



รายงานวิจัยฉบับสมบูรณ์

โครงการ การปรับปรุงการประเมินมลพิษจากไฟฟ้าในพื้นที่
อนุภาคลุ่มน้ำโขงโดยการใช้ข้อมูลดาวเทียมความละเอียดสูง
ร่วมกับการยืนยันข้อมูลเชิงพื้นที่เพื่อสนับสนุนแบบจำลอง
คุณภาพอากาศและการจัดการคุณภาพอากาศ

โดย ดร. เอกพล จันทร์เพ็ญ

กันยายน 2561

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บัณฑิตวิทยาลัยร่วมด้านพลังงานและสิ่งแวดล้อม
มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัยและ
ต้นสังกัด

(ความเห็นในรายงานนี้เป็นของผู้วิจัย
สกว.และต้นสังกัดไม่จำเป็นต้องเห็นด้วยเสมอไป)

Abstract

Project Code : TRG 6080012

Project Title : Improving the estimation of forest fire emissions in the Greater Mekong Sub-region using high resolution satellite products and ground truthing corrective factors to support air quality modeling and management

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Project Period : 18 months

Abstract :

The purpose of this research was to improve the evaluation of air pollution from biomass open burning (wildfires and agricultural fires) in the Greater Mekong Sub-region (consisting of Myanmar, Thailand, Laos, Cambodia, and Vietnam), which is considered to be a wildfire-prone area, particularly in the dry season from December to April of the following year. The scope of improvement encompassed the evaluation of areas damaged from wildfires, which were previously obtained from MCD64A1 monthly gridded 500-meter product of MODIS with medium resolution of 500 m. Concerning the fact that the evaluation of areas damaged from wildfires and crop burning entails the use of burned area data with higher resolution in order to improve the results, this research obtained burned area data (reference fires) from LANDSAT-8 with the resolution of 30 meter. The obtained results were subsequently used to evaluate the actual amount of burned biomass and the amount of air pollution emitted from wildfires and agricultural fires in the Greater Mekong Sub-region (GMS) from 2010 to 2017. In addition, the obtained results were compared with the data derived from the fourth version of Global Fire Emissions Database (GFEDv4) in 2015. The GFEDv4 was used as an emission database to input data concerning the biomass open burning emissions into the air quality model. Based on the

data from MCD64A1, there were approximately 81.403 million hectares (Mha) of burned areas during 2010 to 2017. These areas consisted of croplands (16.410 Mha), deciduous forests (0.340 Mha), evergreen forests (16.679 Mha), mixed forests (4.388 Mha), grasslands (0.562 Mha), savannas (41.986 Mha), shrublands (0.017 Mha), and wetlands (1.022 Mha). The country with the highest number of burned areas was Myanmar (32.684 Mha), followed by Cambodia (22.985 Mha) and Thailand (10.883 Mha). The comparison between the burned area data of MCD64A1 and LANDSAT-8 during 2014 to 2016 in the northern region of Thailand suggested that the total burned area from MCD64A1 was approximately 0.35 times lower than the total burned area from LANDSAT-8. Accordingly, the burned area data obtained from MCD64A1 should be multiplied by a constant, 2.89, to determine the actual number of the total area burned. In the case of categorizing the type of fires occurred in each area, specifically savanna fires, forest fires, and agricultural fires, the data should be multiplied by a constant, 2.11, 3.33, and 5.21, respectively. After applying the adjusted coefficients to the obtained data, it was found that there were 247.614 Mha of total area burned in the GMS during 2010 to 2017. These areas were composed of croplands (85.496 Mha), deciduous forests (1.132 Mha), evergreen forests (55.540 Mha), mixed forests (14.612 Mha), grasslands (1.187 Mha), savannas (88.591 Mha), shrublands (0.035 Mha), and wetlands (1.022 Mha). Moreover, it was found that the total area burned contributed to 1,762.170 million tons (Mt) of biomass burned, categorized into croplands (532.210 Mt), deciduous forests (6.547 Mt), evergreen forests (321.301 Mt), mixed forests (409.721 Mt), grasslands (5.094 Mt), savannas (478.036 Mt), shrublands (0.222 Mt), and wetlands (9.039 Mt). Biomass open burning led to the emission of significant air pollutants, comprising 2,736,136 kt of CO₂, 7,165 kt of CH₄, 281 kt of N₂O, 143,462 kt of CO, 5,335 kt of NO_x, 715 kt of SO₂, 2,191 kt of NH₃, 12,584 kt of PM_{2.5}, 18,737 kt of TPM, 898 kt of BC, and 5,363 kt of OC.

Keywords: biomass open burning, wildfire, agricultural burning, air pollutant, remote sensing, MCD64A1, MCD45A1, GFED, MODIS

Research Content

1. Objective and Scopes

1. To improve biomass open burning emission estimation, especially emissions from small fires in the Greater Mekong Sub-region.
2. To identify the corrective factors to apply for adjusting the burned area from MODIS monthly burned area product (MCD64A1 and MCD45A1).
3. To establish the Greater Mekong Sub-region biomass open burning emission maps supporting air quality modelling and management.

2. Method and Material

2.1 Assessment of Emissions from Biomass Open Burning

The emissions from biomass open burning can be estimated using the equation developed by Seiler, W. and Crutzen, P. J. (1980) [1], which represents the relationship between the combustion process and its emission, as follows:

$$E_i = M \times EF_i \times 10^{-6} \quad (1)$$

Where E_i is the emission of the air pollutant i (kt); M is the mass of dry matter burned (t of dry matter); and EF_i the emission factor of the air pollutant i (g/kg of dry matter burned). The amount of biomass burned is determined using the modified version of the equation provided in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories [2]. The equation can be expressed as follows:

$$M = BA \times BL \times \alpha \quad (2)$$

Where BA is the burned area (ha) while BL is the biomass load (t of dry matter per ha); and α is the fraction of the mass combusted by fire, also known as the burning efficiency (unitless).

Recently, various studies reported the emission factors of biomass burning measured in laboratory or field measurements, often varied widely in different experiments based on the compilation of Akagi et al., 2011 [3], as summarized in Table 1.

Table 1. Value of emission factors in each trace gas.

Species	Emission factors classified by types of biomass (g Specie per kg Dry Matter burned)							
	Crop-lands	Deciduous Forest	Evergreen Forest	Mixed Forests	Grass-lands	Savannas	Shrub-lands	Wetland
CO ₂	1,585	1,643	1,643	1,643	1,683	1,683	1,683	1,703
CO	102	93	93	93	63	63	63	210
CH ₄	5.82	5.07	5.07	5.07	1.94	1.94	1.94	20.8
NO _x	3.11	2.55	2.55	2.55	3.9	3.9	3.9	1
N ₂ O	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
PM _{2.5}	6.3	9.1	9.1	9.1	7.2	7.2	7.2	9.1
TPM	12.4	13	13	13	8.5	8.5	8.5	13
OC	2.3	4.71	4.71	4.71	2.62	2.62	2.62	6.02
BC	0.75	0.52	0.52	0.52	0.37	0.37	0.37	0.04
SO ₂	0.4	0.4	0.4	0.4	0.48	0.48	0.48	0.4
NH ₃	2.17	1.33	1.33	1.33	0.52	0.52	0.52	1.33

2.2 Land Cover Mapping

In this study, we categorize the burned area derived from MODIS burned area product and the reference fires by overlaying the all of burned area with land-cover map of MODIS-based Global Land Cover (MDC 12Q1) [4]. Figure 1 showed the MODIS land cover product (MCD12Q1). This image represents the land cover-types for the GMS in 2015. We reorganize the vegetation types of MCD12Q1 following the Global Fire Emission Database (GFED). The predominant yellow color represents *croplands*. Varying shades of green portray *evergreen forests* and light green portray *deciduous forests*. Medium green shades are areas of *savannas* and Orange shades are areas of *shrublands* while light orange shades presents *grasslands*. Brown represents other lands as *urban and built-up*. Table 2 and Figure 2 show the results of total area categorized by land cover types in the Greater Mekong Sub-region.

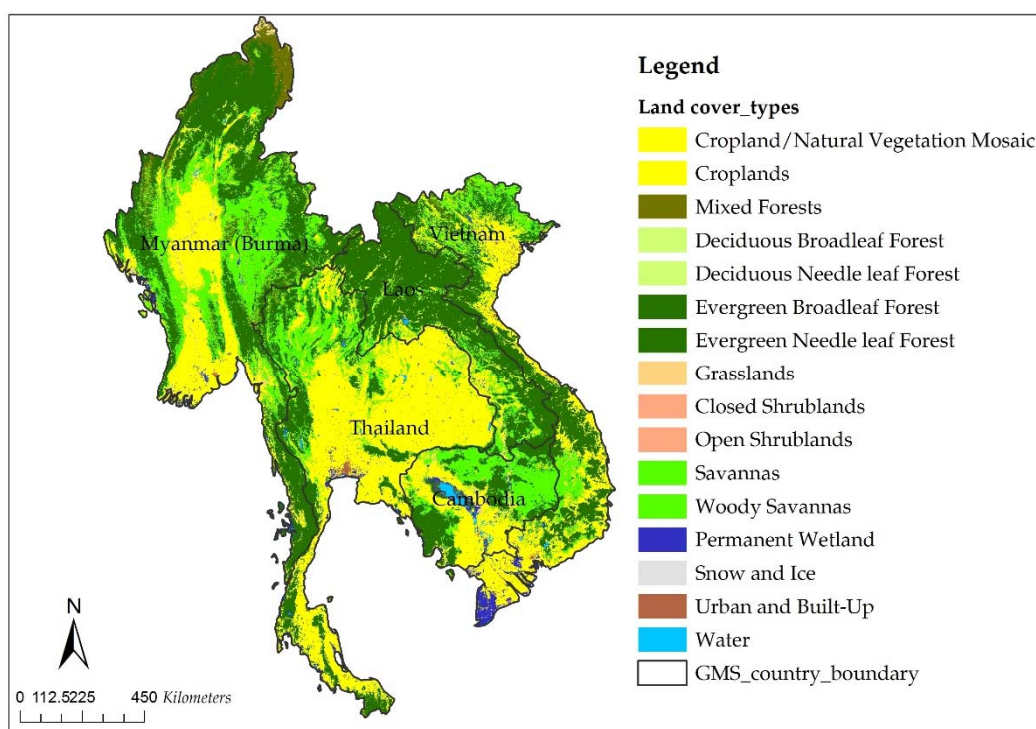


Figure 1. The Moderate Resolution Imaging Spectroradiometer (MODIS) land cover product (MCD12Q1). The predominant yellow color represents *croplands*. Varying shades of green portray *evergreen forests* and light green portray *deciduous forests*. Medium green shades are areas of *savannas* and Orange shades are areas of *shrublands* while light orange shades presents *grasslands*. Brown represents other lands as *urban and built-up*.

Table 2. The total of area categorized by land cover types in the Greater Mekong Sub-region.

Land cover types	The total of area categorized by land cover types in each country (1,000 ha)					
	Myanmar	Cambodia	Laos	Thailand	Vietnam	Grand Total
Croplands	15,527	5,977	2,559	31,582	12,605	68,249
Deciduous Forest	184	16	9	23	33	264
Evergreen Forest	27,271	5,229	17,512	9,885	12,068	71,966
Mixed Forests	4,652	150	43	342	351	5,538
Grasslands	668	308	152	213	179	1,521
Savannas	17,038	5,531	2,678	7,587	5,459	38,292
Shrublands	72	9	13	12	52	159
Wetland	787	565	87	846	1,476	3,761

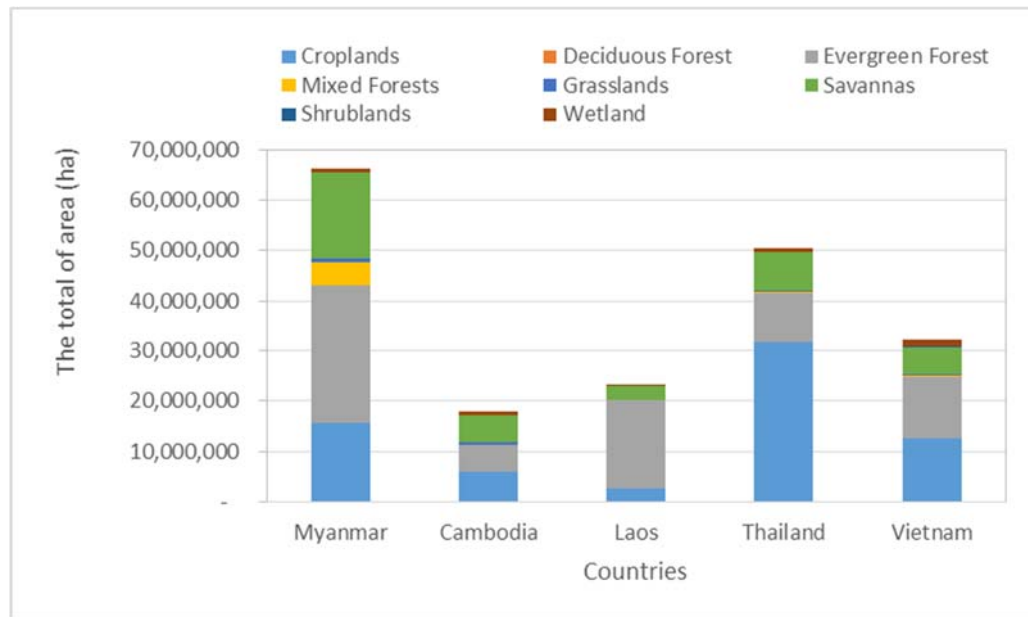


Figure 2. The total of area categorized by land cover types in in the Greater Mekong Sub-region.

2.3 The Modis Burned Area Product (Mcd45a1)

MCD45 are identified by an alphanumeric code of three letters and two numbers; the burned area product is MCD45. MCD indicates that MODIS on board both Aqua and Terra satellite provide input data and 45 indicates the burned area product [5]. There are three different versions of the MODIS burned area product: the official MCD45A1 in MODIS Hierarchical Data Format, NASA Earth Observation System (HDF-EOS), and the Geotiff and Shapefile version. In our study we used the Geotiff version of the MCD45 monthly product, derived from standard MCD45A1 HDF version. The version shows a set of sub-continental windows, which are re-projected in the Plate Carree projection, and was developed by the University of Maryland Information for Resource Management System for the global detection of fires. (Available at <http://modis-fire.umd.edu/>). The algorithm of the product uses a bi-directional reflectance (BRDF) model based on a change detection approach; removes all MODIS band 6 (Mid-Infrared, 1550-1750 nm) multi-temporal tests, which cause omission errors on land surface with temperatures greater than 327.7K. It was used over certain forest and agricultural land and detects the burning per pixel by daily (range 1-366) gridded MODIS at 500 m x 500 m spatial resolution land surface reflectance time series. It detects the approximate date of burning by locating the occurrence of rapid changes on MODIS aboard Terra and aboard Aqua

satellites. This algorithm provides an analysis of the MODIS land surface reflectance bands' abilities to discriminate between daily temporal burned and unburned biomass on land surface.

2.4 The Modis Burned Area Product (Mcd64a1)

MODIS Collection 5.1 Direct Broadcast Monthly Burned Area Product (MCD64A1) is an alternative burned area product which based on an automatic method using 500 m MODIS imagery and 1 km MODIS active fire observations [6]. The algorithm relates on a hybrid approach in several steps to create the mapping of the post-fire burned areas. It builds time series of valid daily band 1, 5 and 7 reflectance for each pixel. A daily burn vegetation index (VI) were estimated using the following equation Eq.3

$$VI = \frac{(B_5 - B_7)}{(B_5 + B_7)} \quad (3)$$

The daily VI data time series is analyzed in two-time spans (10 days before and 10 days after). It calculates descriptive statistics and define a measure of temporal separability and yielding composites images of these parameters. This product covers five layers in a sinusoidal projection as follow: the burn date, the burn date uncertainty, the quality assurance, and first day and last day. The monthly maps were shown in term of a pixel size of 500 m × 500 m and combined to generate the annual maps of burned/non-burned pixels. (Available online; [FTP://ba1.geog.umd.edu/](ftp://ba1.geog.umd.edu/).)

2.5 The Identification of Burned Area

In this study, we analyze the burned area from biomass open burning over the 10 provinces of Northern part of Thailand derived from the MODIS burned area product MCD45A1 and MCD64A1 during 2014-2016. The MCD64A1 and MCD45A1 monthly gridded 500-meter product were downloaded from Land Processes Distributed Active Archive Center which available online at <ftp://fuoco.geog.umd.edu/db/MCD64A1/> and used to generate monthly burned area maps during 2014 - 2016. Figure 3 and 4 show the clasifcation of vegetation fire by using the overlaying between the MODIS burned area product and the land cover map.

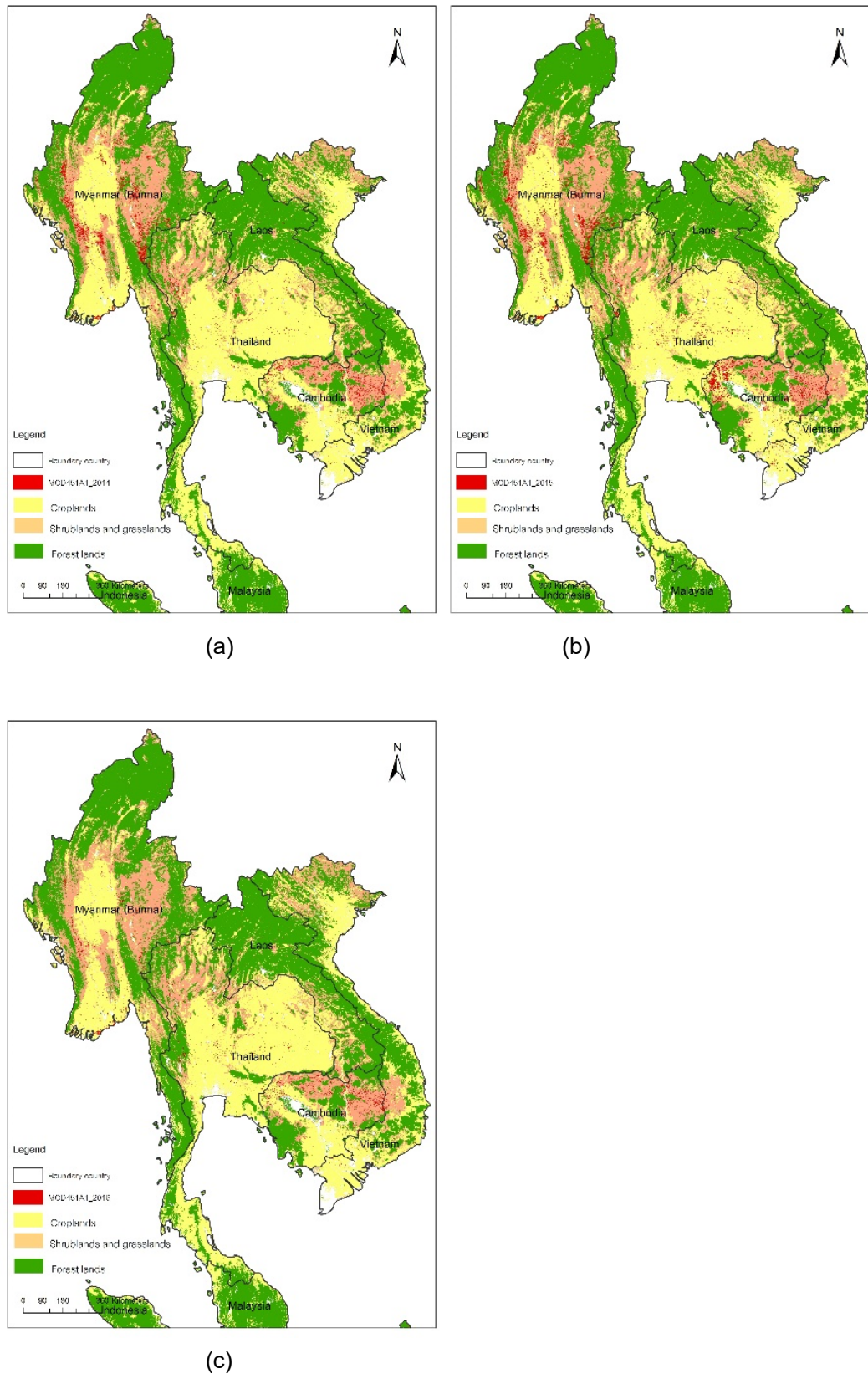


Figure 3. The MCD45A1 burned area product overlay with land cover map in the year a) 2014, b) 2015, and c) 2016.

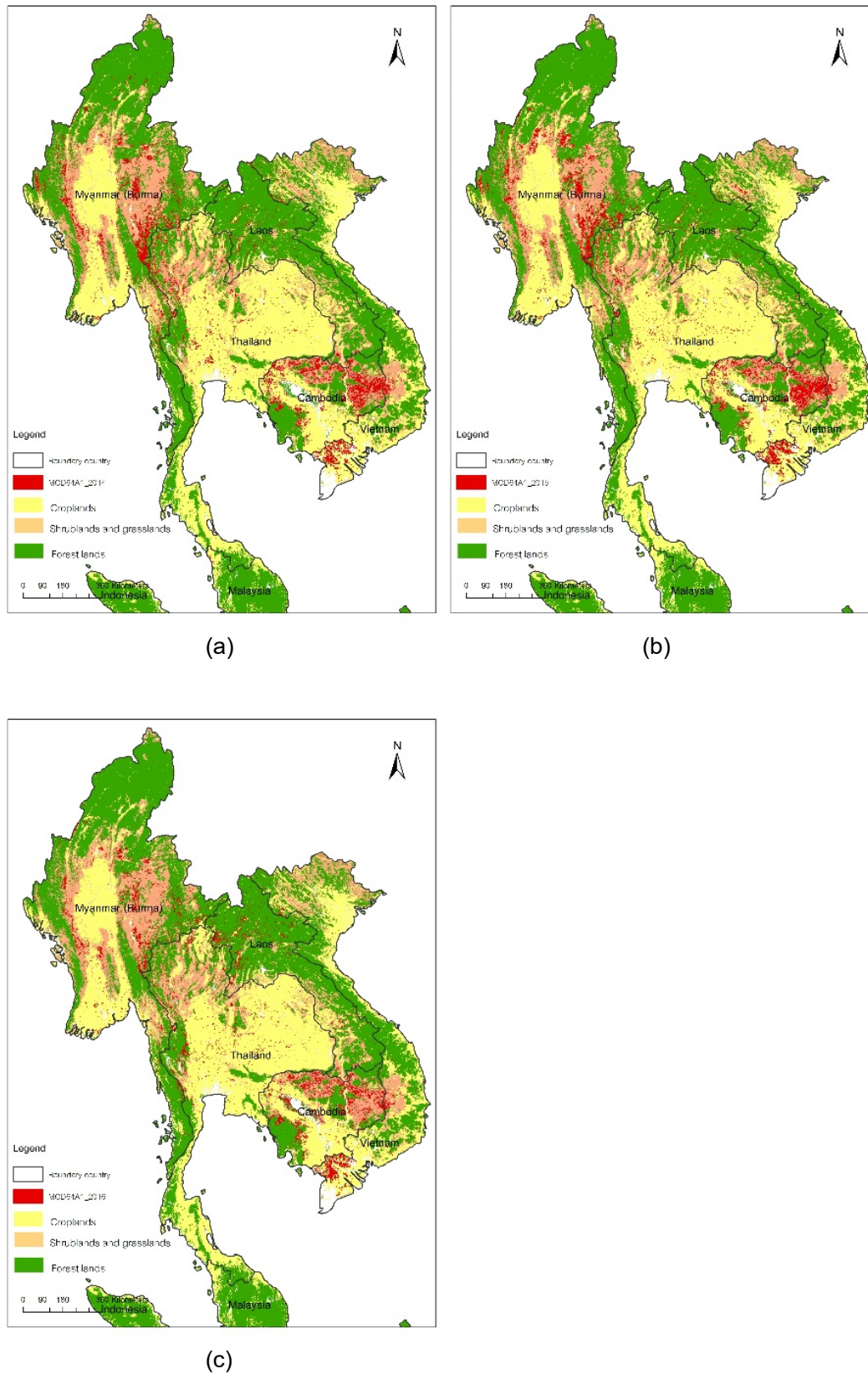


Figure 4. The MCD64A1 burned area product overlay with land cover map in the year a) 2014, b) 2015, and c) 2016.

2.6 The Reference Fires

In this study, we create the reference fires which occurred in the Northern part of Thailand during 2014-2016. The burn scars (reference fires) were created by using high spatial resolution, LANDSAT (OLI/TIRS surface reflectance data products through Earth-Explorer (<http://earthexplorer.usgs.gov>) [7]. LANDSAT imagery are available for acquisition free download from 2013 to present, using the Earth-Explorer tools to select scenes. Reference fires focused on the forest fires occurring in the Northern part of Thailand. The satellite imagery technique involved an analysis of pre-fire and post-fire selected conditions represented equations as Differenced Normalized Burn Ratio (ΔNBR) were derived from Howard et al. (2002) [8] to interpret the polygon of burn scars. The equation is provided in formula:

$$\Delta NBR = (NBR_{pre} - NBR_{post}) \times 1,000 \quad (4)$$

$$NBR_{pre} = (NIR - MIR)/(NIR + MIR) \quad (5)$$

$$NBR_{post} = (NIR - MIR)/(NIR + MIR) \quad (6)$$

Where ΔNBR is a differenced normalized burn ratio. NBR_{pre} is a normalized burn ratio of pre-burn image, NBR_{post} is a normalized burn ratio of post-burn image. NIR is the reflectance of near-infrared and MIR is the reflectance of mid-infrared. Next, the polygon of burn scars classified the fire types by overlaying the polygon of burn scars on the land cover map. In particular, the researchers used the polygon of burn scars occurring in the forestland. For pre-burn, this study selected one period to capture images before the forest fire occurrence on January, 2015 and after burned on February 2015. Figure 5 presented that the pre-fire image (left) is a Landsat 8 images (MIR, NIR, GREEN) acquired on November 24, 2014. b) The post-fire image (right) is a dark purple color Landsat 8 image (MIR, NIR, GREEN) acquired on March 16, 2015.

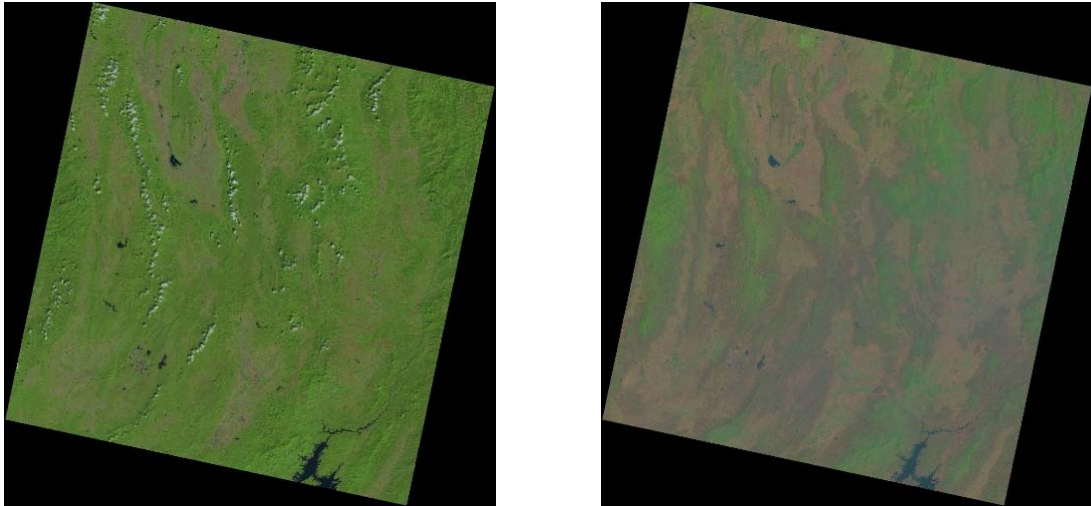
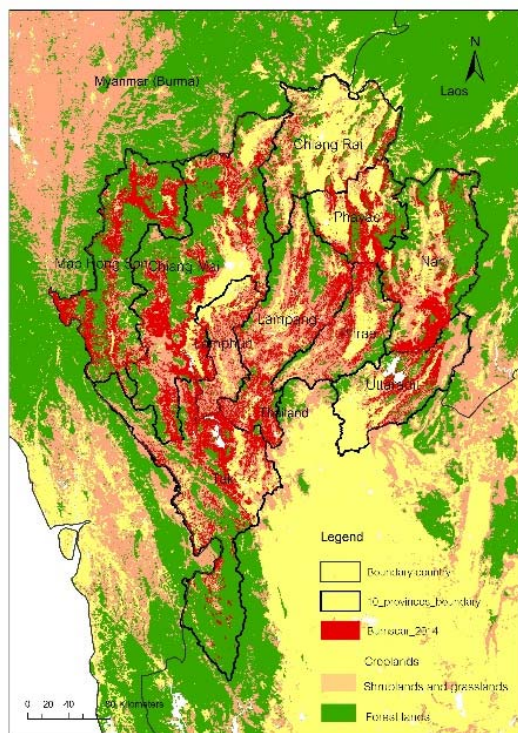
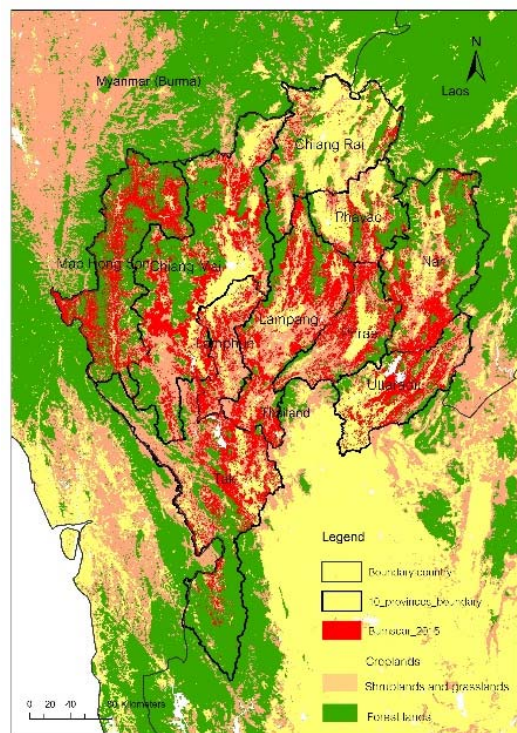


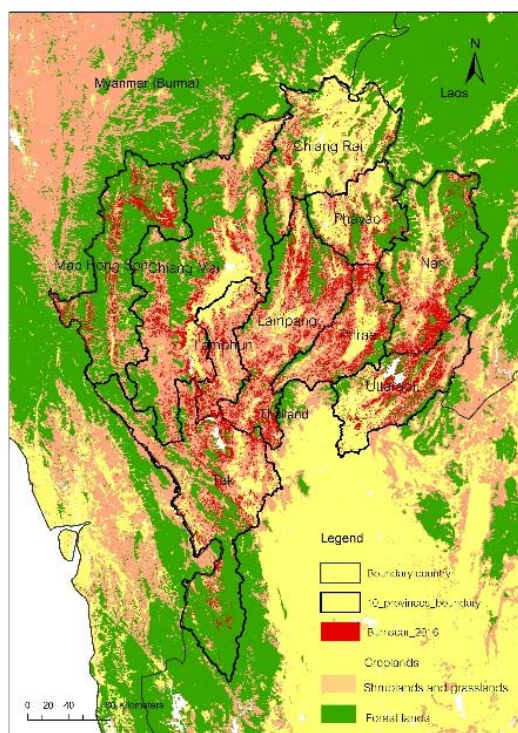
Figure 5. a) The pre-fire image (left) is a Landsat 8 image (MIR, NIR, GREEN) acquired on November 24, 2015. b) The post-fire image (right) is a dark purple color Landsat 8 image (MIR, NIR, GREEN) acquired on March 16, 2015.



(a)



(b)



(c)

Figure 6. The burn scars (reference fires) occurred in the Northern part of Thailand during a) 2014, b) 2015, and c) 2016 overlay with the land cover map.

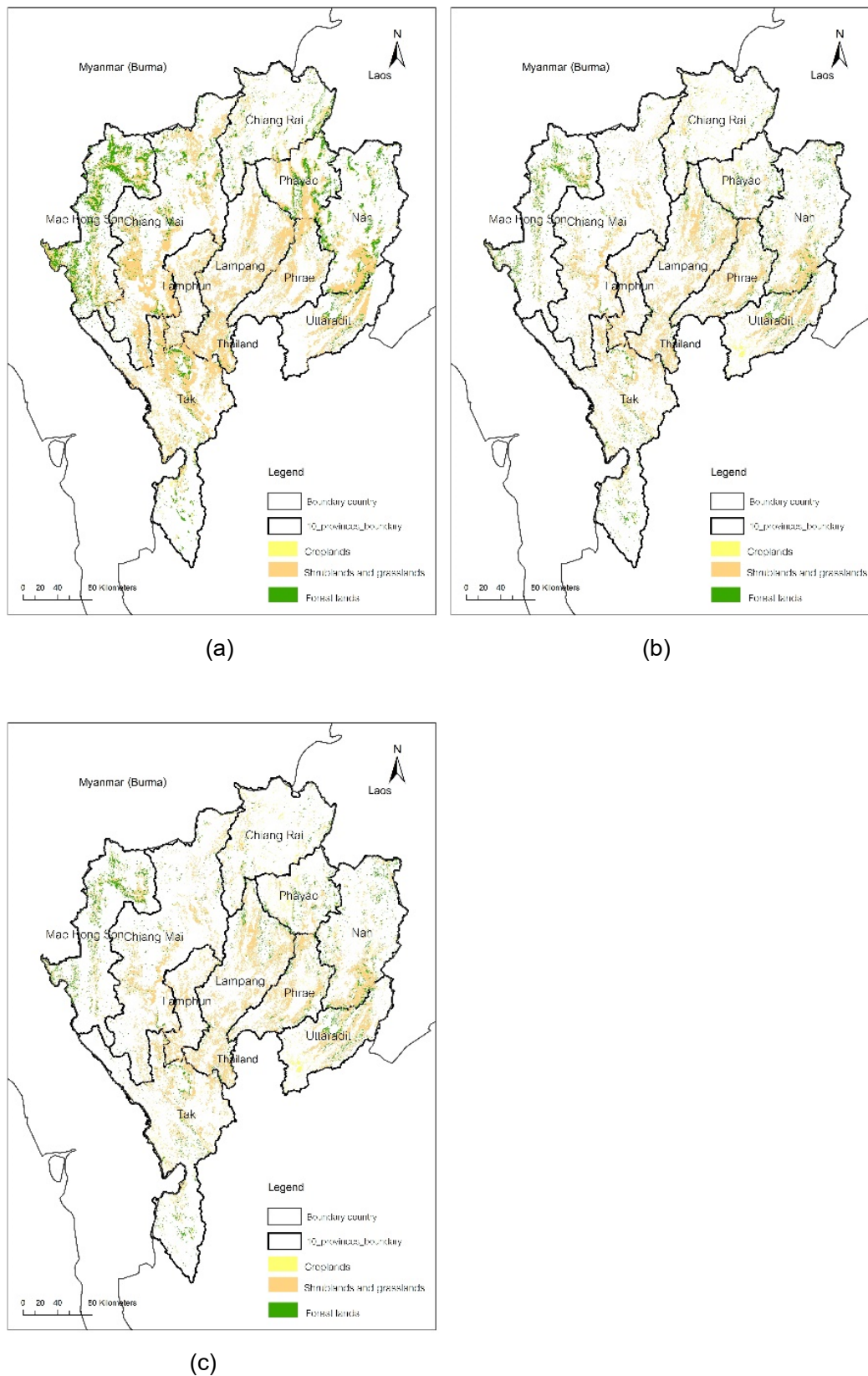


Figure 7. The burn scars (reference fires) categorized by vegetation fires in the year a) 2014, b) 2015, and c) 2016.

2.7 Global Fire Emissions Database

The results of emission from biomass fires in GMS from this study was compared with the Global Fire Emissions Database (GFED) [9] which provides global estimates of monthly burned area, monthly emissions and fractional contributions of different fire types, daily or 3-hourly fields to scale the monthly emissions to higher temporal resolutions, and data for monthly biosphere fluxes. The emission data are at 0.25-degree latitude by 0.25-degree longitude spatial resolution and are available from June 1995 through 2016, depending on the dataset. Emissions data are available for carbon (C), dry matter (DM), carbon dioxide (CO₂), carbon monoxide (CO), methane (CH₄), hydrogen (H₂), nitrous oxide (N₂O), nitrogen oxides (NO_x), non-methane hydrocarbons (NMHC), organic carbon (OC), black carbon (BC), particulate matter less than 2.5 microns (PM_{2.5}), total particulate matter (TPM), and sulfur dioxide (SO₂) among others. These data are yearly totals by region, globally, and by fire source for each region. Figure 8 shows the annual carbon emissions from fires (as g C/m²/year) averaged over 1997 to 2014 derived from GFEDv4. For the comparison, we select the PM_{2.5} emission which is an important source of aerosol particles, such as fine particles (PM_{2.5}, aerodynamic diameters $\leq 2.5 \mu\text{m}$).

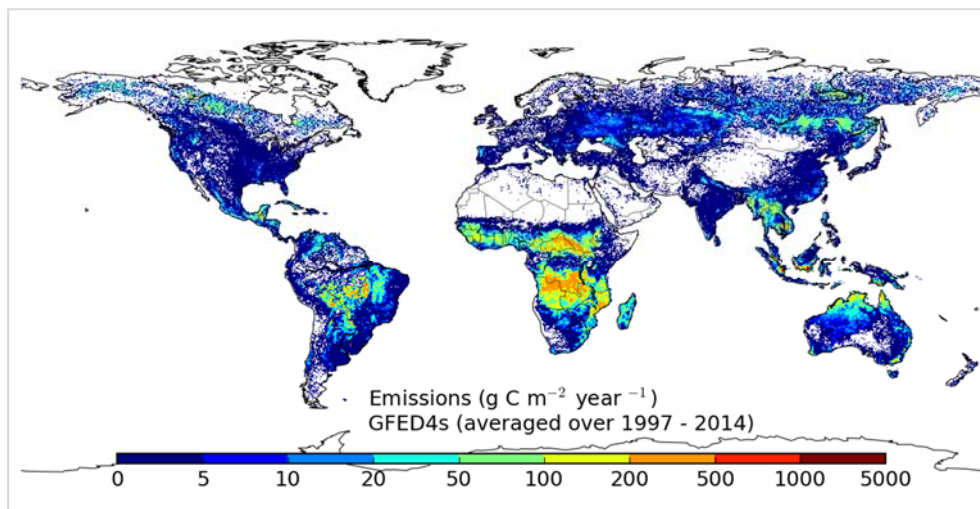


Figure 8. Annual carbon emissions from fires (as g C/m²/year) averaged over 1997 to 2014 [9].

3. Results and Discussion

3.3.1 Assessment of MCD45A1 burned area product

The analysis of MODIS product employs different algorithms for estimating fire data and may influence the spatiotemporal characteristics of burning. In 2015, the peak of burned area in GMS occurred from in the January to March. From 2014 to 2016, the largest expanse of burned area was observed in 2015, at about 4.4 Mha. The smallest expanse of burned area was observed in 2016, at about 1.4 Mha. The annual information of burned area derived by MCD45A1 categorized by vegetation types in GMS during 2011-2015 is shown in Table 3. According to vegetation fires, the detail of monthly burned area in each countries were shown in Figures 9 to 18.

Table 3. General results of burned area estimation derived from MCD45A1 burned area products in GMS classified by vegetation fires, during 2014-2016.

Year	Countries	burned area estimation derived from MCD45A1 (ha)			
		Croplands	Forest	Savanna, grassland, and shrubland	Biomass burning
2014	Myanmar	388,146	636,355	823,680	1,848,181
	Cambodia	130,737	46,851	692,592	870,181
	Laos	18,111	13,693	29,777	61,580
	Thailand	186,628	88,518	181,809	456,955
	Vietnam	27,022	9,214	66,523	102,759
	Total	750,644	794,631	1,794,381	3,339,656
2015	Myanmar	602,398	695,147	915,055	2,212,600
	Cambodia	426,154	43,075	896,523	1,365,752
	Laos	13,110	5,541	25,108	43,759
	Thailand	406,065	97,801	177,139	681,005
	Vietnam	68,668	3,420	38,878	110,966
	Total	1,516,395	844,984	2,052,704	4,414,082
2016	Myanmar	212,875	101,969	161,341	476,185
	Cambodia	95,022	18,839	493,507	607,369
	Laos	4,541	6,679	10,736	21,956
	Thailand	176,491	30,415	79,554	286,461
	Vietnam	16,501	876	33,386	50,764
	Total	505,432	158,778	778,525	1,442,735

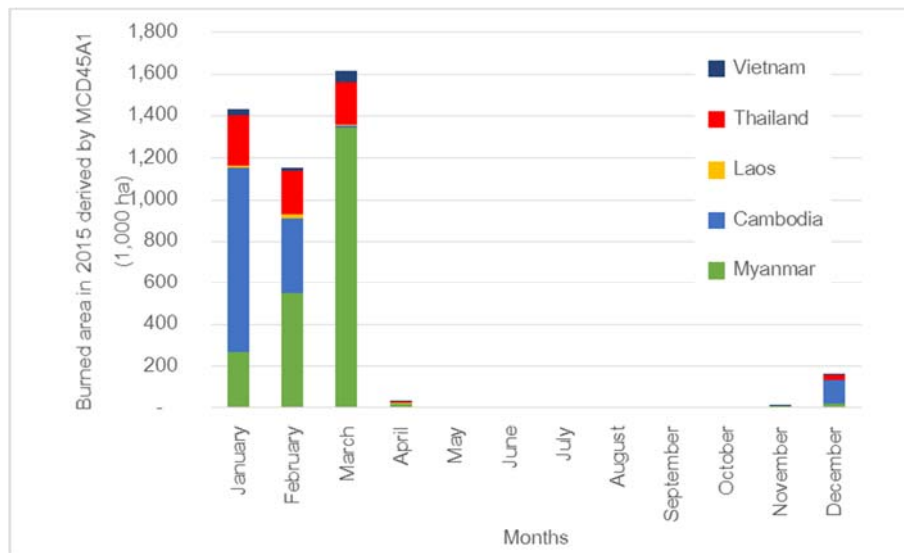


Figure 9. Monthly temporal of total burned area from biomass open burning derived by MCD45A1 in 2015.

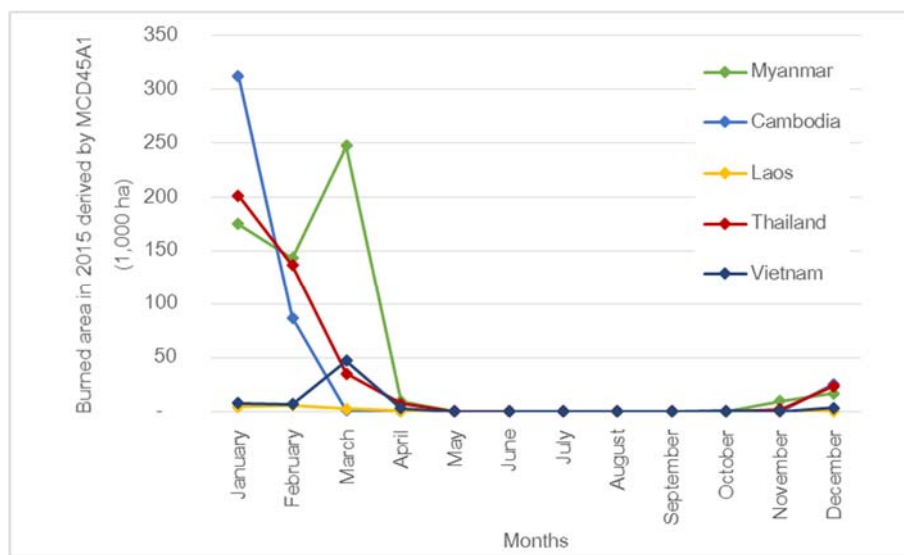


Figure 10. Monthly temporal of burned area from agricultural waste burning derived by MCD45A1 (2015) categorized by countries.

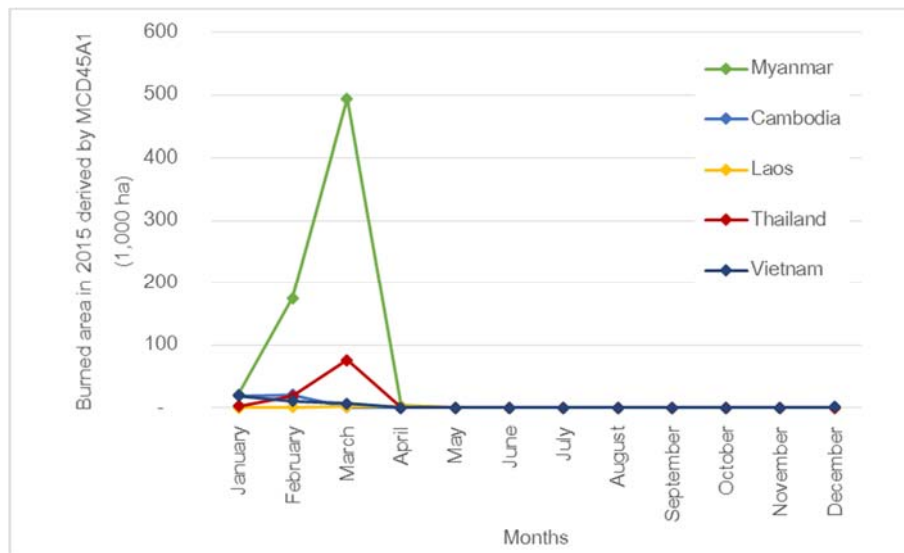


Figure 11. Monthly temporal of burned area from forest fire derived by MCD45A1 (2015) categorized by countries.

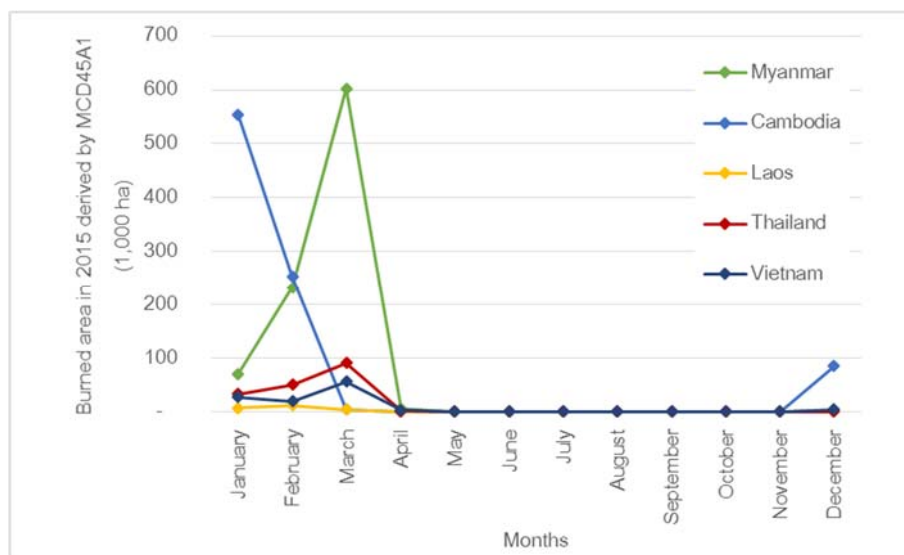


Figure 12. Monthly temporal of burned area from savanna and shrublands fire derived by MCD45A1 (2015) categorized by countries.

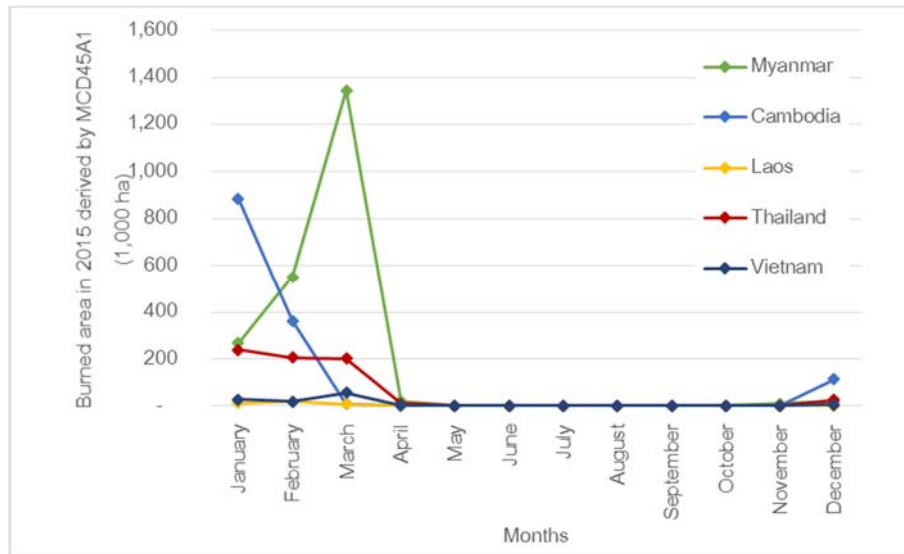


Figure 13. Monthly temporal of burned area from biomass open burning derived by MCD45A1 (2015) categorized by countries.

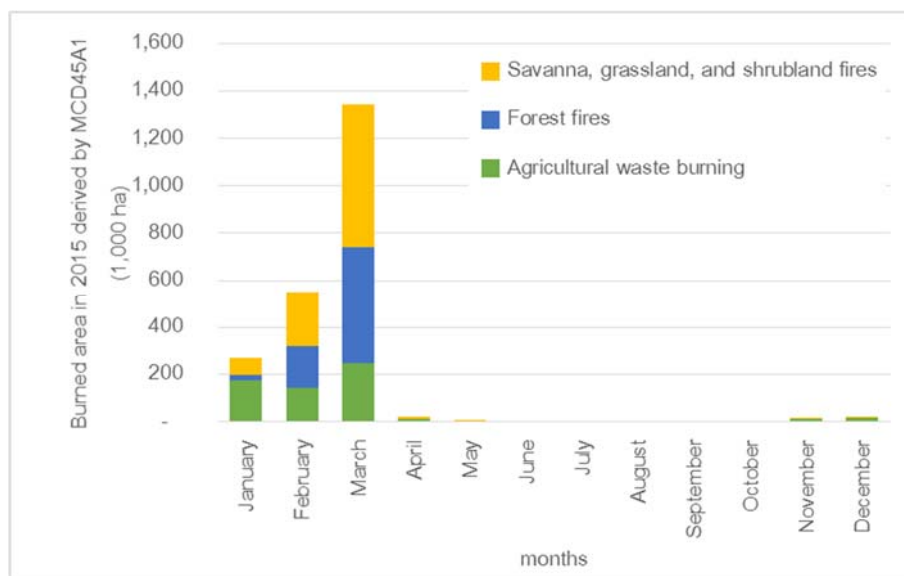


Figure 14. Monthly temporal of burned area from MCD45A1 (2015) in Myanmar categorized by vegetation fires.

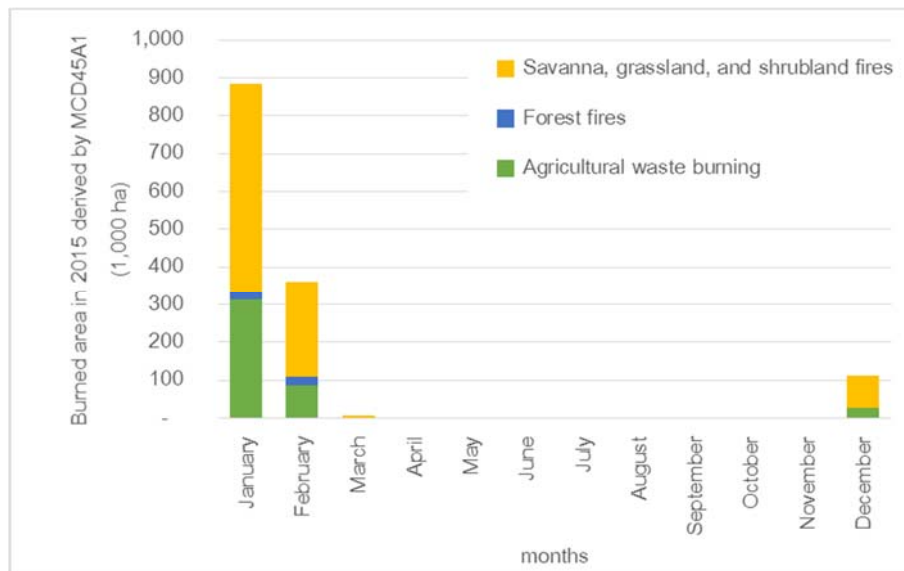


Figure 15. Monthly temporal of burned area from MCD45A1 (2015) in Cambodia categorized by vegetation fires.

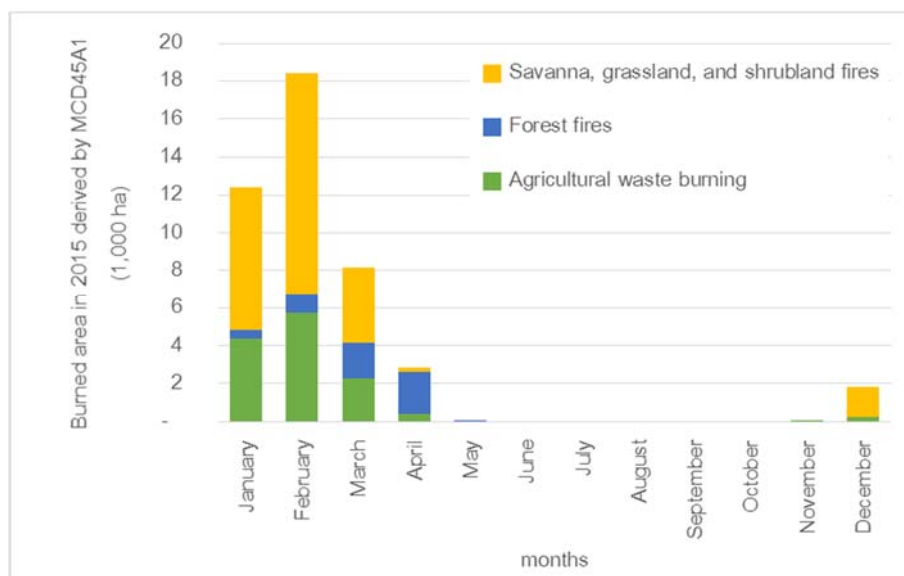


Figure 16. Monthly temporal of burned area from MCD45A1 (2015) in Lao People's Democratic Republic categorized by vegetation fires.

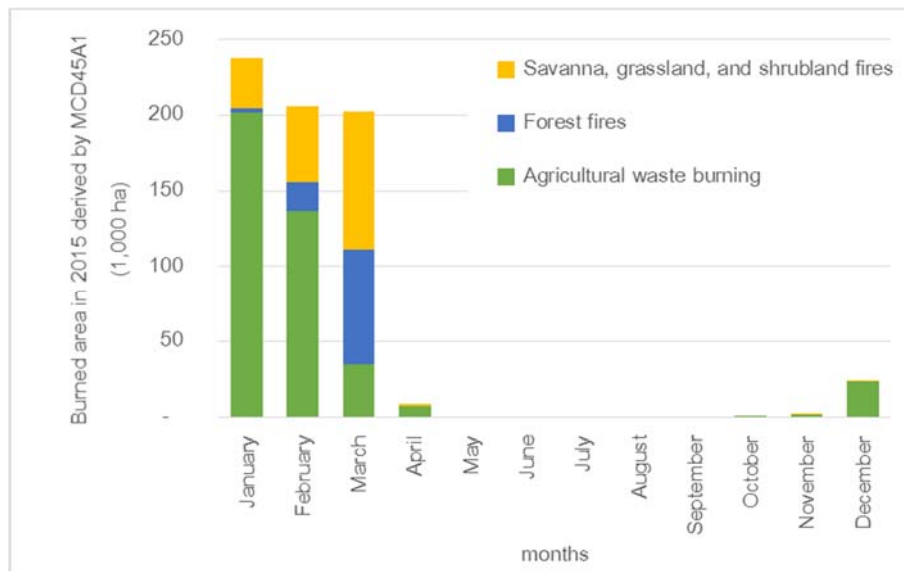


Figure 17. Monthly temporal of burned area from MCD45A1 (2015) in Thailand categorized by vegetation fires.

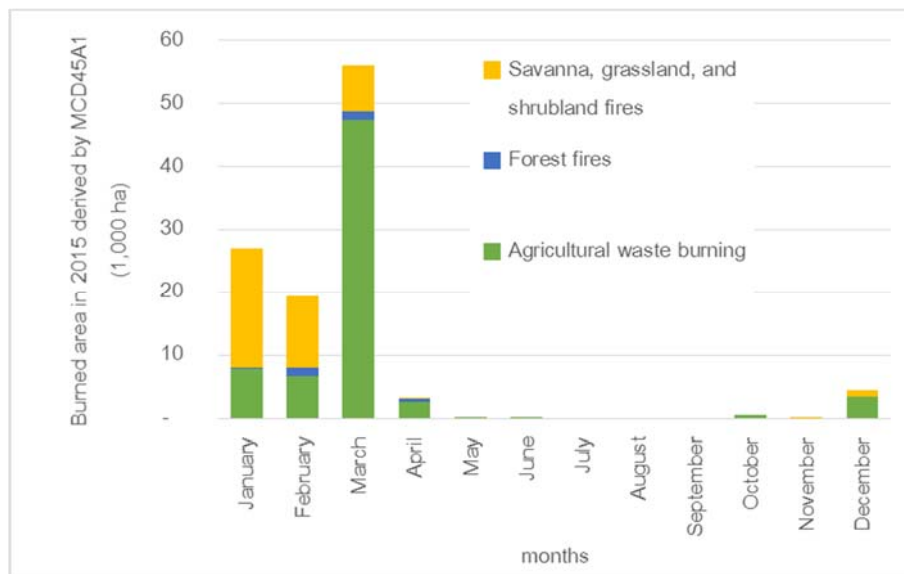


Figure 18. Monthly temporal of burned area from MCD45A1 (2015) in Vietnam categorized by vegetation fires.

3.3.2 Assessment of MCD64A1 burned area product

From 2010 to 2017, the overall burned area was estimated at about 81,403 10³ ha. The largest expanse of burned area was observed in 2014, at about 12,950 10³ ha. The smallest expanse of burned area was observed in 2017, at about 8,052 Mha. The annual information of burned area derived by MCD64A1 categorized by vegetation types in GMS during 2010-2017 is shown in Table 4. Figures 19-34 show the total and percentage share of burned area derived from MCD64A1 burned area products categorized by land cover types in the Greater Mekong Sub-region, during 2010-2017. Figure 35 shows the spatial distribution of burned area occurred in all vegetation, cropland, forestland and savannas derived from MCD64A1 in GMS, 2015. Finally, the spatial and monthly temporal distribution of burned area occurred in GMS in 2015 is illustrated in Figure 36.

Table 4. General results of burned area estimation (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, during 2010-2017.

Year	Countries	Burned area estimation derived from MCD64A1 categorized by land cover types (1,000 ha)							
		Croplands	Deciduous Forest	Evergreen Forest	Mixed Forests	Grass-lands	Savannas	Shrub-lands	Wetland
2010	Myanmar	281.9	45.7	1,332.2	606.2	9.4	2,840.2	0.3	6.8
	Cambodia	361.3	2.7	206.3	16.1	41.0	1,925.3	1.1	40.3
	Laos	147.6	0.3	1,139.6	2.0	2.7	276.0	0.0	1.7
	Thailand	573.7	1.0	183.0	53.2	2.1	572.4	0.0	5.1
	Vietnam	756.4	0.3	275.3	9.6	4.1	219.4	0.1	18.8
	Total	2,120.9	50.0	3,136.4	687.1	59.3	5,833.4	1.5	72.7
2011	Myanmar	437.5	43.6	820.3	360.5	19.5	1,711.5	0.8	67.9
	Cambodia	421.1	3.1	232.5	6.7	53.6	2,492.0	1.2	15.3
	Laos	46.8	0.5	158.8	1.3	1.1	114.6	0.0	0.2
	Thailand	468.7	0.9	22.1	28.9	3.0	270.4	-	3.3
	Vietnam	309.7	0.4	92.2	0.9	1.4	270.7	0.1	5.5
	Total	1,683.8	48.5	1,326.0	398.2	78.7	4,859.2	2.1	92.1
2012	Myanmar	413.6	35.8	1,392.1	498.7	9.4	2,320.2	0.8	74.3
	Cambodia	315.5	1.8	181.2	4.5	46.1	2,304.1	0.6	10.6
	Laos	64.6	0.3	457.5	0.9	2.0	150.6	0.0	0.3
	Thailand	770.7	1.1	166.4	103.8	3.1	605.0	0.0	9.3
	Vietnam	639.8	0.2	161.5	6.5	4.6	296.0	0.1	30.9
	Total	2,204.1	39.1	2,358.7	614.3	65.1	5,676.0	1.5	125.5
2013	Myanmar	362.8	37.3	1,059.2	401.6	14.7	1,747.9	0.7	64.6
	Cambodia	226.5	3.8	294.6	13.8	33.3	2,013.3	1.1	44.6
	Laos	78.5	0.4	588.5	1.0	1.7	185.0	0.0	1.6
	Thailand	710.8	0.9	94.0	38.6	5.0	338.8	0.0	7.5
	Vietnam	815.9	0.4	95.9	2.0	4.5	108.9	0.1	22.5

Year	Countries	Burned area estimation derived from MCD64A1 categorized by land cover types (1,000 ha)							
		Croplands	Deciduous Forest	Evergreen Forest	Mixed Forests	Grass-lands	Savannas	Shrub-lands	Wetland
	Total	2,194.5	42.7	2,132.1	457.0	59.1	4,394.0	2.0	140.7
2014	Myanmar	732.6	44.1	2,287.6	495.4	22.5	2,475.7	1.4	259.0
	Cambodia	386.7	4.1	203.4	3.5	51.6	2,419.4	1.5	11.6
	Laos	48.6	0.4	438.9	1.4	2.1	147.2	0.0	0.6
	Thailand	661.7	1.6	180.7	111.9	4.8	715.7	0.0	7.2
	Vietnam	801.2	0.5	168.6	6.6	6.9	208.6	0.2	34.3
	Total	2,630.8	50.6	3,279.1	618.8	87.9	5,966.6	3.1	312.7
2015	Myanmar	246.7	34.0	587.8	599.9	12.7	2,343.5	0.3	5.2
	Cambodia	368.9	3.5	254.9	17.2	54.8	2,663.0	2.0	44.3
	Laos	65.4	0.4	477.5	1.3	1.7	163.5	0.1	0.9
	Thailand	594.5	1.6	126.6	107.3	5.2	603.5	0.0	3.8
	Vietnam	1,043.4	0.6	127.9	3.8	9.3	271.9	0.2	34.5
	Total	2,318.9	40.0	1,574.7	729.5	83.8	6,045.4	2.6	88.6
2016	Myanmar	216.0	25.6	564.1	300.9	12.7	1,385.8	0.3	7.4
	Cambodia	245.9	3.3	370.3	42.4	37.7	1,650.3	1.4	88.7
	Laos	73.6	0.3	755.2	1.3	2.2	183.2	0.1	1.6
	Thailand	527.4	1.6	329.7	41.4	3.1	506.0	0.1	4.9
	Vietnam	832.3	0.3	144.8	4.9	5.9	161.3	0.2	27.4
	Total	1,895.4	31.2	2,164.1	391.0	61.7	3,886.5	2.0	130.0
2017	Myanmar	260.6	33.8	304.6	403.1	20.1	1,949.8	0.7	32.0
	Cambodia	182.0	2.0	92.2	2.2	35.4	2,417.1	0.9	8.1
	Laos	43.8	0.3	226.9	0.9	2.3	127.2	0.0	0.3
	Thailand	507.1	1.5	58.1	85.0	6.3	636.4	0.0	5.1
	Vietnam	368.1	0.1	25.8	0.8	2.8	194.7	0.1	14.0
	Total	1,361.5	37.6	707.6	492.1	66.9	5,325.1	1.7	59.5
2010-2017	Myanmar	2,951.7	299.9	8,347.9	3,666.3	121.0	16,774.6	5.3	517.2
	Cambodia	2,507.9	24.3	1,835.4	106.4	353.5	17,884.5	9.8	263.5
	Laos	568.9	2.9	4,242.9	10.1	15.8	1,347.3	0.2	7.2
	Thailand	4,814.6	10.2	1,160.6	570.1	32.6	4,248.2	0.1	46.2
	Vietnam	5,566.8	2.8	1,092.0	35.1	39.5	1,731.5	1.1	187.9
	Total	16,409.9	339.7	16,678.7	4,388.0	562.5	41,986.2	16.5	1,021.8

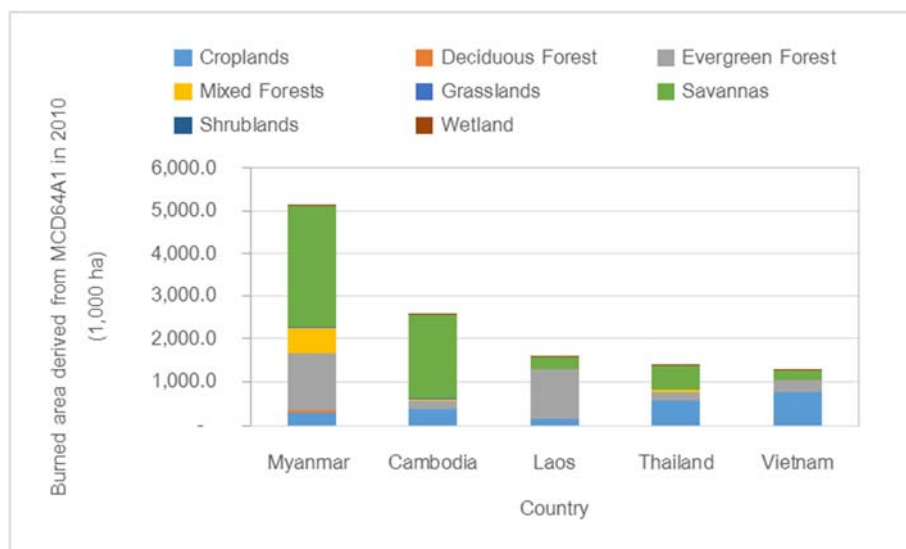


Figure 19. The total of burned area (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, 2010.

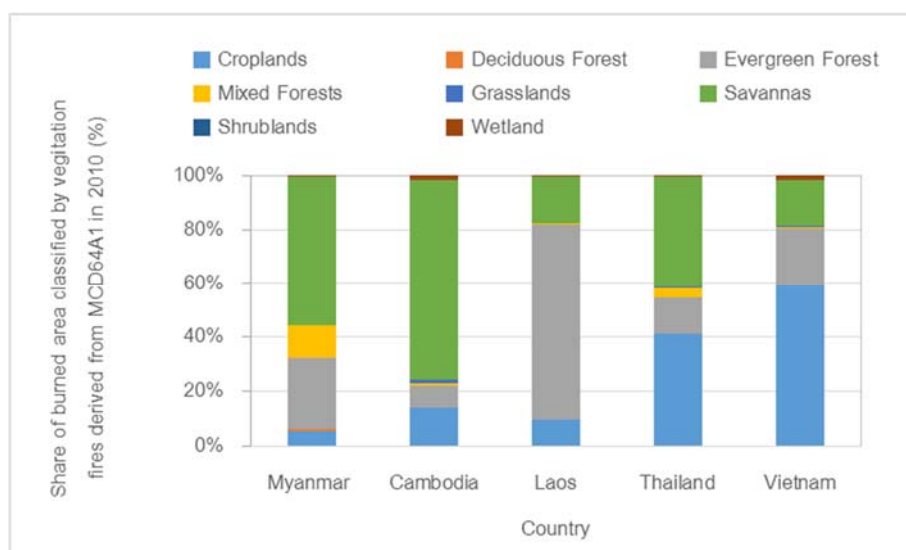


Figure 20. The percentage share of burned area categorized by land cover types derived from MCD64A1 in the Greater Mekong Sub-region, 2010.

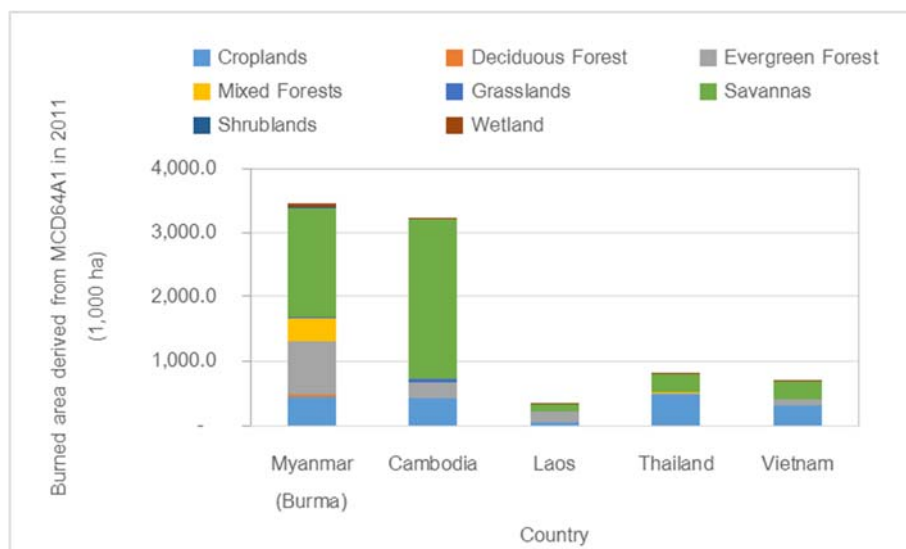


Figure 21. The total of burned area (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, 2011.

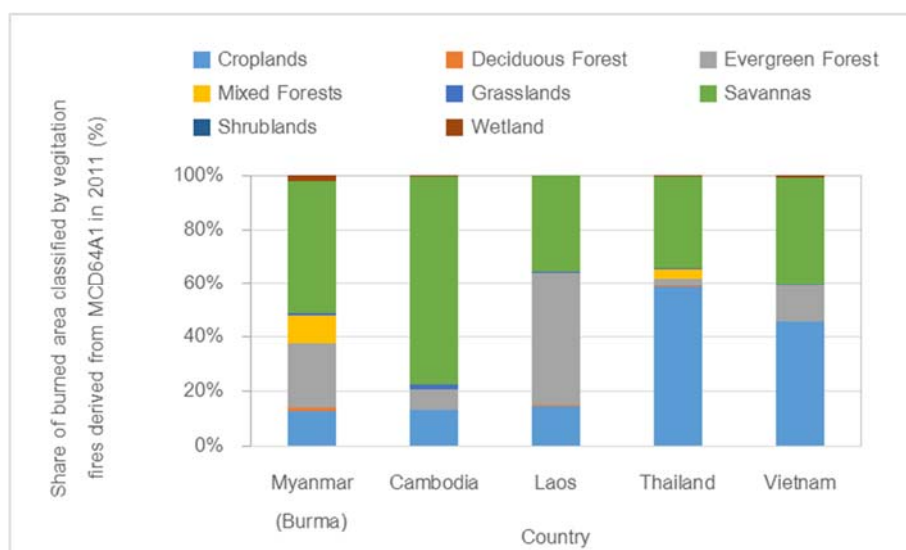


Figure 22. The percentage share of burned area categorized by land cover types derived from MCD64A1 in the Greater Mekong Sub-region, 2011.

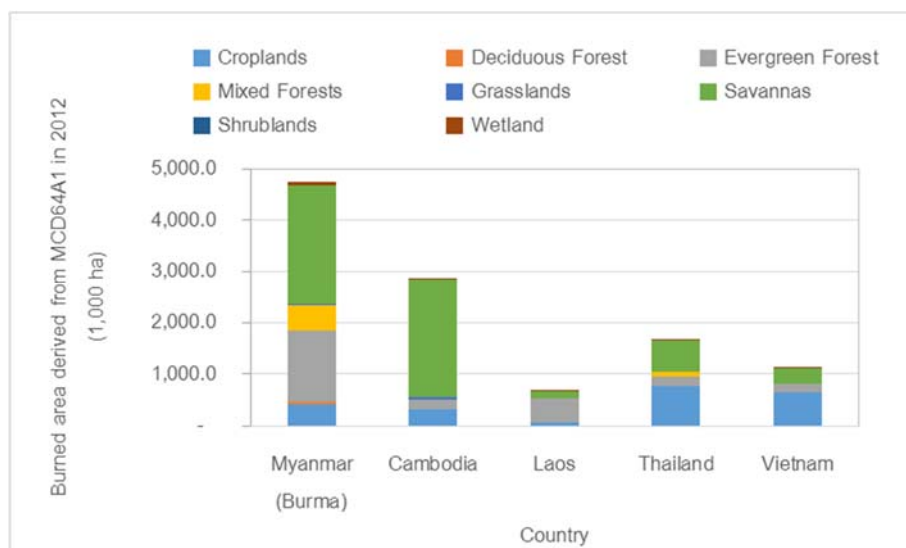


Figure 23. The total of burned area (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, 2012.

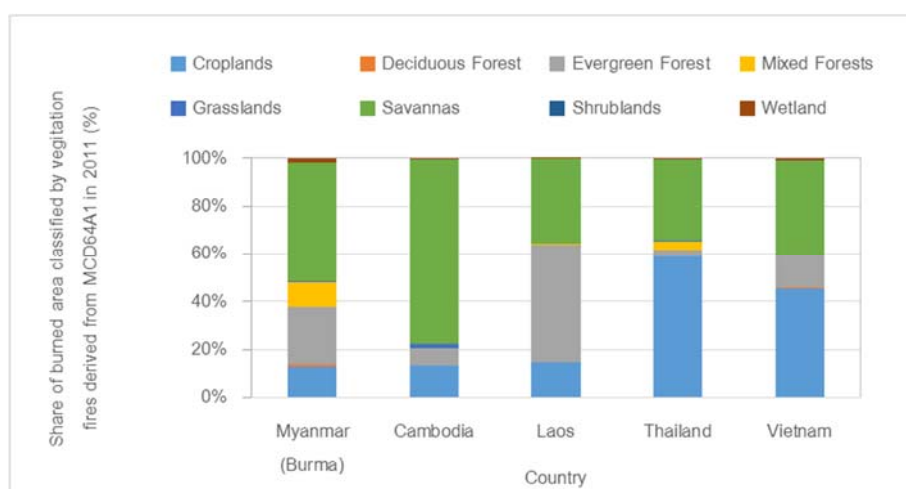


Figure 24. The percentage share of burned area categorized by land cover types derived from MCD64A1 in the Greater Mekong Sub-region, 2012.

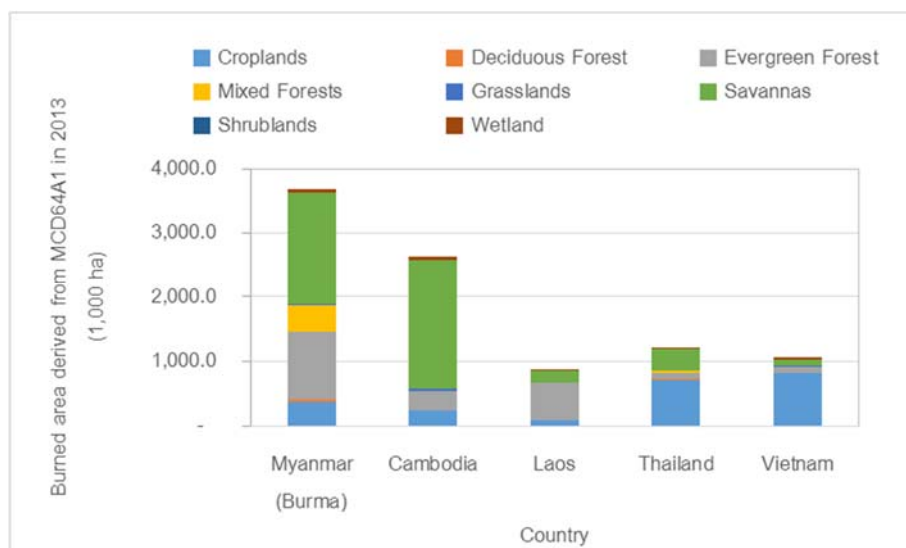


Figure 25. The total of burned area (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, 2013.

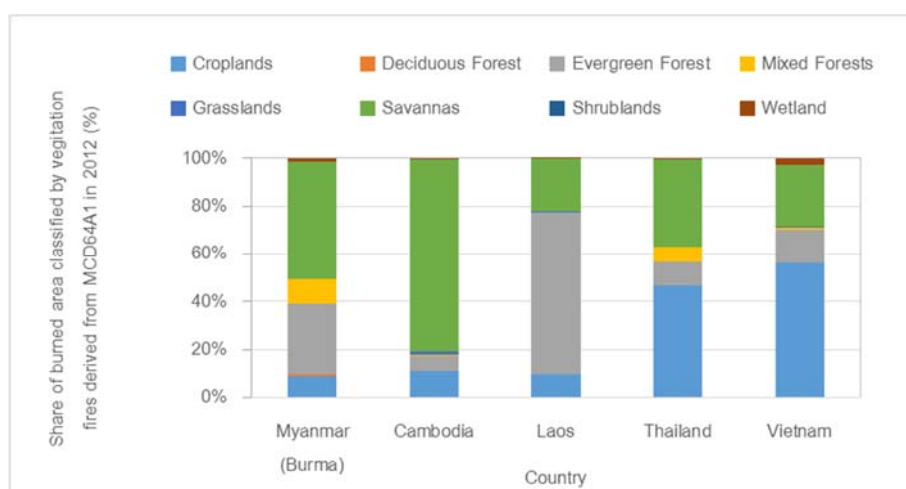


Figure 26. The percentage share of burned area categorized by land cover types derived from MCD64A1 in the Greater Mekong Sub-region, 2013.

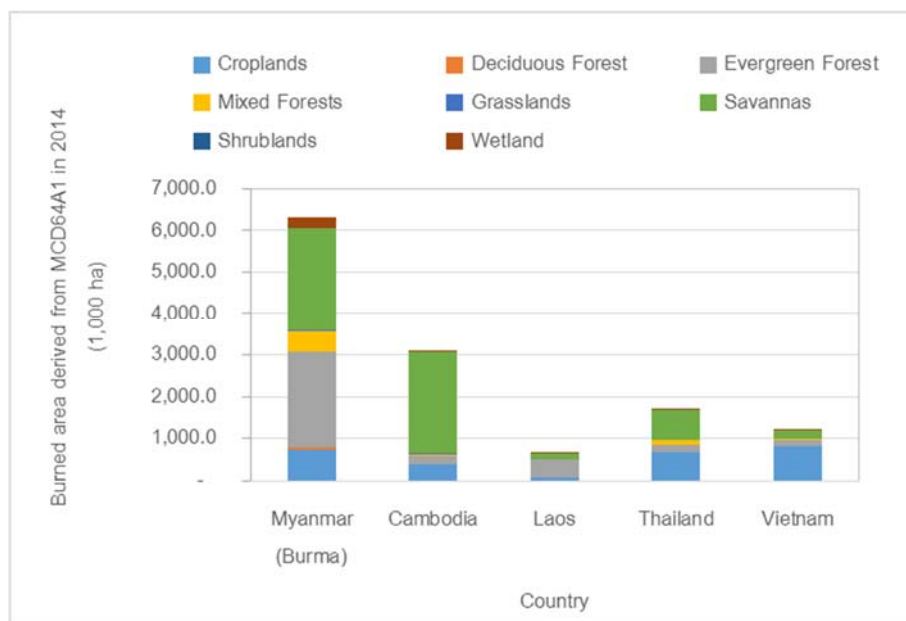


Figure 27. The total of burned area (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, 2014.

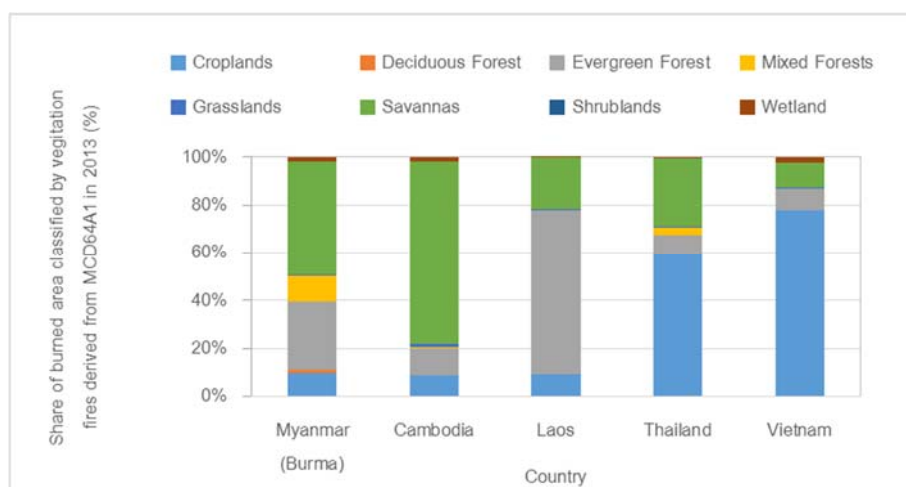


Figure 28. The percentage share of burned area categorized by land cover types derived from MCD64A1 in the Greater Mekong Sub-region, 2014.

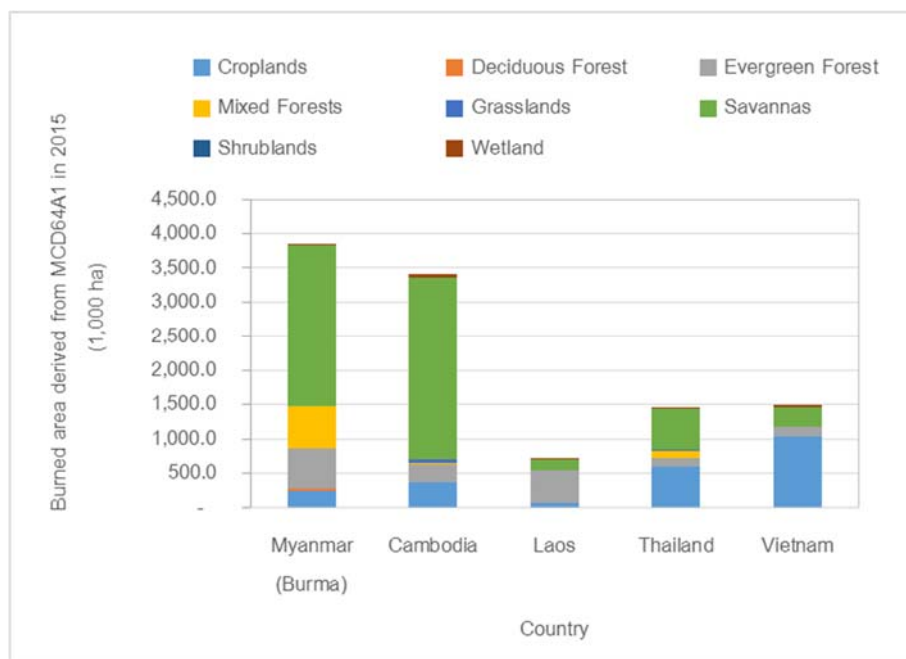


Figure 29. The total of burned area (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, 2015.

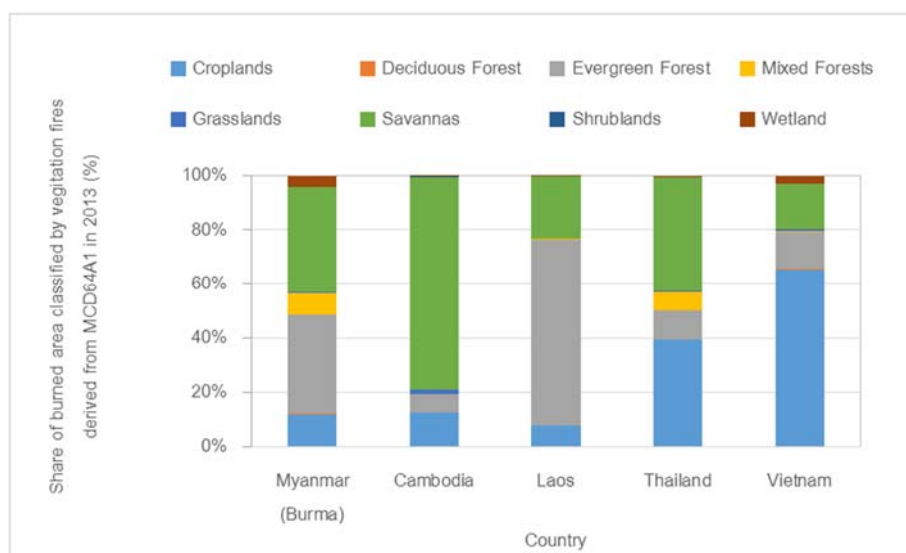


Figure 30. The percentage share of burned area categorized by land cover types derived from MCD64A1 in the Greater Mekong Sub-region, 2015.

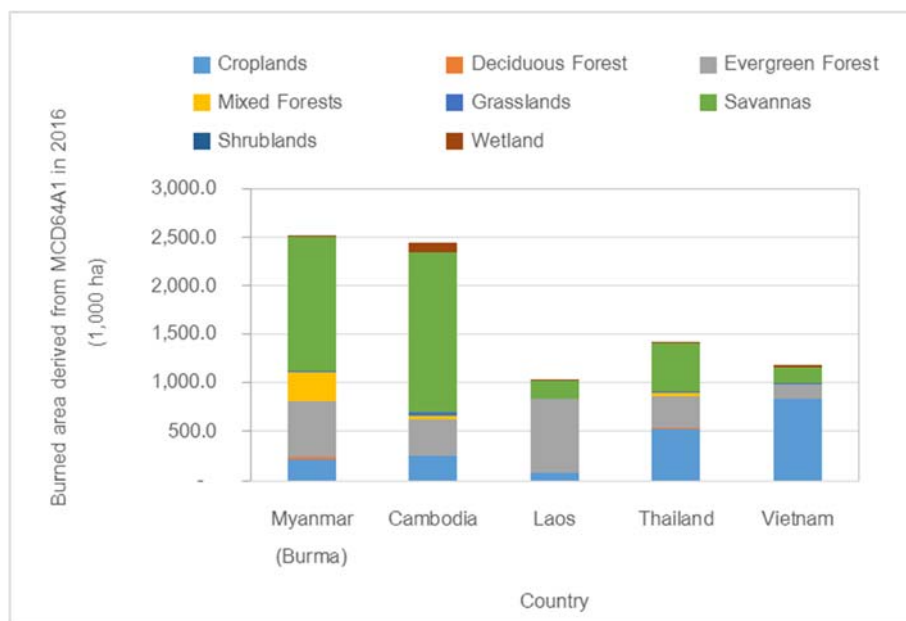


Figure 31. The total of burned area (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, 2016.

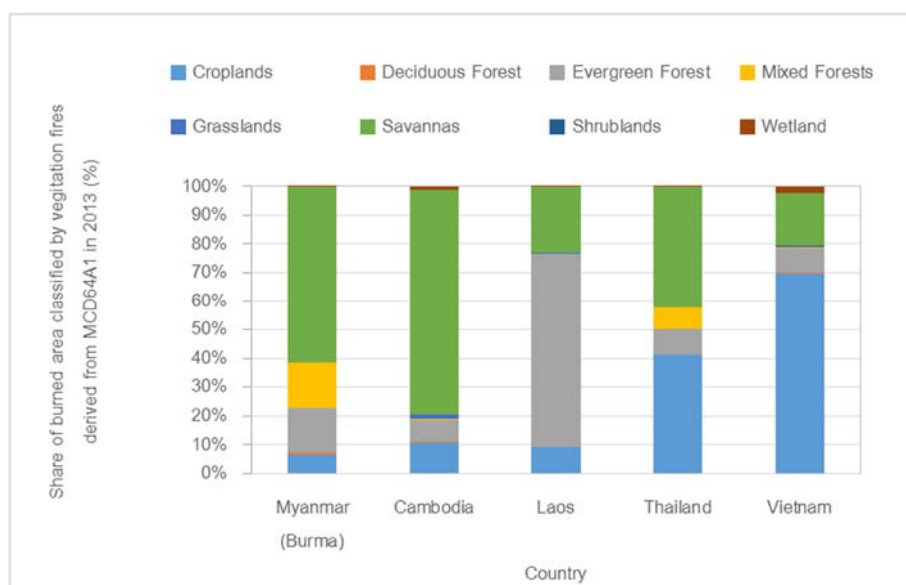


Figure 32. The percentage share of burned area categorized by land cover types derived from MCD64A1 in the Greater Mekong Sub-region, 2016.

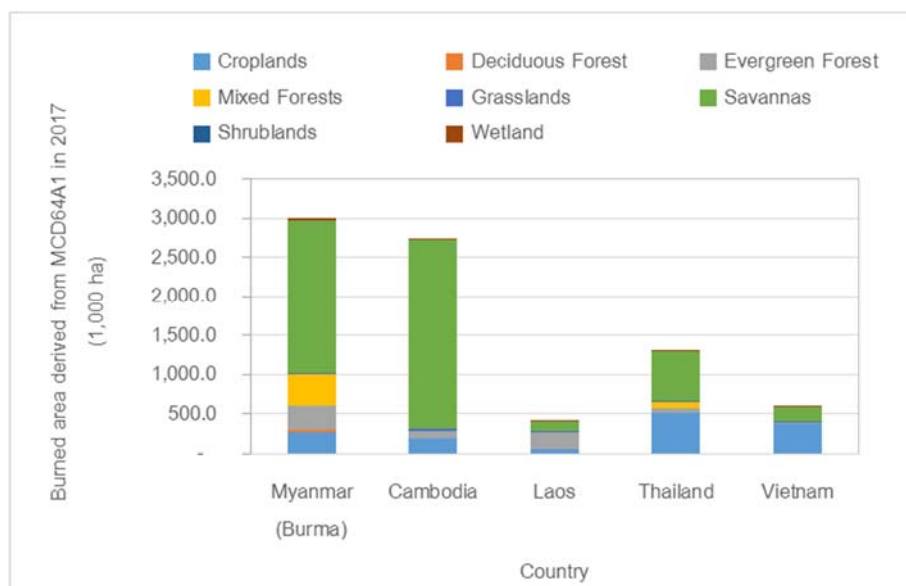


Figure 33. The total of burned area (1,000 ha) categorized by land cover types derived from MCD64A1 burned area products in the Greater Mekong Sub-region, 2017.

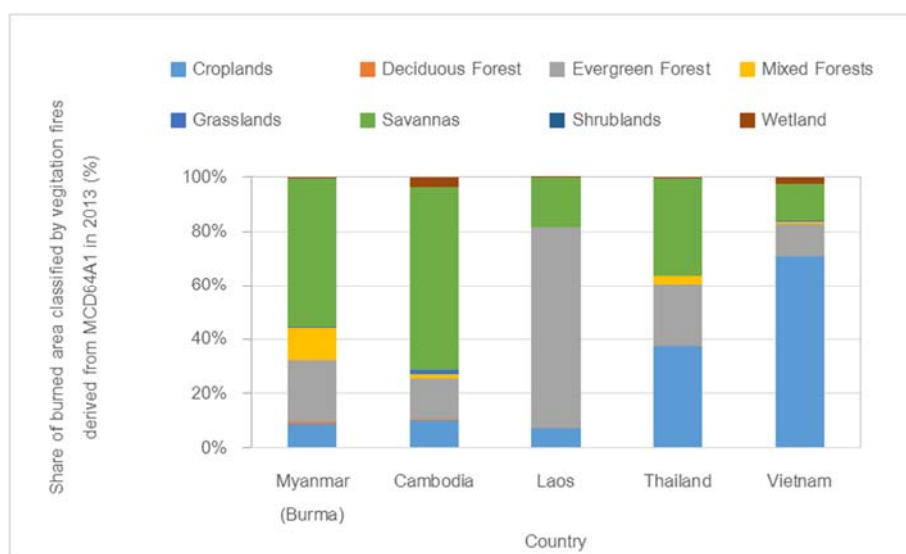
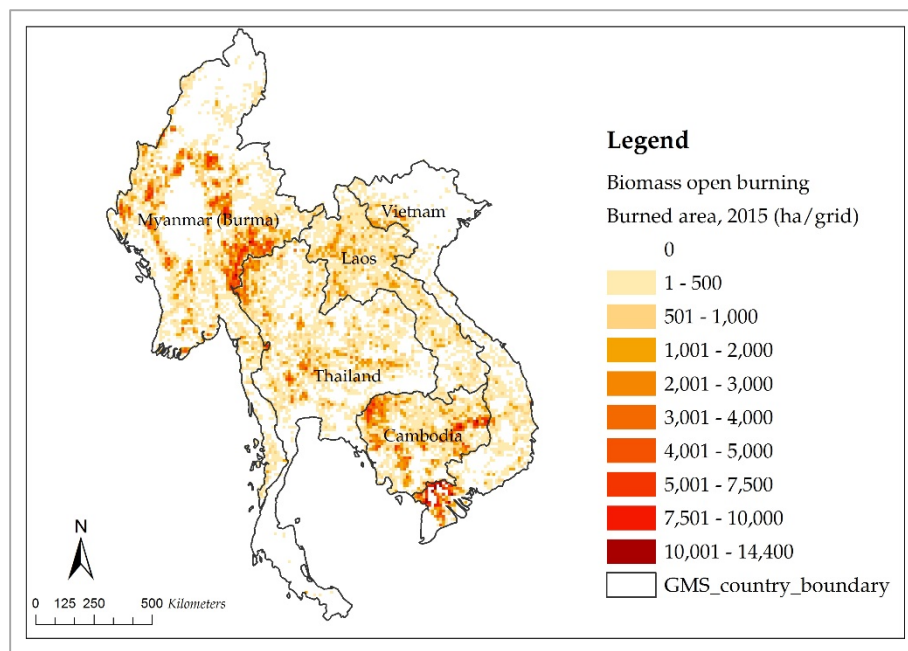
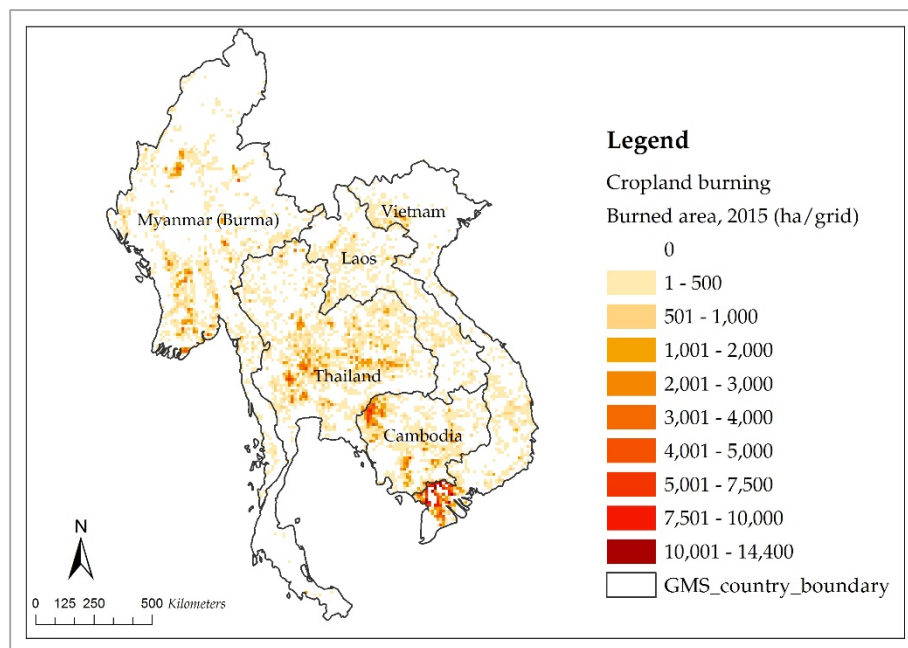


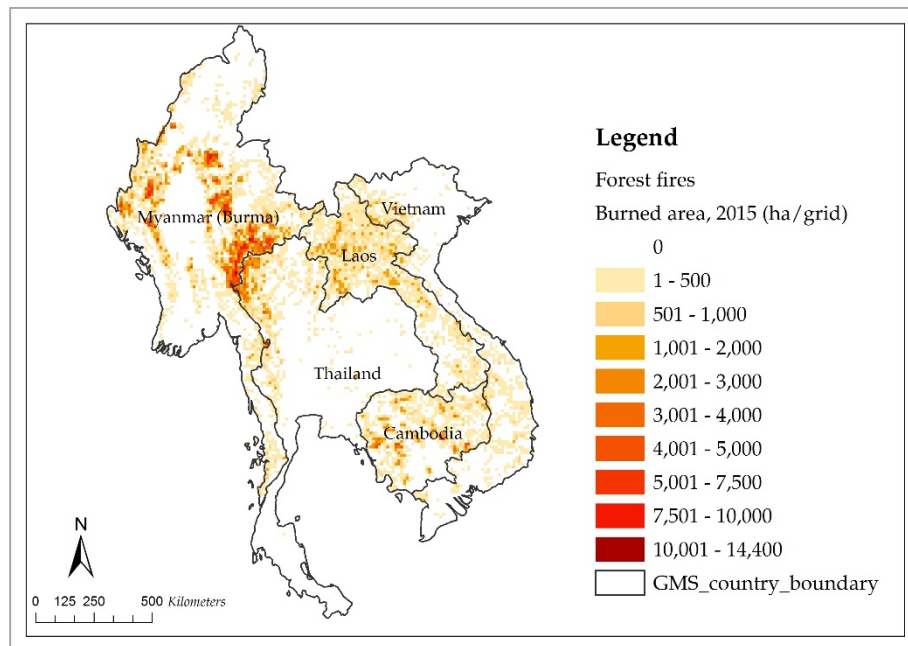
Figure 34. The percentage share of burned area categorized by land cover types derived from MCD64A1 in the Greater Mekong Sub-region, 2017.



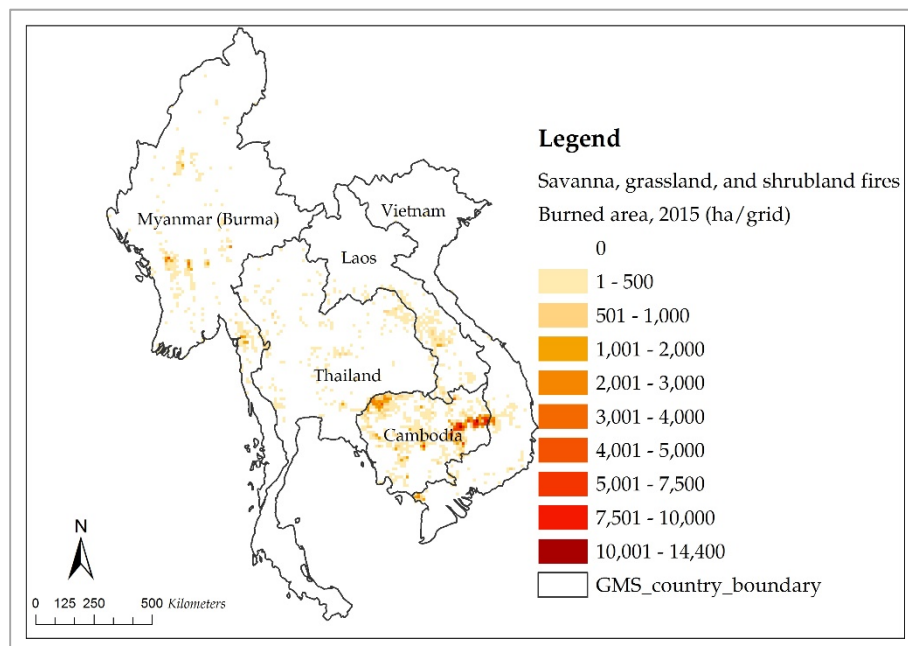
(a) All vegetation



(b) Cropland

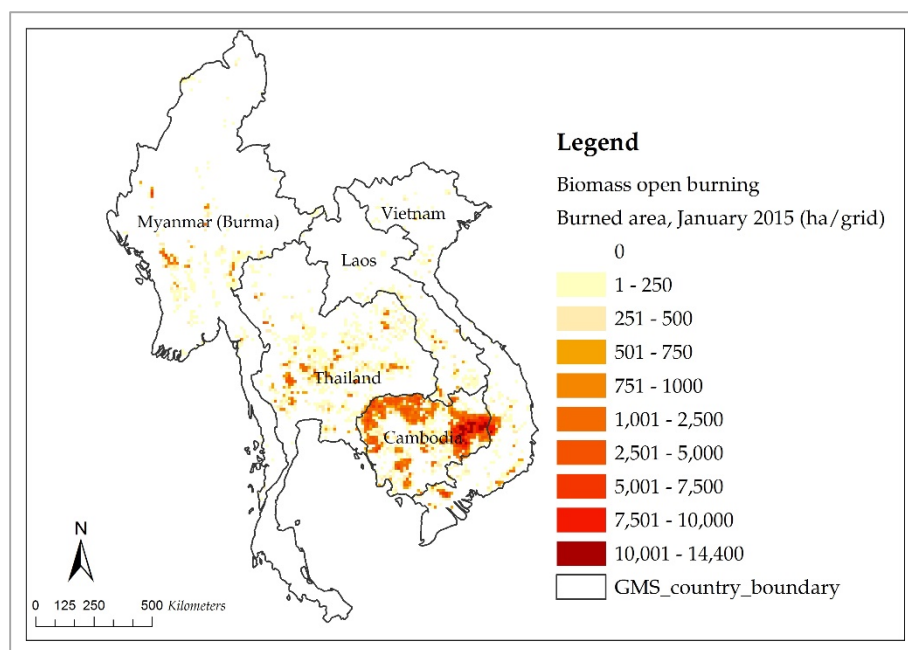


(c) Forestland

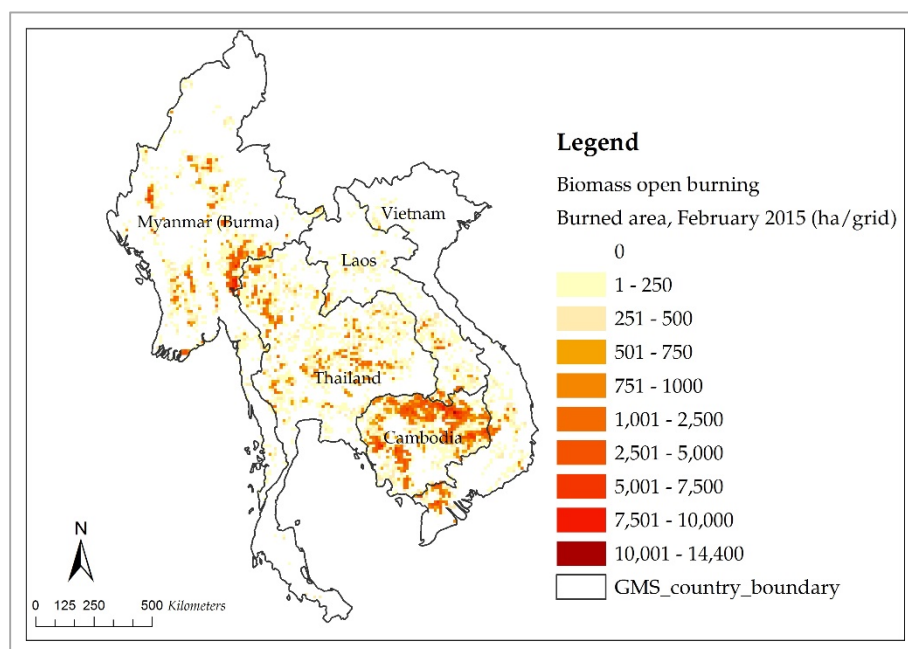


(d) Savannas

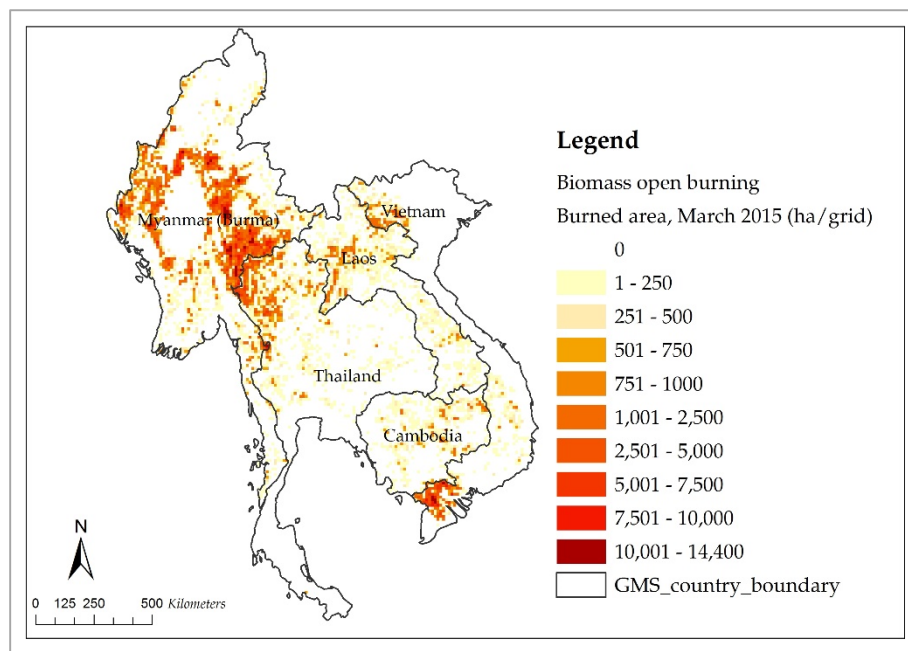
Figure 35. Spatial distribution of burned area occurred in (a) all vegetation, (b) cropland, (c) forestland and (d) savannas derived from MCD64A1 in 2015



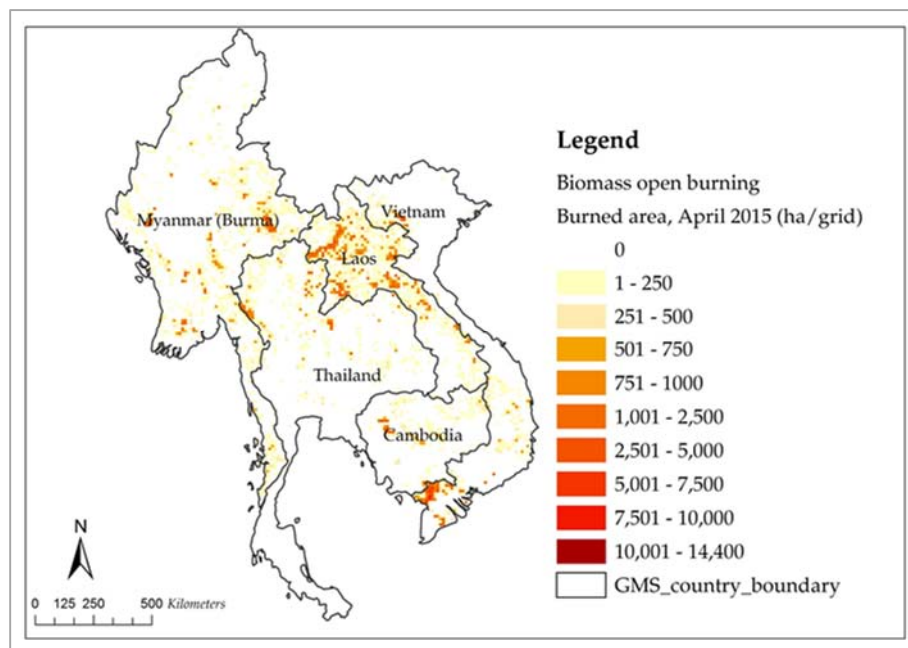
(a) January 2015



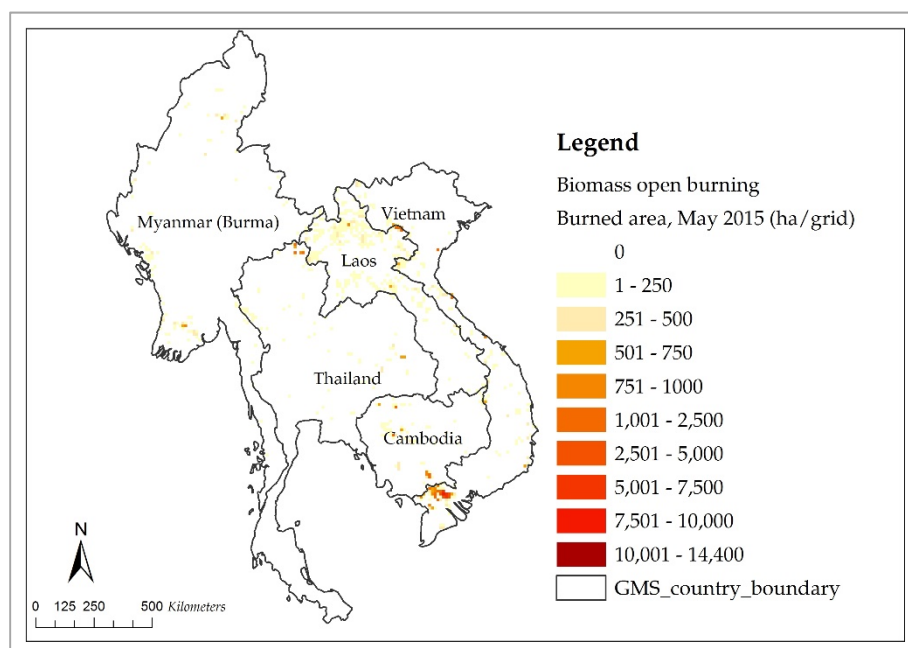
(b) February 2015



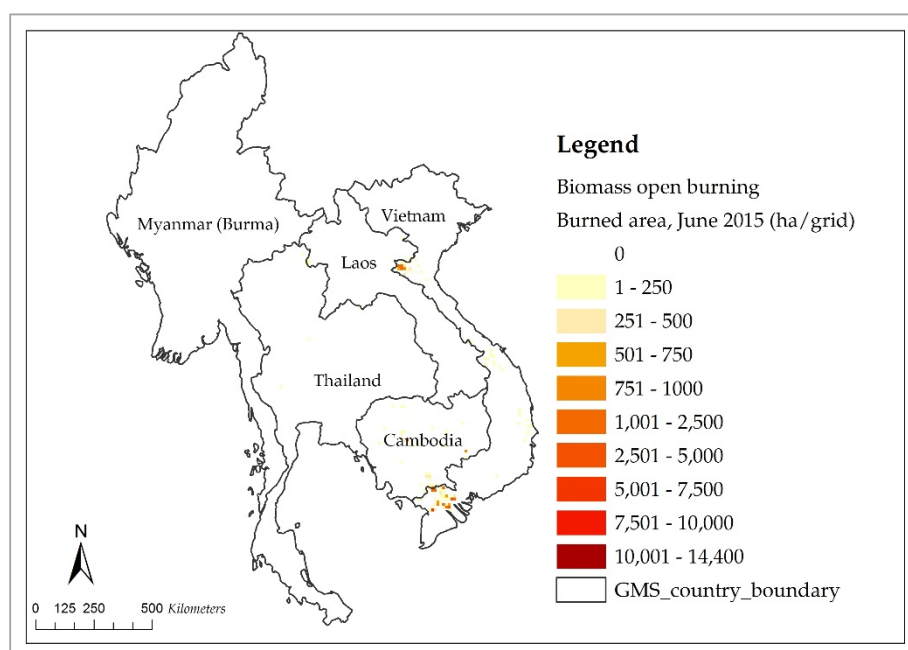
(c) March 2015



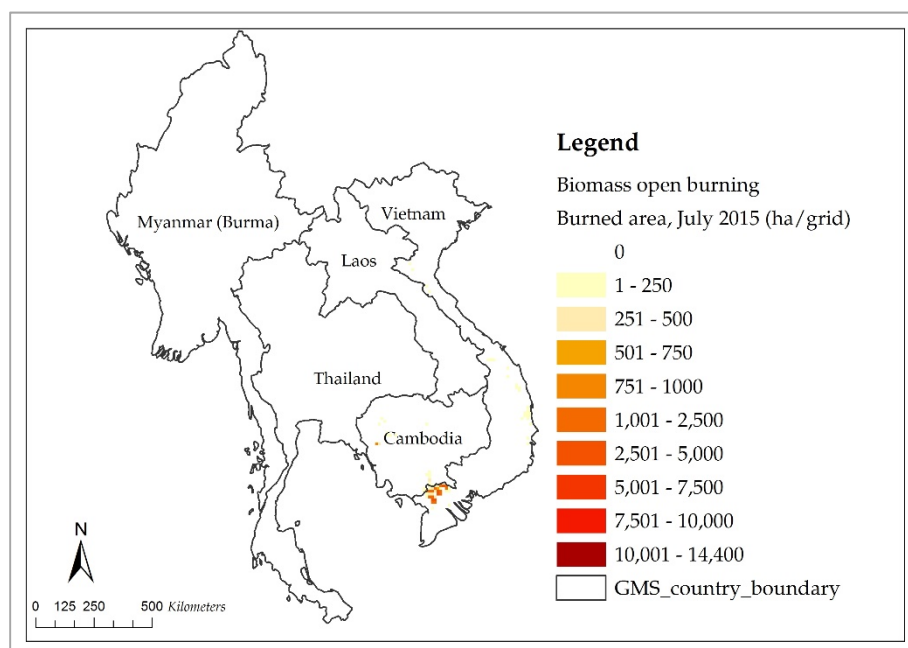
(d) April 2015



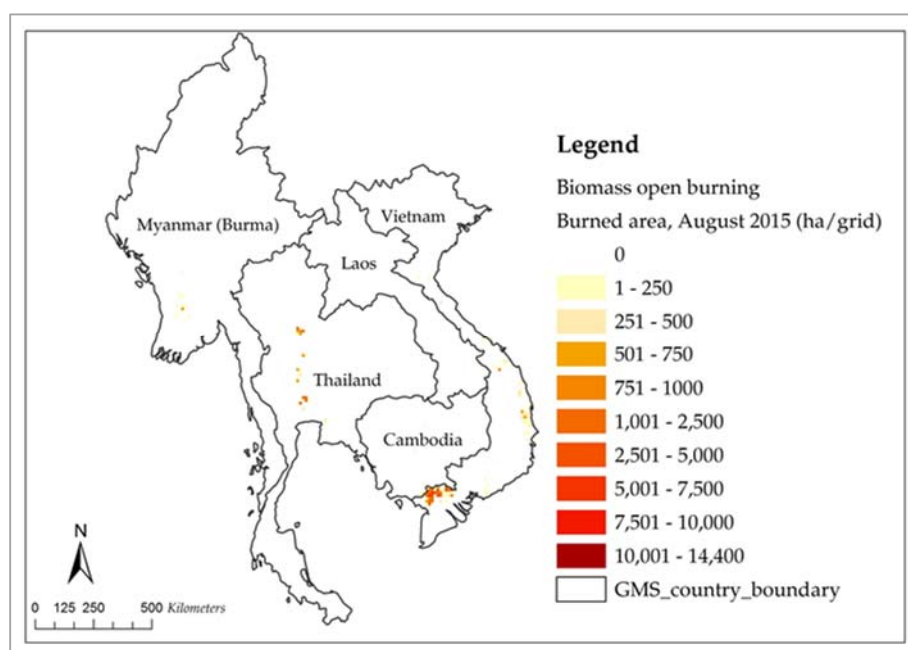
(e) May 2015



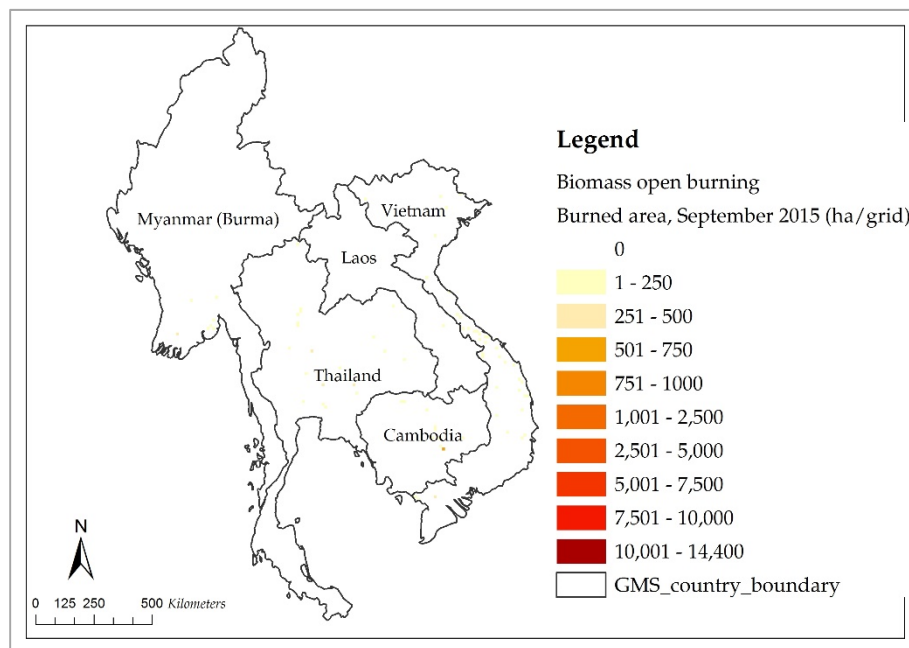
(f) June 2015



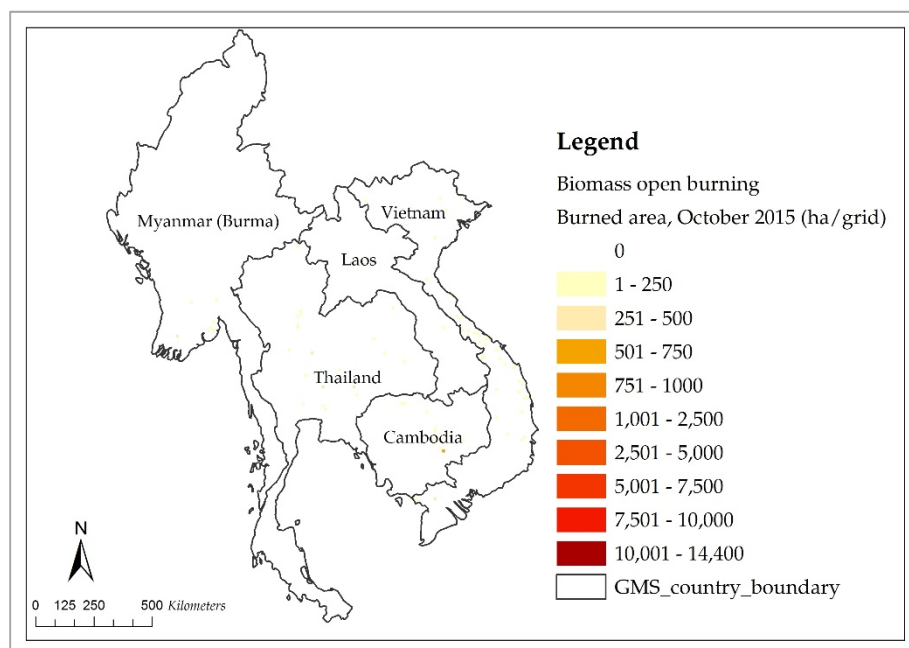
(g) July 2015



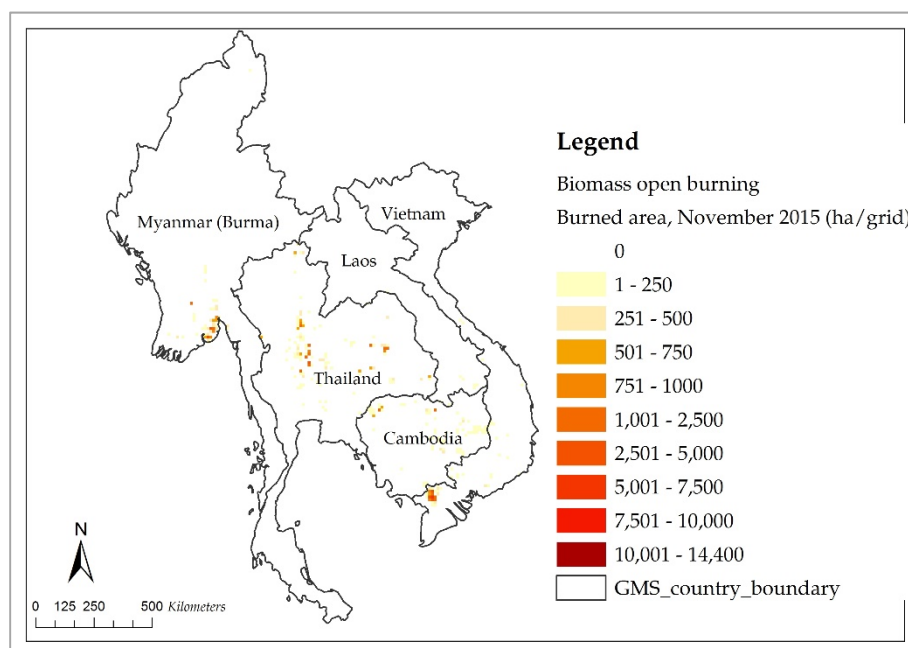
(h) August 2015



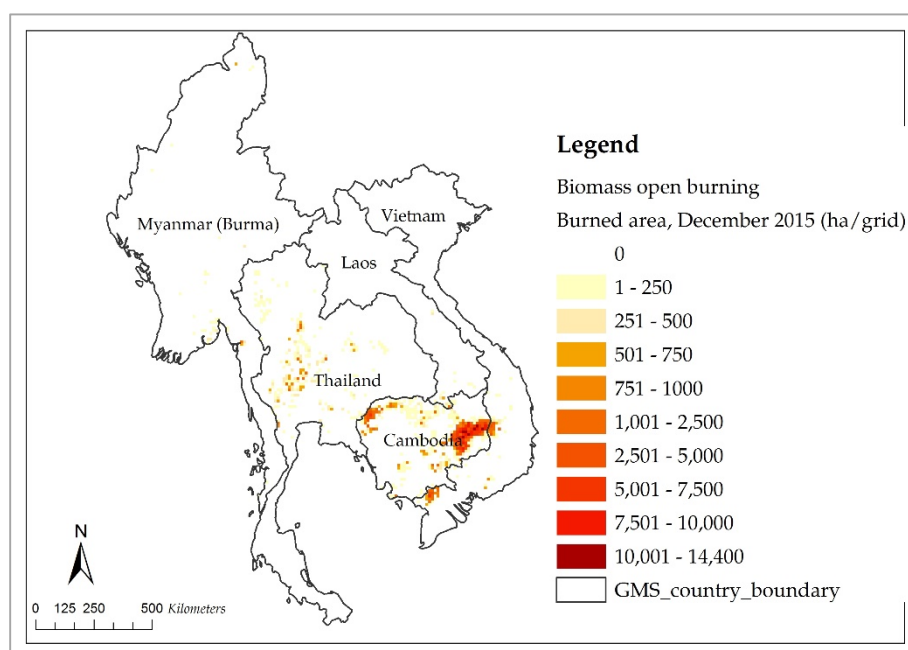
(i) September 2015



(j) October 2015



(k) November 2015



(l) December 2015

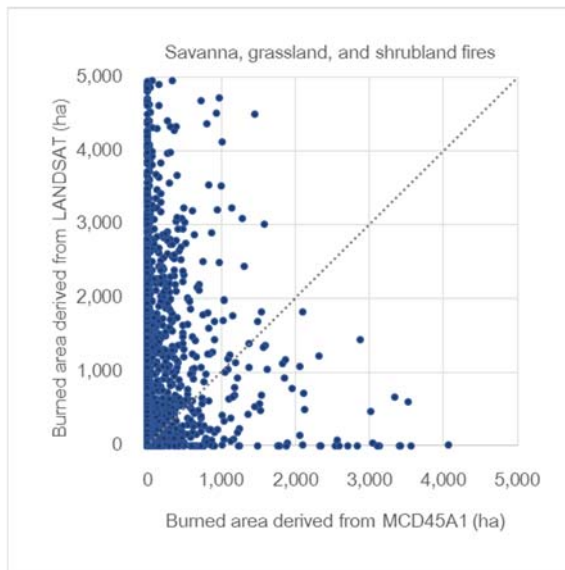
Figure 36. Spatial and monthly temporal distribution of burned area occurred in (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August (i) September, (j) October, (k) November, (l) December in 2015

3.3 Validation of the MCD45A1 and MCD64A1 burned area with the reference fires

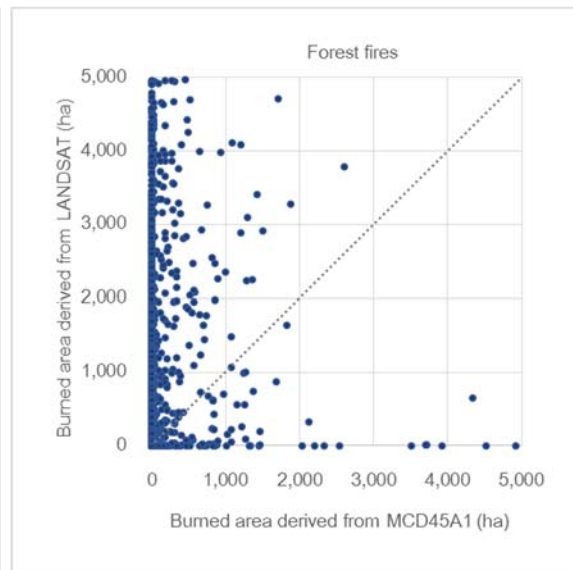
The burned area maps derived from LANDSAT-8 OLI data and MODIS burned area products data for Northern region were categorized by overlying with Land cover map of MODIS-based Global Land Cover (MDC 12Q1). For the year 2014-2016, the results of burned area are overlaid in a grid map with grid squares of 12 km × 12 km spatial resolution. Figure 37 shows the scatter plots for 2,515 grid fires corresponding to the Northern part of Thailand. Good correspondence was observed between the estimates of burned area derived from the LANDSAT-8 OLI data and the MCD64A1 data for the savanna and forest fires. All of MCD64A1 data underestimated burned area for savanna and forest fires and agricultural burning. The agreement between LANDSAT-8 OLI data and the MCD45A1 data estimates was poorer, as evidenced by the low values of correlation.

Table 5 shows the estimation of burned area by main vegetation type of GFED4 derived from the Landsat OLI data and the MCD burned area product data for the total area of the Northern part of Thailand which has 839 grids (for 3 years ~ 2,515 grids). The results (Table 6) show the reference fires were highly detected by MCD64A1 which classified by an ecotype basis, the detection rate were estimated as 72% for savanna, grassland, and shrub land, 70% for forests, and 40% for croplands. The detection rate of gridded forest fires between reference fires and the MCD45A1 was poorer, as evidenced by the low values of detection rate: 34% for savanna, grassland, and shrub land, 21% for forests, and 14% for croplands, respectively.

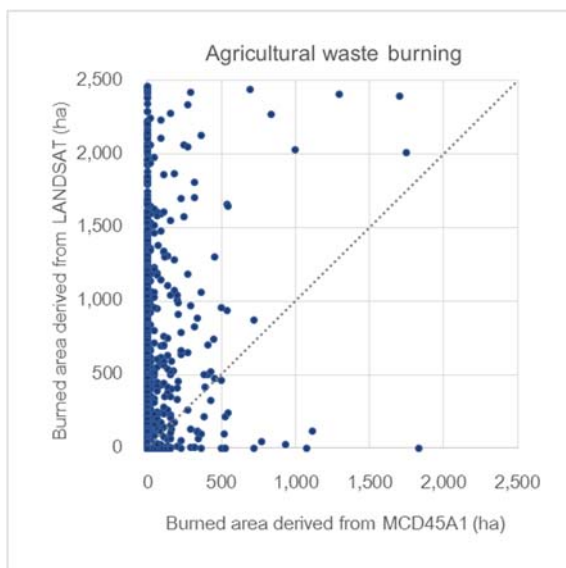
Table 7-8 show the burned area derived from the reference fires and MCD products categorized on an ecotype basis at Northern region from 2014 to 2016. Relatively close MCD65A1/Reference fires values were estimated for croplands (0.20), savanna, grassland, and shrub land (0.24) and forests (0.34). Relatively inaccurate MCD45A1/Reference fires ranged from 0.05 in croplands to 0.12 in savanna and forest land (Table 8). Corresponding to the MCD/Reference fires in each vegetation type, we suggest multiplying the MCD64A1 and MCD45A1 burned area products for GMS by correction factors of 2.11-21.08, depending on the MODIS product and vegetation fires (Table 7-8). From the results, we suggest that the MCD burned area products could be corrected for further regional-scale applications.



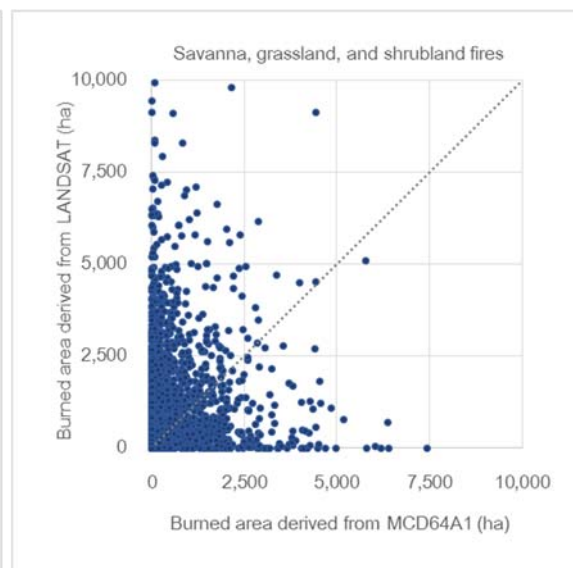
(a)



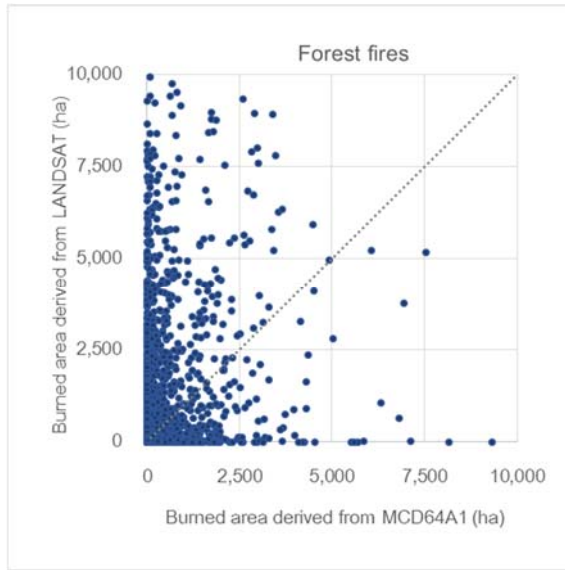
(b)



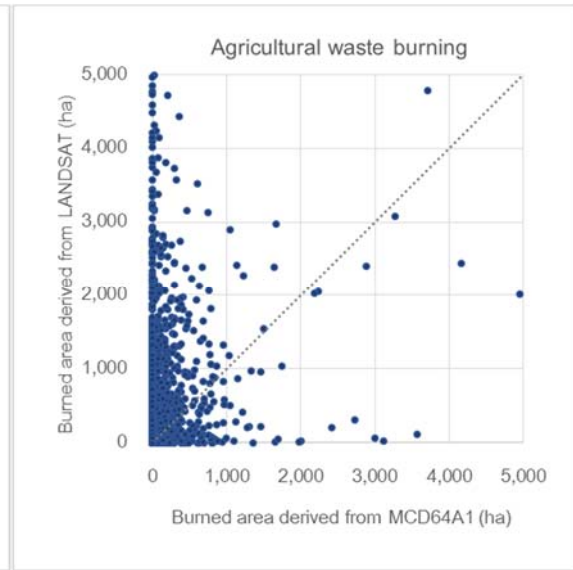
(c)



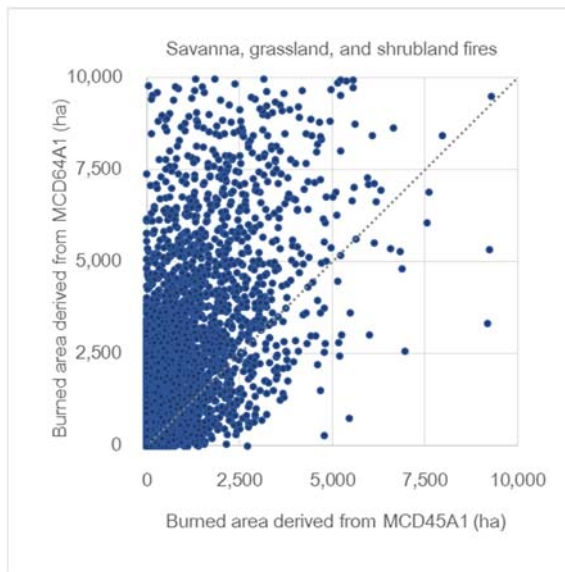
(d)



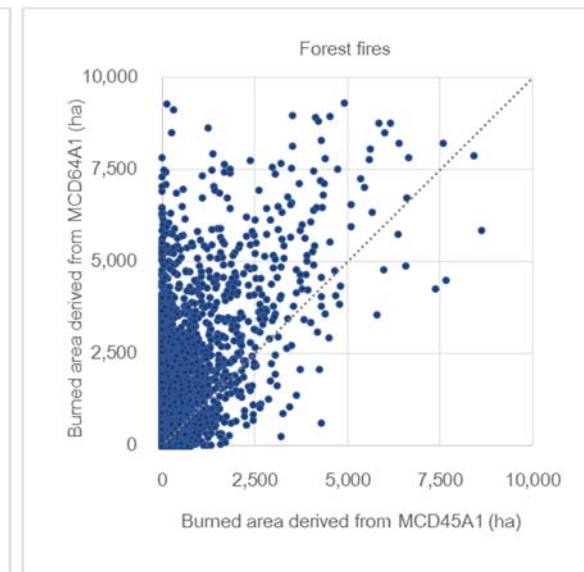
(e)



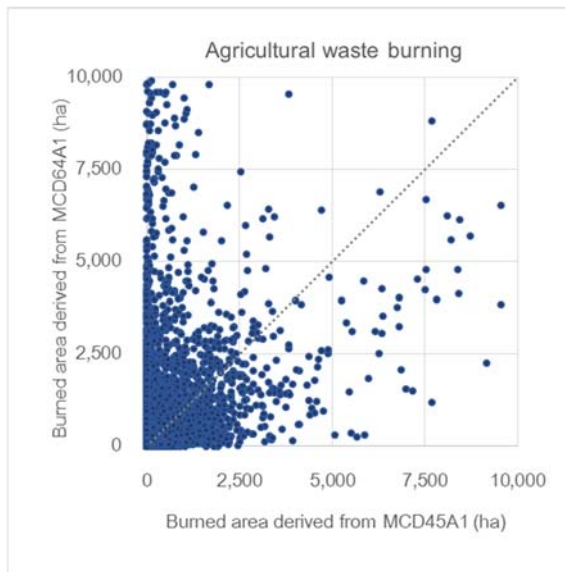
(f)



(g)



(h)



(i)

Figure 37. The scatter plots between the burned area proportion estimates derived from the LANDSAT-8 OLI data and the MODIS burned area product (MCD45A1, MCD64A1), using a continuous grid of 12 km ×12 km that covers the Northern part of Thailand.

Table 5. Estimates of burned area by main vegetation type of GFED4 derived from the Landsat OLI data and the MODIS burned area product data for the total area of the Northern part of Thailand 2515 comparison grids.

Burned area product /Vegetation	No of grid occurrence fires	No of grid without fires	Total of grid	Percent of grid occurrence fires
<i>Reference fires derived from LANDSAT-8 (OLI) images</i>				
Savanna, grassland, and shrub land	2,382	133	2,515	95%
Forest	2019	469	2,515	80%
Cropland	1,964	551	2,515	78%
<i>MCD64A1</i>				
Savanna, grassland, and shrub land	1,784	731	2,515	71%
Forest	1,539	976	2,515	61%
Cropland	896	1,646	2,515	36%
<i>MCD45A1</i>				
Savanna, grassland, and shrub land	847	1,668	2,515	34%
Forest	462	2,053	2,515	18%
Cropland	300	2,215	2,515	12%

Table 6. Detection rate of gridded fire court overlap between MCD64A1 and MCD45A1 burned area products and LANDSAT-8 OLI images.

Detection rate of MCD64A1					
Vegetation	Gridded fire court				Detection rate (%)
	Reference fires	MCD64A1	Overlap MCD45A1 &Ref.	Occurrence Ref. without MCD45A1	
Savanna, grassland, and shrub land	2,382	1,784	1,723	659	72%
Forest	2019	1,539	1,408	638	70%
Cropland	1,964	896	798	1,108	41%
Detection rate of MCD45A1					
Vegetation	Gridded fire court				Detection rate (%)
	Reference fires	MCD45A1	Overlap MCD45A1 &Ref.	Occurrence Ref. without MCD45A1	
Savanna, grassland, and shrub land	2,382	847	812	1,566	34%
Forest	2019	462	425	1,618	21%
Cropland	1,964	300	283	1,679	14%

Table 7. General results of validation of MCD64A1 burned area products in Thailand.

Vegetation	Burned area (ha)		MCD64A1/ Reference fires	Correction Factor
	Reference fires	MCD64A1		
Savanna, grassland, and shrub land	2,640,738	1,250,918	0.47	2.11
Forest	3,254,829	977,060	0.30	3.33
Agriculture	1,193,568	228,913	0.19	5.21
All fires	7,089,135	2,456,891	0.35	2.89

Table 8. General results of validation of MCD45A1 burned area products in Thailand.

Vegetation	Burned area (ha)		MCD45A1/ Reference fires	Correction Factor
	Reference fires	MCD45A1		
Savanna, grassland, and shrub land	2,640,738	316,539	0.12	8.34
Forest	3,254,829	217,162	0.07	14.99
Agriculture	1,193,568	56,620	0.05	21.08
All fires	7,089,135	590,321	0.08	12.01

3.4 Estimation of the Burned Area of Biomass Open Burning in GMS

The burned area calculated by using the correction factors is shown in Table 6. From 2010 to 2017, over the GMS, the forest and agriculture area was combusted by fire at approximately 247.613 Mha. The largest total burned area occurred on the savannas area at over 36% of the total burned area, or approximately 88.591 Mha. The estimation of burned area of biomass burning in the Greater Mekong Sub-region over the 2010 to 2017 time period classified by vegetation fires was shown in Table 9. The trend of adjusted burned area occurred in each vegetation types during 2010-2017 was shown in Figures 38-46.

The annual spatial distribution of burned area density associated with forest fire incidents in 2015 found the highest burned area density to have occurred in the forests situated in the upper northern region of Thailand and the eastern region of Myanmar where deciduous forests. The annual spatial distribution of burned area density associated with crop burning in 2015 found the highest burned area density to have occurred in the croplands situated in the central region of Thailand and the southern region of Vietnam. Figure 47 presents the spatial distribution of burned area in each vegetation fires over the GMS in 2015.

Table 9. The trend of adjusted burned area in each vegetation fires over the GMS during 2010-2017.

Year	Y 2010	Y 2011	Y 2012	Y 2013	Y 2014	Y 2015	Y 2016	Y 2017
Country	The adjusted burned area occurred in croplands during 2010-2017 (1,000 ha)							
Myanmar	1,469	2,280	2,155	1,890	3,817	1,285	1,126	1,358
Cambodia	1,883	2,194	1,644	1,180	2,015	1,922	1,281	948
Laos	769	244	336	409	253	341	384	228
Thailand	2,989	2,442	4,015	3,703	3,448	3,097	2,748	2,642
Vietnam	3,941	1,614	3,333	4,251	4,174	5,436	4,336	1,918
Total	11,050	8,773	11,484	11,433	13,707	12,082	9,875	7,093
Country	The adjusted burned area occurred in deciduous forest during 2010-2017 (1,000 ha)							
Myanmar	152	145	119	124	147	113	85	112
Cambodia	9	10	6	13	14	12	11	7
Laos	1	2	1	1	1	1	1	1
Thailand	3	3	4	3	5	5	5	5
Vietnam	1	1	1	1	2	2	1	0
Total	166	162	130	142	169	133	104	125
Country	The adjusted burned area occurred in evergreen forest during 2010-2017 (1,000 ha)							
Myanmar	4,436	2,732	4,636	3,527	7,618	1,957	1,879	1,014
Cambodia	687	774	603	981	677	849	1,233	307
Laos	3,795	529	1,524	1,960	1,461	1,590	2,515	756
Thailand	609	74	554	313	602	421	1,098	193
Vietnam	917	307	538	319	561	426	482	86
Total	10,444	4,416	7,855	7,100	10,919	5,244	7,206	2,356
Country	The adjusted burned area occurred in mixed forests during 2010-2017 (1,000 ha)							
Myanmar	2,018	1,200	1,661	1,337	1,650	1,998	1,002	1,342
Cambodia	53	22	15	46	11	57	141	7
Laos	7	4	3	3	5	4	4	3
Thailand	177	96	346	128	373	357	138	283
Vietnam	32	3	22	7	22	13	16	3
Total	2,288	1,326	2,046	1,522	2,061	2,429	1,302	1,639
Country	The adjusted burned area occurred in grasslands during 2010-2017 (1,000 ha)							
Myanmar	20	41	20	31	47	27	27	42
Cambodia	86	113	97	70	109	116	80	75
Laos	6	2	4	4	4	4	5	5
Thailand	5	6	6	10	10	11	7	13
Vietnam	9	3	10	9	15	20	12	6
Total	125	166	137	125	185	177	130	141

Year	Y 2010	Y 2011	Y 2012	Y 2013	Y 2014	Y 2015	Y 2016	Y 2017
Country	The adjusted burned area occurred in savannas during 2010-2017 (1,000 ha)							
Myanmar	5,993	3,611	4,896	3,688	5,224	4,945	2,924	4,114
Cambodia	4,062	5,258	4,862	4,248	5,105	5,619	3,482	5,100
Laos	582	242	318	390	311	345	386	268
Thailand	1,208	571	1,277	715	1,510	1,273	1,068	1,343
Vietnam	463	571	625	230	440	574	340	411
Total	12,308	10,253	11,976	9,271	12,590	12,756	8,201	11,236
Country	The adjusted burned area occurred in shrublands during 2010-2017 (1,000 ha)							
Myanmar	0.6	1.6	1.6	1.5	2.9	0.6	0.5	1.5
Cambodia	2.3	2.6	1.3	2.4	3.2	4.2	3.0	1.8
Laos	0.0	0.1	0.0	0.1	0.0	0.2	0.2	0.1
Thailand	0.1	-	0.1	0.1	0.1	0.1	0.2	0.1
Vietnam	0.2	0.2	0.1	0.1	0.4	0.5	0.3	0.1
Total	3.2	4.5	3.1	4.1	6.6	5.5	4.3	3.6
Country	The adjusted burned area occurred in permanent wetland during 2010-2017 (1,000 ha)							
Myanmar	7	68	74	65	259	5	7	32
Cambodia	40	15	11	45	12	44	89	8
Laos	2	0	0	2	1	1	2	0
Thailand	5	3	9	7	7	4	5	5
Vietnam	19	5	31	22	34	35	27	14
Total	73	92	125	141	313	89	130	59
Country	The adjusted burned area from biomass open burning during 2010-2017 (1,000 ha)							
Myanmar	14,096	10,079	13,562	10,664	18,764	10,331	7,050	8,017
Cambodia	6,823	8,390	7,239	6,585	7,946	8,623	6,320	6,454
Laos	5,161	1,023	2,186	2,769	2,036	2,286	3,297	1,261
Thailand	4,996	3,195	6,211	4,880	5,955	5,169	5,069	4,484
Vietnam	5,382	2,505	4,559	4,840	5,248	6,505	5,216	2,437
Total	36,458	25,191	33,756	29,738	39,949	32,915	26,952	22,654

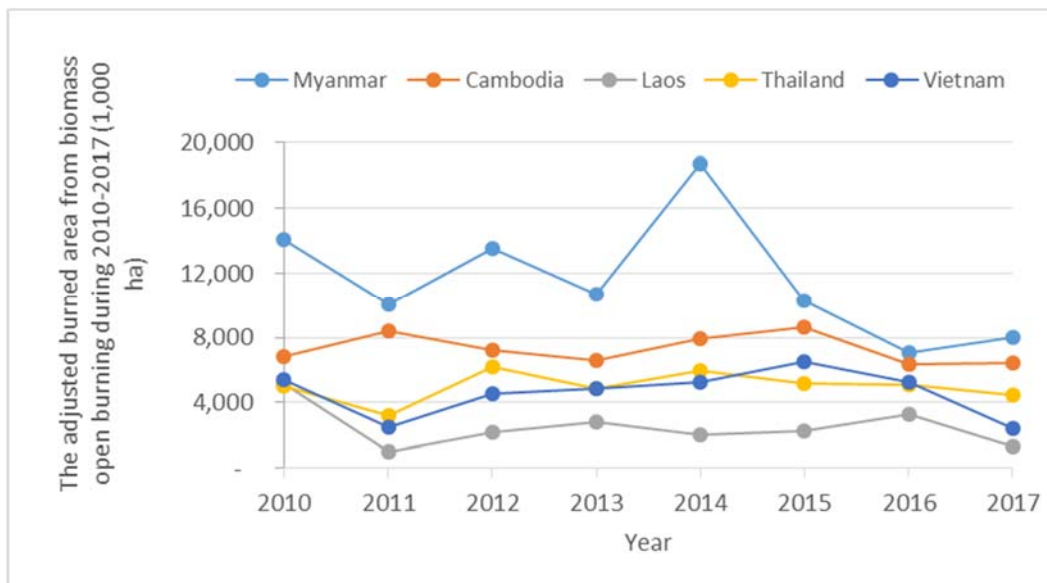


Figure 38. The trend adjusted burned area from biomass open burning during 2010-2017

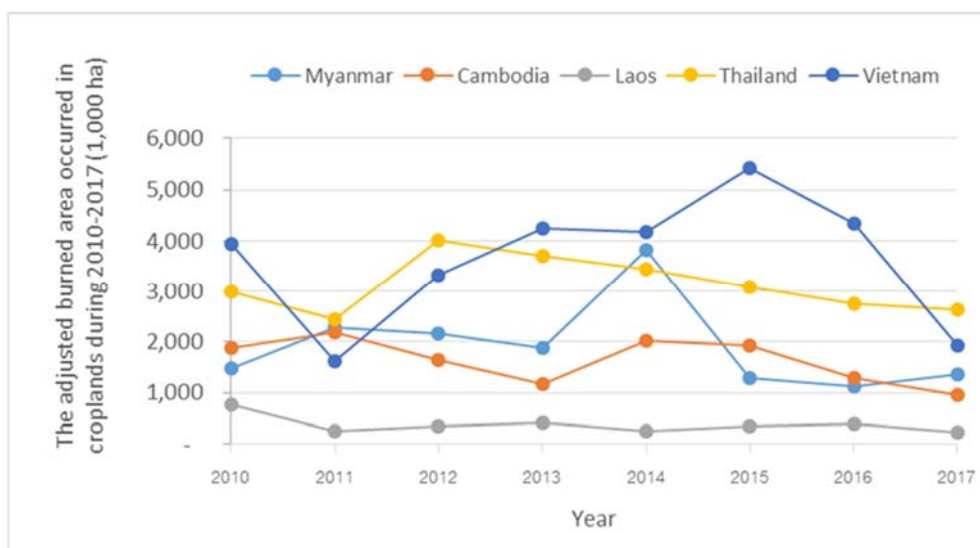


Figure 39. The trend of adjusted burned area occurred in croplands during 2010-2017

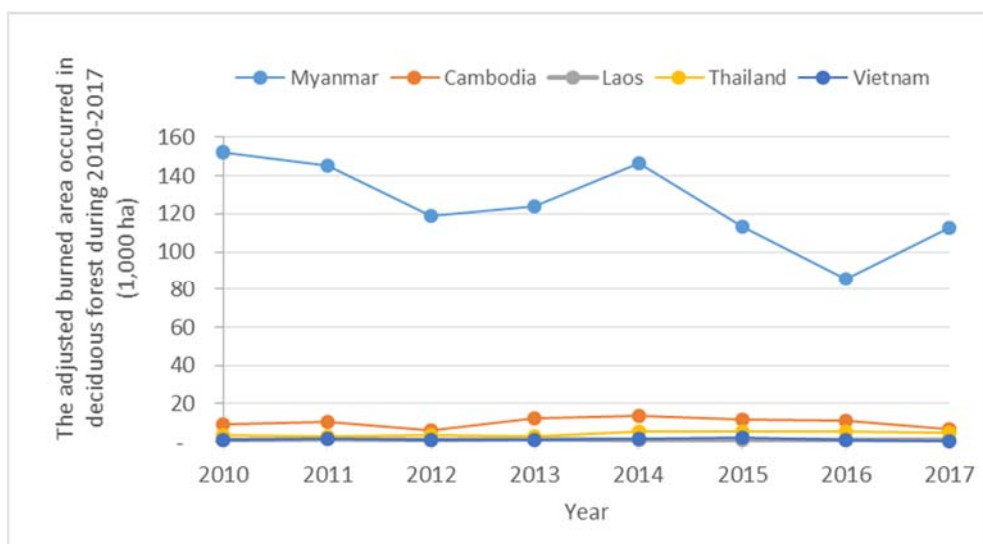


Figure 40. The trend of adjusted burned area occurred in deciduous forest during 2010-2017

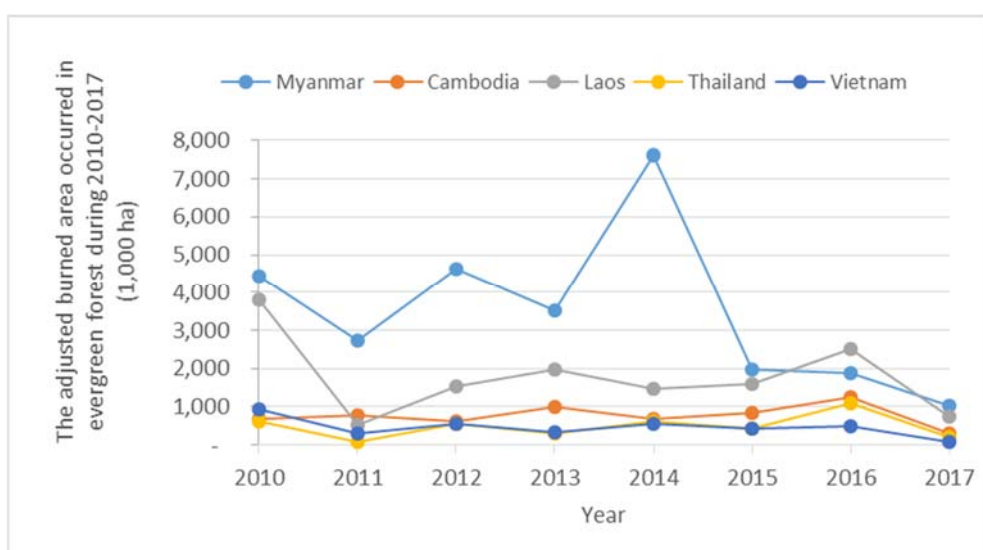


Figure 41. The trend adjusted burned area occurred in evergreen forest during 2010-2017

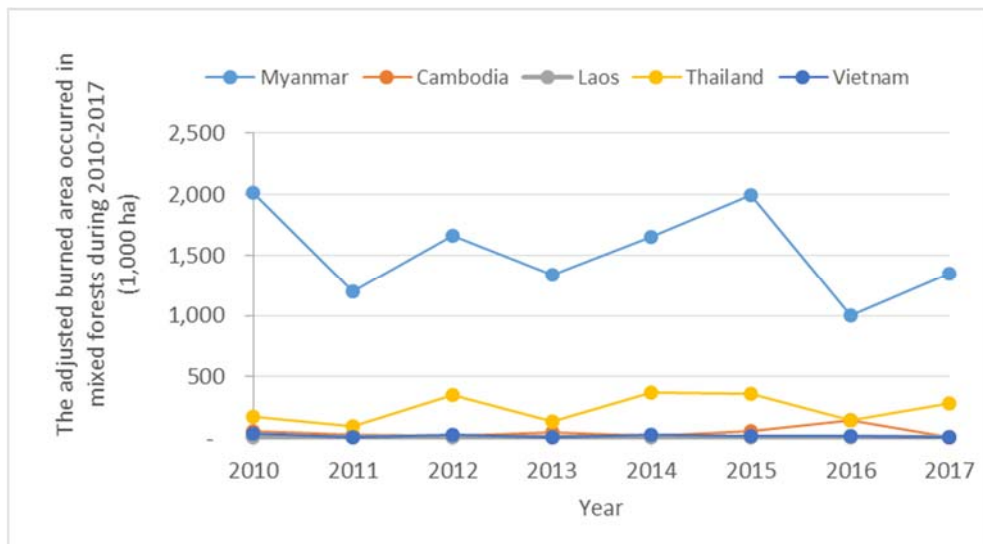


Figure 42. The trend adjusted burned area occurred in mixed forest during 2010-2017

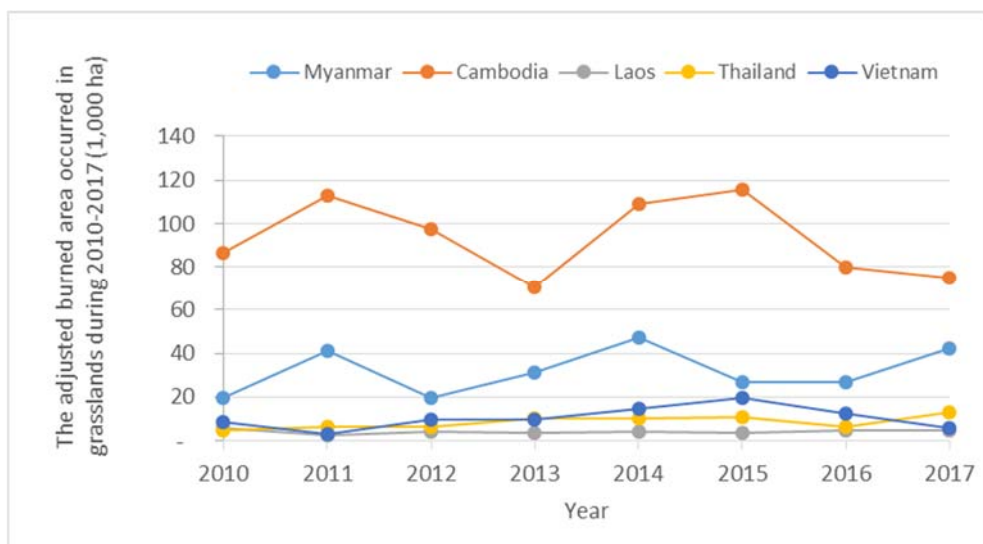


Figure 43. The trend adjusted burned area occurred in grasslands during 2010-2017

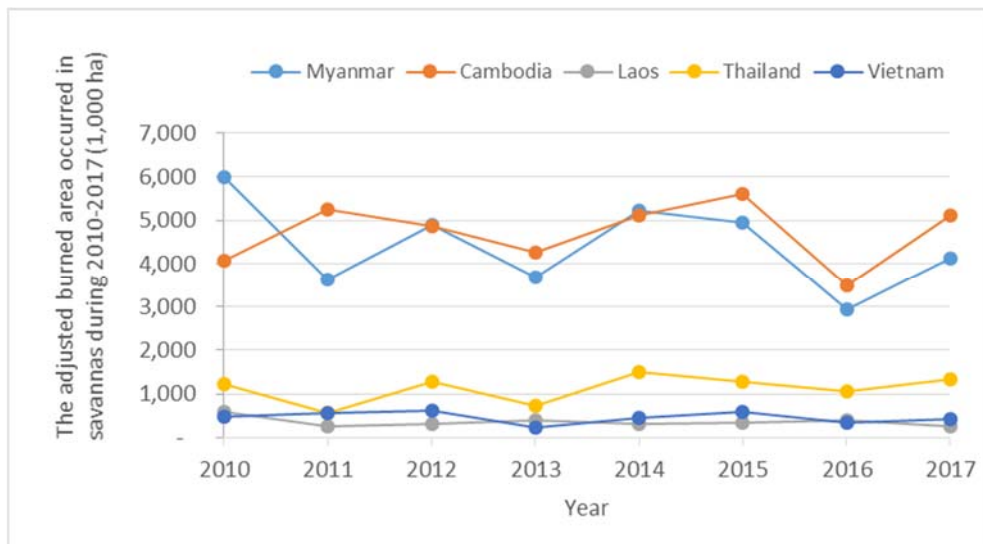


Figure 44. The trend adjusted burned area occurred in savannas during 2010-2017

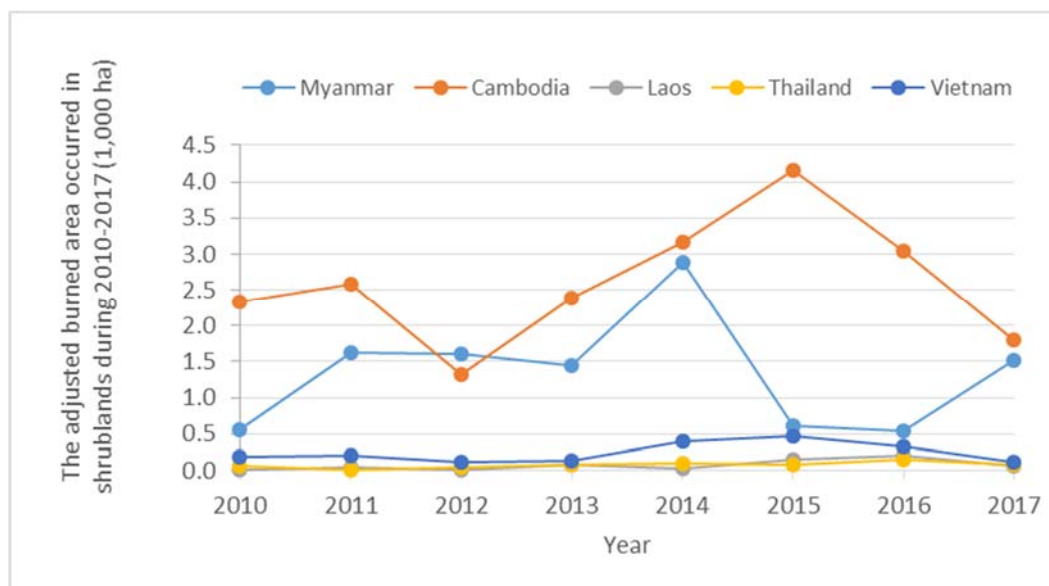


Figure 45. The trend adjusted burned area occurred in shrublands during 2010-2017

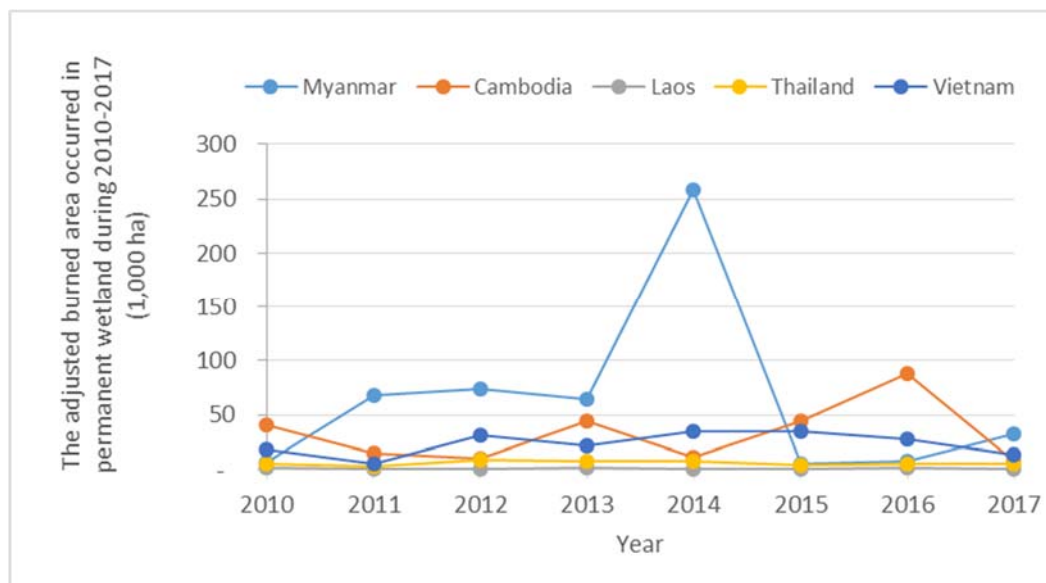
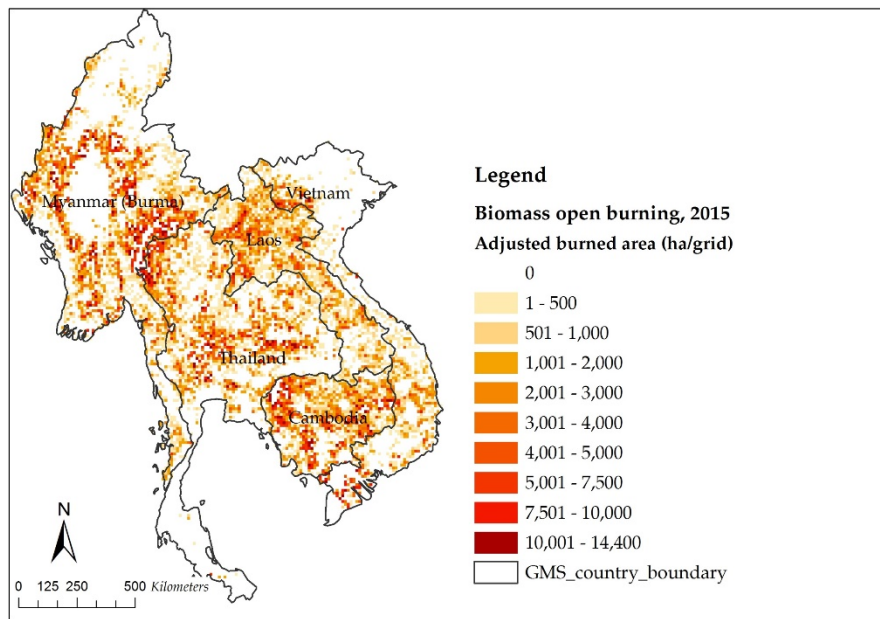
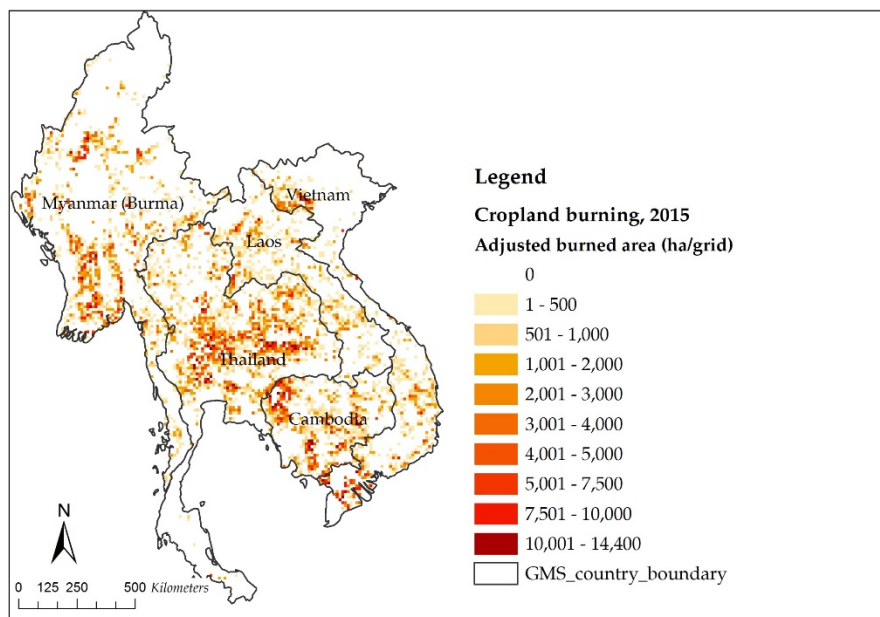


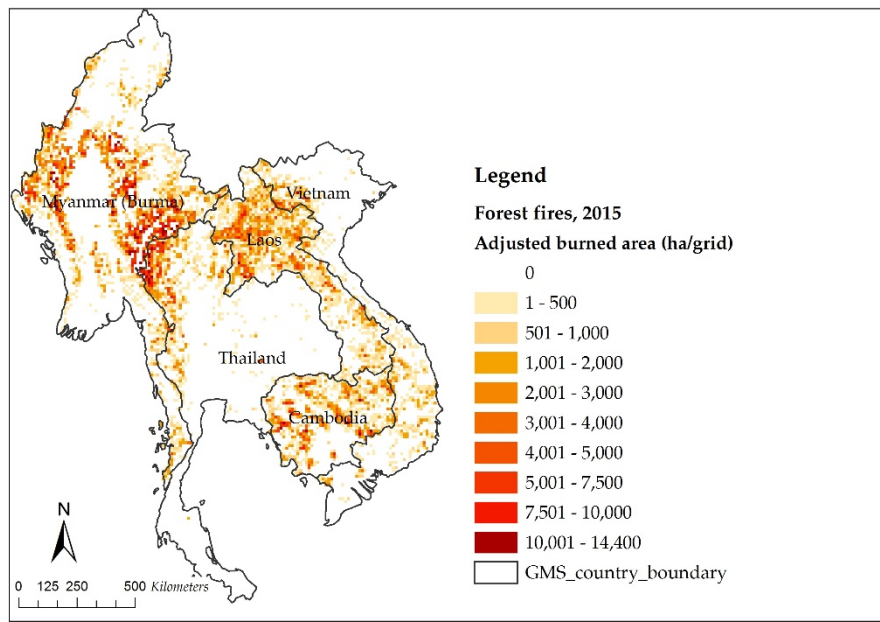
Figure 46. The trend adjusted burned area occurred in permanent wetland during 2010-2017



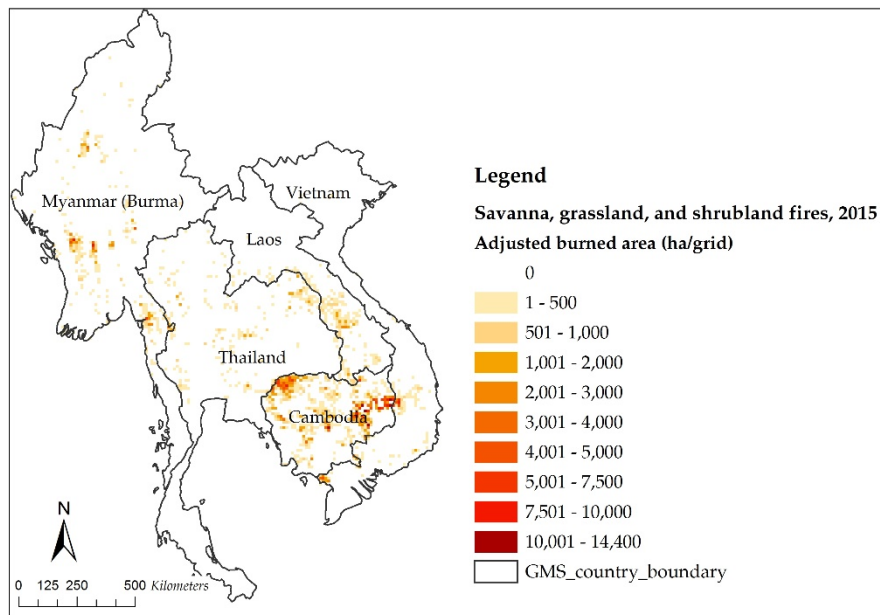
(a) All vegetation



(b) Cropland



(c) Forestland



(d) Savannas

Figure 47. Spatial distribution of adjusted burned area occurred in (a) all vegetation, (b) cropland, (c) forestland and (d) savannas over the GMS in 2015

3.5 Biomass Load and Combustion Efficiency

This study used the results of van Leeuwen, et al. (2014) [10] which was compiled the peer-reviewed literature on fuel combustion for various biomes and fuel categories to understand fuel combustion and its variability better. They provided a database that can be used to constrain biogeochemical models with fire modules. Their study compiled in total 77 studies covering 11 biomes including savanna, tropical forest, temperate forest, boreal forest, pasture, shifting cultivation, crop residue, chaparral, tropical peatland, boreal peatland, and tundra. The average of fuel load and combustion efficiency presented in the Table 10.

Table 10. Value of fuel load and combustion efficiency in each vegetation fires.

Land cover types	Fuel load (t/ha)		Combustion efficiency	
	Value	SD	Value	SD
Croplands	8.3	9.9	0.75	0.210
Deciduous Forest	8.9	1.0	0.65	0.002
Evergreen Forest	8.9	1.0	0.65	0.002
Mixed Forests	8.9	1.0	0.65	0.002
Grasslands	5.3	2.0	0.81	0.160
Savannas	8.9	1.0	0.65	0.002
Shrublands	11.0	9.1	0.58	0.320
Wetland*	23.3	876.0	0.38	0.000

3.6 Assessment of air pollutant emissions from biomass burning

During 2010-2017, the total of emissions from biomass open burning were approximately 2,736,136 kt of CO₂, 7,165 kt of CH₄, 281 kt of N₂O, 143,462 kt of CO, 5,335 kt of NO_x, 715 kt of SO₂, 2,191 kt of NH₃, 12,584 kt of PM_{2.5}, 18,737 kt of TPM, 898 kt of BC, and 5,363 kt of OC. The annual average of emissions from biomass open burning were approximately 342,000 kt of CO₂, 896 kt of CH₄, 35 kt of N₂O, 17,933 kt of CO, 667 kt of NO_x, 89 kt of SO₂, 274 kt of NH₃, 1,573 kt of PM_{2.5}, 2,342 kt of TPM, 112 kt of BC, and 670 kt of OC. The actual amount of air pollutant emissions (CO₂, CH₄, N₂O, CO, NO_x, NH₃, PM_{2.5}, TPM, BC, and OC) from biomass open burning in GMS, during 2010-2017 is presented in the Tables 11 to 21. Considering the amount of PM_{2.5} emission from biomass open burning in 2015 in each country, it can be concluded that the amount of PM_{2.5} emission was about 1,529 kt, consisting of 541 kt, 336 kt, 143 kt, 232 kt and 272 kt for the Myanmar, Cambodia, Laos, Thailand and Vietnam, respectively. The share amount

and percentage of PM_{2.5} emission from biomass open burning in GMS during 2010-2017 is shown in Figures 48 to 63.

Table 11. The actual amount of CO₂ emission from biomass open burning in GMS, during 2010-2017 (Mt)

The actual amount of CO ₂ emission from biomass open burning in GMS, during 2010-2017 (Mt)									
Countries	CO ₂ emission from biomass open burning in GMS, 2010 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	14.49	1.58	57.89	20.95	0.25	65.32	0.01	0.10	160.59
Cambodia	18.57	0.10	8.52	0.60	1.04	42.62	0.03	0.61	72.09
Laos	7.59	0.01	48.28	0.07	0.07	6.91	0.00	0.03	62.96
Thailand	29.49	0.04	7.73	2.08	0.06	15.10	0.00	0.08	54.58
Vietnam	38.89	0.01	11.67	0.35	0.11	5.25	0.00	0.28	56.56
Total	109.03	1.75	134.44	24.01	1.53	133.39	0.04	1.10	405.28
Countries	CO ₂ emission from biomass open burning in GMS, 2011 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	22.49	1.51	35.65	12.46	0.51	39.36	0.02	1.02	113.03
Cambodia	21.64	0.12	9.60	0.25	1.36	55.17	0.03	0.23	88.41
Laos	2.41	0.02	6.73	0.04	0.03	2.87	0.00	0.00	12.10
Thailand	24.09	0.04	0.93	1.13	0.09	7.13	-	0.05	33.46
Vietnam	15.92	0.02	3.91	0.03	0.04	6.47	0.00	0.08	26.47
Total	86.56	1.70	56.84	13.92	2.03	111.11	0.05	1.39	273.60
Countries	CO ₂ emission from biomass open burning in GMS, 2012 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	21.26	1.14	61.22	18.90	0.24	57.83	0.02	1.12	161.73
Cambodia	16.22	0.06	7.47	0.16	1.03	45.59	0.01	0.16	70.70
Laos	3.32	0.01	20.12	0.04	0.05	4.02	0.00	0.00	27.57
Thailand	39.62	0.04	7.34	4.37	0.09	16.49	0.00	0.14	68.09
Vietnam	32.89	0.01	7.09	0.28	0.13	6.21	0.00	0.47	47.07
Total	113.30	1.26	103.27	23.78	1.53	130.97	0.04	1.89	376.04
Countries	CO ₂ emission from biomass open burning in GMS, 2013 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
	18.65	1.28	45.46	14.75	0.41	41.20	0.02	0.97	122.73
Cambodia	11.64	0.15	12.38	0.59	0.80	44.69	0.03	0.67	70.95
Laos	4.03	0.02	25.36	0.04	0.05	4.78	0.00	0.02	34.30
Thailand	36.54	0.03	3.95	1.29	0.14	8.44	0.00	0.11	50.51
Vietnam	41.94	0.02	4.12	0.08	0.11	2.47	0.00	0.34	49.07
Total	112.81	1.50	91.28	16.77	1.50	101.66	0.05	2.12	327.68
Countries	CO ₂ emission from biomass open burning in GMS, 2014 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	37.66	1.48	99.99	18.74	0.58	61.93	0.04	3.90	224.32
Cambodia	19.88	0.14	7.88	0.13	1.27	53.21	0.03	0.17	82.72
Laos	2.50	0.01	18.73	0.06	0.06	3.64	0.00	0.01	25.02
Thailand	34.02	0.06	7.84	4.53	0.13	19.19	0.00	0.11	65.88
Vietnam	41.18	0.02	7.34	0.29	0.18	5.49	0.01	0.52	55.02

The actual amount of CO ₂ emission from biomass open burning in GMS, during 2010-2017 (Mt)									
Total	135.24	1.72	141.86	23.76	2.22	143.84	0.08	4.71	453.42
Countries	CO ₂ emission from biomass open burning in GMS, 2015 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	12.68	1.05	23.71	21.29	0.24	54.72	0.01	0.08	113.78
Cambodia	18.97	0.10	9.40	0.73	0.98	45.93	0.04	0.67	76.80
Laos	3.36	0.01	20.35	0.05	0.04	3.93	0.00	0.01	27.76
Thailand	30.56	0.05	5.19	3.64	0.11	14.20	0.00	0.06	53.81
Vietnam	53.64	0.02	5.33	0.15	0.21	5.69	0.01	0.52	65.57
Total	119.20	1.24	64.06	25.87	1.59	125.29	0.05	1.34	338.64
Countries	CO ₂ emission from biomass open burning in GMS, 2016 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	11.11	0.85	23.69	9.86	0.31	31.93	0.01	0.11	77.87
Cambodia	12.64	0.12	15.22	1.80	0.91	36.35	0.03	1.34	68.42
Laos	3.79	0.01	32.41	0.05	0.06	4.67	0.00	0.02	41.02
Thailand	27.11	0.06	14.35	1.42	0.09	13.04	0.00	0.07	56.14
Vietnam	42.78	0.01	6.28	0.19	0.12	3.53	0.00	0.41	53.33
Total	97.43	1.06	91.98	13.37	1.49	89.64	0.05	1.96	296.98
Countries	CO ₂ emission from biomass open burning in GMS, 2017 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	13.40	1.31	13.11	16.06	0.55	51.55	0.02	0.48	96.48
Cambodia	9.35	0.08	3.92	0.09	0.95	62.25	0.02	0.12	76.78
Laos	2.25	0.01	9.90	0.04	0.07	3.43	0.00	0.00	15.71
Thailand	26.07	0.06	2.51	3.57	0.18	17.79	0.00	0.08	50.25
Vietnam	18.92	0.01	1.14	0.03	0.07	4.81	0.00	0.21	25.19
Total	69.99	1.46	30.58	19.80	1.82	139.90	0.04	0.90	264.49
Countries	The total of CO ₂ emission from biomass open burning in GMS, during 2010-2017 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	151.73	10.20	360.73	133.00	3.08	403.85	0.14	7.79	1,070.524
Cambodia	128.92	0.86	74.39	4.35	8.34	385.82	0.23	3.97	606.884
Laos	29.24	0.11	181.89	0.40	0.42	34.25	0.01	0.11	246.437
Thailand	247.49	0.39	49.86	22.02	0.87	111.37	0.01	0.70	432.705
Vietnam	286.16	0.11	46.87	1.41	0.97	39.92	0.02	2.83	378.299
Grand	843.55	11.69	714.31	161.27	13.71	975.80	0.41	15.39	2,736.136
Countries	The annual average of CO ₂ emission from biomass open burning in GMS, during 2010-2017 (Mt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	18.97	1.28	45.09	16.62	0.39	50.48	0.02	0.97	133.82
Cambodia	16.12	0.11	9.30	0.54	1.04	48.23	0.03	0.50	75.86
Laos	3.66	0.01	22.74	0.05	0.05	4.28	0.00	0.01	30.80
Thailand	30.94	0.05	6.23	2.75	0.11	13.92	0.00	0.09	54.09
Vietnam	35.77	0.01	5.86	0.18	0.12	4.99	0.00	0.35	47.29
Total	105.44	1.46	89.29	20.16	1.71	121.97	0.05	1.92	342.02

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 12. The actual amount of CH₄ emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of CH ₄ emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	CH ₄ emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	53.21	4.89	178.64	64.64	0.28	75.30	0.01	1.25	378.22
Cambodia	68.20	0.30	26.29	1.84	1.20	49.13	0.03	7.41	154.42
Laos	27.86	0.04	148.99	0.22	0.08	7.96	0.00	0.31	185.46
Thailand	108.28	0.13	23.86	6.40	0.07	17.41	0.00	0.95	157.10
Vietnam	142.78	0.04	36.00	1.09	0.13	6.05	0.00	3.46	189.56
Total	400.33	5.41	414.85	74.10	1.76	153.76	0.04	13.39	1,063.64
Countries	CH ₄ emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	82.59	4.67	110.00	38.44	0.59	45.37	0.02	12.49	294.18
Cambodia	79.48	0.36	29.63	0.77	1.57	63.59	0.04	2.82	178.26
Laos	8.83	0.06	20.77	0.14	0.03	3.31	0.00	0.03	33.17
Thailand	88.47	0.12	2.88	3.47	0.10	8.22	-	0.60	103.86
Vietnam	58.46	0.05	12.05	0.10	0.04	7.46	0.00	1.01	79.18
Total	317.83	5.26	175.38	42.94	2.34	128.08	0.06	16.95	688.84
Countries	CH ₄ emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	78.07	3.51	188.92	58.31	0.27	66.66	0.02	13.68	409.44
Cambodia	59.56	0.19	23.04	0.51	1.18	52.55	0.02	1.94	138.98
Laos	12.19	0.03	62.10	0.12	0.06	4.63	0.00	0.06	79.19
Thailand	145.47	0.13	22.66	13.49	0.10	19.00	0.00	1.72	202.57
Vietnam	120.76	0.03	21.87	0.88	0.14	7.16	0.00	5.69	156.53
Total	416.04	3.89	318.66	73.37	1.77	150.97	0.04	23.09	987.83
Countries	CH ₄ emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
	68.48	3.95	140.29	45.50	0.47	47.49	0.02	11.88	318.08
Cambodia	42.75	0.46	38.21	1.82	0.92	51.51	0.03	8.20	143.91
Laos	14.81	0.06	78.25	0.13	0.05	5.51	0.00	0.29	99.11
Thailand	134.16	0.10	12.19	3.99	0.16	9.73	0.00	1.38	161.72
Vietnam	154.00	0.05	12.72	0.25	0.12	2.85	0.00	4.13	174.12
Total	414.22	4.62	281.67	51.73	1.73	117.18	0.06	25.88	897.10
Countries	CH ₄ emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	138.28	4.56	308.56	57.83	0.67	71.38	0.04	47.66	628.99
Cambodia	73.00	0.43	24.31	0.40	1.47	61.34	0.04	2.13	163.12
Laos	9.18	0.05	57.81	0.18	0.07	4.20	0.00	0.10	71.59
Thailand	124.90	0.19	24.21	13.99	0.15	22.12	0.00	1.33	186.88
Vietnam	151.23	0.07	22.64	0.88	0.21	6.33	0.01	6.32	187.67
Total	496.58	5.30	437.76	73.32	2.55	165.80	0.09	57.54	1,238.96
Countries	CH ₄ emission from biomass open burning in GMS, 2015 (kt)								

The actual amount of CH ₄ emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	46.56	3.25	73.17	65.69	0.27	63.08	0.01	0.95	252.97
Cambodia	69.64	0.31	29.00	2.24	1.13	52.95	0.04	8.15	163.46
Laos	12.34	0.04	62.80	0.15	0.05	4.53	0.00	0.16	80.07
Thailand	112.21	0.16	16.02	11.23	0.13	16.36	0.00	0.69	156.81
Vietnam	196.96	0.07	16.45	0.46	0.25	6.56	0.01	6.35	227.10
Total	437.71	3.83	197.69	79.82	1.83	144.43	0.06	16.31	881.67
Countries	CH ₄ emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	40.78	2.62	73.12	30.42	0.36	36.80	0.01	1.36	185.46
Cambodia	46.42	0.38	46.98	5.57	1.05	41.90	0.04	16.31	158.65
Laos	13.90	0.04	100.01	0.17	0.07	5.38	0.00	0.29	119.87
Thailand	99.56	0.19	44.28	4.37	0.10	15.03	0.00	0.91	164.43
Vietnam	157.10	0.03	19.38	0.59	0.14	4.07	0.00	5.05	186.36
Total	357.76	3.26	283.84	41.26	1.72	103.33	0.06	23.92	815.15
Countries	CH ₄ emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	49.19	4.05	40.46	49.57	0.64	59.42	0.02	5.88	209.22
Cambodia	34.35	0.23	12.08	0.28	1.10	71.76	0.02	1.49	121.31
Laos	8.27	0.03	30.56	0.12	0.08	3.95	0.00	0.06	43.07
Thailand	95.71	0.18	7.75	11.01	0.21	20.51	0.00	0.94	136.31
Vietnam	69.47	0.02	3.52	0.10	0.09	5.54	0.00	2.58	81.32
Total	256.98	4.51	94.38	61.09	2.10	161.26	0.05	10.94	591.32
Countries	The total of CH ₄ emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	557.16	31.49	1,113.14	410.40	3.55	465.52	0.16	95.15	2,676.57
Cambodia	473.39	2.67	229.55	13.44	9.62	444.73	0.26	48.45	1,222.11
Laos	107.38	0.34	561.29	1.23	0.49	39.48	0.01	1.31	711.53
Thailand	908.76	1.20	153.84	67.95	1.01	128.38	0.01	8.51	1,269.67
Vietnam	1,050.77	0.35	144.64	4.34	1.12	46.02	0.03	34.59	1,281.84
Total	3,097.46	36.09	2,204.24	497.64	15.80	1,124.81	0.47	188.02	7,164.52
Countries	The annual average of CH ₄ emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	69.64	3.94	139.14	51.30	0.44	58.19	0.02	11.89	334.57
Cambodia	59.17	0.33	28.69	1.68	1.20	55.59	0.03	6.06	152.76
Laos	13.42	0.04	70.16	0.15	0.06	4.94	0.00	0.16	88.94
Thailand	113.60	0.15	19.23	8.49	0.13	16.05	0.00	1.06	158.71
Vietnam	131.35	0.04	18.08	0.54	0.14	5.75	0.00	4.32	160.23
Total	387.18	4.51	275.53	62.20	1.98	140.60	0.06	23.50	895.57

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 13. The actual amount of N₂O emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of N ₂ O emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	N ₂ O emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	0.91	0.19	7.05	2.55	0.03	7.76	0.00	0.01	18.51
Cambodia	1.17	0.01	1.04	0.07	0.12	5.07	0.00	0.07	7.56
Laos	0.48	0.00	5.88	0.01	0.01	0.82	0.00	0.00	7.20
Thailand	1.86	0.01	0.94	0.25	0.01	1.79	0.00	0.01	4.87
Vietnam	2.45	0.00	1.42	0.04	0.01	0.62	0.00	0.03	4.59
Total	6.88	0.21	16.36	2.92	0.18	15.85	0.00	0.13	42.55
Countries	N ₂ O emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	1.42	0.18	4.34	1.52	0.06	4.68	0.00	0.12	12.32
Cambodia	1.37	0.01	1.17	0.03	0.16	6.56	0.00	0.03	9.33
Laos	0.15	0.00	0.82	0.01	0.00	0.34	0.00	0.00	1.32
Thailand	1.52	0.00	0.11	0.14	0.01	0.85	-	0.01	2.64
Vietnam	1.00	0.00	0.48	0.00	0.00	0.77	0.00	0.01	2.27
Total	5.46	0.21	6.92	1.69	0.24	13.20	0.01	0.16	27.90
Countries	N ₂ O emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	1.34	0.14	7.45	2.30	0.03	6.87	0.00	0.13	18.27
Cambodia	1.02	0.01	0.91	0.02	0.12	5.42	0.00	0.02	7.52
Laos	0.21	0.00	2.45	0.00	0.01	0.48	0.00	0.00	3.15
Thailand	2.50	0.01	0.89	0.53	0.01	1.96	0.00	0.02	5.92
Vietnam	2.07	0.00	0.86	0.03	0.01	0.74	0.00	0.05	3.78
Total	7.15	0.15	12.57	2.89	0.18	15.56	0.00	0.22	38.74
Countries	N ₂ O emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
	1.18	0.16	5.53	1.80	0.05	4.90	0.00	0.11	13.72
Cambodia	0.73	0.02	1.51	0.07	0.09	5.31	0.00	0.08	7.82
Laos	0.25	0.00	3.09	0.01	0.01	0.57	0.00	0.00	3.93
Thailand	2.31	0.00	0.48	0.16	0.02	1.00	0.00	0.01	3.98
Vietnam	2.65	0.00	0.50	0.01	0.01	0.29	0.00	0.04	3.51
Total	7.12	0.18	11.11	2.04	0.18	12.08	0.01	0.25	32.97
Countries	N ₂ O emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	2.38	0.18	12.17	2.28	0.07	7.36	0.00	0.46	24.90
Cambodia	1.25	0.02	0.96	0.02	0.15	6.32	0.00	0.02	8.75
Laos	0.16	0.00	2.28	0.01	0.01	0.43	0.00	0.00	2.89
Thailand	2.15	0.01	0.95	0.55	0.02	2.28	0.00	0.01	5.97
Vietnam	2.60	0.00	0.89	0.03	0.02	0.65	0.00	0.06	4.26
Total	8.53	0.21	17.27	2.89	0.26	17.09	0.01	0.55	46.82
Countries	N ₂ O emission from biomass open burning in GMS, 2015 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total

The actual amount of N ₂ O emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	0.80	0.13	2.89	2.59	0.03	6.50	0.00	0.01	12.95
Cambodia	1.20	0.01	1.14	0.09	0.12	5.46	0.00	0.08	8.10
Laos	0.21	0.00	2.48	0.01	0.00	0.47	0.00	0.00	3.17
Thailand	1.93	0.01	0.63	0.44	0.01	1.69	0.00	0.01	4.72
Vietnam	3.38	0.00	0.65	0.02	0.03	0.68	0.00	0.06	4.82
Total	7.52	0.15	7.80	3.15	0.19	14.89	0.01	0.16	33.86
Countries	N2O emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	0.70	0.10	2.88	1.20	0.04	3.79	0.00	0.01	8.73
Cambodia	0.80	0.01	1.85	0.22	0.11	4.32	0.00	0.16	7.47
Laos	0.24	0.00	3.95	0.01	0.01	0.56	0.00	0.00	4.76
Thailand	1.71	0.01	1.75	0.17	0.01	1.55	0.00	0.01	5.21
Vietnam	2.70	0.00	0.76	0.02	0.01	0.42	0.00	0.05	3.97
Total	6.15	0.13	11.20	1.63	0.18	10.65	0.01	0.23	30.17
Countries	N2O emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	0.85	0.16	1.60	1.96	0.07	6.13	0.00	0.06	10.81
Cambodia	0.59	0.01	0.48	0.01	0.11	7.40	0.00	0.01	8.61
Laos	0.14	0.00	1.21	0.00	0.01	0.41	0.00	0.00	1.77
Thailand	1.64	0.01	0.31	0.43	0.02	2.11	0.00	0.01	4.54
Vietnam	1.19	0.00	0.14	0.00	0.01	0.57	0.00	0.02	1.94
Total	4.42	0.18	3.72	2.41	0.22	16.63	0.01	0.11	27.68
Countries	The total of N2O emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	9.57	1.24	43.91	16.19	0.37	47.99	0.02	0.91	120.205
Cambodia	8.13	0.11	9.06	0.53	0.99	45.85	0.03	0.47	65.157
Laos	1.85	0.01	22.14	0.05	0.05	4.07	0.00	0.01	28.183
Thailand	15.61	0.05	6.07	2.68	0.10	13.23	0.00	0.08	37.833
Vietnam	18.05	0.01	5.71	0.17	0.12	4.74	0.00	0.33	29.140
Total	53.22	1.42	86.95	19.63	1.63	115.96	0.05	1.81	280.672
Countries	The annual average of N2O emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	1.20	0.16	5.49	2.02	0.05	6.00	0.00	0.11	15.03
Cambodia	1.02	0.01	1.13	0.07	0.12	5.73	0.00	0.06	8.14
Laos	0.23	0.00	2.77	0.01	0.01	0.51	0.00	0.00	3.52
Thailand	1.95	0.01	0.76	0.34	0.01	1.65	0.00	0.01	4.73
Vietnam	2.26	0.00	0.71	0.02	0.01	0.59	0.00	0.04	3.64
Total	6.65	0.18	10.87	2.45	0.20	14.49	0.01	0.23	35.08

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 14. The actual amount of CO emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of CO emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	CO emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	932.54	89.69	3,276.79	1,185.67	9.23	2,445.21	0.26	12.63	7,952.01
Cambodia	1,195.32	5.59	482.31	33.82	39.01	1,595.56	1.07	74.80	3,427.48
Laos	488.18	0.72	2,732.93	4.07	2.60	258.58	0.00	3.17	3,490.24
Thailand	1,897.73	2.41	437.59	117.49	2.26	565.23	0.03	9.56	3,032.31
Vietnam	2,502.39	0.67	660.34	20.08	4.19	196.44	0.09	34.97	3,419.18
Total	7,016.16	99.31	7,609.62	1,359.20	57.29	4,993.15	1.45	135.14	21,271.32
Countries	CO emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	1,447.44	85.68	2,017.75	705.14	19.19	1,473.48	0.75	126.12	5,875.55
Cambodia	1,392.89	6.57	543.60	14.12	51.04	2,065.15	1.19	28.45	4,103.01
Laos	154.83	1.05	380.92	2.55	1.07	107.34	0.03	0.30	648.09
Thailand	1,550.45	2.17	52.82	63.69	3.21	267.02	-	6.07	1,945.42
Vietnam	1,024.63	0.93	221.11	1.77	1.45	242.35	0.09	10.16	1,502.49
Total	5,570.23	96.47	3,217.08	787.65	75.99	4,159.28	2.06	171.11	14,079.86
Countries	CO emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	1,368.29	64.34	3,465.33	1,069.56	8.83	2,164.89	0.75	138.10	8,280.11
Cambodia	1,043.75	3.43	422.69	9.29	38.46	1,706.47	0.51	19.60	3,244.20
Laos	213.60	0.61	1,139.12	2.17	2.03	150.37	0.00	0.59	1,508.49
Thailand	2,549.45	2.43	415.68	247.40	3.19	617.10	0.03	17.35	3,852.64
Vietnam	2,116.35	0.52	401.17	16.08	4.68	232.64	0.06	57.47	2,828.97
Total	7,291.45	71.41	5,845.24	1,345.93	57.38	4,902.51	1.36	233.11	19,748.39
Countries	CO emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
	1,200.24	72.38	2,573.32	834.70	15.19	1,542.18	0.70	119.98	6,358.69
Cambodia	749.26	8.48	700.90	33.45	29.87	1,672.77	1.06	82.79	3,278.59
Laos	259.64	1.01	1,435.37	2.35	1.71	178.99	0.04	2.94	1,882.05
Thailand	2,351.29	1.91	223.65	73.24	5.25	315.85	0.04	13.88	2,985.12
Vietnam	2,699.02	0.90	233.24	4.53	3.96	92.41	0.06	41.73	3,075.85
Total	7,259.45	84.78	5,166.78	948.97	56.16	3,805.35	1.90	261.32	17,584.70
Countries	CO emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	2,423.38	83.71	5,660.00	1,060.79	21.75	2,318.15	1.46	481.19	12,050.42
Cambodia	1,279.33	7.93	445.98	7.37	47.61	1,991.99	1.29	21.53	3,803.05
Laos	160.91	0.83	1,060.45	3.39	2.12	136.43	0.02	1.03	1,365.18
Thailand	2,189.04	3.43	444.00	256.56	4.73	718.45	0.05	13.41	3,629.67
Vietnam	2,650.37	1.20	415.31	16.14	6.69	205.49	0.20	63.79	3,359.19
Total	8,703.03	97.17	8,030.01	1,344.92	82.94	5,384.23	3.04	580.95	24,226.28
Countries	CO emission from biomass open burning in GMS, 2015 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total

The actual amount of CO emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	815.97	59.63	1,342.10	1,204.93	8.90	2,048.46	0.29	9.58	5,489.86
Cambodia	1,220.47	5.68	531.86	41.17	36.64	1,719.35	1.41	82.32	3,638.91
Laos	216.34	0.69	1,151.90	2.73	1.46	147.27	0.08	1.66	1,522.14
Thailand	1,966.62	2.91	293.92	206.03	4.17	531.43	0.04	6.97	3,012.09
Vietnam	3,451.81	1.26	301.81	8.46	8.04	212.91	0.21	64.14	4,048.63
Total	7,671.20	70.19	3,626.25	1,464.17	59.37	4,690.12	2.05	164.67	17,748.03
Countries	CO emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	714.68	48.00	1,341.22	558.02	11.68	1,195.21	0.25	13.69	3,882.76
Cambodia	813.60	6.94	861.72	102.09	34.03	1,360.76	1.28	164.71	3,345.13
Laos	243.64	0.74	1,834.57	3.06	2.33	174.86	0.08	2.95	2,262.24
Thailand	1,744.85	3.46	812.17	80.14	3.18	487.95	0.08	9.16	3,140.99
Vietnam	2,753.31	0.62	355.54	10.80	4.45	132.12	0.15	50.94	3,307.93
Total	6,270.08	59.82	5,206.59	756.82	55.79	3,355.68	1.83	241.45	15,948.07
Countries	CO emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	862.05	74.21	742.09	909.25	20.65	1,929.69	0.76	59.36	4,598.05
Cambodia	601.95	4.30	221.61	5.17	35.60	2,330.23	0.78	15.00	3,214.63
Laos	144.86	0.62	560.65	2.18	2.50	128.32	0.03	0.58	839.74
Thailand	1,677.38	3.34	142.17	201.95	6.68	665.92	0.04	9.52	2,706.99
Vietnam	1,217.59	0.32	64.56	1.76	2.78	180.03	0.06	26.03	1,493.13
Total	4,503.83	82.80	1,731.20	1,120.58	68.23	5,236.88	1.67	110.49	12,855.68
Countries	The total of CO emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	9,764.59	577.64	20,418.61	7,528.06	115.43	15,117.27	5.22	960.65	54,487.46
Cambodia	8,296.57	48.91	4,210.67	246.48	312.27	14,442.28	8.59	489.20	28,054.99
Laos	1,881.99	6.27	10,295.91	22.51	15.83	1,282.16	0.28	13.22	13,518.17
Thailand	15,926.80	22.05	2,822.01	1,246.49	32.68	4,168.96	0.30	85.93	24,305.21
Vietnam	18,415.48	6.42	2,653.08	79.62	36.24	1,494.38	0.93	349.23	23,035.37
Total	54,285.43	661.95	40,432.77	9,128.24	513.14	36,527.19	15.37	1,898.24	143,462
Countries	The annual average of CO emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	1,220.57	72.20	2,552.33	941.01	14.43	1,889.66	0.65	120.08	6,810.93
Cambodia	1,037.07	6.11	526.33	30.81	39.03	1,805.29	1.07	61.15	3,506.87
Laos	235.25	0.78	1,286.99	2.81	1.98	160.27	0.03	1.65	1,689.77
Thailand	1,990.85	2.76	352.75	155.81	4.08	521.12	0.04	10.74	3,038.15
Vietnam	2,301.93	0.80	331.63	9.95	4.53	186.80	0.12	43.65	2,879.42
Total	6,785.68	82.74	5,054.10	1,141.03	64.14	4,565.90	1.92	237.28	17,932.79

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 15. The actual amount of NO_x emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of NO _x emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	NO _x emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	28.43	2.46	89.85	32.51	0.57	151.37	0.02	0.06	305.27
Cambodia	36.45	0.15	13.22	0.93	2.42	98.77	0.07	0.36	152.36
Laos	14.88	0.02	74.94	0.11	0.16	16.01	0.00	0.02	106.13
Thailand	57.86	0.07	12.00	3.22	0.14	34.99	0.00	0.05	108.33
Vietnam	76.30	0.02	18.11	0.55	0.26	12.16	0.01	0.17	107.57
Total	213.92	2.72	208.65	37.27	3.55	309.10	0.09	0.64	775.95
Countries	NO _x emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	44.13	2.35	55.33	19.33	1.19	91.22	0.05	0.60	214.19
Cambodia	42.47	0.18	14.91	0.39	3.16	127.84	0.07	0.14	189.15
Laos	4.72	0.03	10.44	0.07	0.07	6.64	0.00	0.00	21.98
Thailand	47.27	0.06	1.45	1.75	0.20	16.53	-	0.03	67.28
Vietnam	31.24	0.03	6.06	0.05	0.09	15.00	0.01	0.05	52.52
Total	169.84	2.65	88.21	21.60	4.70	257.48	0.13	0.81	545.41
Countries	NO _x emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	41.72	1.76	95.02	29.33	0.55	134.02	0.05	0.66	303.10
Cambodia	31.82	0.09	11.59	0.25	2.38	105.64	0.03	0.09	151.91
Laos	6.51	0.02	31.23	0.06	0.13	9.31	0.00	0.00	47.26
Thailand	77.73	0.07	11.40	6.78	0.20	38.20	0.00	0.08	134.46
Vietnam	64.53	0.01	11.00	0.44	0.29	14.40	0.00	0.27	90.95
Total	222.32	1.96	160.27	36.90	3.55	303.49	0.08	1.11	729.69
Countries	NO _x emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	36.60	1.98	70.56	22.89	0.94	95.47	0.04	0.57	229.05
Cambodia	22.85	0.23	19.22	0.92	1.85	103.55	0.07	0.39	149.07
Laos	7.92	0.03	39.36	0.06	0.11	11.08	0.00	0.01	58.57
Thailand	71.69	0.05	6.13	2.01	0.33	19.55	0.00	0.07	99.83
Vietnam	82.29	0.02	6.40	0.12	0.25	5.72	0.00	0.20	95.01
Total	221.34	2.32	141.67	26.02	3.48	235.57	0.12	1.24	631.76
Countries	NO _x emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	73.89	2.30	155.19	29.09	1.35	143.50	0.09	2.29	407.70
Cambodia	39.01	0.22	12.23	0.20	2.95	123.31	0.08	0.10	178.10
Laos	4.91	0.02	29.08	0.09	0.13	8.45	0.00	0.00	42.68
Thailand	66.74	0.09	12.17	7.03	0.29	44.48	0.00	0.06	130.88
Vietnam	80.81	0.03	11.39	0.44	0.41	12.72	0.01	0.30	106.12
Total	265.36	2.66	220.18	36.88	5.13	333.31	0.19	2.77	866.47
Countries	NO _x emission from biomass open burning in GMS, 2015 (kt)								

The actual amount of NO _x emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	24.88	1.64	36.80	33.04	0.55	126.81	0.02	0.05	223.78
Cambodia	37.21	0.16	14.58	1.13	2.27	106.44	0.09	0.39	162.26
Laos	6.60	0.02	31.58	0.07	0.09	9.12	0.00	0.01	47.49
Thailand	59.96	0.08	8.06	5.65	0.26	32.90	0.00	0.03	106.94
Vietnam	105.25	0.03	8.28	0.23	0.50	13.18	0.01	0.31	127.78
Total	233.90	1.92	99.43	40.15	3.68	290.34	0.13	0.78	670.32
Countries	NO _x emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	21.79	1.32	36.78	15.30	0.72	73.99	0.02	0.07	149.98
Cambodia	24.81	0.19	23.63	2.80	2.11	84.24	0.08	0.78	138.63
Laos	7.43	0.02	50.30	0.08	0.14	10.82	0.00	0.01	68.82
Thailand	53.20	0.09	22.27	2.20	0.20	30.21	0.00	0.04	108.21
Vietnam	83.95	0.02	9.75	0.30	0.28	8.18	0.01	0.24	102.72
Total	191.18	1.64	142.76	20.75	3.45	207.73	0.11	1.15	568.78
Countries	NO _x emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	26.28	2.03	20.35	24.93	1.28	119.46	0.05	0.28	194.66
Cambodia	18.35	0.12	6.08	0.14	2.20	144.25	0.05	0.07	171.27
Laos	4.42	0.02	15.37	0.06	0.15	7.94	0.00	0.00	27.97
Thailand	51.14	0.09	3.90	5.54	0.41	41.22	0.00	0.05	102.36
Vietnam	37.12	0.01	1.77	0.05	0.17	11.14	0.00	0.12	50.40
Total	137.32	2.27	47.47	30.73	4.22	324.19	0.10	0.53	546.83
Countries	The total of NO _x emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	297.72	15.84	559.87	206.41	7.15	935.83	0.32	4.57	2,027.7
Cambodia	252.96	1.34	115.45	6.76	19.33	894.05	0.53	2.33	1,292.8
Laos	57.38	0.17	282.31	0.62	0.98	79.37	0.02	0.06	420.9
Thailand	485.61	0.60	77.38	34.18	2.02	258.08	0.02	0.41	858.3
Vietnam	561.49	0.18	72.75	2.18	2.24	92.51	0.06	1.66	733.1
Total	1,655.17	18.15	1,108.64	250.29	31.77	2,261.21	0.95	9.04	5,335.2
Countries	The annual average of NO _x emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	37.22	1.98	69.98	25.80	0.89	116.98	0.04	0.57	253.46
Cambodia	31.62	0.17	14.43	0.84	2.42	111.76	0.07	0.29	161.59
Laos	7.17	0.02	35.29	0.08	0.12	9.92	0.00	0.01	52.61
Thailand	60.70	0.08	9.67	4.27	0.25	32.26	0.00	0.05	107.29
Vietnam	70.19	0.02	9.09	0.27	0.28	11.56	0.01	0.21	91.63
Total	206.90	2.27	138.58	31.29	3.97	282.65	0.12	1.13	666.90

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 16. The actual amount of SO₂ emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of SO ₂ emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	SO ₂ emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	3.66	0.39	14.09	5.10	0.07	18.63	0.00	0.02	41.96
Cambodia	4.69	0.02	2.07	0.15	0.30	12.16	0.01	0.14	19.54
Laos	1.91	0.00	11.75	0.02	0.02	1.97	0.00	0.01	15.69
Thailand	7.44	0.01	1.88	0.51	0.02	4.31	0.00	0.02	14.18
Vietnam	9.81	0.00	2.84	0.09	0.03	1.50	0.00	0.07	14.34
Total	27.51	0.43	32.73	5.85	0.44	38.04	0.01	0.26	105.27
Countries	SO ₂ emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	5.68	0.37	8.68	3.03	0.15	11.23	0.01	0.24	29.37
Cambodia	5.46	0.03	2.34	0.06	0.39	15.73	0.01	0.05	24.08
Laos	0.61	0.00	1.64	0.01	0.01	0.82	0.00	0.00	3.09
Thailand	6.08	0.01	0.23	0.27	0.02	2.03	-	0.01	8.66
Vietnam	4.02	0.00	0.95	0.01	0.01	1.85	0.00	0.02	6.86
Total	21.84	0.41	13.84	3.39	0.58	31.69	0.02	0.33	72.09
Countries	SO ₂ emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	5.37	0.28	14.90	4.60	0.07	16.49	0.01	0.26	41.98
Cambodia	4.09	0.01	1.82	0.04	0.29	13.00	0.00	0.04	19.30
Laos	0.84	0.00	4.90	0.01	0.02	1.15	0.00	0.00	6.91
Thailand	10.00	0.01	1.79	1.06	0.02	4.70	0.00	0.03	17.62
Vietnam	8.30	0.00	1.73	0.07	0.04	1.77	0.00	0.11	12.01
Total	28.59	0.31	25.14	5.79	0.44	37.35	0.01	0.44	98.07
Countries	SO ₂ emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	4.71	0.31	11.07	3.59	0.12	11.75	0.01	0.23	31.78
Cambodia	2.94	0.04	3.01	0.14	0.23	12.74	0.01	0.16	19.27
Laos	1.02	0.00	6.17	0.01	0.01	1.36	0.00	0.01	8.59
Thailand	9.22	0.01	0.96	0.31	0.04	2.41	0.00	0.03	12.98
Vietnam	10.58	0.00	1.00	0.02	0.03	0.70	0.00	0.08	12.43
Total	28.47	0.36	22.22	4.08	0.43	28.99	0.01	0.50	85.07
Countries	SO ₂ emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	9.50	0.36	24.34	4.56	0.17	17.66	0.01	0.92	57.53
Cambodia	5.02	0.03	1.92	0.03	0.36	15.18	0.01	0.04	22.59
Laos	0.63	0.00	4.56	0.01	0.02	1.04	0.00	0.00	6.27
Thailand	8.58	0.01	1.91	1.10	0.04	5.47	0.00	0.03	17.15
Vietnam	10.39	0.01	1.79	0.07	0.05	1.57	0.00	0.12	13.99
Total	34.13	0.42	34.54	5.78	0.63	41.02	0.02	1.11	117.65
Countries	SO ₂ emission from biomass open burning in GMS, 2015 (kt)								

The actual amount of SO ₂ emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	3.20	0.26	5.77	5.18	0.07	15.61	0.00	0.02	30.11
Cambodia	4.79	0.02	2.29	0.18	0.28	13.10	0.01	0.16	20.82
Laos	0.85	0.00	4.95	0.01	0.01	1.12	0.00	0.00	6.95
Thailand	7.71	0.01	1.26	0.89	0.03	4.05	0.00	0.01	13.97
Vietnam	13.54	0.01	1.30	0.04	0.06	1.62	0.00	0.12	16.68
Total	30.08	0.30	15.60	6.30	0.45	35.73	0.02	0.31	88.80
Countries	SO ₂ emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	2.80	0.21	5.77	2.40	0.09	9.11	0.00	0.03	20.40
Cambodia	3.19	0.03	3.71	0.44	0.26	10.37	0.01	0.31	18.32
Laos	0.96	0.00	7.89	0.01	0.02	1.33	0.00	0.01	10.22
Thailand	6.84	0.01	3.49	0.34	0.02	3.72	0.00	0.02	14.46
Vietnam	10.80	0.00	1.53	0.05	0.03	1.01	0.00	0.10	13.51
Total	24.59	0.26	22.39	3.26	0.43	25.57	0.01	0.46	76.96
Countries	SO ₂ emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	3.38	0.32	3.19	3.91	0.16	14.70	0.01	0.11	25.78
Cambodia	2.36	0.02	0.95	0.02	0.27	17.75	0.01	0.03	21.41
Laos	0.57	0.00	2.41	0.01	0.02	0.98	0.00	0.00	3.99
Thailand	6.58	0.01	0.61	0.87	0.05	5.07	0.00	0.02	13.22
Vietnam	4.77	0.00	0.28	0.01	0.02	1.37	0.00	0.05	6.50
Total	17.66	0.36	7.45	4.82	0.52	39.90	0.01	0.21	70.93
Countries	The total of SO ₂ emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	38.29	2.48	87.82	32.38	0.88	115.18	0.04	1.83	278.9
Cambodia	32.54	0.21	18.11	1.06	2.38	110.04	0.07	0.93	165.3
Laos	7.38	0.03	44.28	0.10	0.12	9.77	0.00	0.03	61.7
Thailand	62.46	0.09	12.14	5.36	0.25	31.76	0.00	0.16	112.2
Vietnam	72.22	0.03	11.41	0.34	0.28	11.39	0.01	0.67	96.3
Total	212.88	2.85	173.90	39.26	3.91	278.30	0.12	3.62	714.8
Countries	The annual average of SO ₂ emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	4.79	0.31	10.98	4.05	0.11	14.40	0.00	0.23	34.86
Cambodia	4.07	0.03	2.26	0.13	0.30	13.75	0.01	0.12	20.67
Laos	0.92	0.00	5.54	0.01	0.02	1.22	0.00	0.00	7.71
Thailand	7.81	0.01	1.52	0.67	0.03	3.97	0.00	0.02	14.03
Vietnam	9.03	0.00	1.43	0.04	0.03	1.42	0.00	0.08	12.04
Total	26.61	0.36	21.74	4.91	0.49	34.79	0.01	0.45	89.36

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 17. The actual amount of NH₃ emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of NH ₃ emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	NH ₃ emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	19.84	1.28	46.86	16.96	0.08	20.18	0.00	0.08	105.28
Cambodia	25.43	0.08	6.90	0.48	0.32	13.17	0.01	0.47	46.87
Laos	10.39	0.01	39.08	0.06	0.02	2.13	0.00	0.02	51.71
Thailand	40.37	0.03	6.26	1.68	0.02	4.67	0.00	0.06	53.09
Vietnam	53.24	0.01	9.44	0.29	0.03	1.62	0.00	0.22	64.86
Total	149.27	1.42	108.83	19.44	0.47	41.21	0.01	0.86	321.50
Countries	NH ₃ emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	30.79	1.23	28.86	10.08	0.16	12.16	0.01	0.80	84.08
Cambodia	29.63	0.09	7.77	0.20	0.42	17.05	0.01	0.18	55.36
Laos	3.29	0.02	5.45	0.04	0.01	0.89	0.00	0.00	9.69
Thailand	32.98	0.03	0.76	0.91	0.03	2.20	-	0.04	36.95
Vietnam	21.80	0.01	3.16	0.03	0.01	2.00	0.00	0.06	27.08
Total	118.50	1.38	46.01	11.26	0.63	34.33	0.02	1.08	213.21
Countries	NH ₃ emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	29.11	0.92	49.56	15.30	0.07	17.87	0.01	0.87	113.71
Cambodia	22.21	0.05	6.04	0.13	0.32	14.09	0.00	0.12	42.96
Laos	4.54	0.01	16.29	0.03	0.02	1.24	0.00	0.00	22.14
Thailand	54.24	0.03	5.94	3.54	0.03	5.09	0.00	0.11	68.99
Vietnam	45.02	0.01	5.74	0.23	0.04	1.92	0.00	0.36	53.32
Total	155.12	1.02	83.59	19.25	0.47	40.47	0.01	1.48	301.41
Countries	NH ₃ emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	25.53	1.04	36.80	11.94	0.13	12.73	0.01	0.76	88.93
Cambodia	15.94	0.12	10.02	0.48	0.25	13.81	0.01	0.52	41.15
Laos	5.52	0.01	20.53	0.03	0.01	1.48	0.00	0.02	27.61
Thailand	50.02	0.03	3.20	1.05	0.04	2.61	0.00	0.09	57.03
Vietnam	57.42	0.01	3.34	0.06	0.03	0.76	0.00	0.26	61.89
Total	154.44	1.21	73.89	13.57	0.46	31.41	0.02	1.66	276.66
Countries	NH ₃ emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	51.56	1.20	80.94	15.17	0.18	19.13	0.01	3.05	171.24
Cambodia	27.22	0.11	6.38	0.11	0.39	16.44	0.01	0.14	50.80
Laos	3.42	0.01	15.17	0.05	0.02	1.13	0.00	0.01	19.80
Thailand	46.57	0.05	6.35	3.67	0.04	5.93	0.00	0.08	62.69
Vietnam	56.39	0.02	5.94	0.23	0.06	1.70	0.00	0.40	64.73
Total	185.15	1.39	114.84	19.23	0.68	44.44	0.03	3.68	369.44
Countries	NH ₃ emission from biomass open burning in GMS, 2015 (kt)								

The actual amount of NH ₃ emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	17.36	0.85	19.19	17.23	0.07	16.91	0.00	0.06	71.68
Cambodia	25.96	0.08	7.61	0.59	0.30	14.19	0.01	0.52	49.27
Laos	4.60	0.01	16.47	0.04	0.01	1.22	0.00	0.01	22.36
Thailand	41.84	0.04	4.20	2.95	0.03	4.39	0.00	0.04	53.50
Vietnam	73.44	0.02	4.32	0.12	0.07	1.76	0.00	0.41	80.12
Total	163.20	1.00	51.86	20.94	0.49	38.71	0.02	1.04	277.27
Countries	NH ₃ emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	15.20	0.69	19.18	7.98	0.10	9.87	0.00	0.09	53.10
Cambodia	17.31	0.10	12.32	1.46	0.28	11.23	0.01	1.04	43.76
Laos	5.18	0.01	26.24	0.04	0.02	1.44	0.00	0.02	32.96
Thailand	37.12	0.05	11.61	1.15	0.03	4.03	0.00	0.06	54.04
Vietnam	58.58	0.01	5.08	0.15	0.04	1.09	0.00	0.32	65.27
Total	133.39	0.86	74.46	10.82	0.46	27.70	0.02	1.53	249.23
Countries	NH ₃ emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	18.34	1.06	10.61	13.00	0.17	15.93	0.01	0.38	59.50
Cambodia	12.81	0.06	3.17	0.07	0.29	19.23	0.01	0.09	35.74
Laos	3.08	0.01	8.02	0.03	0.02	1.06	0.00	0.00	12.22
Thailand	35.69	0.05	2.03	2.89	0.06	5.50	0.00	0.06	46.27
Vietnam	25.90	0.00	0.92	0.03	0.02	1.49	0.00	0.16	28.53
Total	95.82	1.18	24.76	16.03	0.56	43.23	0.01	0.70	182.29
Countries	The total of NH ₃ emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	207.74	8.26	292.01	107.66	0.95	124.78	0.04	6.08	747.5
Cambodia	176.51	0.70	60.22	3.52	2.58	119.21	0.07	3.10	365.9
Laos	40.04	0.09	147.24	0.32	0.13	10.58	0.00	0.08	198.5
Thailand	338.83	0.32	40.36	17.83	0.27	34.41	0.00	0.54	432.6
Vietnam	391.78	0.09	37.94	1.14	0.30	12.33	0.01	2.21	445.8
Total	1,154.90	9.47	578.23	130.54	4.24	301.49	0.13	12.02	2,191.0
Countries	The annual average of NH ₃ emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	25.97	1.03	36.50	13.46	0.12	15.60	0.01	0.76	93.44
Cambodia	22.06	0.09	7.53	0.44	0.32	14.90	0.01	0.39	45.74
Laos	5.00	0.01	18.41	0.04	0.02	1.32	0.00	0.01	24.81
Thailand	42.35	0.04	5.04	2.23	0.03	4.30	0.00	0.07	54.07
Vietnam	48.97	0.01	4.74	0.14	0.04	1.54	0.00	0.28	55.73
Total	144.36	1.18	72.28	16.32	0.53	37.69	0.02	1.50	273.88

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 18. The actual amount of PM_{2.5} emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of PM _{2.5} emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	PM _{2.5} emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	57.60	8.78	320.63	116.02	1.05	279.45	0.03	0.55	784.11
Cambodia	73.83	0.55	47.19	3.31	4.46	182.35	0.12	3.24	315.05
Laos	30.15	0.07	267.42	0.40	0.30	29.55	0.00	0.14	328.02
Thailand	117.21	0.24	42.82	11.50	0.26	64.60	0.00	0.41	237.04
Vietnam	154.56	0.07	64.61	1.97	0.48	22.45	0.01	1.52	245.66
Total	433.35	9.72	744.60	133.00	6.55	570.65	0.17	5.86	1,903.88
Countries	PM _{2.5} emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	89.40	8.38	197.44	69.00	2.19	168.40	0.09	5.47	540.36
Cambodia	86.03	0.64	53.19	1.38	5.83	236.02	0.14	1.23	384.47
Laos	9.56	0.10	37.27	0.25	0.12	12.27	0.00	0.01	59.59
Thailand	95.76	0.21	5.17	6.23	0.37	30.52	-	0.26	138.52
Vietnam	63.29	0.09	21.64	0.17	0.17	27.70	0.01	0.44	113.50
Total	344.04	9.44	314.79	77.07	8.68	475.35	0.24	7.41	1,237.02
Countries	PM _{2.5} emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	84.51	6.30	339.08	104.66	1.01	247.42	0.09	5.98	789.04
Cambodia	64.47	0.34	41.36	0.91	4.40	195.03	0.06	0.85	307.40
Laos	13.19	0.06	111.46	0.21	0.23	17.19	0.00	0.03	142.37
Thailand	157.47	0.24	40.67	24.21	0.36	70.53	0.00	0.75	294.23
Vietnam	130.72	0.05	39.25	1.57	0.54	26.59	0.01	2.49	201.21
Total	450.35	6.99	571.95	131.70	6.56	560.29	0.15	10.10	1,738.10
Countries	PM _{2.5} emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	74.13	7.08	251.80	81.68	1.74	176.25	0.08	5.20	597.95
Cambodia	46.28	0.83	68.58	3.27	3.41	191.17	0.12	3.59	317.26
Laos	16.04	0.10	140.45	0.23	0.20	20.46	0.00	0.13	177.60
Thailand	145.23	0.19	21.88	7.17	0.60	36.10	0.00	0.60	211.77
Vietnam	166.70	0.09	22.82	0.44	0.45	10.56	0.01	1.81	202.89
Total	448.38	8.30	505.57	92.86	6.42	434.90	0.22	11.32	1,507.95
Countries	PM _{2.5} emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	149.68	8.19	553.83	103.80	2.49	264.93	0.17	20.85	1,103.93
Cambodia	79.02	0.78	43.64	0.72	5.44	227.66	0.15	0.93	358.33
Laos	9.94	0.08	103.76	0.33	0.24	15.59	0.00	0.04	130.00
Thailand	135.21	0.34	43.44	25.10	0.54	82.11	0.01	0.58	287.33
Vietnam	163.70	0.12	40.64	1.58	0.76	23.48	0.02	2.76	233.07
Total	537.54	9.51	785.73	131.60	9.48	615.34	0.35	25.17	2,114.72
Countries	PM _{2.5} emission from biomass open burning in GMS, 2015 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total

The actual amount of PM _{2.5} emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	50.40	5.83	131.32	117.90	1.02	234.11	0.03	0.42	541.03
Cambodia	75.38	0.56	52.04	4.03	4.19	196.50	0.16	3.57	336.42
Laos	13.36	0.07	112.71	0.27	0.17	16.83	0.01	0.07	143.49
Thailand	121.47	0.28	28.76	20.16	0.48	60.74	0.00	0.30	232.19
Vietnam	213.20	0.12	29.53	0.83	0.92	24.33	0.02	2.78	271.74
Total	473.81	6.87	354.83	143.27	6.78	536.01	0.23	7.14	1,528.94
Countries	PM _{2.5} emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	44.14	4.70	131.24	54.60	1.34	136.60	0.03	0.59	373.23
Cambodia	50.25	0.68	84.32	9.99	3.89	155.52	0.15	7.14	311.93
Laos	15.05	0.07	179.51	0.30	0.27	19.98	0.01	0.13	215.32
Thailand	107.77	0.34	79.47	7.84	0.36	55.77	0.01	0.40	251.96
Vietnam	170.06	0.06	34.79	1.06	0.51	15.10	0.02	2.21	223.80
Total	387.27	5.85	509.46	74.05	6.38	383.51	0.21	10.46	1,377.19
Countries	PM _{2.5} emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	53.24	7.26	72.61	88.97	2.36	220.54	0.09	2.57	447.64
Cambodia	37.18	0.42	21.68	0.51	4.07	266.31	0.09	0.65	330.91
Laos	8.95	0.06	54.86	0.21	0.29	14.66	0.00	0.03	79.06
Thailand	103.60	0.33	13.91	19.76	0.76	76.10	0.00	0.41	214.89
Vietnam	75.20	0.03	6.32	0.17	0.32	20.57	0.01	1.13	103.75
Total	278.18	8.10	169.40	109.65	7.80	598.50	0.19	4.79	1,176.60
Countries	The total of PM _{2.5} emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	603.11	56.52	1,997.95	736.62	13.19	1,727.69	0.60	41.63	5,177.3
Cambodia	512.44	4.79	412.01	24.12	35.69	1,650.55	0.98	21.20	2,661.8
Laos	116.24	0.61	1,007.45	2.20	1.81	146.53	0.03	0.57	1,275.5
Thailand	983.71	2.16	276.13	121.97	3.73	476.45	0.03	3.72	1,867.9
Vietnam	1,137.43	0.63	259.60	7.79	4.14	170.79	0.11	15.13	1,595.6
Total	3,352.92	64.77	3,956.32	893.19	58.64	4,174.54	1.76	82.26	12,584.4
Countries	The annual average of PM _{2.5} emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	75.39	7.07	249.74	92.08	1.65	215.96	0.07	5.20	647.16
Cambodia	64.05	0.60	51.50	3.01	4.46	206.32	0.12	2.65	332.72
Laos	14.53	0.08	125.93	0.28	0.23	18.32	0.00	0.07	159.43
Thailand	122.96	0.27	34.52	15.25	0.47	59.56	0.00	0.47	233.49
Vietnam	142.18	0.08	32.45	0.97	0.52	21.35	0.01	1.89	199.45
Total	419.12	8.10	494.54	111.65	7.33	521.82	0.22	10.28	1,573.05

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 19. The actual amount of TPM emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of TPM emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	TPM emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	113.37	12.54	458.05	165.74	1.25	329.91	0.03	0.78	1,081.66
Cambodia	145.31	0.78	67.42	4.73	5.26	215.27	0.14	4.63	443.55
Laos	59.35	0.10	382.02	0.57	0.35	34.89	0.00	0.20	477.47
Thailand	230.70	0.34	61.17	16.42	0.31	76.26	0.00	0.59	385.80
Vietnam	304.21	0.09	92.31	2.81	0.56	26.50	0.01	2.16	428.67
Total	852.94	13.88	1,063.71	190.00	7.73	673.68	0.20	8.37	2,810.50
Countries	TPM emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	175.96	11.98	282.05	98.57	2.59	198.80	0.10	7.81	777.86
Cambodia	169.33	0.92	75.99	1.97	6.89	278.63	0.16	1.76	535.65
Laos	18.82	0.15	53.25	0.36	0.14	14.48	0.00	0.02	87.22
Thailand	188.49	0.30	7.38	8.90	0.43	36.03	-	0.38	241.91
Vietnam	124.56	0.13	30.91	0.25	0.20	32.70	0.01	0.63	189.38
Total	677.16	13.49	449.70	110.10	10.25	561.17	0.28	10.59	1,832.75
Countries	TPM emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	166.34	8.99	484.40	149.51	1.19	292.09	0.10	8.55	1,111.18
Cambodia	126.89	0.48	59.09	1.30	5.19	230.24	0.07	1.21	424.46
Laos	25.97	0.09	159.23	0.30	0.27	20.29	0.00	0.04	206.19
Thailand	309.93	0.34	58.11	34.58	0.43	83.26	0.00	1.07	487.73
Vietnam	257.28	0.07	56.08	2.25	0.63	31.39	0.01	3.56	351.27
Total	886.41	9.98	817.08	188.14	7.74	661.45	0.18	14.43	2,585.42
Countries	TPM emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	145.91	10.12	359.71	116.68	2.05	208.07	0.09	7.43	850.06
Cambodia	91.09	1.19	97.98	4.68	4.03	225.69	0.14	5.13	429.91
Laos	31.56	0.14	200.64	0.33	0.23	24.15	0.00	0.18	257.24
Thailand	285.84	0.27	31.26	10.24	0.71	42.62	0.01	0.86	371.80
Vietnam	328.12	0.13	32.60	0.63	0.53	12.47	0.01	2.58	377.07
Total	882.52	11.85	722.24	132.65	7.58	513.42	0.26	16.18	2,286.69
Countries	TPM emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	294.61	11.70	791.18	148.28	2.93	312.77	0.20	29.79	1,591.46
Cambodia	155.53	1.11	62.34	1.03	6.42	268.76	0.17	1.33	496.70
Laos	19.56	0.12	148.24	0.47	0.29	18.41	0.00	0.06	187.15
Thailand	266.12	0.48	62.06	35.86	0.64	96.93	0.01	0.83	462.93
Vietnam	322.20	0.17	58.05	2.26	0.90	27.72	0.03	3.95	415.28
Total	1,058.02	13.58	1,122.47	188.00	11.19	726.44	0.41	35.96	3,156.08
Countries	TPM emission from biomass open burning in GMS, 2015 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total

The actual amount of TPM emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	99.20	8.34	187.61	168.43	1.20	276.38	0.04	0.59	741.78
Cambodia	148.37	0.79	74.35	5.76	4.94	231.98	0.19	5.10	471.47
Laos	26.30	0.10	161.02	0.38	0.20	19.87	0.01	0.10	207.98
Thailand	239.08	0.41	41.09	28.80	0.56	71.70	0.01	0.43	382.07
Vietnam	419.63	0.18	42.19	1.18	1.08	28.73	0.03	3.97	496.99
Total	932.58	9.81	506.89	204.67	8.01	632.79	0.28	10.19	2,305.23
Countries	TPM emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	86.88	6.71	187.48	78.00	1.58	161.26	0.03	0.85	522.79
Cambodia	98.91	0.97	120.46	14.27	4.59	183.59	0.17	10.20	433.16
Laos	29.62	0.10	256.45	0.43	0.31	23.59	0.01	0.18	310.70
Thailand	212.12	0.48	113.53	11.20	0.43	65.83	0.01	0.57	404.18
Vietnam	334.72	0.09	49.70	1.51	0.60	17.83	0.02	3.15	407.61
Total	762.24	8.36	727.80	105.79	7.53	452.75	0.25	14.95	2,079.67
Countries	TPM emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	104.80	10.37	103.73	127.10	2.79	260.36	0.10	3.67	612.92
Cambodia	73.18	0.60	30.98	0.72	4.80	314.40	0.11	0.93	425.71
Laos	17.61	0.09	78.37	0.30	0.34	17.31	0.00	0.04	114.06
Thailand	203.92	0.47	19.87	28.23	0.90	89.85	0.01	0.59	343.83
Vietnam	148.02	0.05	9.02	0.25	0.38	24.29	0.01	1.61	183.62
Total	547.52	11.57	242.00	156.64	9.21	706.56	0.23	6.84	1,680.57
Countries	The total of TPM emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	1,187.07	80.74	2,854.21	1,052.31	15.57	2,039.63	0.70	59.47	7,290
Cambodia	1,008.60	6.84	588.59	34.45	42.13	1,948.56	1.16	30.28	3,661
Laos	228.79	0.88	1,439.21	3.15	2.14	172.99	0.04	0.82	1,848
Thailand	1,936.20	3.08	394.47	174.24	4.41	562.48	0.04	5.32	3,080
Vietnam	2,238.74	0.90	370.86	11.13	4.89	201.62	0.13	21.62	2,850
Total	6,599.41	92.53	5,651.89	1,275.99	69.23	4,928.27	2.07	117.51	18,737
Countries	The annual average of TPM emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	148.38	10.09	356.78	131.54	1.95	254.95	0.09	7.43	911.21
Cambodia	126.08	0.85	73.57	4.31	5.27	243.57	0.14	3.79	457.58
Laos	28.60	0.11	179.90	0.39	0.27	21.62	0.00	0.10	231.00
Thailand	242.02	0.39	49.31	21.78	0.55	70.31	0.01	0.66	385.03
Vietnam	279.84	0.11	46.36	1.39	0.61	25.20	0.02	2.70	356.24
Total	824.93	11.57	706.49	159.50	8.65	616.03	0.26	14.69	2,342.11

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 20. The actual amount of BC emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of BC emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	BC emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	6.86	0.50	18.32	6.63	0.05	14.36	0.00	0.00	46.73
Cambodia	8.79	0.03	2.70	0.19	0.23	9.37	0.01	0.01	21.33
Laos	3.59	0.00	15.28	0.02	0.02	1.52	0.00	0.00	20.43
Thailand	13.95	0.01	2.45	0.66	0.01	3.32	0.00	0.00	20.41
Vietnam	18.40	0.00	3.69	0.11	0.02	1.15	0.00	0.01	23.39
Total	51.59	0.56	42.55	7.60	0.34	29.32	0.01	0.03	131.99
Countries	BC emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	10.64	0.48	11.28	3.94	0.11	8.65	0.00	0.02	35.14
Cambodia	10.24	0.04	3.04	0.08	0.30	12.13	0.01	0.01	25.84
Laos	1.14	0.01	2.13	0.01	0.01	0.63	0.00	0.00	3.93
Thailand	11.40	0.01	0.30	0.36	0.02	1.57	-	0.00	13.65
Vietnam	7.53	0.01	1.24	0.01	0.01	1.42	0.00	0.00	10.22
Total	40.96	0.54	17.99	4.40	0.45	24.43	0.01	0.03	88.81
Countries	BC emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	10.06	0.36	19.38	5.98	0.05	12.71	0.00	0.03	48.57
Cambodia	7.67	0.02	2.36	0.05	0.23	10.02	0.00	0.00	20.36
Laos	1.57	0.00	6.37	0.01	0.01	0.88	0.00	0.00	8.85
Thailand	18.75	0.01	2.32	1.38	0.02	3.62	0.00	0.00	26.11
Vietnam	15.56	0.00	2.24	0.09	0.03	1.37	0.00	0.01	19.30
Total	53.61	0.40	32.68	7.53	0.34	28.79	0.01	0.04	123.40
Countries	BC emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	8.83	0.40	14.39	4.67	0.09	9.06	0.00	0.02	37.46
Cambodia	5.51	0.05	3.92	0.19	0.18	9.82	0.01	0.02	19.68
Laos	1.91	0.01	8.03	0.01	0.01	1.05	0.00	0.00	11.02
Thailand	17.29	0.01	1.25	0.41	0.03	1.86	0.00	0.00	20.85
Vietnam	19.85	0.01	1.30	0.03	0.02	0.54	0.00	0.01	21.75
Total	53.38	0.47	28.89	5.31	0.33	22.35	0.01	0.05	110.79
Countries	BC emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	17.82	0.47	31.65	5.93	0.13	13.61	0.01	0.09	69.71
Cambodia	9.41	0.04	2.49	0.04	0.28	11.70	0.01	0.00	23.98
Laos	1.18	0.00	5.93	0.02	0.01	0.80	0.00	0.00	7.95
Thailand	16.10	0.02	2.48	1.43	0.03	4.22	0.00	0.00	24.28
Vietnam	19.49	0.01	2.32	0.09	0.04	1.21	0.00	0.01	23.17
Total	63.99	0.54	44.90	7.52	0.49	31.62	0.02	0.11	149.19
Countries	BC emission from biomass open burning in GMS, 2015 (kt)								

The actual amount of BC emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	6.00	0.33	7.50	6.74	0.05	12.03	0.00	0.00	32.66
Cambodia	8.97	0.03	2.97	0.23	0.22	10.10	0.01	0.02	22.55
Laos	1.59	0.00	6.44	0.02	0.01	0.86	0.00	0.00	8.92
Thailand	14.46	0.02	1.64	1.15	0.02	3.12	0.00	0.00	20.42
Vietnam	25.38	0.01	1.69	0.05	0.05	1.25	0.00	0.01	28.43
Total	56.41	0.39	20.28	8.19	0.35	27.55	0.01	0.03	113.20
Countries	BC emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	5.26	0.27	7.50	3.12	0.07	7.02	0.00	0.00	23.23
Cambodia	5.98	0.04	4.82	0.57	0.20	7.99	0.01	0.03	19.64
Laos	1.79	0.00	10.26	0.02	0.01	1.03	0.00	0.00	13.11
Thailand	12.83	0.02	4.54	0.45	0.02	2.87	0.00	0.00	20.73
Vietnam	20.24	0.00	1.99	0.06	0.03	0.78	0.00	0.01	23.11
Total	46.10	0.33	29.11	4.23	0.33	19.71	0.01	0.05	99.87
Countries	BC emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	6.34	0.41	4.15	5.08	0.12	11.33	0.00	0.01	27.46
Cambodia	4.43	0.02	1.24	0.03	0.21	13.69	0.00	0.00	19.62
Laos	1.07	0.00	3.13	0.01	0.01	0.75	0.00	0.00	4.98
Thailand	12.33	0.02	0.79	1.13	0.04	3.91	0.00	0.00	18.23
Vietnam	8.95	0.00	0.36	0.01	0.02	1.06	0.00	0.00	10.40
Total	33.12	0.46	9.68	6.27	0.40	30.76	0.01	0.02	80.71
Countries	The total of BC emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	71.80	3.23	114.17	42.09	0.68	88.78	0.03	0.18	320.96
Cambodia	61.00	0.27	23.54	1.38	1.83	84.82	0.05	0.09	173.00
Laos	13.84	0.04	57.57	0.13	0.09	7.53	0.00	0.00	79.19
Thailand	117.11	0.12	15.78	6.97	0.19	24.48	0.00	0.02	164.68
Vietnam	135.41	0.04	14.83	0.45	0.21	8.78	0.01	0.07	159.78
Total	71.80	3.23	114.17	42.09	0.68	88.78	0.03	0.18	320.96
Countries	The annual average of BC emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	8.97	0.40	14.27	5.26	0.08	11.10	0.00	0.02	40.12
Cambodia	7.63	0.03	2.94	0.17	0.23	10.60	0.01	0.01	21.62
Laos	1.73	0.00	7.20	0.02	0.01	0.94	0.00	0.00	9.90
Thailand	14.64	0.02	1.97	0.87	0.02	3.06	0.00	0.00	20.58
Vietnam	16.93	0.00	1.85	0.06	0.03	1.10	0.00	0.01	19.97
Total	49.89	0.46	28.26	6.38	0.38	26.82	0.01	0.05	112.25

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

Table 21. The actual amount of OC emission from biomass open burning in GMS, during 2010-2017 (kt)

The actual amount of OC emission from biomass open burning in GMS, during 2010-2017 (kt)									
Countries	OC emission from biomass open burning in GMS, 2010 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	21.03	4.54	165.95	60.05	0.38	101.69	0.01	0.36	354.02
Cambodia	26.95	0.28	24.43	1.71	1.62	66.35	0.04	2.14	123.54
Laos	11.01	0.04	138.41	0.21	0.11	10.75	0.00	0.09	160.61
Thailand	42.79	0.12	22.16	5.95	0.09	23.51	0.00	0.27	94.90
Vietnam	56.43	0.03	33.44	1.02	0.17	8.17	0.00	1.00	100.27
Total	158.21	5.03	385.39	68.84	2.38	207.65	0.06	3.87	831.43
Countries	OC emission from biomass open burning in GMS, 2011 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	32.64	4.34	102.19	35.71	0.80	61.28	0.03	3.62	240.60
Cambodia	31.41	0.33	27.53	0.71	2.12	85.88	0.05	0.82	148.86
Laos	3.49	0.05	19.29	0.13	0.04	4.46	0.00	0.01	27.48
Thailand	34.96	0.11	2.67	3.23	0.13	11.10	-	0.17	52.38
Vietnam	23.10	0.05	11.20	0.09	0.06	10.08	0.00	0.29	44.87
Total	125.60	4.89	162.93	39.89	3.16	172.97	0.09	4.91	514.43
Countries	OC emission from biomass open burning in GMS, 2012 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	30.85	3.26	175.50	54.17	0.37	90.03	0.03	3.96	358.17
Cambodia	23.54	0.17	21.41	0.47	1.60	70.97	0.02	0.56	118.74
Laos	4.82	0.03	57.69	0.11	0.08	6.25	0.00	0.02	69.00
Thailand	57.49	0.12	21.05	12.53	0.13	25.66	0.00	0.50	117.49
Vietnam	47.72	0.03	20.32	0.81	0.19	9.67	0.00	1.65	80.40
Total	164.42	3.62	296.03	68.16	2.39	203.88	0.06	6.68	745.24
Countries	OC emission from biomass open burning in GMS, 2013 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	27.06	3.67	130.33	42.27	0.63	64.14	0.03	3.44	271.57
Cambodia	16.90	0.43	35.50	1.69	1.24	69.57	0.04	2.37	127.74
Laos	5.85	0.05	72.69	0.12	0.07	7.44	0.00	0.08	86.32
Thailand	53.02	0.10	11.33	3.71	0.22	13.14	0.00	0.40	81.91
Vietnam	60.86	0.05	11.81	0.23	0.16	3.84	0.00	1.20	78.15
Total	163.69	4.29	261.67	48.06	2.34	158.25	0.08	7.49	645.88
Countries	OC emission from biomass open burning in GMS, 2014 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	54.64	4.24	286.65	53.72	0.90	96.41	0.06	13.79	510.42
Cambodia	28.85	0.40	22.59	0.37	1.98	82.84	0.05	0.62	137.70
Laos	3.63	0.04	53.71	0.17	0.09	5.67	0.00	0.03	63.34
Thailand	49.36	0.17	22.49	12.99	0.20	29.88	0.00	0.38	115.48
Vietnam	59.76	0.06	21.03	0.82	0.28	8.55	0.01	1.83	92.34
Total	196.24	4.92	406.68	68.11	3.45	223.92	0.13	16.65	920.11
Countries	OC emission from biomass open burning in GMS, 2015 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total

The actual amount of OC emission from biomass open burning in GMS, during 2010-2017 (kt)									
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	18.40	3.02	67.97	61.02	0.37	85.19	0.01	0.27	236.26
Cambodia	27.52	0.29	26.94	2.09	1.52	71.50	0.06	2.36	132.28
Laos	4.88	0.03	58.34	0.14	0.06	6.12	0.00	0.05	69.63
Thailand	44.35	0.15	14.89	10.43	0.17	22.10	0.00	0.20	92.29
Vietnam	77.83	0.06	15.29	0.43	0.33	8.85	0.01	1.84	104.65
Total	172.98	3.55	183.65	74.15	2.47	195.05	0.09	4.72	636.66
Countries	OC emission from biomass open burning in GMS, 2016 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	16.12	2.43	67.93	28.26	0.49	49.71	0.01	0.39	165.33
Cambodia	18.35	0.35	43.64	5.17	1.42	56.59	0.05	4.72	130.29
Laos	5.49	0.04	92.91	0.16	0.10	7.27	0.00	0.08	106.06
Thailand	39.34	0.18	41.13	4.06	0.13	20.29	0.00	0.26	105.40
Vietnam	62.08	0.03	18.01	0.55	0.19	5.49	0.01	1.46	87.82
Total	141.38	3.03	263.69	38.33	2.32	139.55	0.08	6.92	595.30
Countries	OC emission from biomass open burning in GMS, 2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	19.44	3.76	37.58	46.05	0.86	80.25	0.03	1.70	189.67
Cambodia	13.57	0.22	11.22	0.26	1.48	96.91	0.03	0.43	124.13
Laos	3.27	0.03	28.39	0.11	0.10	5.34	0.00	0.02	37.26
Thailand	37.82	0.17	7.20	10.23	0.28	27.69	0.00	0.27	83.67
Vietnam	27.46	0.02	3.27	0.09	0.12	7.49	0.00	0.75	39.18
Total	101.56	4.19	87.68	56.75	2.84	217.79	0.07	3.17	474.04
Countries	The total of OC emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	220.18	29.25	1,034.10	381.26	4.80	628.69	0.22	27.54	2,326.0
Cambodia	187.08	2.48	213.25	12.48	12.99	600.62	0.36	14.02	1,043.3
Laos	42.44	0.32	521.44	1.14	0.66	53.32	0.01	0.38	619.7
Thailand	359.13	1.12	142.92	63.13	1.36	173.38	0.01	2.46	743.5
Vietnam	415.25	0.33	134.37	4.03	1.51	62.15	0.04	10.01	627.7
Total	1,224.08	33.52	2,047.72	462.30	21.34	1,519.07	0.64	54.42	5,363.1
Countries	The annual average of OC emission from biomass open burning in GMS, during 2010-2017 (kt)								
	CL	DF	EF	MF	GL	SV	SL	WT	Total
Myanmar	27.52	3.66	129.26	47.66	0.60	78.59	0.03	3.44	290.76
Cambodia	23.38	0.31	26.66	1.56	1.62	75.08	0.04	1.75	130.41
Laos	5.30	0.04	65.18	0.14	0.08	6.67	0.00	0.05	77.46
Thailand	44.89	0.14	17.87	7.89	0.17	21.67	0.00	0.31	92.94
Vietnam	51.91	0.04	16.80	0.50	0.19	7.77	0.00	1.25	78.46
Total	153.01	4.19	255.97	57.79	2.67	189.88	0.08	6.80	670.39

Note: CL = Croplands; DF = Deciduous Forest; EF = Evergreen Forest; GL = Grasslands; SV = Savannas; SL = Shrublands; WL = wetland.

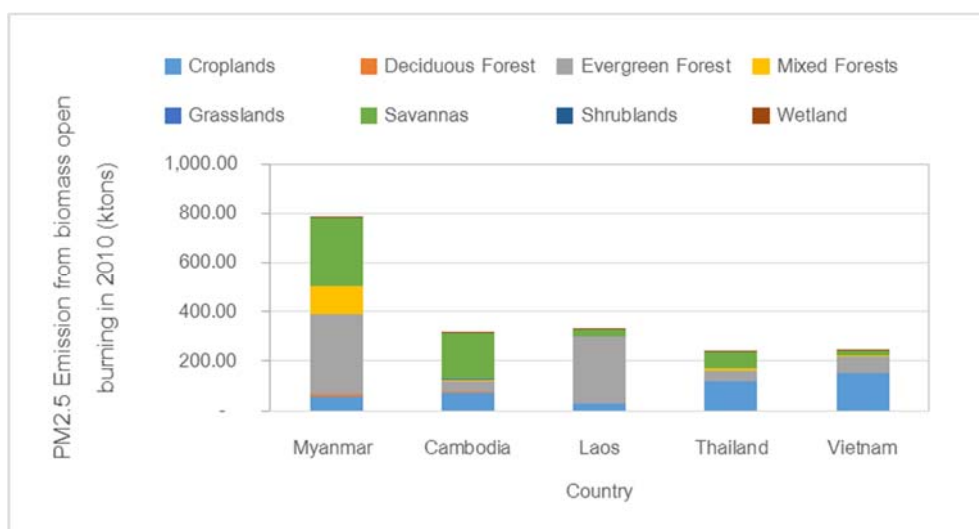


Figure 48. The actual amount of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2010

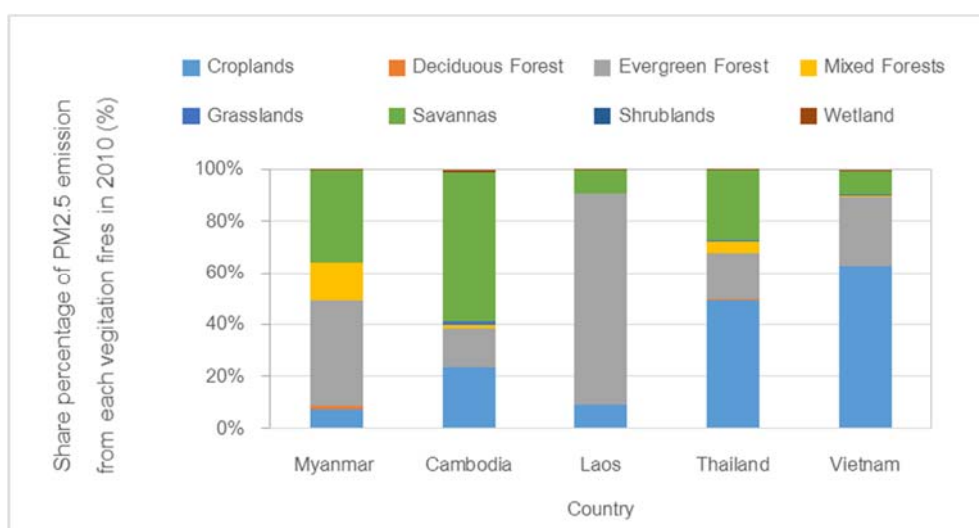


Figure 49. The share percentage of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2010

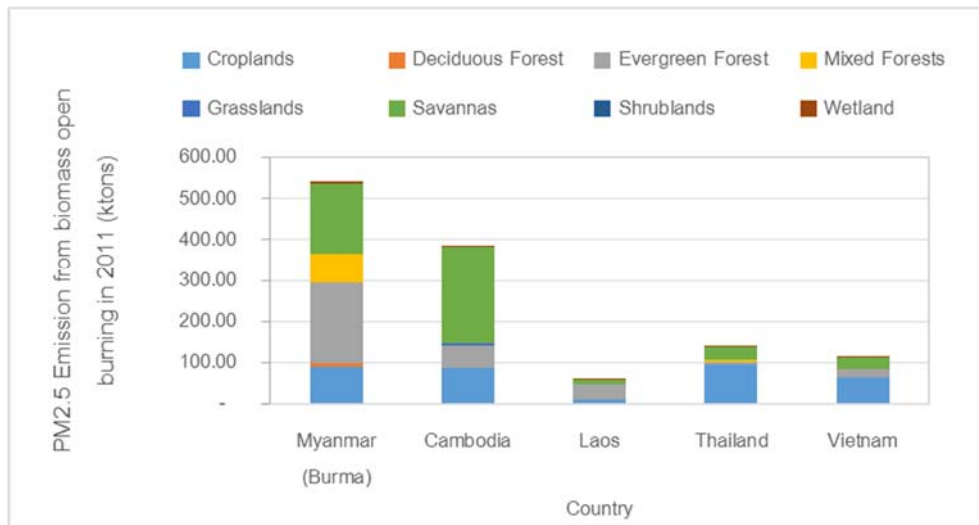


Figure 50. The actual amount of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2011

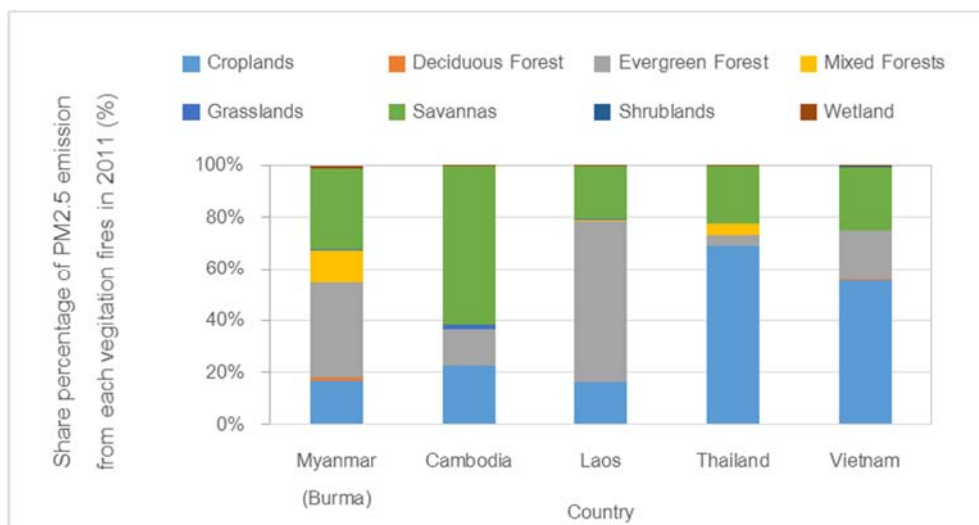


Figure 51. The share percentage of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2011

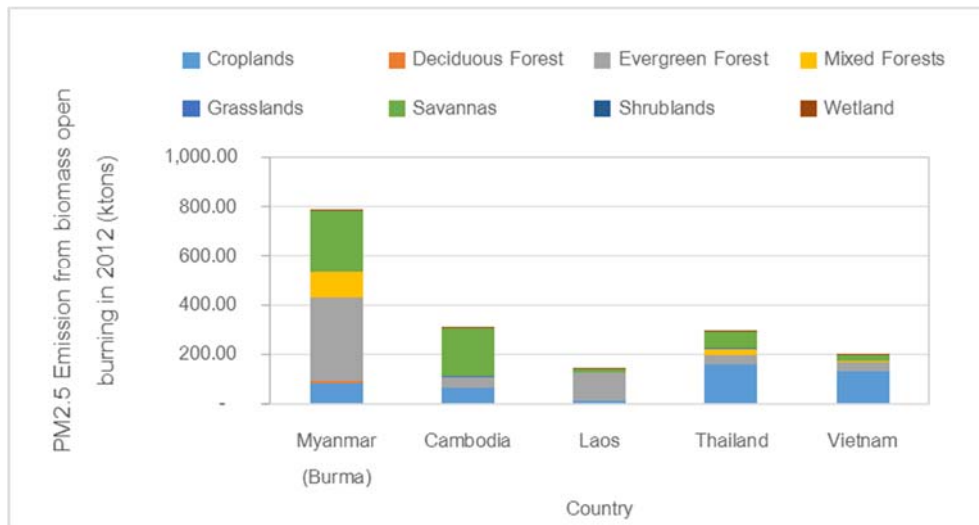


Figure 52. The actual amount of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2012

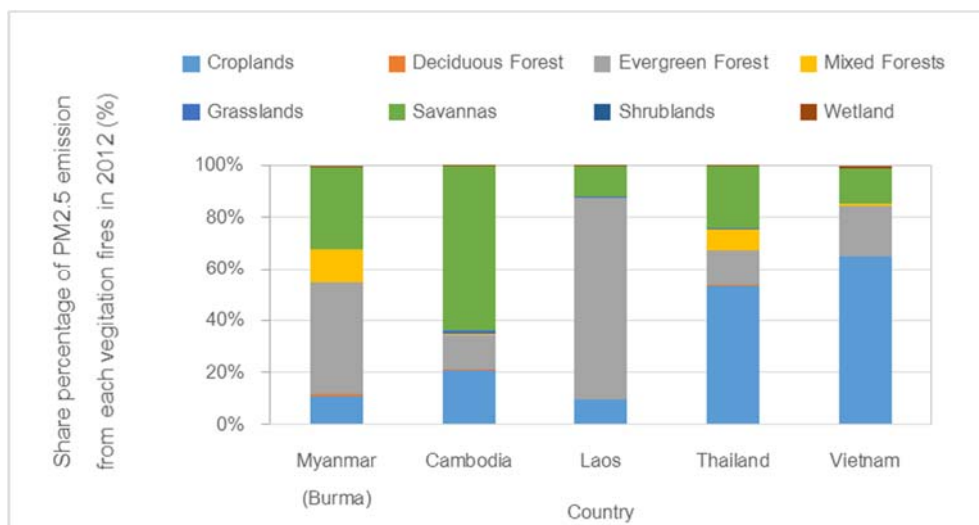


Figure 53. The share percentage of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2012

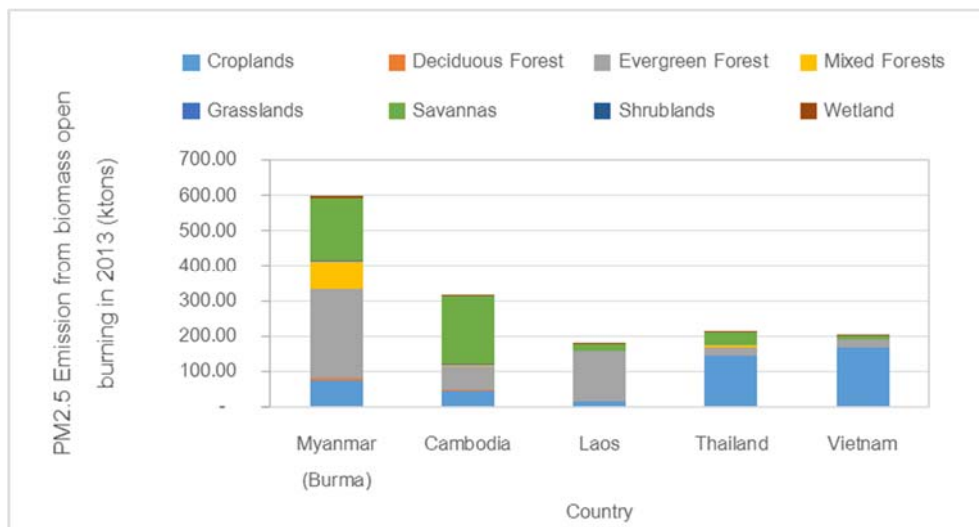


Figure 54. The actual amount of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2013

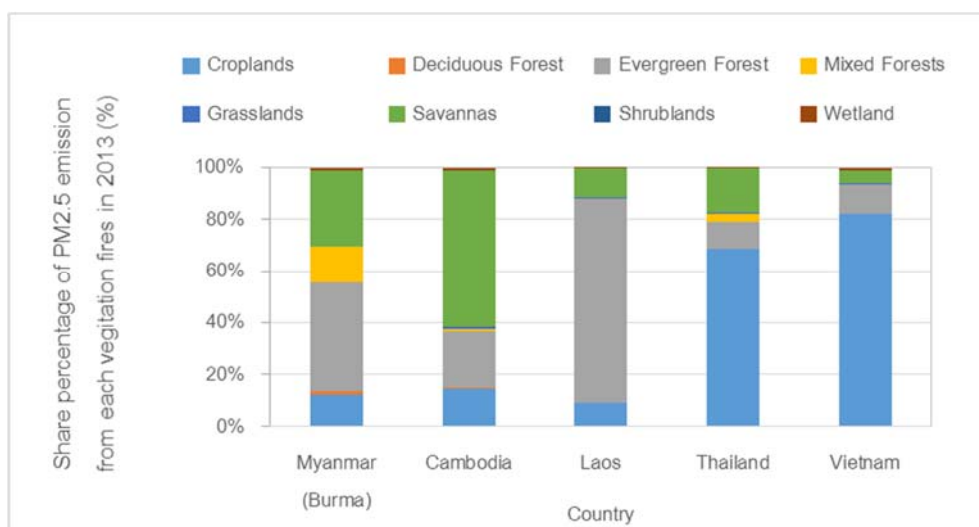


Figure 55. The share percentage of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2013

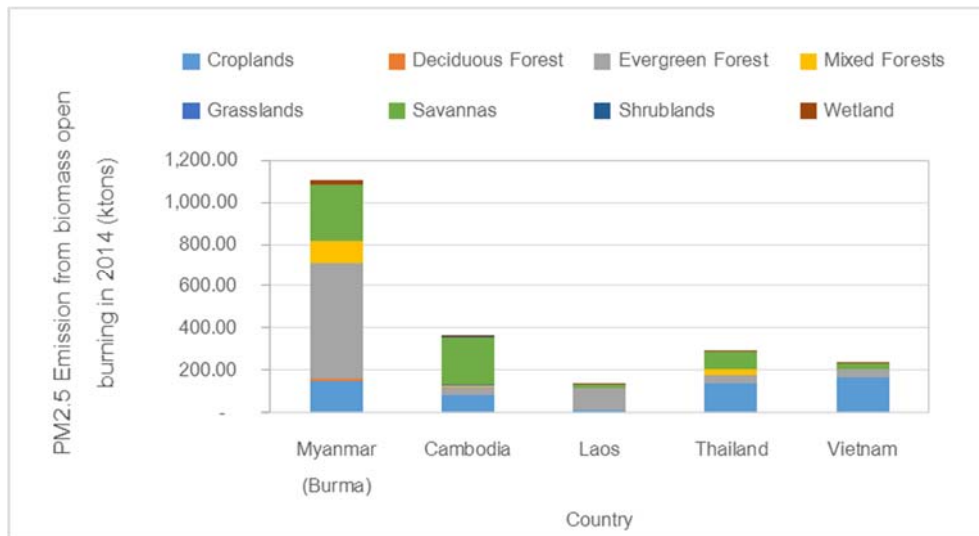


Figure 56. The actual amount of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2014

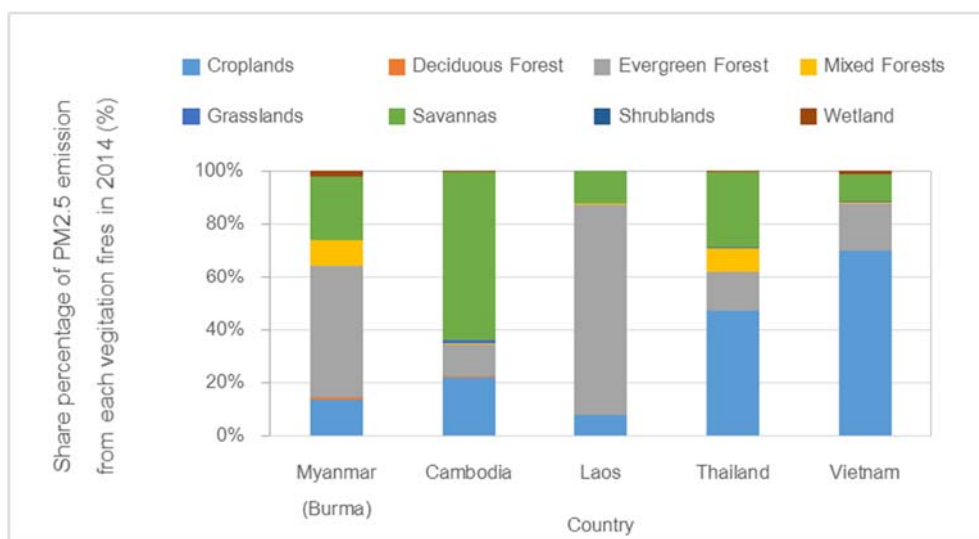


Figure 57. The share percentage of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2014

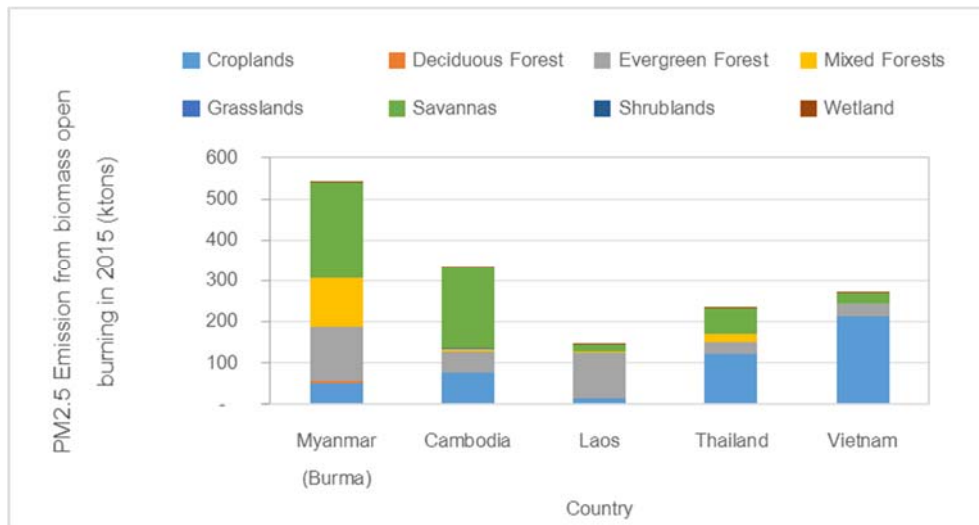


Figure 58. The actual amount of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2015

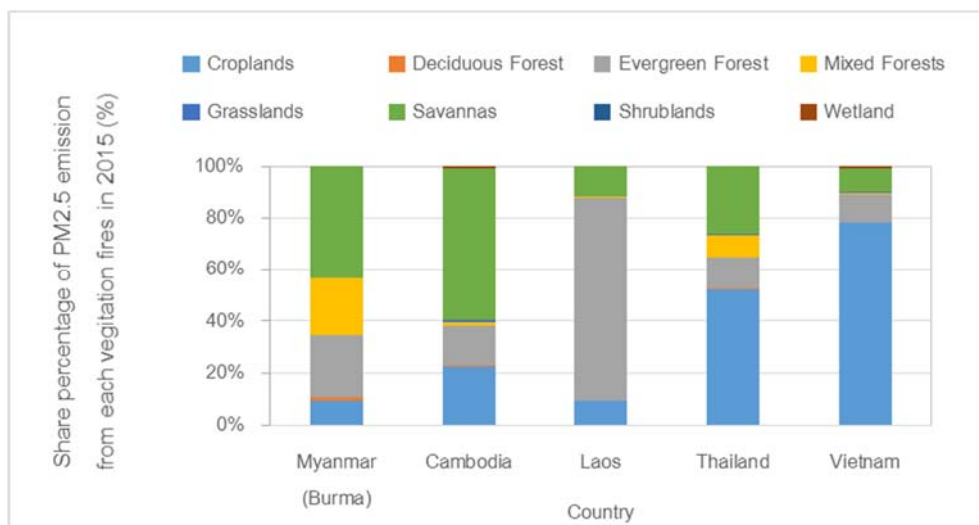


Figure 59. The share percentage of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2015

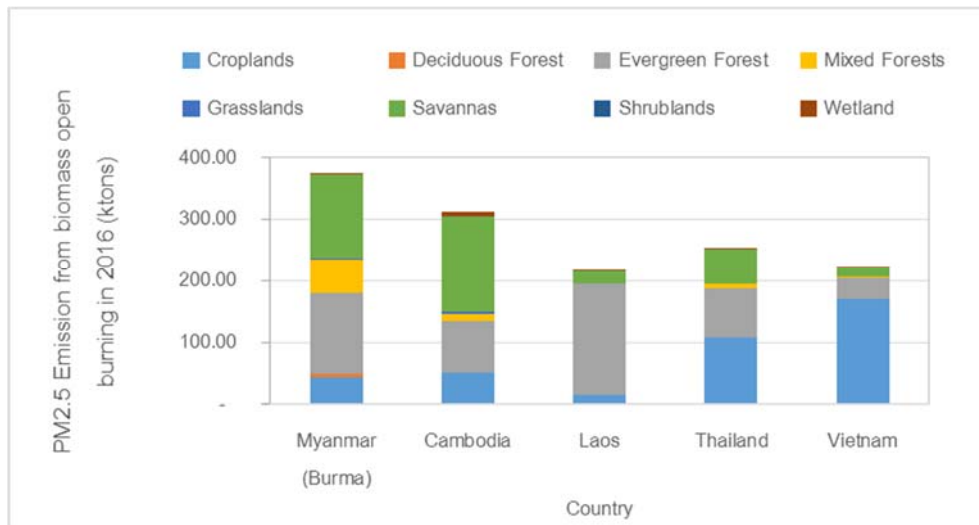


Figure 60. The actual amount of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2016

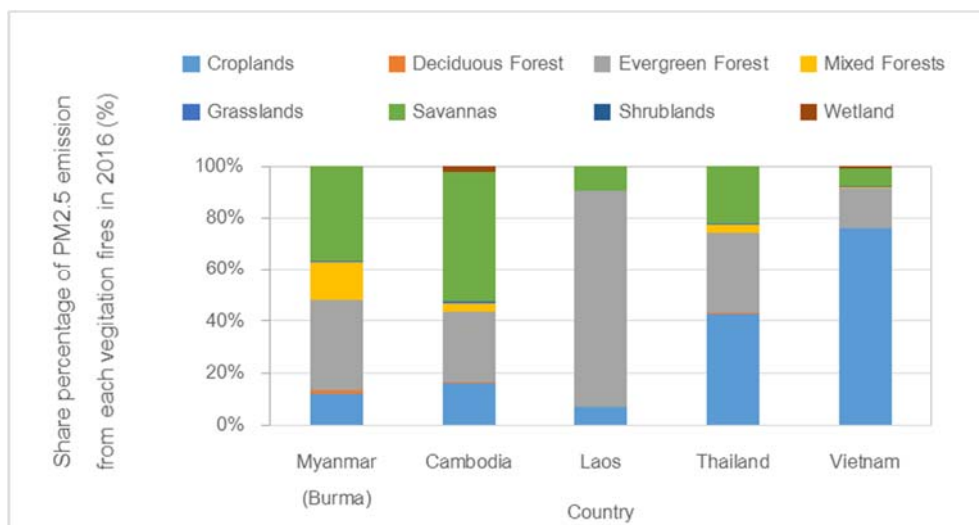


Figure 61. The share percentage of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2016

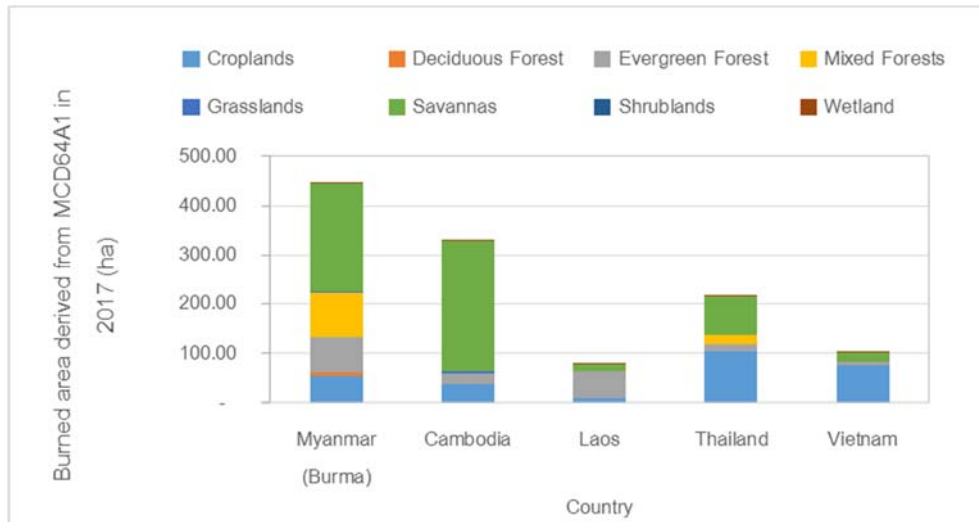


Figure 62. The actual amount of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2017

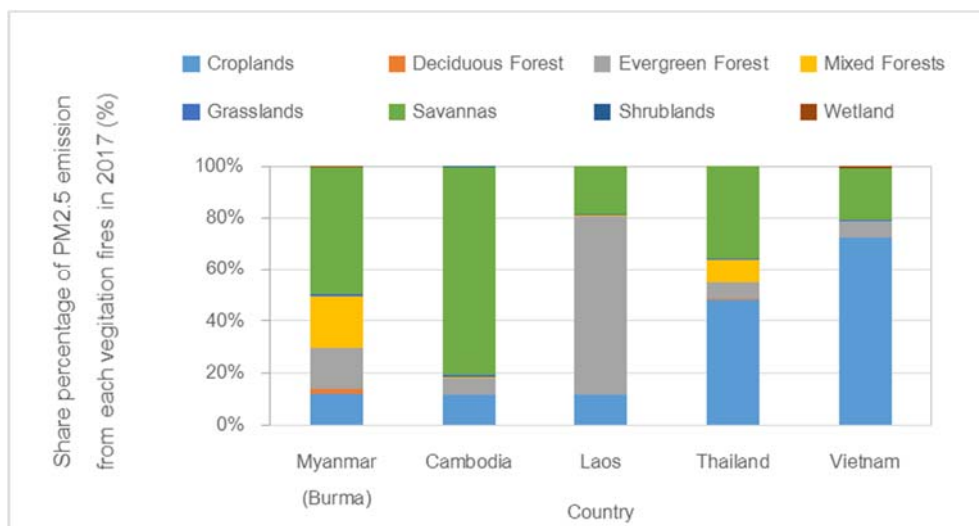


Figure 63. The share percentage of PM_{2.5} emission from biomass open burning in GMS classified by vegetation fires, 2017

3.7 Spatial distribution of emission from biomass open burning in GMS

Taking into consideration the spatial distribution of PM_{2.5} emission from forest and savannas fires, as demonstrated in Figures 64 and 65, the density of PM_{2.5} emission was 1,000–2,500 t/grid (grid size 144 km²); these were mostly allocated at the northern region of Thailand, the western region of Myanmar and the northern regions of Cambodia and Laos, the density was only 500-1,000 t/grid for the central region of Myanmar, Cambodia and Laos,. Regarding agricultural fires, as presented in Figure 66, the densities were 1,000-2,500 t/grid for the central region of Thailand, the western region of Cambodia and the southern region of Vietnam, 500-1,000 t/grid for the central regions of Myanmar and Cambodia, and only 100-500 t/grid for the other regions of all countries.

Combining both forest fires and agricultural fires, as demonstrated in Figure 67, the highest PM_{2.5} emission was in the northern region of Thailand, the western region of Myanmar and the central and northern regions of Cambodia, at the density of 1,000–2,500 t/grid, followed by the central and north-eastern regions of Thailand, the whole of both countries Laos and Vietnam at the density of 500-1,000 t/grid, and others region of all countries at the density of 100-500 t/grid. Hence, these regions entail effective mitigation measures to reduce the amount of smoke and smog pollution, such as extending the no-burning period by local authorities and promoting alternative uses of straw.

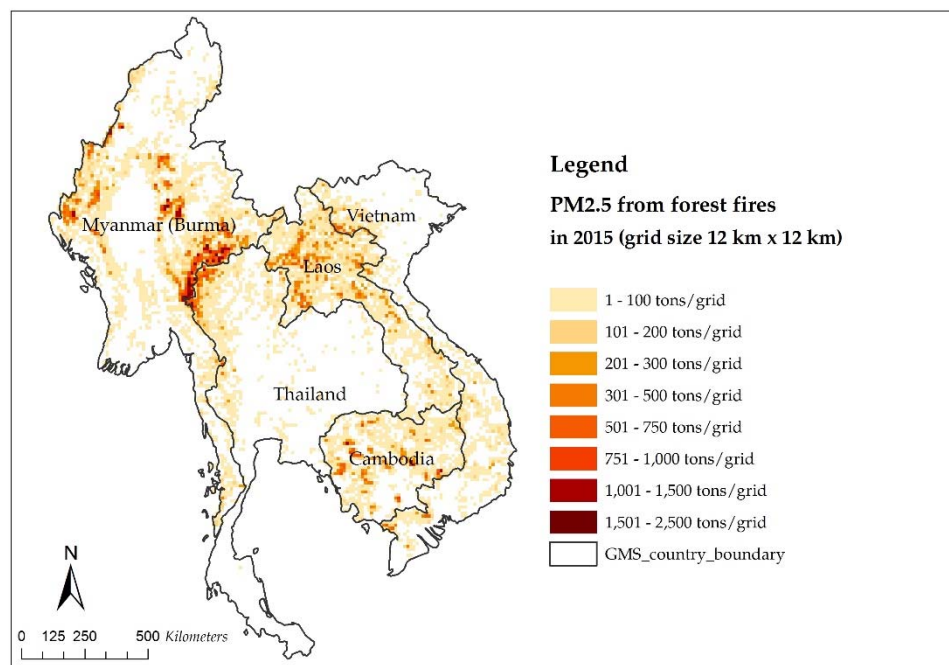


Figure 64. Spatial distribution of gridded PM_{2.5} emission from forest fires in GMS, 2015

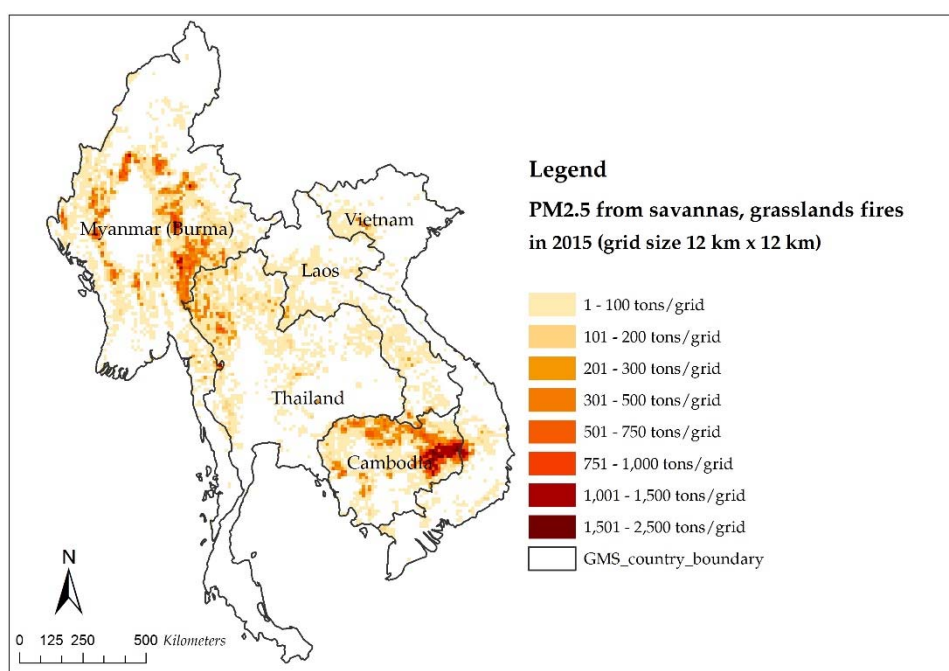


Figure 65. Spatial distribution of gridded PM_{2.5} emission from savannas fires in GMS, 2015

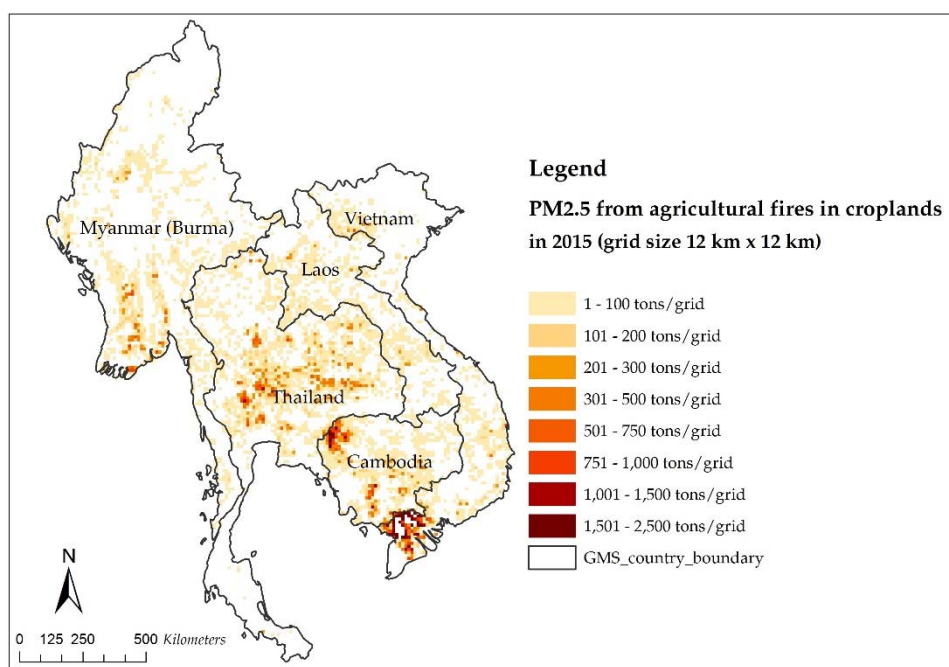


Figure 66. Spatial distribution of gridded PM_{2.5} emission from agricultural fires in GMS, 2015

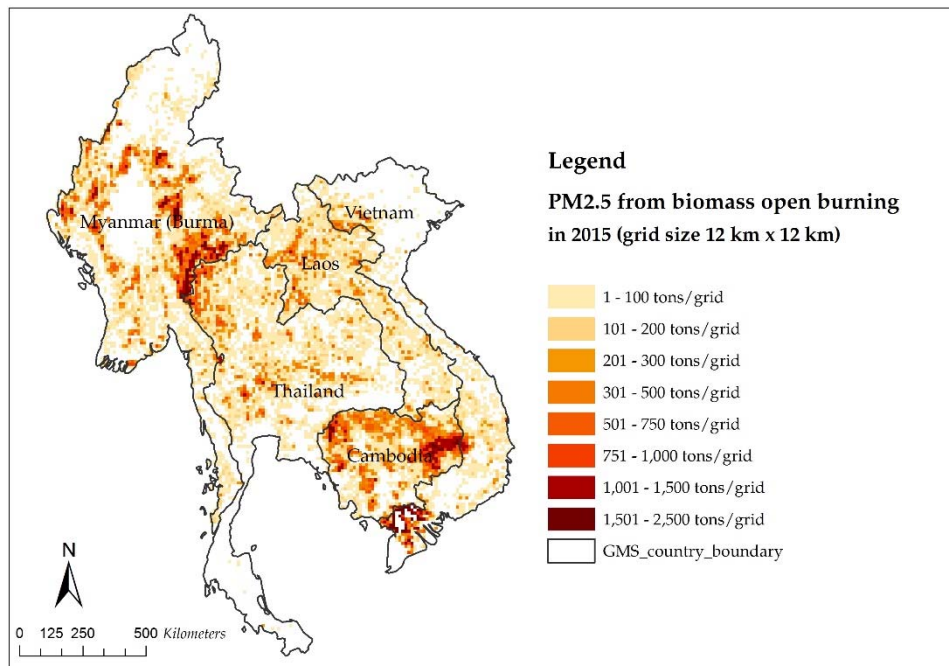


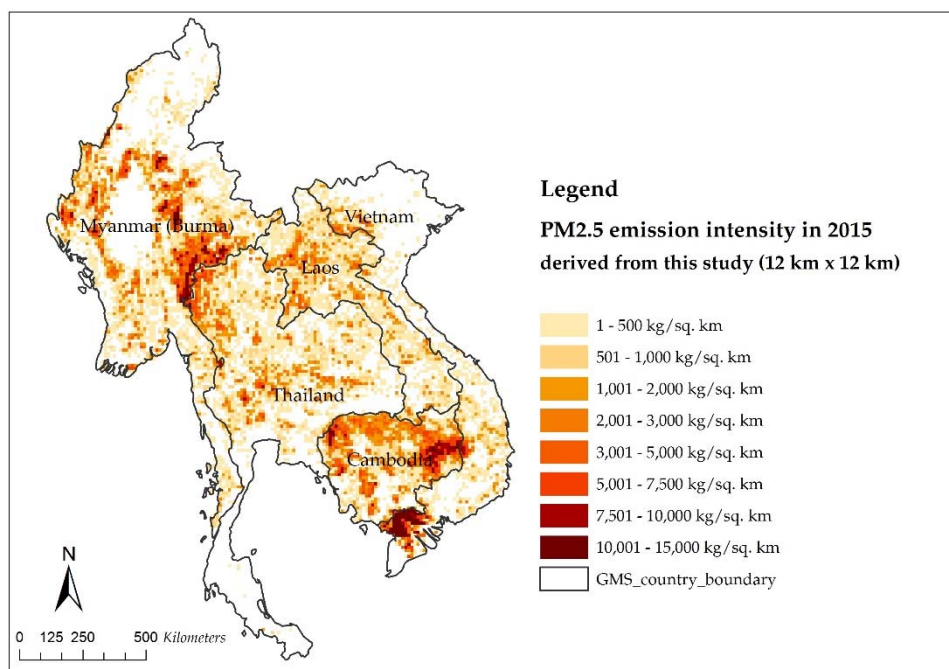
Figure 67. Spatial distribution of gridded PM_{2.5} emission from biomass open burning in GMS, 2015

3.8 Comparison with Global Fire Emission Database

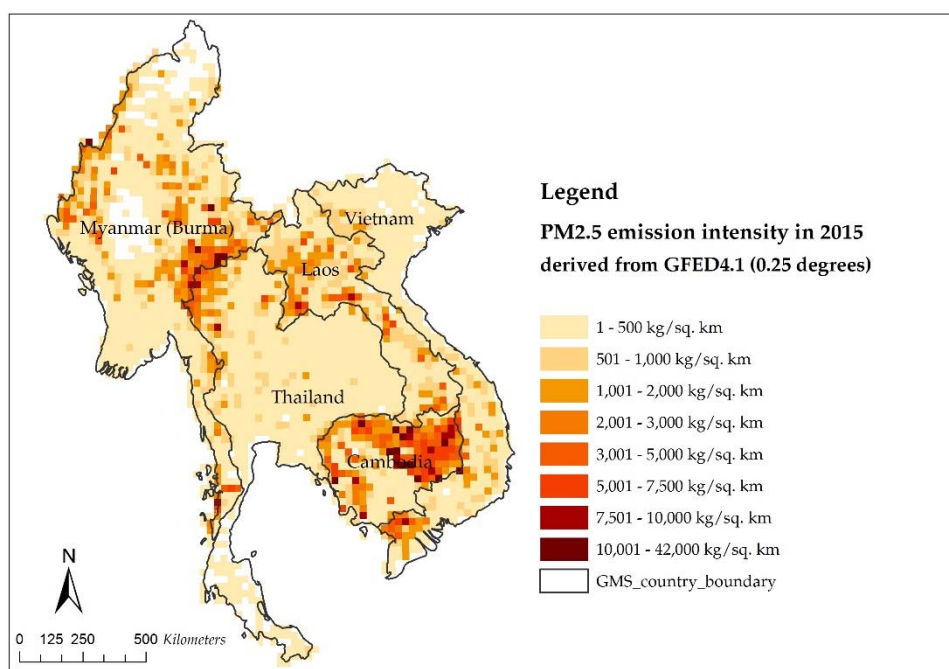
Based on the comparison of PM_{2.5} emissions between this study and the Global Fire Emission Database version 4.1 (GFEDv4), as presented in Table 22, it can be observed that the results of this study are slightly lower than GFEDv4, the difference is varying by a range of 1.08 to 1.80 times, with the exception of PM_{2.5} in Vietnam which is higher than GFEDv4 in 1.35 times. After improving of the emission estimation, this study provides the 12 km × 12 km gridded map for the spatial allocation of the PM_{2.5} emission intensity, which is useful for the government officers in acquiring an explicit understanding of the biomass open burning behaviors in GMS. Likewise, this information can be used as the input data in the air quality modeling in order to simulate air quality at the regional and national level. Figure 68 shows the comparison of the PM_{2.5} emission intensity from biomass open burning in GMS between this study and GFEDv4, 2015.

Table 22. Comparison of PM_{2.5} emission between this study and GFEDv4.

Country	PM _{2.5} emission derived from this study (kt)				PM _{2.5} emission derived from GFED4.1 (kt)				Ratio (GFED4.1/ this study)
	Crop fires	Savan- nas fires	Forest fires	Total	Crop fires	Savan- nas fires	Forest fires	Total	
Myanmar	50	235	255	541	14	368	204	585	1.08
Cambodia	75	201	60	336	26	232	347	605	1.80
Laos	13	17	113	143	4	155	89	248	1.73
Thailand	121	61	50	232	34	196	49	280	1.21
Vietnam	213	25	33	272	50	93	59	202	0.74
Total	474	543	512	1,529	128	1,043	749	1,920	1.26



(a)



(b)

Figure 68. Comparison of the PM2.5 emission intensity from biomass open burning in GMS between (a) this study and (b) GFEDv4, 2015.

4. Conclusion

This research emphasized on improving the estimation of areas burned from biomass open burning that employed remote sensing data from MODIS burned area products (MCD64A1 and MCD45A1), which are widely used in the evaluation of burned areas from vegetation fires. The said improvement was performed by using reference fires obtained from high-resolution remote sensing data, namely LANDSAT-8 (OLI/TIRS surface reflectance data products). Upon analysis of the burned area data, it was found that the data obtained from MCD64A1 and MCD45A1 had lower values than the reference fires for all types of fires (agricultural fires, forest fires, and savanna fires). Furthermore, the burned area data obtained from MCD64A1 were more consistent with the reference fires than the data obtained from MCD45A1. Specifically, the burned area data obtained from the reference fires were 2.11-5.21 times (mean = 2.89) higher than the data obtained from MCD64A1 and 8.34-21.08 times (mean = 12.01) higher than the data obtained from MCD45A1. Accordingly, the MCD64A1 burned area product should be used in place of the MCD45A1 product when evaluating the number of areas burned from biomass open burning in the GMS so as to obtain results that are more consistent with the actual biomass burning activity. Upon adjustment of the burned area data obtained from MCD64A1, it was found that there were approximately 22.654 Mha of areas burned in the GMS during 2010 to 2017. The country with the highest number of areas burned was Myanmar (8.017 Mha), followed by Cambodia (6.454 Mha) and Thailand (4.484 Mha). These burned areas accounted for 249.564 Mt of biomass burned, which were found in croplands (66.526 Mt), forestlands (99.064 Mt), and savannas (83.975 Mt). Likewise, the foregoing biomass burning contributed to the emission of various air pollutants, including 2,736,136 kt of CO₂, 7,165 kt of CH₄, 281 kt of N₂O, 143,462 kt of CO, 5,335 kt of NO_x, 715 kt of SO₂, 2,191 kt of NH₃, 12,584 kt of PM_{2.5}, 18,737 kt of TPM, 898 kt of BC, and 5,363 kt of OC. The results of air pollution emissions from biomass open burning were compared with the Global Fire Emissions Database (GFED), Version 4.1, particularly the PM_{2.5} that is considered to have significant effects on air quality in the GMS. Upon comparison, it was found that, in 2015, the PM_{2.5} emissions obtained from GFEDv4 were 1.08-1.80 times higher than the results obtained from this research for every country, except Vietnam whereof the PM_{2.5} emissions were found to be 0.74 times lower than the results of this research. This research proposed a modified method of evaluating air pollution from biomass open burning that delivers more accurate results and higher resolution of spatial emission data than the data obtained from GFED, and thus can be

applied to the air quality model. With respect to future researches, the study area should be expanded to cover other regions in the GMS in order to enhance the accuracy of the evaluation of burned areas, concerning the fact that this research only focused on 10 Northern provinces of Thailand. Likewise, other variables relating to the evaluation of air pollution emissions from biomass open burning should be taken into account, which include fuel load, combustion efficiency, and emission factors. Additionally, it is recommended to analyze and review data that are specific to each country in order to obtain results that are more accurate and representative of each area.

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Output จากโครงการวิจัยที่ได้รับทุนจาก สกว.

1. ผลงานตีพิมพ์ในวารสารวิชาการนานาชาติ (ระบุชื่อผู้แต่ง ชื่อเรื่อง ชื่อวารสาร ปี เล่มที่ เลขที่ และหน้า) หรือผลงานตามที่ได้คาดไว้ในสัญญาโครงการ
International Journal
 - Jirataya Pansuk, Agapol Junpen* and Savitri Garivait. Assessment of Air Pollution from Household Solid Waste Open Burning in Thailand, *Sustainability*, 2018, 10, p. 2553; doi:10.3390/su10072553.
 - Agapol Junpen, Jirataya Pansuk, Orachorn Kamnoet, Penwadee Cheewaphongphan, Savitri Garivait. Emission of Air Pollutants from Rice Residue Open Burning in Thailand, in 2018. The manuscript was accepted to *Atmosphere* on 12 November 2018.
 - Agapol Junpen, Athipthep Boonman and Savitri Garivait. Estimation of biomass open burning emissions in the Greater Mekong Sub-region by using remote sensing information. The manuscript have been prepared to submit the *Environmental pollution*.
2. การนำผลงานวิจัยไปใช้ประโยชน์
 - เชิงพาณิชย์ (มีการนำไปผลิต/ขาย/ก่อให้เกิดรายได้ หรือมีการนำไปประยุกต์ใช้โดยภาคธุรกิจ/บุคคลทั่วไป)
 -
 - เชิงนโยบาย (มีการกำหนดนโยบายอิงงานวิจัย/เกิดมาตรการใหม่/เปลี่ยนแปลงระเบียบข้อบังคับหรือวิธีทำงาน)
 - ผลงานวิจัยถูกใช้เป็นฐานข้อมูลในส่วนของคุณค่าเชิงพื้นที่และเวลาของการปล่อยมลพิษทางอากาศจากการเผาชีวมวลในที่โล่งเพื่อนำเข้าสู่โมเดลในการวิเคราะห์คุณภาพอากาศของประเทศไทยในปี 2015
 - เชิงสาธารณะ (มีเครือข่ายความร่วมมือ/สร้างกระแสความสนใจในวงกว้าง)
 -
 - เชิงวิชาการ (มีการพัฒนาการเรียนการสอน/สร้างนักวิจัยใหม่)

- สร้างนักวิจัยในการพัฒนางานองค์ความรู้การประยุกต์ใช้ข้อมูลการสำรวจระยะไกลในการประเมินหาพื้นที่เผาของการเผาชีวมวลในที่โล่ง รวมถึงการประเมินการปล่อยมลพิษทางอากาศจากการเผาชีวมวลในที่โล่ง
3. อื่นๆ (เช่น ผลงานตีพิมพ์ในวารสารวิชาการในประเทศ การเสนอผลงานในที่ประชุมวิชาการ หนังสือ การจดสิทธิบัตร)

International Conference

- Orachorn Kamnoet, Agapol Junpen and Savitri Garivait. Improving the Estimation of Burned Area from Biomass Open Burning in The Greater Mekong Sub-Region using High Resolution Satellite Products. Oral presentation in 7th International Conference on Sustainable Energy and Environment (SEE 2018): Technology & Innovation for Global Energy Revolution 28-30 November 2018, Bangkok, Thailand