et al., 2004). However, another research (Vongmahadlek et al., 2009) has been calculated annual emissions in Thailandbased on the bottom-up approach using local specific data in year 2005. The annual emission estimation is found as 9.46 Tg of CO, 2.58 Tg of NMVOC, 0.89 Tg of SO_2, 0.79 Tg of NO_x, 0.44 Tg of NH_3 1,28 Tg of PM_{10}, 0.33 Tg of organic carbon, and 0.14 Tg of black carbon.

In all estimations the large uncertainties associated with inherent in burned areas, fuel loads, combustion factors and emission factors. An activity data were taken directly from official statistics and/or estimated using a single parameter for the whole county (Garivait et al., 2004; Streets et al., 2003). A few measurements have been made to determine spatial and temporal distributions of characteristic of biomass stoves in local scale as historical data to improve the estimating accuracy of air quality modeling. However, in Northern Thailand does not have report about air pollutant estimates from open burning separately from types of vegetation land cover. Therefore, an accurate estimation of characteristics of burned areas, fuel loads, combustion factors and emission factors of vegetation burning and up-to-date information in local scale are urgently needed and remain to develop.

Objectives

1. To characterize the spatial and temporal distribution and variability of biomass burning in 17 Provinces Northern Thailand for the years 2003 through 2012 .
2. To develop the preliminary database of total emission of gaseous pollutants from biomass burning considered as specific in terms of source and species of Land cover type in Northern Thailand.

Data and Methodology

1. Study domain

The study domain is set between the latitudes 14˚51’50.1’’ N and 20˚30’37.9’’ N and between the longitudes 97˚14’1.3’’ E and 101˚51’29.7’’ E. This domain covers 17 provinces in Northern Thailand. The domain is divided into 2 parts (Upper and Lower) under condition of differences of topography, vegetation type and agricultural traditional plantation/burning. The upper north (UPN) includes 8 provinces (black line boundary) and lower north (LWN) includes 9 provinces (red line boundary) that show in Figure1.

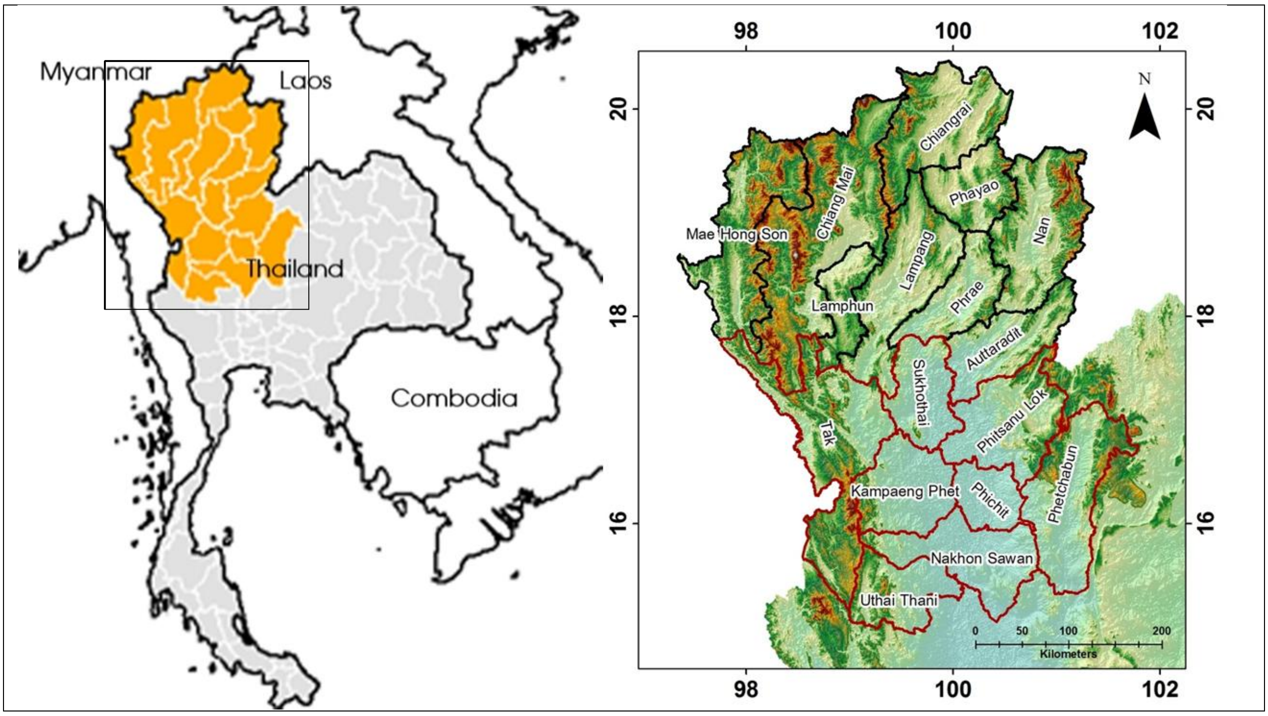


Figure 1 : The study domain set cover 17 provinces(orange) in Northern Thailand

2. Conceptual Framework

The methods for estimating biomass burning emission rates were based on the amount of biomass burned (Figure2). The spatial and temporal data of fire was adopted MODIS data to represent a number and location of fire daily for extract the burned area (A). Landsat 7^{TM} imageries was used for supported the scar of location of fire from

MODIS. The landuse vector data was derived from LDD (Land Development Department, Thailand) to represent the biomass sources and fuel characteristics that associated with the fuel loads (FL), Combustion Factors (CF) and Emission Factors (EF). MODIS fire hotspot data has been clip by administrator boundary for extract data inside the study domain. The amount of biomass burning emission rate was estimated based on the equation *(original by Seiler and Crutzen, 1980)*. Finally all spatial and attribute data will be collecting to geodatabase.

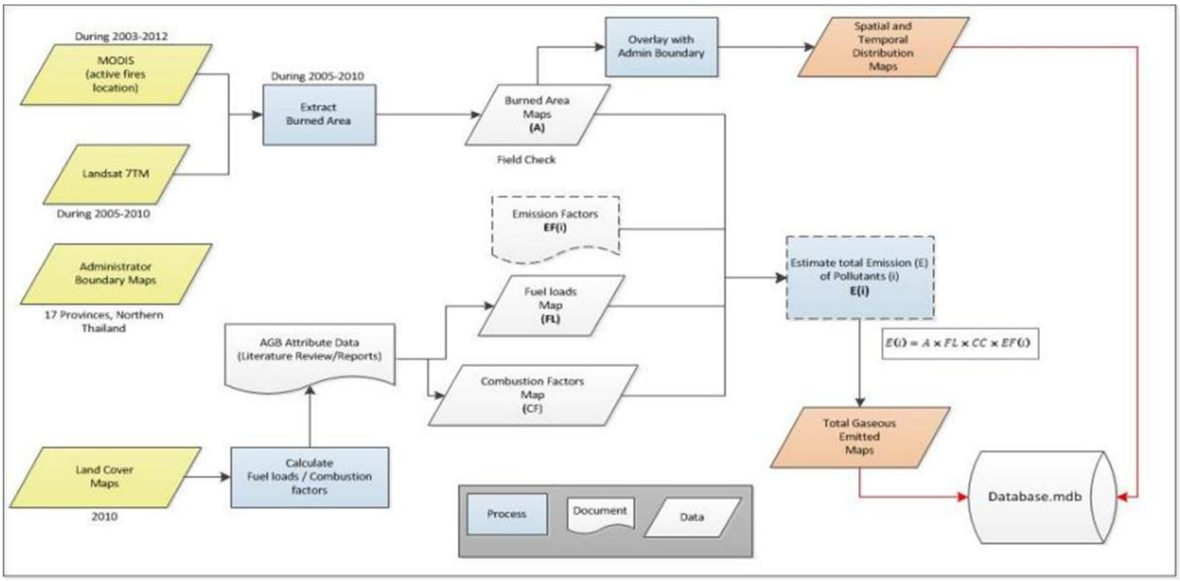


Figure 2 : Show conceptual framework diagram of study

3. *The spatial and temporal distribution of biomass burning*

The methods to estimate amount of biomass burned area monthly on spatially and temporally are

a. Mapping burn area

The MODIS hotspot/fire locations are good for determining the location of active fires, providing information on the spatial and temporal distribution of fires and comparing data monthly between years. Active fire detections from 1 km MODIS active Fire Product (TERRA/AQUA) (Giglioa et al., 2003) were obtained from the MODIS Fire Information for Resource Management System (FIRMS). Active fire data represent in shape point of the centroid location of actively burning in 1 km pixels. The advance GIS functions were used to estimate the burning area from the actual spatial resolution of MODIS scanned pixel.

b. Determination of fuel loads and combustion factors

Fuel loads is the second most important parameter in quantifying fire emissions and the emissions can be very high due to large fuel loads. The value of dry aboveground biomass can used to estimate the total of fuel loads and combustion factors in each biomass type that is affect to the value of gases emitted into the atmosphere. In forest area due to the limitations of field measurements, the plots data will be receive from literature reviews, reports and thesis for different forest type's cover in northern Thailand.

c. Determination of emission factors

The emission factors were chosen mainly from the research results based upon local or countries measurements. When domestic emission factors were not available, the research results from foreign studies were used, and emission factors from the countries which have similar environmental and climates were preferentially selected. To knowledge, emission factors for leaf letter in Dry Dipterocarp forest ,rice straw and maize residue in Northern Thailand are available by Environmental Chemistry Research Laboratory, Chiang Mai University but the other biomass in the other forest type and other crop residue (sugarcane, soybean, cassava and the vegetable) are not available at present. In this study, the average values of those reported in literatures were applied.

d. Spatial allocation

In this study, a GIS (Geographic Information System) –based approach was adopted for allocating the gases and particulate matter emissions map from biomass burning. For different biomass burning sources, emissions from field burning of crop residues are allocated on the basis of available land distribution, since crop residues are generally burned in farmland to remove rice straws or maize residue from field. The map of fuel loads was generating on spatial map that surrogate for forest fire. The allocation factors are the ratios of the surrogate amount in a grid cell to the total amount of emission rate in an area with the aid of GIS software tool.

e. Temporal characteristic

Significant seasonal variations in biomass burning emissions were observed in this study. Estimation of the seasonality of biomass burning rely primarily on surrogates, such as agricultural activities, seasonal rainfall pattern and fire hotspots. For the agricultural crop residues burning and forest fire, the fire-counts data used to determine the seasonal variations. The collection of fire-counts data in northern Thailand from 2003 to 2012 used to average monthly value of the ten-years data to describe the monthly variations in emissions from the crop residues burning and forest fire sources.

4. Estimate total emission of gaseous pollutants

The emissions of gases pollutants map from biomass burning were estimated based on the amounts of burned areas, fuel loads, combustion factors and emission factors. The complex burning process can only be considered in a simplified way when determining vegetation fire emissions over large spatial and temporal scales. Traditionally, fire emissions (E) for a specific gas species (i) are calculated as the product of burned area (A), fuel load (FL), combustion completeness (CC) and specific emission factors (EF) (original by Seiler and Crutzen, 1980) show in Eq.1

$$E(i) = A \times FL \times CC \times EF(i) \quad (1)$$

Each single factor in equation (1) has considerable spatial (x,y,z) and temporal (t) variability, so that fire emissions should read as E(x,y,z,t,i). The spatial and temporal dependencies have been omitted in equation (1) to increase readability. Representing these variations is a challenge for fire emission inventories.

5. Validation data

The goal of the validation was to quantify the accuracy of the burned area estimations. In this study the validation data derive from 2 sources, GPS polygons survey collect over agricultural crop residue burning over harvest seasons to represent the location of burned area boundaries and second source is High resolution imagery was utilized to produce burned area polygons (digitized) with in forest and crop such as Landsat TM images. In this study Landsat images index row 46-50 and path 129-132 was used and there are totally 17 images each year cover study domain. The Data has been derived from GIST-North (Geo-Informatics and Space Technology Development Agency: Northern Thailand, Faculty of Social Science, Chiang Mai University) during 2003-2010.

6. Develop the preliminary database

GIS is used as the main component of the system for capturing, storing, checking and manipulating data that are spatially referenced. The mapping and attribute of hotsports fire location, burned areas, fuel loads, combustion factors and emission factors are used to estimate the emissions and spatial distribution of air pollutants, which will be computed and stored in relational databases. This database will be suited for searching and developing in other dynamic environmental models.

Result and Discussion

1. The spatial and temporal distribution of biomass burning

a. Landuse area

In Northern Thailand over 57.72% of landuse is Forest area (98,842 sq.km), 37.43% is agricultural area (64,101 sq.km) , 4.84% is urban area , other area and water body (8,295 sq.km) (source : Land development department, 2010) that show in Table 1 and Figure 3. As a difference of topography in this study domain were divided to 2 parts (upper and lower) in Northern. From table 2, It was founded the area of forest in upper part (68,179 sq.km) has more than lower part (30,663 sq.km.). The forest types in northern include Deciduous dipterocarp forest, Mixed deciduous forest, Dry evergreen forest and a little area of Hill evergreen forest and tropical pine forest (natural/plantation). In contrast, agricultural area in lower part (41,277 sq.km) has much more area than upper part (22,850 sq.km.). The major crop types in lower part are irrigated paddy rice, sugar cane and orchard. For upper part the major crop types are maize, upland rice, soybean and mixed swidden cultivation.

Table 1 : Major types of landuse area in Notrhern Thailand

Landuse Type	Area (sq.km)	Area (%)
Forest Area	98,842.58	57.72
Agricultural Area	64,101.75	37.43
Urban Area	4,378.50	2.56
Water body	1,345.86	0.79
Other Area	2,571.29	1.50
Total	171,239.99	100.00

Source : Land Development Department, Thailand (2010)

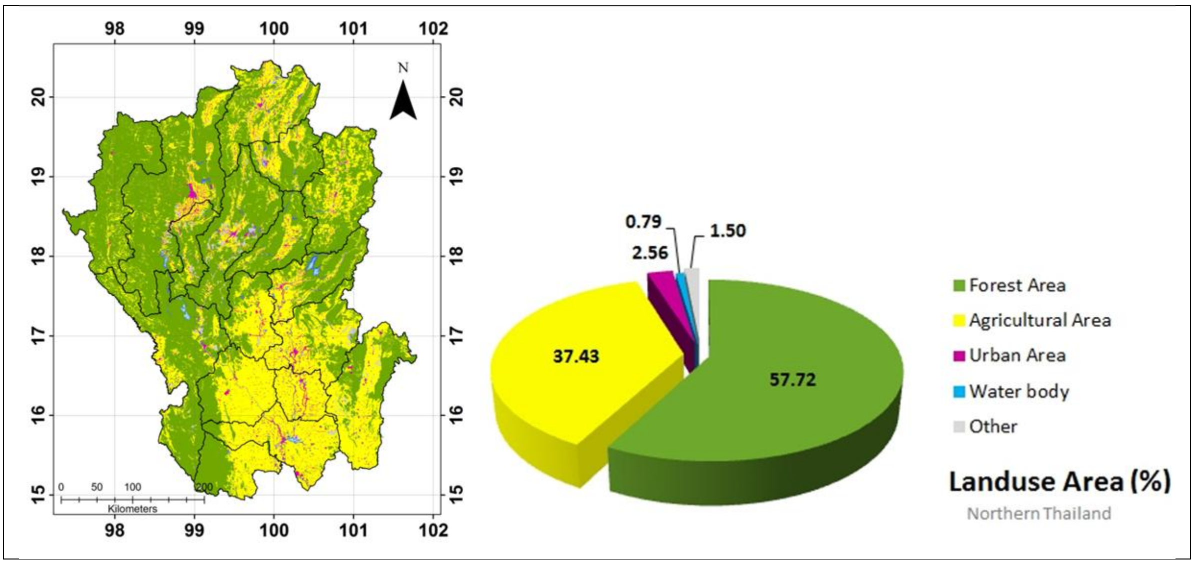


Figure 3 : Show major types of Landuse in Northern Thailand 2010

Table2 : Minor landuse area in Northern Thailand

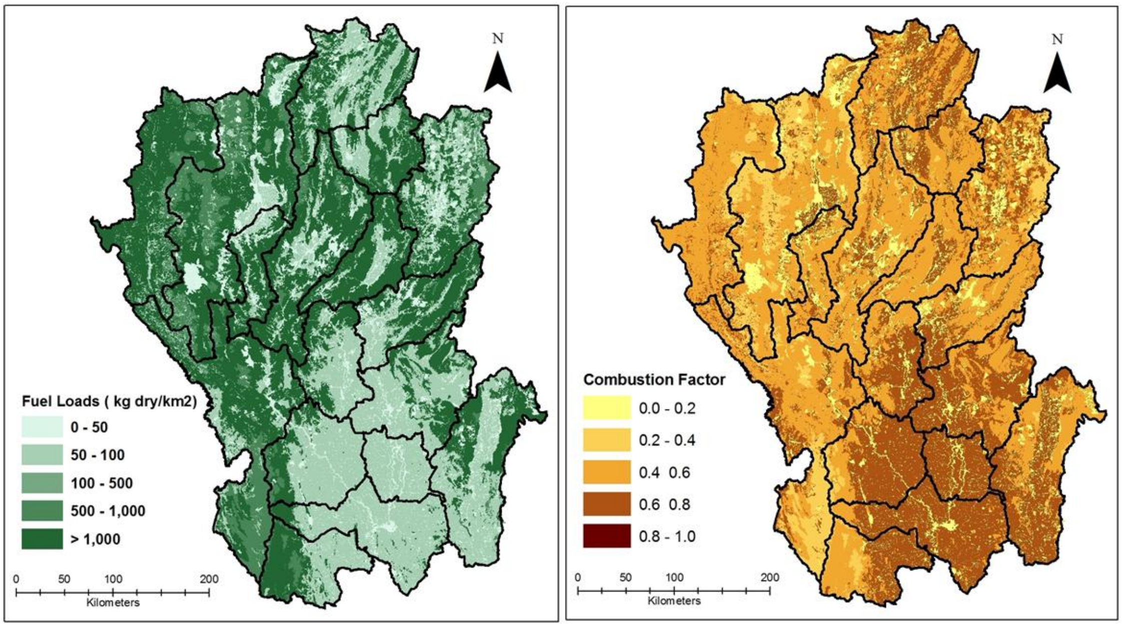
Landuse Type		Area (sq.km)		
Major	Minor	Upper	Lower	Total
Forest Area	Dry deciduous forest	23,016.93	6,780.57	29,797.51
Forest Area	Evergreen Forest	11,345.25	5,924.77	17,270.01
Forest Area	Mixed deciduous forest	31,076.38	17,383.80	48,460.19
Forest Area	Other Forest	2,740.62	574.26	3,314.88
Agricultural Area	Paddy Fields	8,807.99	22,447.73	31,255.72
Agricultural Area	Field Crop	10,725.08	16,883.45	27,608.53
Agricultural Area	Other Agricultural	3,307.57	1,929.92	5,237.49
Other Area	Grass	449.95	701.06	1,151.01
Urban Area	Urban	2,316.06	2,062.45	4,378.50
Water Body	Water Body	805.99	539.88	1,345.86
Other Area	Other	1,008.26	412.02	1,420.28
Total Area		95,600.09	75,639.91	171,239.99

b. **Determination of fuel loads and combustion factors**

The one of parameters to estimate gaseous emitted from biomass burned were fuel loads and combustion factors. In this study the fuel loads and combustion factors were estimate based on landuse type show in table 3. and the results map was show in Figure 4.

Table 3 : The value of fuel loads and combustion factors based on landuse type.

Vegetation Type	Fuel loads (kg dry matter/sq.km)	Combustion Factor
Evergreen Forest	839	0.32
Dry deciduous forest	1634	0.45
Mixed deciduous forest	1604	0.5
Paddy Fields	55	0.8
Field Crop	100	0.8
Grass	52	0.74
Other	0	0
Urban	0	0



(a) (b)

Figure 4 : Maps of fuel loads (a) and combustion factors(b).

c. Determination of emission factors

The emission factors were chosen mainly from the latest research results based upon local measurements. In this study some emission factors were derived from Environmental Chemistry Research Laboratory (ECRL) under “Biomass Burning Project” Department of chemistry, Faculty of Science , Chiang Mai University show in Table 2. The emission factor of evergreen forest and mixed deciduous forest was similar with Dry deciduous forest it’s represent the value in tropical forest(IPCC Guideline, 2006).

Table 4 : Emission factors for Open Burning

Vegetation Type	Emission Factor (g/kgdry)				
	CO	SO_2	NO_2	NO_x	PM_{10}
Evergreen Forest [a]	64.84	0.22	3.19	5.26	1.52
Dry deciduous forest [a]	64.84	0.22	3.19	5.26	1.52
Mixed deciduous forest [a]	64.84	0.22	3.19	5.26	1.52
Rice Straw [b]	0.69	0.43	1.84	2.76	0.69
Maize Residue [b]	0.9	-9	2.77	4.95	0.9
Grass [a]	65 [a]	-9	0.21	3.9	-9

Remark : [a] IPCC Guidelines Volume 4, 2006 , [b] ECRL, 2013 , -9 no data

d. **Spatial and temporal characteristic of burned area**

The burned area has been extracted from MODIS hotspot data (represent in point shapefile) which request and downloaded from FIRMS website during 2003-2012 cover study domain. Each hotspot detection represents the center of a 1km (approximately) pixel flagged as containing one or more hotspots within that pixel. The actual pixel size varies with the scan and track field on attribute data. The scan value represents the spatial-resolution in the East-West direction of the scan and the track value represents the North-South spatial resolution of the scan. Then, Buffer function in GIS were used to generate the burning boundary of hotspots by calculate the area from “scan” and “track” field. However, the duplicate of hotspot point were occur in nearly area because it’s was detected from difference satellite on differences time (AQUA in day time and TERRA in night time). The dissolve function were used to generalize data and eliminate the duplicate area. The total burned area were recalculate for this study(Figure 5).

The results analysis of distribution monthly burned area between 2003-2012 was showed highest burned area in March 2007 (Figure 6). The seasonal patterns of burning was similar in every year, start burning around November, peak in March and low in May to September because the rainy season in Thailand was start in May and end in September. In hypothesis of biomass burning in Northern Thailand were a major sources of pollutants in dry season. The statistical analysis used to determine the relationship between the number of hotspot and PM10 concentration value that locate on center of Chiang Mai (Chiang Mai City Hall, latitudes 18.84089 and longitudes 98.96974) to representative the PM10 concentration in Northern Thailand (Figure 7) and low effected pollutants concentration from traffic. It’s was found that, the results from SPSS programs show Pearson Correlation were strongly correlated and positive correlation between both data which was statistically significant ($r=0.836$, $p< 0.0005$, $n=139$) and Correlation is significant at the 0.01 level (2-tailed). These results can confirm the biomass burning are a major sources of PM10 concentration in Northern Thailand.

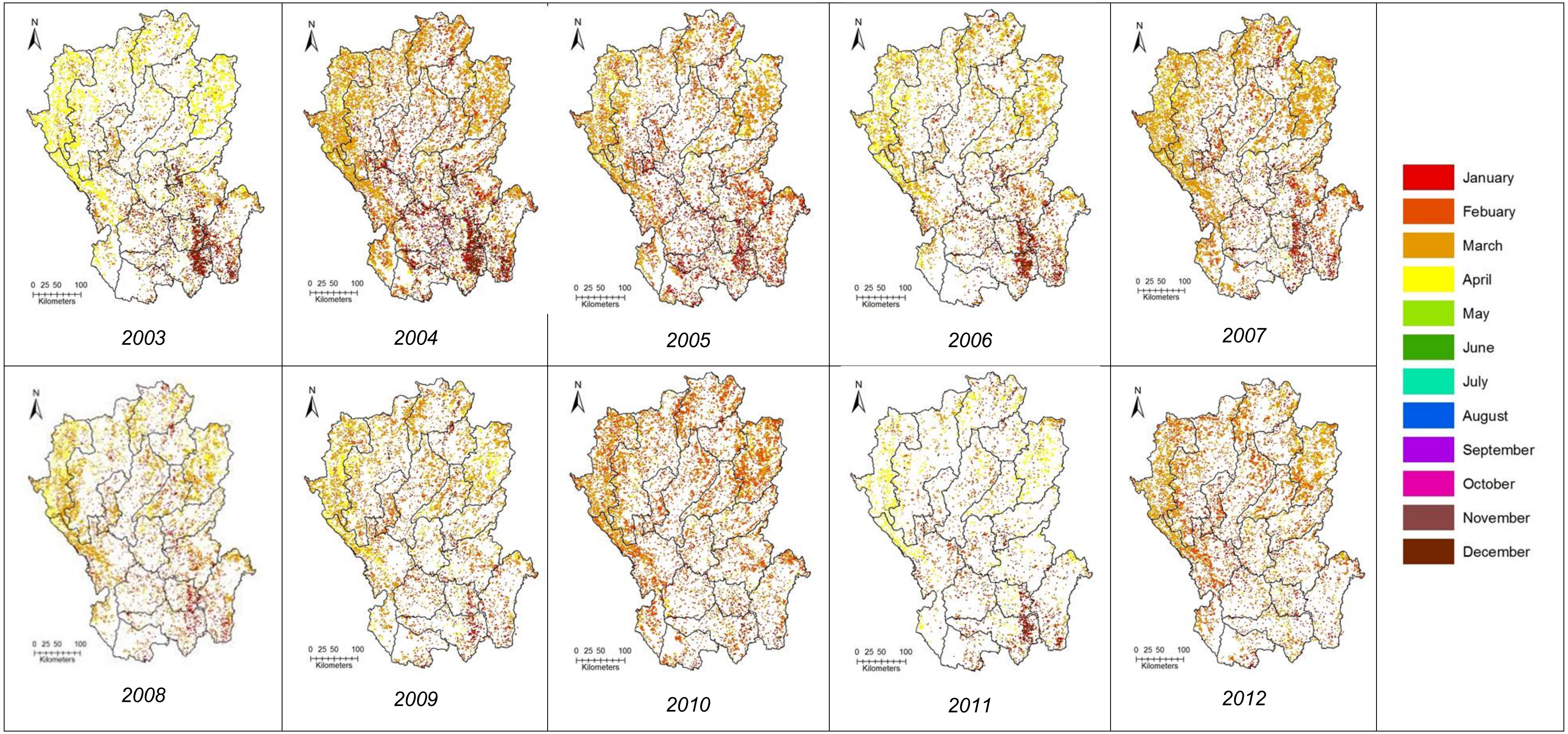


Figure 5 : Monthly Spatial and temporal burned area distribution during 2003-2012 in Northern, Thailand.

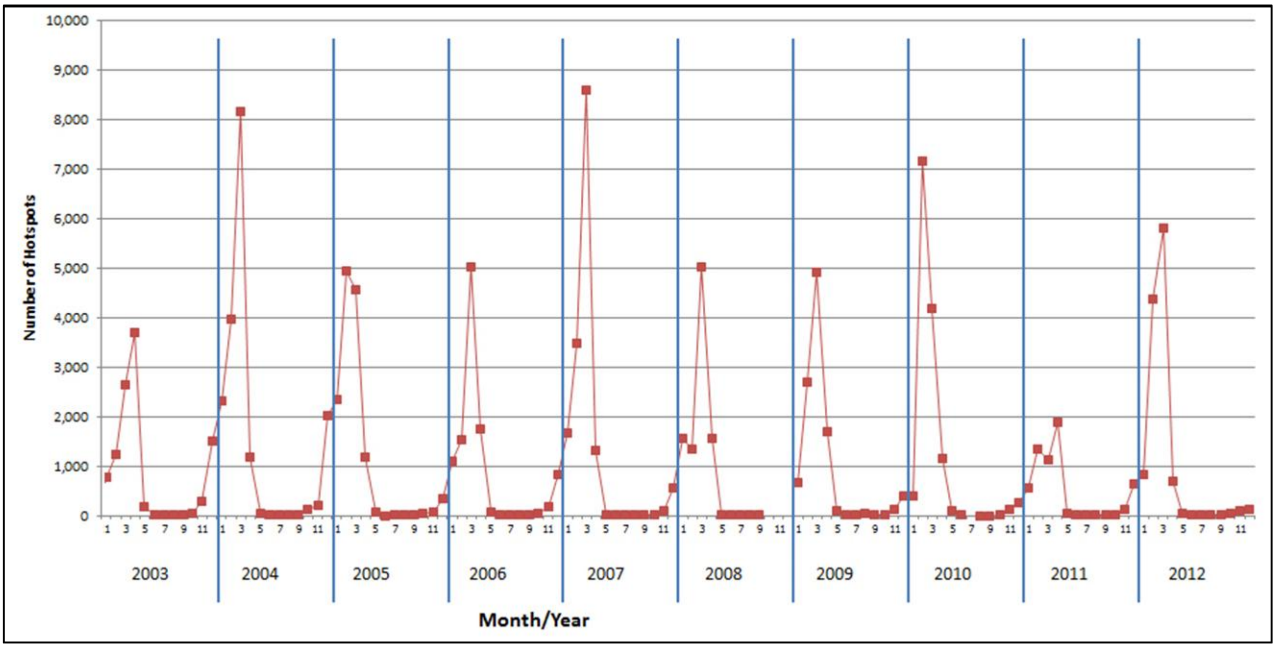


Figure 6 : Show the number of Monthly Hotspot distribution during 2003 – 2012

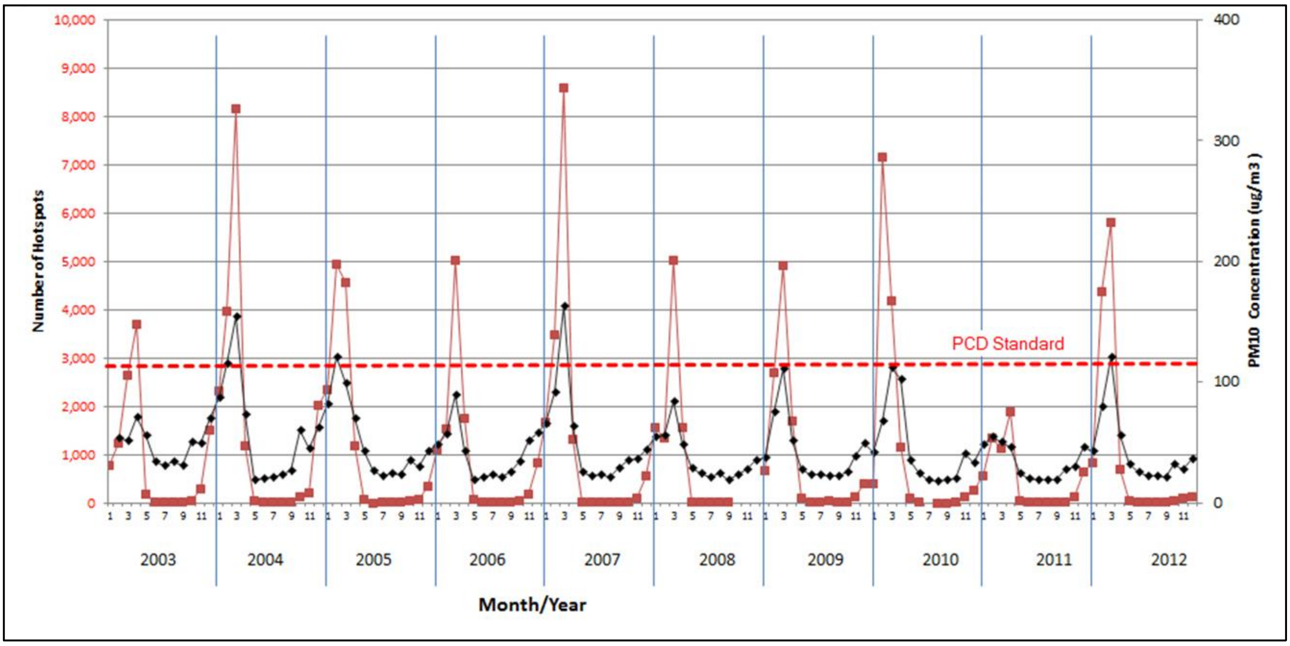


Figure 7 : Show relationship between the number of hotspot and PM10 concentration during 2003 – 2012.

In upper north, total highest burned area showed in 2007 (27,243 sq.km) , 2004 (26,499 sq.km) and 2010 (23,041 sq.km) respectively (table 5). Figure 8 show the distribution of burning area show highest in March, April and February in every year because the traditional of farmer in this area have to clear and remove crop residue out-off the area especially in upland area to preparing land before rain coming in May and the burning is the fast and low cost to do it.

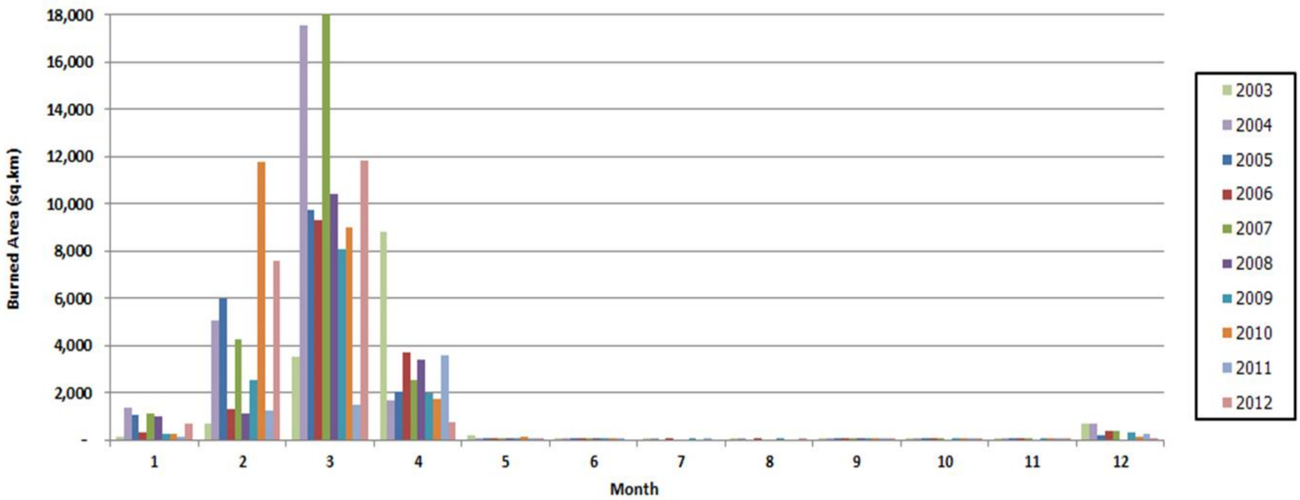


Figure 8 : Monthly Spatial and temporal burned area distribution during 2003-2012 in Upper North.

But difference in lower north, the highest monthly burned area show similar in upper north but the results show a little bit area was burned in December and January more than upper north (Figures 9) and highest burned area showed in 2004 (19,894 sq.km) , 2007 (14,343 sq.km) and 2005 (14,321 sq.km) respectively (table 6). Most of farmer in this area was burned rice straw and sugarcane. Paddy field in lower path can be plant 2-3 times per year because it's located in irrigated area. The burning is easily and fast to remove rice straw before preparing land to next planting. We found sugarcane has been traditional burning dry leaf before cutting in December and January.

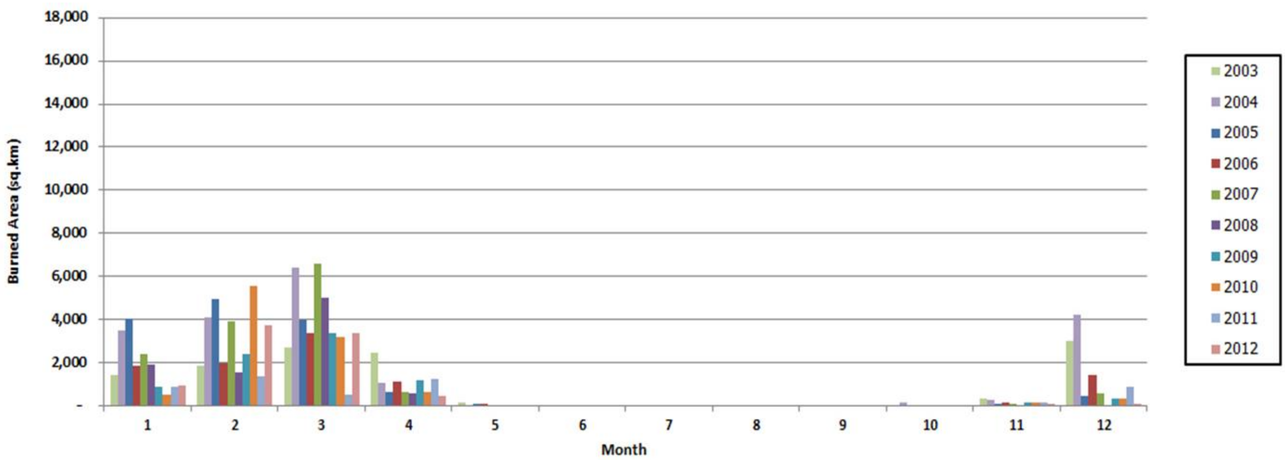


Figure 9 : Monthly Spatial and temporal burned area distribution during 2003-2012 in Lower North

Table 5 : Monthly burned area distribution during 2003-2012 in Upper North

Year	Area (sq.km) / Month												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
2003	116.30	701.76	3,553.49	8,802.39	212.96	6.20	4.63	1.00	8.77	6.93	95.48	667.06	14,176.97
2004	1,363.04	5,082.87	17,574.55	1,693.13	29.57	5.78	1.32	3.32	1.10	12.47	60.10	672.61	26,499.84
2005	1,055.66	5,961.88	9,736.70	2,029.68	65.37	14.14	-		4.96	2.00	7.07	200.32	19,077.77
2006	307.79	1,307.35	9,342.39	3,687.98	53.20	3.10	1.68	2.32	4.45	6.63	88.25	416.29	15,221.42
2007	1,100.12	4,290.03	18,827.99	2,563.53	26.11	25.17			1.32	2.10	33.96	373.64	27,243.96
2008	978.47	1,128.80	10,441.70	3,374.89	4.53	9.62			2.10				15,940.11
2009	281.49	2,528.70	8,059.86	1,983.94	64.61	2.32	1.21	8.21	6.20	3.59	55.72	340.72	13,336.56
2010	267.34	11,754.86	8,982.90	1,736.65	123.09	21.62			1.32	1.00	36.76	116.16	23,041.68
2011	160.67	1,277.30	1,503.14	3,617.31	30.75	1.21	2.68		8.23	5.42	44.90	275.13	6,926.74
2012	675.34	7,582.43	11,812.07	773.54	49.94			2.43	7.16	4.00	34.58	67.95	21,009.45

Table 6 : Monthly burned area distribution during 2003-2012 in Lower North

Year	Area (sq.km) / Month												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
2003	1,408.75	1,863.72	2,724.99	2,491.85	134.71	10.87	12.43	6.45	5.78	55.72	325.67	2,989.68	12,030.62
2004	3,522.69	4,103.46	6,437.14	1,090.20	48.33	11.18	20.41	2.00	10.49	139.27	276.88	4,232.05	19,894.10
2005	4,064.20	4,961.60	3,981.35	616.03	74.71	1.32	25.63	11.95	7.00	46.42	84.81	446.94	14,321.95
2006	1,856.54	2,003.61	3,349.36	1,135.87	68.97	5.91	3.10	6.32	12.47	35.52	164.49	1,422.25	10,064.41
2007	2,420.72	3,908.58	6,569.95	649.51	11.30	5.37	15.48	25.60	5.43	16.15	113.47	601.81	14,343.38
2008	1,921.79	1,552.03	5,043.95	556.26	30.72	4.00	2.68	13.76	9.21				9,134.40
2009	895.46	2,377.17	3,371.81	1,162.87	64.80	4.88	3.48	32.85	17.07	8.76	130.95	326.75	8,396.84
2010	498.30	5,553.53	3,192.40	664.55	44.95	10.11		1.00		5.53	146.05	362.31	10,478.72
2011	910.94	1,343.95	522.33	1,241.60	42.61	6.07	3.20	13.36	7.25	4.90	141.76	892.49	5,130.45
2012	951.04	3,745.91	3,366.88	470.70	45.03	4.68	8.00	1.00	14.16	38.05	103.45	97.81	8,846.71

The landuse was divide to 3 majors are forest area, agricultural area and other area that include urban area, water body and other area to analysis the major landuse was burned in study domain (Table 7). The results found that, the highest burned area occur 46,393 sq.km in 2004 and average highest burned area during 2003-2012 was in forest area 15,274 sq.km (57.09%) while agricultural area was average burned 9,659 sq.km (39.67%)(Figure 10)

Table 7 : Analysis of burned area distribution on 3 majors of landuse area during 2003-2012

Year	Forest Area		Agricultural Area		OtherArea		Total	
	Area (sq.km)	Area (%)	Area (sq.km)	Area (%)	Area (sq.km)	Area (%)	Area (sq.km)	Area (%)
2003	13,555.63	51.72	11,737.99	44.79	913.96	3.49	26,207.59	100
2004	26,967.82	58.13	17,919.47	38.62	1,506.64	3.25	46,393.94	100
2005	19,133.75	57.29	13,183.93	39.47	1,082.05	3.24	33,399.73	100
2006	13,901.60	54.98	10,502.44	41.53	881.79	3.49	25,285.83	100
2007	26,346.71	63.35	14,029.36	33.73	1,211.27	2.91	41,587.34	100
2008	15,404.06	61.43	8,940.09	35.65	730.37	2.91	25,074.52	100
2009	13,028.35	59.95	7,933.42	36.50	771.62	3.55	21,733.40	100
2010	22,096.25	65.92	10,513.64	31.36	910.51	2.72	33,520.40	100
2011	6,342.05	52.60	5,244.88	43.50	470.25	3.90	12,057.19	100
2012	20,180.17	67.59	8,995.19	30.13	680.80	2.28	29,856.16	100
Average	15,274.04	57.09	9,659.04	39.67	803.59	3.23	25,736.67	100

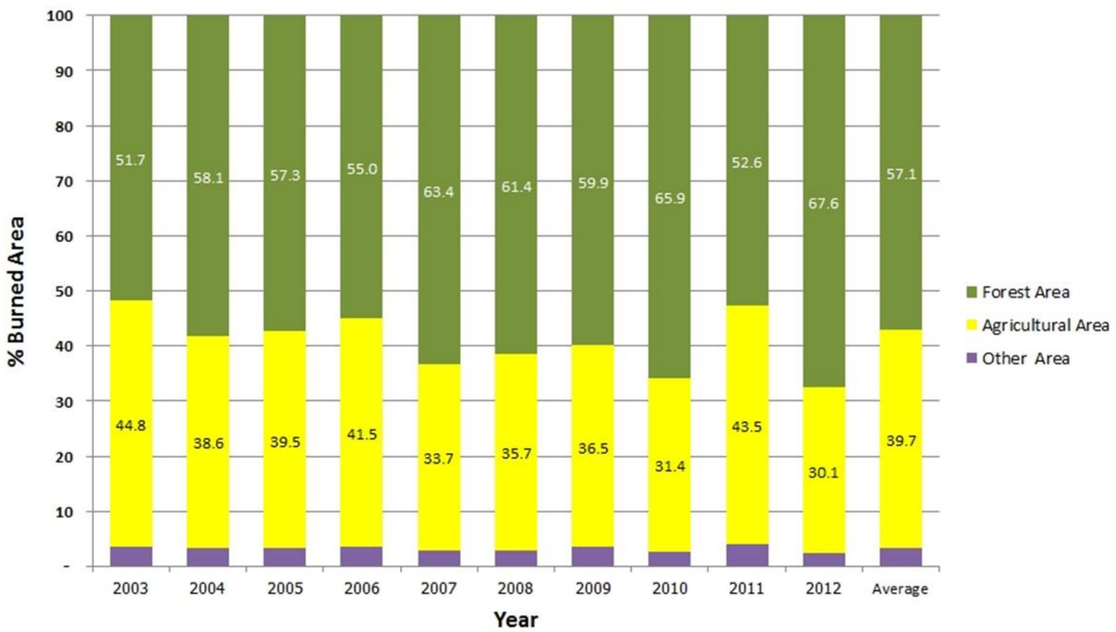


Figure 10 : Graph of burned area distribution on 3 majors of landuse area during 2003-2012

Focusing on forest area burned. In upper part of Northern, The result of total monthly forest burned area distribution show (table 8) top-tree highest area in March 2007 (13,957 sq.km), March 2004 (13,327 sq.km) and Febuary 2010 (8,175). Annual burning be start in December and increasing in February, high in March and decreasing in April and be stop burning in May (Figure 11) In lower part, The pattern of starting burned area were similar start and stop month in upper part but the area burned were lower (Figure 12). The highest forest burned area in lower part was show in March 2007 (4,336 sq.km), March 2004 (3,968 sq.km) and February 2010 (8,715 sq.km) show in table 9.

Montly Agricultural burned area distribution in upper part of Northern show the highest area in March 2007 (4,565 sq.km), March 2004 (3,968 sq.km) and March 2012 (2,828 sq.km) (table 10). Annual burning be start in December and increasing in February, high in March and decreasing in April and be stop burning in May (Figure 13) to preparing soil in May. In lower part, the pattern of starting burned area not similar start and stop month in upper part (Figure 14). Annual burning starting in November until stop in May and there are no peak burning month similar in upper part because the differences of traditional paddy variety and growing period. The highest forest burned area in lower part was show in December 2004 (3,409 sq.km), January 2005 (2,940 sq.km) and January 2004 (2,640 sq.km) show in table 11.

Table 8 : Monthly Forest burned area distribution during 2003-2012 in Upper North

Year	Area (sq.km) / Month												Total	% Total Burned
	1	2	3	4	5	6	7	8	9	10	11	12		
2003	35.23	439.63	2,516.76	6,423.24	131.07	5.33	1.97		3.67	2.46	19.18	168.71	9,747.25	68.75
2004	752.59	3,674.22	13,327.13	1,269.45	12.90	1.20		1.30		2.52	13.21	106.20	19,160.70	72.30
2005	592.51	4,361.36	6,986.11	1,461.71	34.10		7.22		2.13		2.25	10.86	13,458.24	70.54
2006	111.86	790.70	6,826.28	2,731.20	31.28	0.64		0.81	0.36	3.60	9.29	44.02	10,550.06	69.31
2007	522.56	3,025.46	13,957.93	1,800.24	13.13	10.29				0.78	2.31	72.49	19,405.20	71.23
2008	377.77	732.24	7,857.21	2,505.25	0.73	1.32							11,474.52	71.99
2009	97.88	1,789.07	5,927.36	1,386.47	18.27	1.00	1.02	1.38	0.38	1.38	4.39	39.93	9,268.53	69.50
2010	100.38	8,715.04	6,606.75	1,334.29	61.91	11.95					5.81	10.50	16,846.64	73.11
2011	52.52	895.24	1,066.09	2,665.85	22.13		0.57		0.92	2.33	11.54	41.20	4,758.39	68.70
2012	397.98	6,142.49	8,866.59	434.36	26.39				0.39	1.00	6.79	3.98	15,879.96	75.58

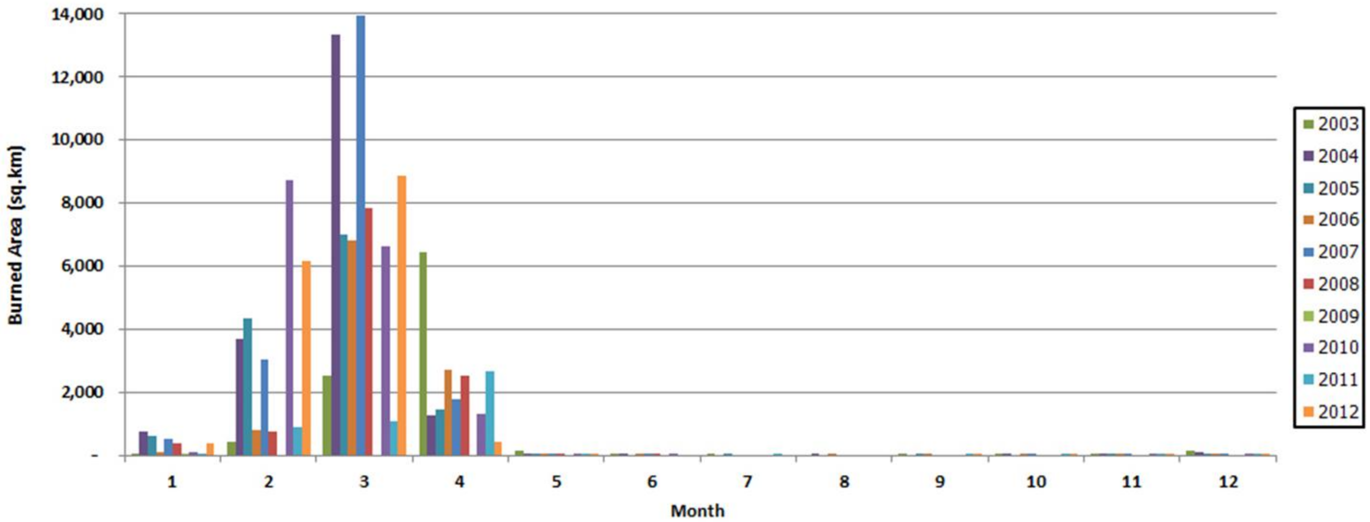


Figure 11 : Monthly Spatial and temporal forest burned area distribution during 2003-2012 in upper North

Table 9 : Monthly Forest burned area distribution during 2003-2012 in lower North

Year	Area (sq.km) / Month												Total	% Total Burned
	1	2	3	4	5	6	7	8	9	10	11	12		
2003	162.47	591.68	1,347.38	1,461.90	27.11			0.62	0.03	1.76	12.71	202.73	3,808.38	31.66
2004	739.91	1,926.94	3,890.40	565.95	10.42	0.25			0.98	0.15	21.75	650.37	7,807.12	39.24
2005	964.80	2,187.13	2,259.18	235.67	12.46		1.02			0.80	0.41	14.03	5,675.50	39.63
2006	258.02	587.30	1,775.50	661.42	6.51						3.91	58.88	3,351.54	33.30
2007	540.12	1,789.55	4,336.69	232.47	0.59	0.96					3.10	38.02	6,941.51	48.40
2008	259.31	666.92	2,763.38	233.79	6.00				0.15				3,929.54	43.02
2009	109.98	1,087.80	1,959.77	560.59	15.95	0.15		0.73			2.79	22.06	3,759.82	44.78
2010	113.60	2,914.83	1,846.37	344.38	16.59	1.62				1.38	2.97	7.89	5,249.61	50.10
2011	103.16	643.00	173.23	593.46	3.81						7.63	59.35	1,583.67	30.87
2012	335.89	2,255.09	1,603.08	81.37	17.88					1.90	1.09	3.90	4,300.20	48.61

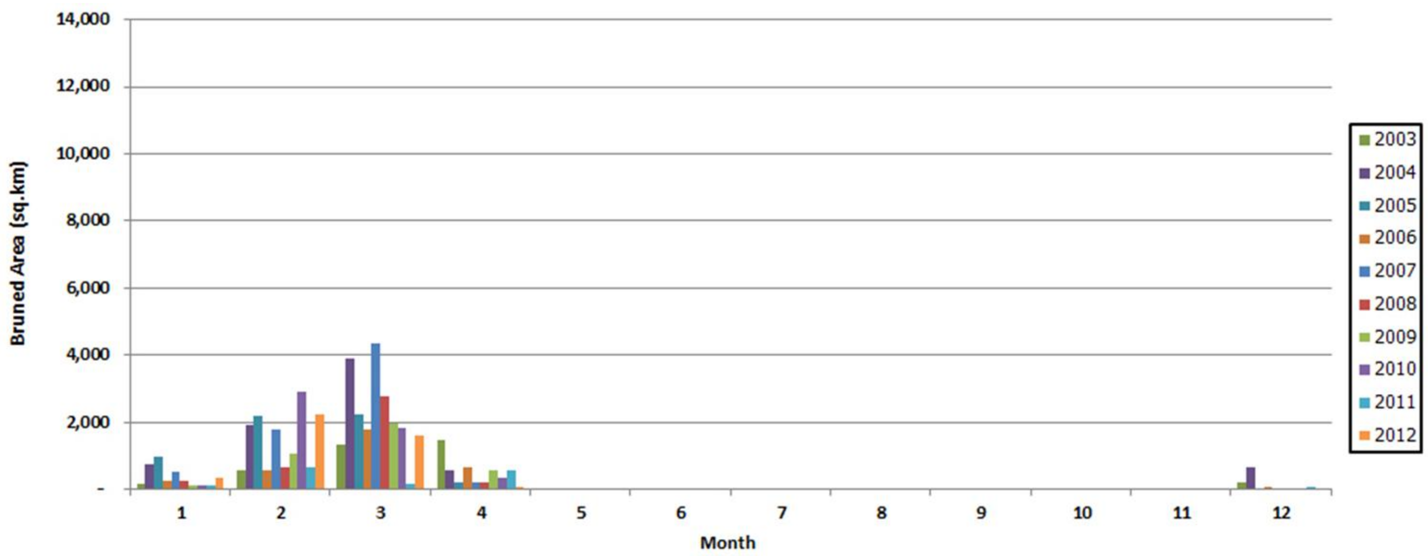


Figure 12 : Monthly Spatial and temporal forest burned area distribution during 2003-2012 in lower North

Table 10 : Monthly Agricultural burned area distribution during 2003-2012 in upper North

Year	Area (sq.km) / Month												Total	% Total Burned
	1	2	3	4	5	6	7	8	9	10	11	12		
2003	67.94	198.72	887.99	2,270.01	75.64	0.76	0.34	1.00	3.80	4.46	57.76	402.25	3,970.65	28.01
2004	464.04	1,169.51	3,968.58	393.58	11.91	2.75	0.13			7.03	33.27	437.56	6,488.35	24.48
2005	357.02	1,356.38	2,562.82	538.40	25.80		5.19		1.69	1.97	4.24	155.37	5,008.87	26.26
2006	139.46	396.96	2,346.20	902.25	19.65	1.46	1.66		1.41	0.06	59.72	267.48	4,136.30	27.17
2007	452.06	1,068.59	4,565.23	690.61	8.43	9.75				1.32	20.87	212.43	7,029.29	25.80
2008	456.07	312.99	2,399.77	824.80	3.54	5.72			0.30				4,003.18	25.11
2009	143.27	573.62	1,948.93	554.39	39.69		0.19	4.22	4.71	0.91	41.81	232.02	3,543.77	26.57
2010	140.09	2,686.26	2,257.64	368.63	36.92	6.33			0.03	1.00	25.78	72.04	5,594.71	24.28
2011	91.72	306.16	390.28	905.56	6.95		1.56		0.51	1.81	27.25	161.84	1,893.63	27.34
2012	214.11	1,246.73	2,828.84	311.30	16.85			0.45	1.35	2.91	18.28	41.61	4,682.42	22.29

Table 11 : Monthly Agricultural burned area distribution during 2003-2012 in lower North

Year	Area (sq.km) / Month												Total	% Total Burned
	1	2	3	4	5	6	7	8	9	10	11	12		
2003	1,173.26	1,207.82	1,290.12	982.24	101.19	10.87	10.48	3.89	4.67	51.23	295.36	2,636.19	7,767.34	64.56
2004	2,640.16	2,042.32	2,413.40	479.82	33.67	10.52	18.66	2.00	9.36	131.22	240.81	3,409.17	11,431.13	57.46
2005	2,940.93	2,626.84	1,625.68	350.36	57.81	1.32	24.01	11.89	5.80	38.62	78.70	413.10	8,175.05	57.08
2006	1,511.70	1,333.65	1,502.88	450.33	58.82	4.87	3.10	5.66	10.93	35.06	154.62	1,294.54	6,366.15	63.25
2007	1,794.80	1,995.35	2,117.47	393.01	7.08	2.75	13.99	21.67	4.05	15.03	103.04	531.82	7,000.07	48.80
2008	1,581.97	839.69	2,157.88	308.39	24.01	3.36	2.56	12.59	6.47				4,936.91	54.05
2009	748.79	1,219.99	1,349.48	566.97	45.05	1.97	3.48	28.42	12.69	6.26	117.04	289.52	4,389.66	52.28
2010	367.18	2,480.51	1,286.39	280.52	25.59	3.39		0.26		1.41	132.00	341.67	4,918.93	46.94
2011	768.57	648.83	327.47	617.57	36.72	4.73	3.08	12.48	6.29	4.14	125.62	795.76	3,351.25	65.32
2012	578.59	1,420.19	1,683.53	372.65	21.95	3.56	6.53		8.83	30.32	97.17	89.46	4,312.77	48.75

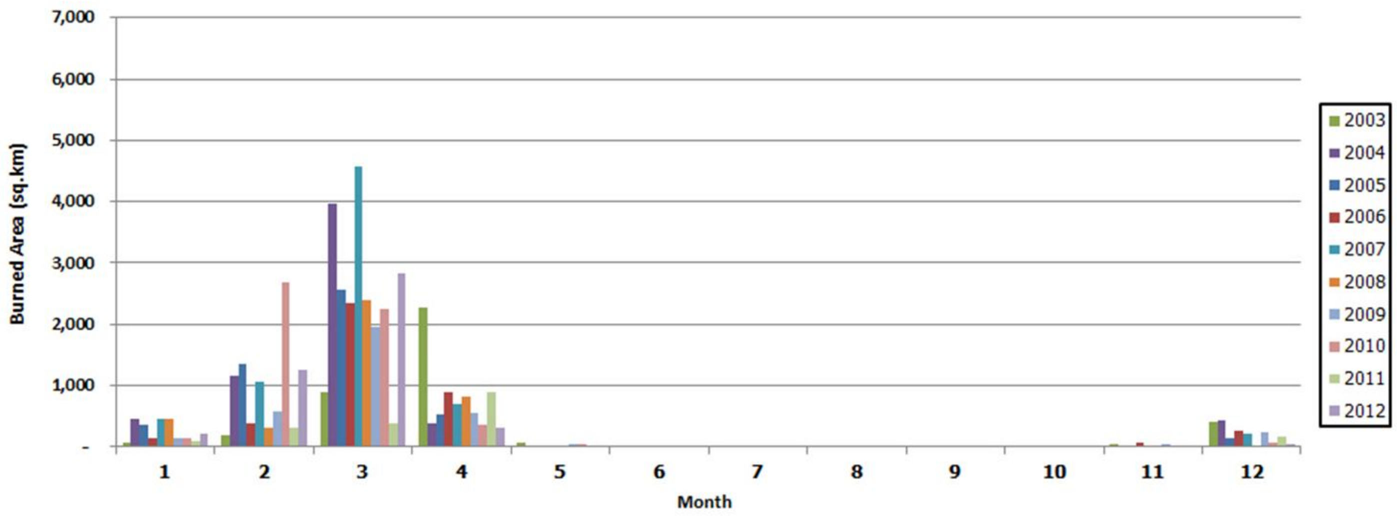


Figure 13 : Monthly temporal agricultural burned area distribution during 2003-2012 in upper North

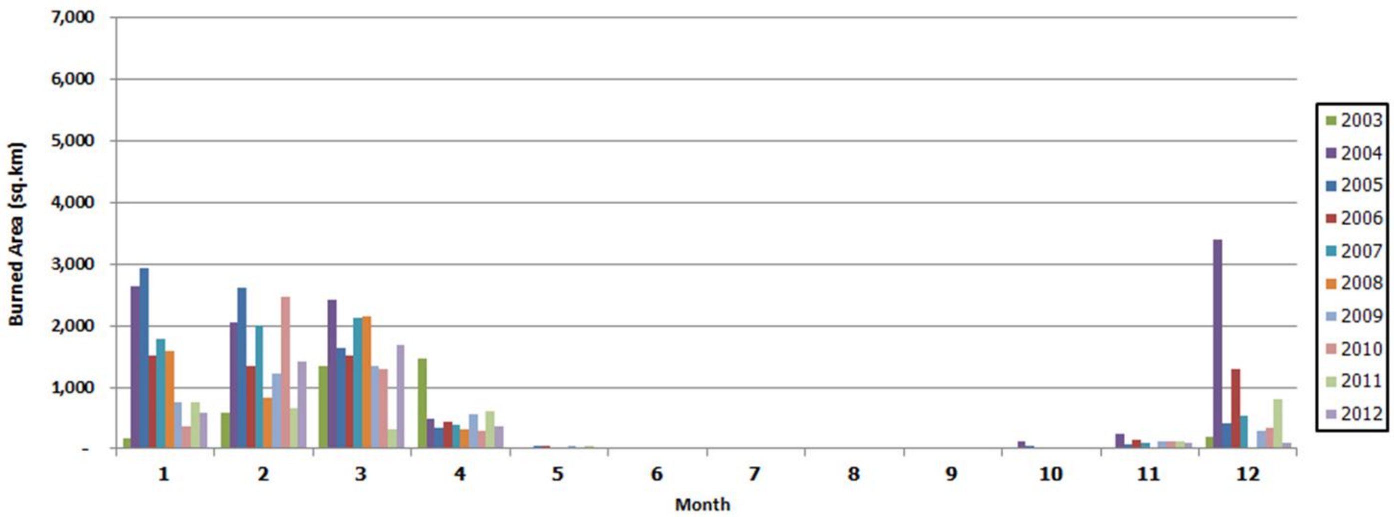
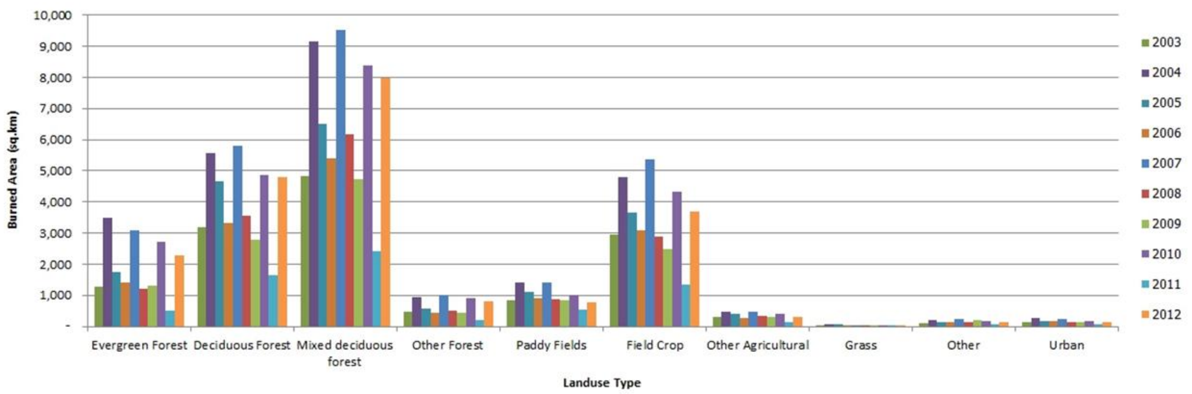
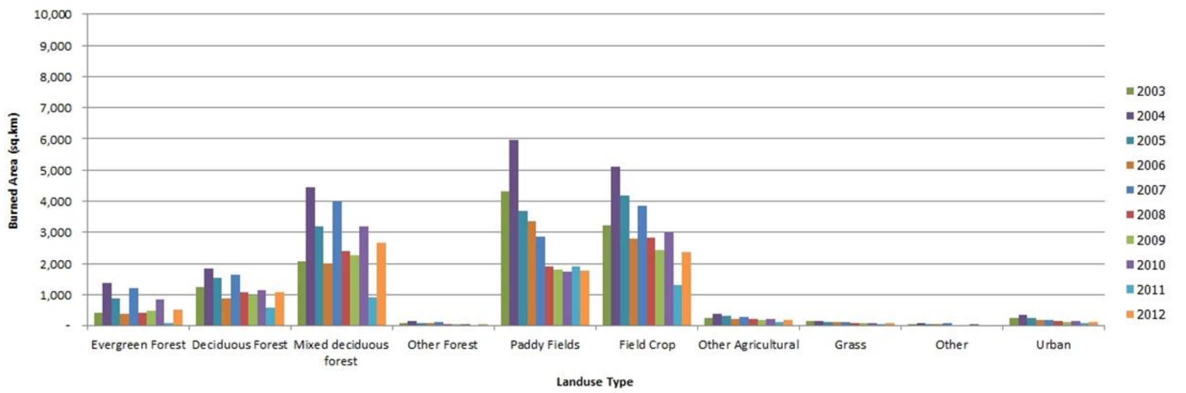


Figure 14 : Monthly temporal agricultural burned area distribution during 2003-2012 in lower North

The total burning area show highest in Mixed deciduous forest than other landuse type in every year (table 12). Top-tree highest burning area were found on 13,588 sq.km in 2004, 13,503 sq.km in 2007 and 11,551 sq.km in 2010 We have a little found area burned in grass area (average 142 sq.km). Figure 15 present the spatial and temporal of burned area distribution on landuse type during 2003-2012.split by upper (a) and lower(b) part of Northern. The results show in upper part was highest annual burned in Mixed deciduous forest type and the second burned show in Field crop and dry deciduous forest area. Top-tree highest burning area that show in table 13 were found on Mixed deciduous forest 9,537 sq.km in 2007, 9,152 sq.km in 2004 and 8,371 sq.km in 2010. But in lower north were differences from the upper. The highest burned area found in paddy fields and field crop area on the level with Mixed deciduous forest area (Figure 15 b). Top-tree highest burning area were found on Paddy field 5,977 sq.km in 2004, field crop 5,097 sq.km in 2004 and mixed deciduous forest 4,436 sq.km in 2004 The differences burning area on landuse type between upper part and lower part because of the characteristic of topography, water irrigated management , soil suitability and the type of commercial crops in each area.



(a)



(b)

Figure 15 : Spatial and temporal of landuse burned area distribution during 2003-2012 in Upper North (a) and Lower North(b).

Table 12 : Total minor Landuse Burned area distribution during 2003-2012.

Landuse Type / Year	Burned Area (sq.km)									
	Evergreen Forest	Dry deciduous forest	Mixed deciduous forest	Other Forest	Paddy Fields	Field Crop	Other Agricultural	Grass	Other	Urban
2003	1,696.03	4,437.37	6,878.08	544.15	5,168.93	6,151.87	536.45	180.45	147.68	382.70
2004	4,888.26	7,415.50	13,588.18	1,075.88	7,389.45	9,903.13	858.04	220.81	318.60	601.26
2005	2,599.16	6,191.07	9,687.31	656.21	4,776.86	7,838.69	736.59	185.05	205.83	422.97
2006	1,783.06	4,198.42	7,407.28	512.84	4,269.47	5,899.57	491.66	139.69	169.07	340.72
2007	4,294.10	7,439.27	13,503.29	1,110.05	4,263.40	9,197.89	784.96	159.99	297.66	435.09
2008	1,622.56	4,641.51	8,580.38	559.61	2,762.08	5,726.02	553.42	98.94	166.61	292.26
2009	1,786.25	3,756.26	6,989.54	496.31	2,641.36	4,908.82	470.88	123.16	217.47	268.01
2010	3,572.29	6,005.36	11,551.87	966.73	2,734.39	7,295.27	592.13	140.25	213.04	323.43
2011	571.54	2,230.92	3,328.46	211.13	2,436.21	2,649.74	255.65	69.89	102.09	156.85
2012	2,818.65	5,864.83	10,656.83	839.86	2,548.87	6,050.76	473.60	109.40	165.85	253.08
Average	2,563.19	5,218.05	9,217.12	697.28	3,899.10	6,562.18	575.34	142.76	200.39	347.64

Table 13 : Minor Landuse Burned area distribution during 2003-2012 in upper north.

Landuse Type / Year	Burned Area (sq.km)									
	Evergreen Forest	Dry deciduous forest	Mixed deciduous forest	Other Forest	Paddy Fields	Field Crop	Other Agricultural	Grass	Other	Urban
2003	1,279.15	3,180.90	4,822.13	465.07	853.88	2,936.15	295.33	42.68	101.87	143.53
2004	3,502.24	5,579.59	9,152.16	926.70	1,412.00	4,805.71	482.18	60.05	218.35	261.02
2005	1,738.61	4,664.14	6,493.94	561.55	1,107.34	3,646.52	419.29	56.38	145.68	174.92
2006	1,405.88	3,309.07	5,391.39	443.72	920.36	3,100.20	269.15	34.15	127.50	162.61
2007	3,084.75	5,789.34	9,537.32	993.80	1,394.93	5,353.65	487.38	45.56	227.67	246.91
2008	1,202.32	3,567.43	6,187.47	517.30	876.59	2,886.61	335.79	28.53	135.75	149.37
2009	1,312.32	2,783.66	4,740.72	431.83	838.93	2,490.97	296.47	47.74	191.20	144.79
2010	2,717.17	4,855.61	8,371.89	901.97	993.76	4,315.29	388.53	48.16	162.46	185.85
2011	492.04	1,657.29	2,412.28	196.77	525.87	1,330.31	130.42	16.94	74.98	59.92
2012	2,292.95	4,797.90	7,994.51	794.60	772.13	3,680.23	306.49	39.60	138.50	133.67

Table 14 : Minor Landuse Burned area distribution during 2003-2012 in lower north.

Landuse Type / Year	Burned Area (sq.km)									
	Evergreen Forest	Dry deciduous forest	Mixed deciduous forest	Other Forest	Paddy Fields	Field Crop	Other Agricultural	Grass	Other	Urban
2003	416.88	1,256.47	2,055.95	79.08	4,315.05	3,215.72	241.12	137.77	45.81	239.16
2004	1,386.02	1,835.91	4,436.02	149.17	5,977.45	5,097.42	375.86	160.75	100.24	340.24
2005	860.55	1,526.93	3,193.37	94.65	3,669.52	4,192.17	317.30	128.67	60.14	248.05
2006	377.17	889.36	2,015.89	69.12	3,349.11	2,799.37	222.51	105.54	41.56	178.12
2007	1,209.35	1,649.93	3,965.97	116.26	2,868.47	3,844.25	297.57	114.43	69.99	188.19
2008	420.24	1,074.08	2,392.91	42.31	1,885.49	2,839.41	217.64	70.40	30.86	142.89
2009	473.92	972.59	2,248.82	64.48	1,802.43	2,417.85	174.41	75.41	26.26	123.21
2010	855.12	1,149.74	3,179.98	64.76	1,740.63	2,979.98	203.60	92.09	50.58	137.58
2011	79.49	573.63	916.19	14.36	1,910.34	1,319.43	125.23	52.96	27.12	96.94
2012	525.70	1,066.93	2,662.32	45.25	1,776.75	2,370.53	167.12	69.80	27.35	119.41

Focusing on Spatial distribution of burning area divided by province boundary. The results of total forest area, burning area on forest and percentage from burning of total forest area show in figure 16 and table 15. Highest forest area found in Chiang Mai Province (17,528 sq.km) while the burning area and percentage of burning were found highest in Mae Hong Son Province (average burning area 3,224 sq.km or 28.32% of total forest area).Top five of the highest percent burned area found in Mae Hong Son Province (28.32%), Nan Province(26.09%), Chiang Rai Province(25.82%), Tak Province(20.68%) and the last is Lamphun Province(17.45%). Most of highest percentage of burned area on province that located in Upper North that has mostly forest area over 58% of the study area.

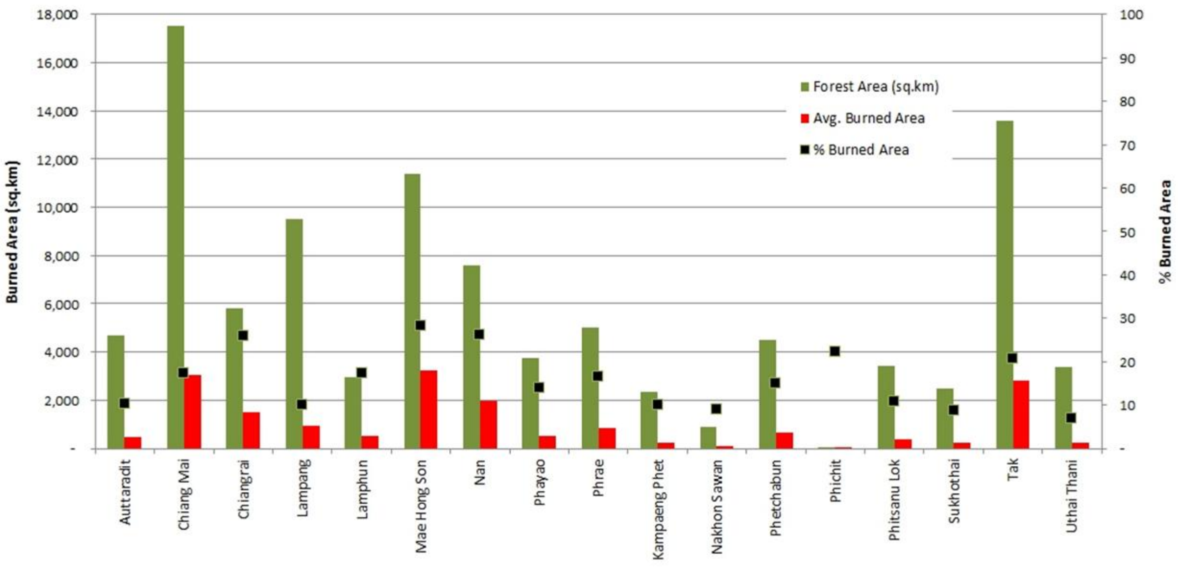


Figure 16 : Spatial patterns average burned area from 2003-2012 in forest area.

Table 15 : Burned area from 2003-2012 in forest area in 17 provinces Northern, Thailand.

Province Name	Forest Area (sq.km)	Burned Area (sq.km)											
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Avg.	%
Auttaradit	4,682.90	383.40	777.54	616.72	278.26	672.85	383.27	351.38	633.62	161.50	586.69	484.52	10.35
Chiang Mai	17,528.78	2,145.32	4,886.48	2,941.48	2,284.97	4,473.86	2,388.71	2,788.97	3,749.84	1,109.52	3,615.66	3,038.48	17.33
Chiangrai	5,801.07	1,062.85	2,149.10	1,410.46	1,398.03	2,241.03	975.67	1,517.37	1,832.04	648.10	1,741.24	1,497.59	25.82
Lampang	9,493.46	571.36	1,096.34	1,021.81	753.26	1,276.07	868.70	1,021.83	1,176.13	469.74	1,313.11	956.83	10.08
Lamphun	2,969.59	493.48	636.94	666.76	370.58	664.38	510.44	590.34	494.54	139.84	615.20	581.25	17.45
Mae Hong Son	11,387.73	2,878.45	5,325.97	3,226.84	2,780.01	4,726.21	3,185.53	1,463.22	3,936.72	1,136.37	3,585.81	3,224.51	28.32
Nan	7,574.34	1,526.26	2,470.39	2,152.39	1,621.04	3,276.25	1,743.72	772.14	3,108.05	603.08	2,484.42	1,975.77	26.09
Phayao	3,736.06	306.70	846.37	469.55	446.29	901.35	374.35	108.23	823.78	148.68	777.76	520.31	13.93
Phrae	5,005.24	379.43	971.59	952.24	617.62	1,173.21	1,044.13	655.05	1,091.93	296.39	1,046.44	822.80	16.44
Kampaeng Phet	2,332.40	178.73	483.28	232.20	169.63	359.18	107.78	236.92	306.35	112.48	150.60	233.71	10.02
Nakhon Sawan	896.76	65.56	253.59	92.57	62.97	100.71	46.11	74.02	45.36	32.90	40.18	81.40	9.08
Phetchabun	4,505.07	708.57	1,003.33	943.54	475.99	1,019.37	693.31	548.29	688.75	224.31	418.48	672.39	14.93
Phichit	12.77	4.69	5.78	1.09	6.05	1.13	3.32	0.96	0.91	1.65		2.84	22.26
Phitsanu Lok	3,441.92	450.28	543.59	517.02	326.61	609.51	313.12	301.70	360.74	77.65	228.57	372.88	10.83
Sukhothai	2,489.95	166.82	347.01	216.02	142.82	213.94	195.13	164.10	268.73	167.13	294.77	217.65	8.74
Tak	13,591.56	2,204.88	4,639.31	3,163.03	2,139.88	4,215.14	2,475.20	2,258.14	3,252.80	898.65	2,855.03	2,810.21	20.68
Uthai Thani	3,392.96	28.85	531.24	510.03	27.59	422.52	95.58	175.69	325.96	59.48	160.38	233.73	6.89

Spatial distribution of landuse area and burning area in agricultural area show in figure 17 and table 5. Highest agricultural area found in Nakhon Sawan Province (7.829 sq.km) while the burning area and percentage of burning were found highest in Nan Province (average burning area 1,640 sq.km) and Mae Hong Son Province around 40.84% of total agricultural area. Top five of the highest percent burned area found in Mae Hong Son Province (40.84%), Nan Province(39.74%), Tak Province(28.44%), Chiang Rai Province(22.45%) and the last province is Phrae Province(18.14%). The first-four highest percentage of burned area located in Upper North that have upland crop such as Maize, soybean and upland rice. These areas locate in complex and steep slope so that why farmer need to burned crop residue for remove from the area. In contrast with lower part, the results show highest agricultural area but low value of burning area because this area locate in flat area and plough up and over rice straw to the land.

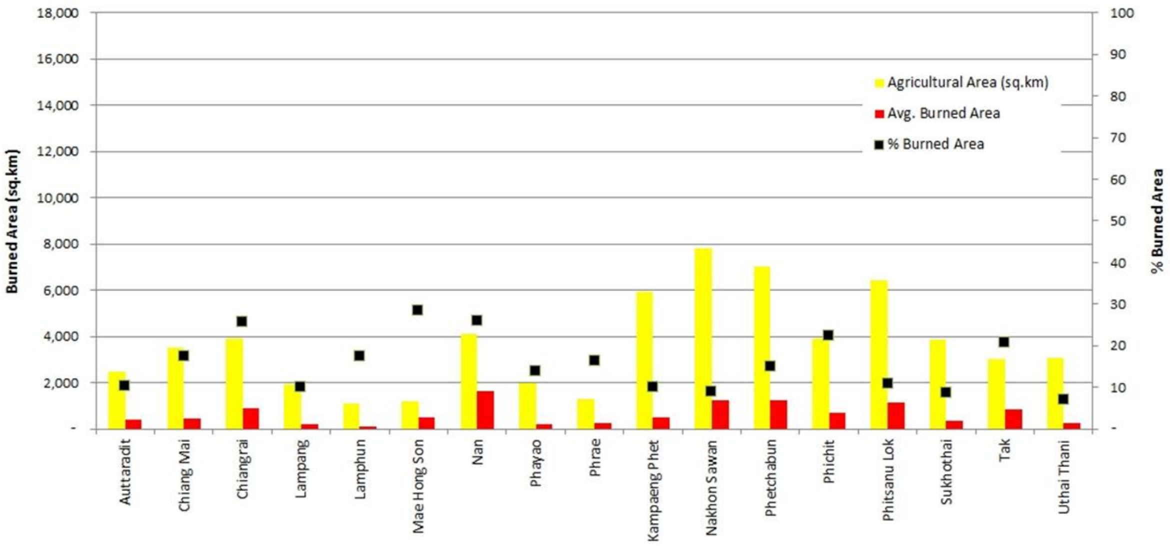


Figure 17 : Spatial patterns average burned area from 2003-2012 in Agricultural Area.

Table 16 : Burned area from 2003-2012 in agricultural area in 17 provinces Northern, Thailand.

Province Name	Agricultural Area (sq.km)	Burned Area (sq.km)											
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Avg.	%
Auttaradit	2,485.63	463.19	596.45	438.00	406.82	424.59	332.77	273.49	359.98	191.25	344.48	383.10	15.41
Chiang Mai	3,514.88	391.73	719.31	459.87	353.59	649.13	386.46	449.58	544.55	175.88	511.67	464.18	13.21
Chiangrai	3,897.78	628.19	1,282.39	966.41	826.42	1,516.25	588.44	824.93	940.34	418.49	759.71	875.16	22.45
Lampang	1,939.47	125.82	250.02	201.71	159.66	307.09	181.95	220.18	248.59	112.42	258.55	206.60	10.65
Lamphun	1,089.31	129.13	137.48	132.05	91.91	183.17	85.63	93.55	122.72	42.88	88.80	110.73	10.17
Mae Hong Son	1,208.80	475.07	754.73	472.65	421.57	648.21	528.48	378.06	516.13	185.89	555.42	493.62	40.84
Nan	4,127.61	1,493.28	2,079.71	1,806.25	1,443.50	2,613.37	1,470.43	885.69	2,280.33	594.04	1,738.07	1,640.47	39.74
Phayao	1,964.89	127.01	348.21	260.26	229.90	325.92	162.74	175.55	289.54	93.16	200.41	221.27	11.26
Phrae	1,295.10	137.22	320.05	271.67	202.93	361.56	266.27	242.74	292.53	58.61	195.10	234.87	18.14
Kampaeng Phet	5,938.40	646.49	990.65	648.16	451.29	450.18	390.92	426.40	361.97	284.98	398.66	504.97	8.50
Nakhon Sawan	7,829.77	1,782.42	2,572.89	1,611.51	1,473.53	1,116.32	682.28	799.63	779.99	1,025.24	653.76	1,249.76	15.96
Phetchabun	7,014.81	1,488.74	2,260.44	1,586.30	1,360.63	1,405.38	1,106.55	831.64	883.54	673.52	648.20	1,224.49	17.46
Phichit	3,906.23	1,043.07	1,267.20	838.29	797.79	741.24	525.24	401.20	346.20	400.07	378.44	673.87	17.25
Phitsanu Lok	6,438.88	1,404.48	1,802.97	1,659.68	1,167.25	1,479.20	1,045.14	814.38	967.23	267.98	774.07	1,138.24	17.68
Sukhothai	3,873.45	311.95	716.71	424.77	232.14	362.26	259.64	273.49	355.76	206.71	342.09	348.55	9.00
Tak	3,026.83	828.32	1,370.38	976.47	773.04	1,156.64	774.46	607.96	1,043.74	291.00	786.37	860.84	28.44
Uthai Thani	3,075.09	261.87	449.88	429.89	110.47	288.86	152.68	234.97	180.50	192.09	272.20	257.34	8.37

2 . Ground-Truth Data

The ground check has been confirms burning location was derived from MODIS on December 2012 in study domain (figure 18). Total 68 point was checked and confirms burned area has been locate on agricultural area such as paddy area , field crop such as upland rice and sugar cane that show in figure 19. False alarm from MODIS was not found in this checked.

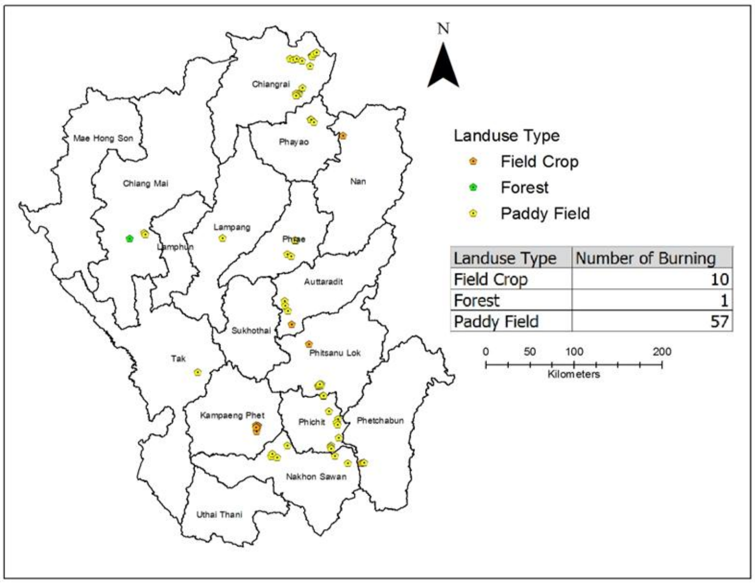


Figure 18 : Show ground checked 68 points burned location with hotspots were derived from MODIS.

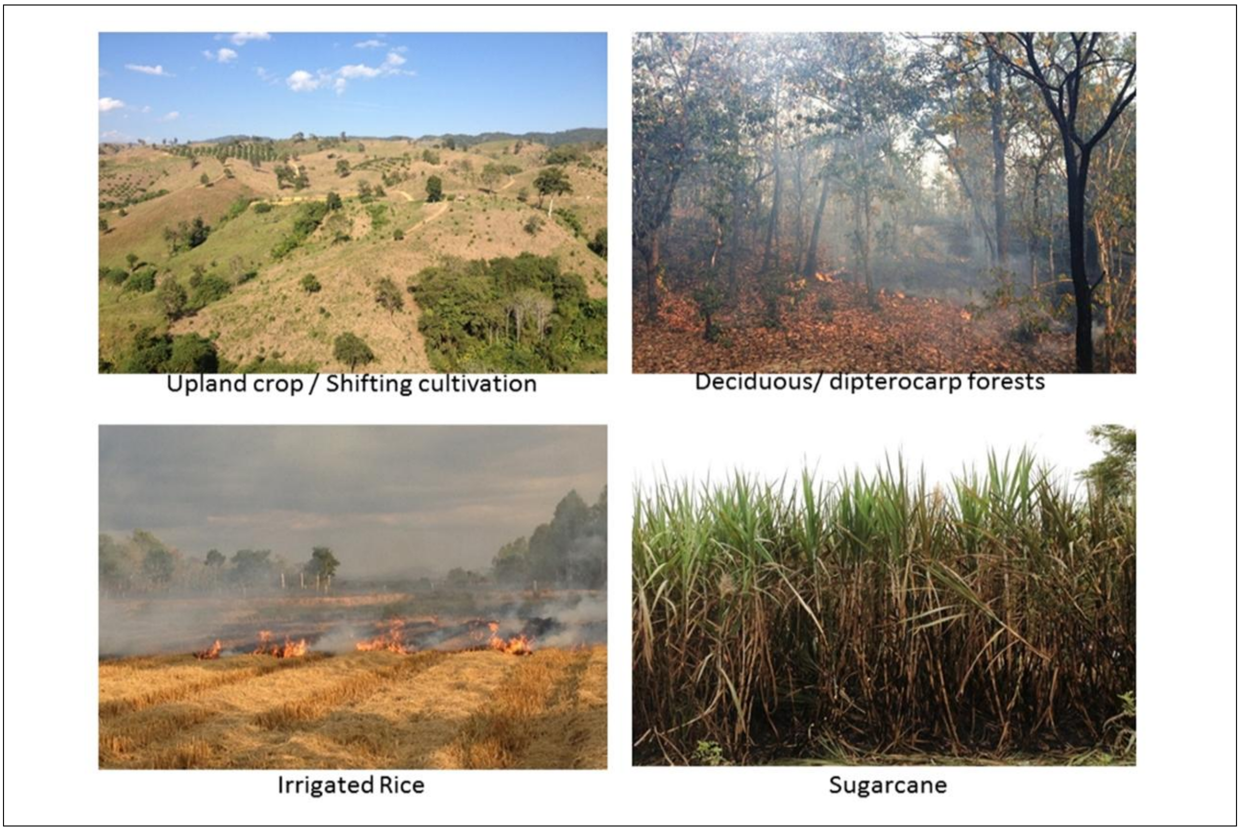


Figure 19 : Show traditional burning by farmer in Northern, Thailand.

3. Estimate total emission of gaseous

According to Eq.1 the emissions of pollutant CO, SO2, NO2, NOx and PM10 from biomass burning during 2003 – 2012 was computed for emission rate. The spatial and temporal maps of pollutants for CO, SO2, NO2, NOx and PM10 show in figure 20-24 respectively. The amount of total pollutants emitted in Northern Thailand in 10 year during 2003 to 2012 approximately 7.736 million tons of CO, 26,955 tons of SO2, 397,866 tons of NO2, 657,776 tons of NOx and 187,048 tons of PM10. Mostly pollutants emitted from forest area.

The highest average CO emission rate in 10 years (table 17) was found in Mixed deciduous forest (479,305 tons) and highest value found in year 2004 (706,608 tons) and lower CO emission rate found in paddy field in 2012.

For SO2, the highest average SO2 emission rate in 10 years (table 18) was found in Mixed deciduous forest (1.626 tons) and highest value found in year 2004 (2,397 tons) in Mixed deciduous forest also and lower SO2 emission rate found in paddy field in 2011 (46.09 tons).

The highest average of NO2 emission rate in 10 years (table 19) was found in Mixed deciduous forest (23,580 tons) and highest value found in year 2004 (34,763 tons) in Mixed deciduous forest also and lower NO2 emission rate found in grass land in 2011 (0.56 tons). In the similar pattern of NO2, the highest average of NOx emission rate in 10 years (table 20) was found in Mixed deciduous forest (38,882 tons) and highest value found in year 2004 (57,322 tons) in Mixed deciduous forest also and lower NOx emission rate found in grass land in 2011 (10.49 tons).

For particulate matter (PM10), the highest average PM10 emission rate in 10 years (table 21) was found in Mixed deciduous forest (11,236 tons) and highest value found in year 2004 (16,564 tons) in Mixed deciduous forest also and lower PM10 emission rate found in paddy field in 2011 (73.96 tons).

From the results, it's show the high value of spatial distribution of emission rate on Mixed deciduous forest every year because it's was a highest burning area and the emission rate from forest area was higher than agricultural area because in the fuel load in kilogram dry matter per sq.km was higher more than 10 times.

Table 17: Emission rate of CO in Northern Thailand 2003-2012 on Landuse Type

Landuse Type	Emission Rate CO (ton/Year)										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Evergreen Forest	29,524.90	85,096.02	45,246.81	31,039.87	74,752.72	28,245.88	31,095.43	62,187.36	9,949.46	49,067.82	44,620.63
Dry deciduous forest	211,559.74	353,547.79	295,170.78	200,167.61	354,680.86	221,292.59	179,086.59	286,316.46	106,363.28	279,616.54	248,780.22
Mixed deciduous forest	357,671.93	706,608.33	503,756.36	385,191.14	702,193.69	446,194.21	363,467.74	600,716.40	173,085.74	554,172.88	479,305.84
Paddy Fields	156.93	224.34	145.03	129.62	129.44	83.86	80.19	83.02	73.96	77.38	118.38
Field Crop	442.93	713.03	564.39	424.77	662.25	412.27	353.43	525.26	190.78	435.66	472.48
Grass	451.35	552.28	462.86	349.40	400.17	247.46	308.04	350.79	174.81	273.62	357.08

Table 18: Emission rate of SO2 in Northern Thailand 2003-2012 on Landuse Type

Landuse Type	Emission Rate SO2 (ton/Year)										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Evergreen Forest	100.18	288.73	153.52	105.32	253.63	95.84	105.51	211.00	33.76	166.49	151.40
Dry deciduous forest	717.82	1,199.58	1,001.50	679.16	1,203.42	750.84	607.63	971.46	360.89	948.73	844.10
Mixed deciduous forest	1,213.57	2,397.50	1,709.23	1,306.94	2,382.52	1,513.92	1,233.23	2,038.21	587.27	1,880.29	1,626.27
Paddy Fields	97.80	139.81	90.38	80.78	80.66	52.26	49.97	51.73	46.09	48.22	73.77
Field Crop	-	-	-	-	-	-	-	-	-	-	-
Grass	-	-	-	-	-	-	-	-	-	-	-

Table 19 : Emission rate of NO2 in Northern Thailand 2003-2012 on Landuse Type

Landuse Type	Emission Rate NO2 (ton/Year)										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Evergreen Forest	1,452.57	4,186.56	2,226.05	1,527.10	3,677.69	1,389.64	1,529.83	3,059.50	489.49	2,414.04	2,195.25
Dry deciduous forest	10,408.32	17,393.85	14,521.82	9,847.85	17,449.60	10,887.16	8,810.71	14,086.20	5,232.86	13,756.58	12,239.50
Mixed deciduous forest	17,596.75	34,763.74	24,783.82	18,950.64	34,546.54	21,951.87	17,881.90	29,554.06	8,515.48	27,264.21	23,580.90
Paddy Fields	418.48	598.25	386.73	345.66	345.16	223.62	213.84	221.38	197.24	206.36	315.67
Field Crop	1,363.25	2,194.53	1,737.05	1,307.34	2,038.25	1,268.89	1,087.79	1,616.63	587.18	1,340.85	1,454.18
Grass	1.46	1.78	1.50	1.13	1.29	0.80	1.00	1.13	0.56	0.88	1.15

Table 20: Emission rate of NOx in Northern Thailand 2003-2012 on Landuse Type

Landuse Type	Emission Rate NOx (ton/Year)										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Evergreen Forest	2,395.14	6,903.22	3,670.55	2,518.04	6,064.15	2,291.38	2,522.55	5,044.81	807.13	3,980.52	3,619.75
Dry deciduous forest	17,162.31	28,680.77	23,945.07	16,238.15	28,772.69	17,951.87	14,528.00	23,226.78	8,628.48	22,683.27	20,181.74
Mixed deciduous forest	29,015.34	57,322.02	40,866.11	31,247.77	56,963.89	36,196.51	29,485.51	48,731.77	14,041.19	44,956.04	38,882.61
Paddy Fields	627.71	897.38	580.10	518.48	517.75	335.43	320.77	332.06	295.85	309.54	473.51
Field Crop	2,436.14	3,921.64	3,104.12	2,336.23	3,642.37	2,267.50	1,943.89	2,888.93	1,049.30	2,396.10	2,598.62
Grass	27.08	33.14	27.77	20.96	24.01	14.85	18.48	21.05	10.49	16.42	21.42

Table 21: Emission rate of PM10 in Northern Thailand 2003-2012 on Landuse Type

Landuse Type	Emission Rate PM10 (ton/Year)										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Evergreen Forest	692.13	1,994.85	1,060.69	727.65	1,752.38	662.15	728.95	1,457.82	233.24	1,150.26	1,046.01
Dry deciduous forest	4,959.45	8,287.98	6,919.49	4,692.39	8,314.54	5,187.61	4,198.20	6,711.92	2,493.40	6,554.86	5,831.99
Mixed deciduous forest	8,384.66	16,564.54	11,809.22	9,029.77	16,461.05	10,459.83	8,520.53	14,082.19	4,057.53	12,991.10	11,236.04
Paddy Fields	156.93	224.34	145.03	129.62	129.44	83.86	80.19	83.02	73.96	77.38	118.38
Field Crop	442.93	713.03	564.39	424.77	662.25	412.27	353.43	525.26	190.78	435.66	472.48
Grass	-	-	-	-	-	-	-	-	-	-	-

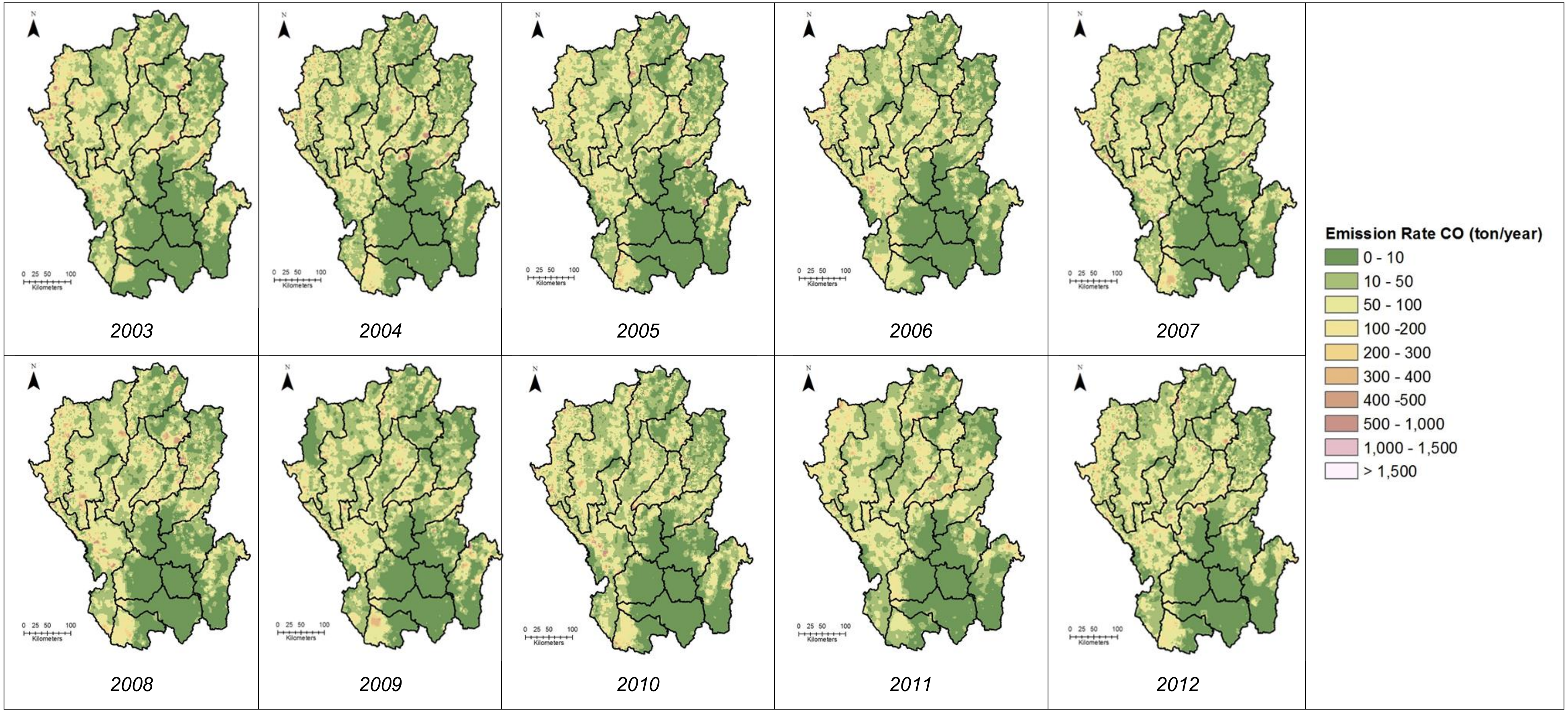


Figure 20: Maps of CO emission rate in year 2003-2012

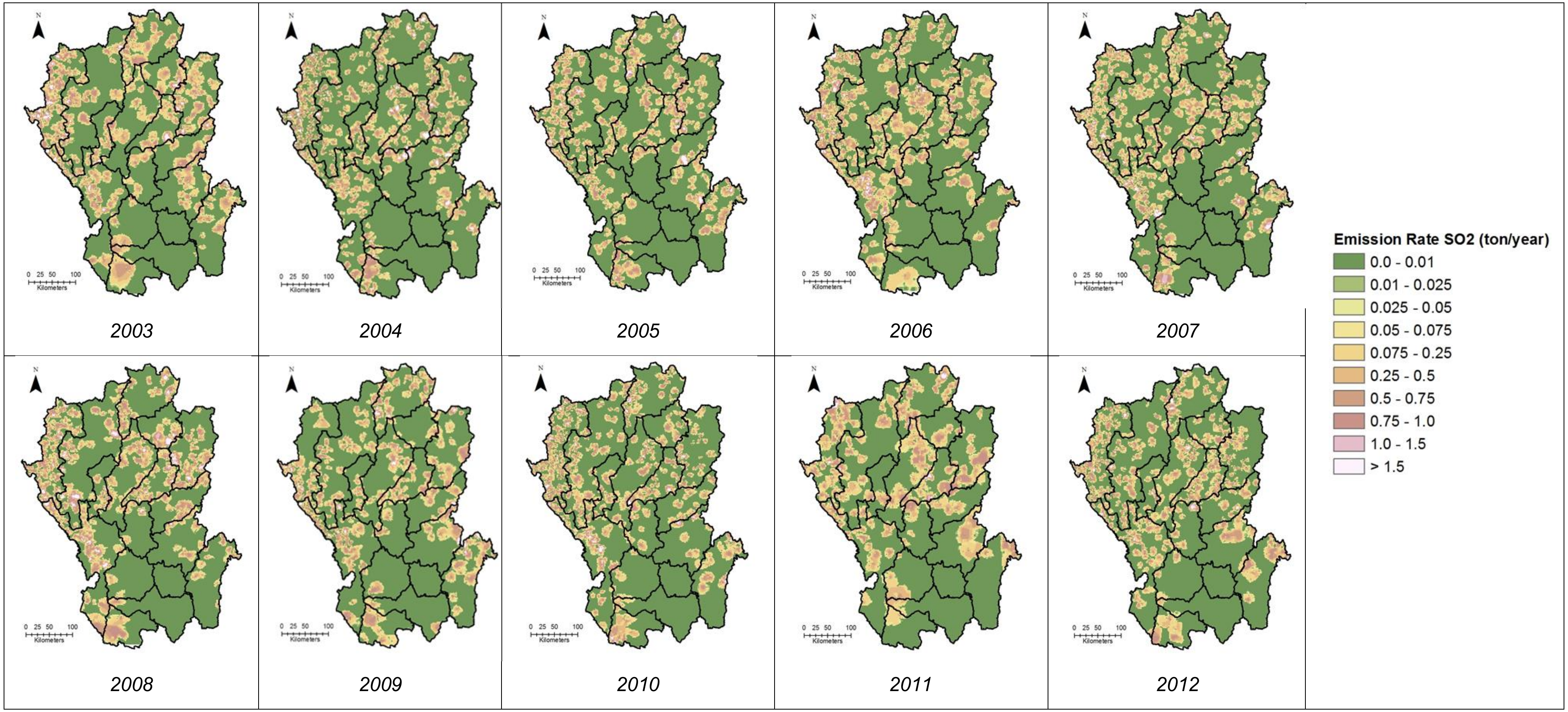


Figure 21: Maps of SO2 emission rate in year 2003-2012