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Assessment of vegetation fires in Myanmar: Spatio-temporal distribution, land cover types, prone areas, and driving factors

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ပတ်ဝန်းကျင်ထိန်းသိမ်းရေးဦးစီးဌာန

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သဘာဝပေါက်ပင်များ လောင်ကျွမ်းခြင်းမှ ဖြစ်ပေါ်သော မီးခိုးမြှုပ်ငွေ့ညစ်ညမ်းမှုသည် အာဆီယံဒေသအတွင်းတွင် လတ်တလောဖြစ်ပေါ်နေသည့် အဓိကပြဿနာ တစ်ရပ်ဖြစ်ပါ သည်။ ထိုပြဿနာကြောင့် ၂၀၀၂ ခုနှစ်တွင် အာဆီယံနိုင်ငံများမှ သဘာဝပေါက်ပင်များ လောင် ကျွမ်းမှုကို တားဆီးကာကွယ်ရန်နှင့် မီးခိုးမြှုပ်ငွေ့ညစ်ညမ်းမှုကို လျှော့ချရန်စတင်ကြိုးပမ်း ဆောင်ရွက်ခဲ့ကြပါသည်။ မြန်မာနိုင်ငံတွင် အဆိုပါအကြောင်းအရာနှင့် ပတ်သတ်၍ သုတေ သနပြုလေ့လာ ထားသော အချက်အလက်များရှားပါးခြင်းကြောင့် ၂၀၀၆ ခုနှစ်မှ ၂၀၁၇ ခုနှစ် အတွင်းမြန်မာနိုင်ငံတွင်ဖြစ်ပေါ်ပွားခဲ့သော မီးလောင်ကျွမ်းမှုအခြေအနေများ၊ အဓိက လောင် ကျွမ်း သောနေရာဒေသများနှင့် လောင်ကျွမ်းရသည့် အကြောင်းအရာများကို လေ့လာ ဖော်ပြ ထားပါသည်။ အဆိုပါအချက် အလက်များအား ဂြိုလ်ထု (MODIS) သတင်းအချက် အလက် များကို အခြေခံ၍ Geographic Information System (GIS) နည်းပညာဖြင့် အဓိက လေ့လာ ဆန်းစစ်ထားခြင်းဖြစ်ပါသည်။ တွေ့ရှိချက်များအရ ၂၀၀၆ ခုနှစ်မှ ၂၀၁၇ ခုနှစ်အတွင်း မြန်မာ နိုင်ငံတွင် မီးလောင်ကျွမ်းမှု အကြိမ်ရေ ၈၁၁,၁၄၃ ကြိမ်ခန့်ဖြစ်ပွားခဲ့ကြောင့် MODIS ဂြိုလ်ထုမှ လေ့လာခဲ့ရပါသည်။ ၂၀၀၇ ခုနှစ်တွင် အကြိမ်ရေ ၉၅,၂၆၀ ဖြင့် မီးလောင် ကျွမ်းမှု အများဆုံး ဖြစ်ပေါ်ခဲ့ပြီး ၂၀၁၇ နှစ်တွင် အကြိမ်ရေ ၄၇,၁၃၉ ကြိမ်ဖြင့် အနည်းဆုံး ဖြစ်ပေါ် ခဲ့ကြောင်း လေ့လာတွေ့ရှိရပါသည်။ မီးလောင် ကျွမ်းမှုများ၏ ၄၆% ကို သစ်တော မြေများတွင် တွေ့ရှိရပြီး ၃၇% မှာ ရွက်အုပ်ဖုံးလွှမ်းမှု (၅-၁၀%) ခန့်သာ ရှိသော အခြားသော သစ်တောမြေများတွင် ဖြစ်ပွားပြီး ၁၆%မှာ စိုက်ပျိုးမြေများ ဖြစ်ပြီး ကျန်၁%မှာ အခြားမြေအသုံးချမှုများမှ ဖြစ်ကြောင်း လေ့လာတွေ့ရှိရပါသည်။ ခြောက် သွေ့ ကာလဖြစ်သော ဇန်နဝါရီလမှ မေလ အတွင်း တွင် မီးလောင်ကျွမ်းမှုများကို အများဆုံး တွေ့ရှိရပြီး အဓိကဖြစ်ပွားသော အချိန်မှာ မတ်လနှင့်ဧပြီလ ဖြစ်ပါသည်။ မီးလောင်ကျွမ်းမှု ထိန်းချုပ်ရန် အဓိကဆောင်ရွက်ရမည့် တိုင်းဒေသကြီးနှင့် ပြည်နယ်များမှာ ရှမ်း၊ ချင်း၊ စစ်ကိုင်း၊ ရခိုင်၊ မကွေး၊ ကချင်၊ ပဲခူး၊ ကယားနှင့် ကရင်တို့ ဖြစ်ပါ သည်။ လေ့လာဆန်းစစ်မှုရလဒ်များအရ မီးလောင်ကျွမ်း မှုဖြစ်ပွားရသည့် အဓိက အကြောင်း အရင်းများမှာ မြေအပြောင်ရှင်း လင်းရန် မီးရှို့ခြင်း (စိုက်ပျိုးမြေ ဧရိယာချဲ့ထွင်ခြင်း၊ ရွှေ့ပြောင်း တောင်ယာစိုက်ပျိုးခြင်း၊ စိုက်ခင်းများ တည်ထောင်ခြင်း၊ မြို့ပြ ဖွံ့ဖြိုးမှုများ ဆောင်ရွက်ခြင်း၊ အမဲလိုက်ခြင်း)၊ သစ်နှင့်သစ်မဟုတ်သော အခြားသစ်တောထွက် ပစ္စည်းများထုတ်ယူခြင်း၊ ပေါ့ဆ မီးလောင်ကျွမ်းခြင်း (စခန်းချခြင်း၊ သစ်ထုတ်ခြင်းနှင့် တရားမဝင် သစ်ထုတ်ခြင်း)၊

စိုက်ပျိုးရေးစွန့်ပစ်ပစ္စည်းများမီးရှို့ခြင်းတို့ကြောင့် ဖြစ်ပါသည်။ ခြောက်သွေ့ခြင်း၊ အပူချိန်များခြင်းစသည်ဖြင့် သဘာဝကြောင့်ဖြစ်ပေါ်သည့် မီးလောင်ကျွမ်းမှုများမှာ အလွန်နည်းပါးကြောင်းကိုလည်း လေ့လာတွေ့ရှိရပါသည်။

Assessment of vegetation fires in Myanmar:
Spatio-temporal distribution, land cover types, prone areas, and driving factors

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Abstract

Haze pollution from vegetation fires in the ASEAN region is a recurrent issue. Due to this problem, in 2002, ASEAN countries gathered efforts to tackle vegetation fires and reduce haze pollution in the region. Due to a lack of published information on the subject in Myanmar, this study aimed at identifying the trend and types of vegetation exposed to fires in the country based on fire hotspot count and density, including, areas affected by fires and potential drivers over the period 2006-2017. The investigations were performed using active fire data from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the National Oceanic and Atmospheric Administration (NOAA-18, 19) as well as geographic information system and remote sensing techniques. The results showed that 811.143 fire hotspots (FHS) were detected by MODIS and 369,690 FHS by NOAA during 2006-2017. According to MODIS satellite, the highest number of FHS occurred in 2007 with 95,260 counts and the lowest in 2017 with 47,139 counts. Most of the FHS were found to occur on forest land, followed by other wooded land, crop land, and other land. Otherwise, the highest fire density was found to dominate in other wooded land, followed by forest land, crop land and other land. The most significant number of FHS was observed during January-May, with a peak in March and April each year. Based on the number of fire hotspots, land cover areas and fire density, this study found that 9 states and regions including Shan, Chin, Sagaing, Rakhine, Magway, Kachin, Bago, Kayah and Kayin out of 15 states and regions in Myanmar as priority areas to control fires. Based on expert judgement, in order of importance, the main causes of vegetation fires include in decreasing order of importance: burning for land clearances (agricultural expansion, shifting cultivation practices, plantations, urban development, fire prevention in the forest areas and grazing), burning for collection of wood and non-wood forest products, careless and accidental fires (camping, logging and illegal logging), burning for hunting and burning for the removal of agricultural residues. Fires from prolong drought in Myanmar were rarely seem to occur.

Keywords: Fire Hotspots, MODIS Data, Myanmar, Spatio-temporal distribution, Vegetation Fires Drivers

Assessment of Vegetation Fires in Myanmar:

Spatio–temporal Distribution, Land Cover Types, Prone Areas, and Driving Factors

1. Introduction

Fire is usually used as a land clearance tool in the Southeast Asian (SEA) region [1]. Vegetation fires can be wildfire incidents or prescribed burning operations that use vegetation as fuel [2]. Biomass burning is the burning of various biomass materials from forests, grasses, crop residues and municipal solid wastes (MSWs) [5]. Vegetation fires are one of the major sources of air pollutant emissions in SEA [4]. They emit an obvious amount of smoke into the air [4]. Emissions from vegetation fires are an important topic in the region in terms of air quality, global atmospheric chemistry, climate change and haze pollution [5].

In the ASEAN region, haze pollution from vegetation fires is an observed recurrent issue each year. The haze from one source can travel long distances due to strong wind directions. When haze travels across borders, it becomes transboundary pollution [6]. Transboundary haze pollution means haze pollution, physical origin is situated wholly or in part within the area under the national jurisdiction of one Member State, which is transported into the area under the jurisdiction of another Member State [7]. Transboundary haze pollution is not a domestic problem but a national problem. Therefore, all of ASEAN member states still need to cooperate to reduce and mitigate transboundary haze pollution [6].

Information on fire hotspots (FHS) from the ASEAN Specialized Meteorological Center ASMC website shows that Myanmar is the largest contributor to vegetation fires in the Northern ASEAN Region [8]. However, among ASEAN countries, Myanmar is the least studied country with regard to vegetation fires and its contribution to haze pollution remains to be clarified. This is due to poor data availability because of insufficient capacity and technical knowledge, inaccessible and limited efficient road networks particularly in the transboundary areas, high cost and limited finance for fire protection, poor people’s awareness and participation, weak coordination, lack of

monitoring and research on frequency, extent and severity of fire, updated information of hotspots (on ground), and database information and monitoring systems for implementing the ASEAN Agreement on Transboundary Haze Pollution (AATHP) [9].

The literature review suggests that the Moderate Resolution Imaging Spectroradiometer (MODIS) is better suited to assess fire detection than the National Oceanic and Atmospheric Administration (NOAA). The NOAA sensor (AVHRR) has mainly been designed for weather surveillance and sea surface temperature management and so contains some weaknesses with regard to fire detection while MODIS was mainly produced for fire hotspots detection [10]. Satellite data can help to detect vegetation fires especially over a large area and using remotely sensed data to assess and monitor the areas affected by vegetation fires is the cost–effective way [11]. However, the fire hotspots published by the ASMC are based on data collected from the NOAA satellite with Advanced Very High–Resolution Radiometer (AVHRR) sensor. That is why this study mainly analyzed satellite data from MODIS Aqua and Terra satellites although data from NOAA series satellites was also considered in the initial investigations of fire hotspots distribution.

This study focused therefore on investigating the status of vegetation fires in Myanmar over the period 2006–2017, including, the spatiotemporal distribution of fires, the land cover and areas most impacted by fires and main driving factors leading to vegetation fires.

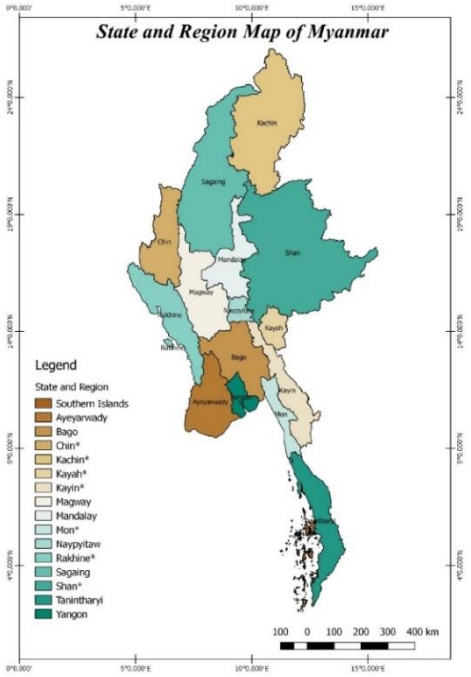
2. Study Area

The Republic of the Union of Myanmar is geographically located in Southeast Asia between latitudes 9°32’N and 28°31’N and longitudes 92°10’E and 101°11E. Myanmar is surrounded in the north and northeast by China, in the east and southeast by Laos and Thailand, in the south by the Andaman Sea and the Bay of Bengal and in the west by Bangladesh and India. The total area of Myanmar is 676,577 km^2. It stretches 936 km from east to west and 2051 km from north to south. Myanmar is composed of seven states, seven regions and one union territory [12]. The administrative boundaries for states and regions in Myanmar are shown in figure 1. The landscape of Myanmar is significantly heterogeneous in terms of climate, topography as well as land cover. The

major land categories by percentage of the country's total area include: forest land (27.42%), agricultural land (18.41%), vacant land/virgin land/ cultivable waste land (29.54%) and other land types (24.62%) [13].

The topography can roughly be divided into five parts such as the western Hill Region, the Central Valley Region, the Eastern Hills Region, the Northern Hill Region, and the Coastal Land and Delta Region [13, 14]. The mountainous and hill regions are found in the northern and western parts of the country while the Shan plateau is located in the east. The central region consists of plains and is the base of agricultural land [14]. Nearly 45.04% of the country's total land area is still covered by forests [12]. Myanmar's forests are diverse and varied in composition and structure, and constitute a valuable ecosystem due to their wide extent, varied topography and different climatic conditions. The forests are distributed over three main climatically distinct regions (Tropical, Subtropical and Temperate). The Forest Department of Myanmar recognized and adopted eight dominant forests, including, tidal/mangrove forest, hill and temperate forest, evergreen forest, mixed deciduous forest, deciduous dipterocarp forest and dry forest [13].

The climate is mainly influenced by Southwest Monsoon [14]. Myanmar has three seasons, i.e. summer, rainy and cold seasons [12]. Due to a large country, the mean annual rainfall varies and is highly dependent on its topography [14]. The central region of Myanmar has an annual rainfall of less than 1,000 mm while the Rakhine coast receives more than 5,000 mm and the Delta region around 2,500 mm. The temperature fluctuates between 30°C and 35°C during the hot season (March to May), between 25°C and 30°C during the rainy season (June to October) and between 20°C and 24°C during the cold season (November to February) [12].



Note: States are marked with asterisk to differentiate from regions

Figure 1. State and region map of Myanmar

3. Material and Methods

3.1 Satellite Data

In this study, monthly active fire hotspot data over the period 2006–2017 were gathered from two main sources: (1) the Fire Information for Resource Management System (FIRMS) – monthly active fire data (MCD14ML) from Terra and Aqua (MODIS satellites); and (2) from ASMC – monthly fire data from NOAA (NOAA–18, 19). The fire hotspot data contributed by FIRMS based on MODIS satellites and ASMC based on NOAA series satellites were downloaded from their respective websites. The spatial resolution of these both satellites is one kilometer.

MODIS (from the National Aeronautics and Space Administration, NASA) is the first sensor which contains fire monitoring capabilities and MODIS is one of the most important data sources for global mapping of fires location. MODIS sensors are mounted aboard two satellites, the Terra spacecraft lunched in December 1999 and the

Aqua spacecraft lunched in May 2002 [15]. MODIS Terra and Aqua are polar orbiting satellites that pass over the equator 4 times per day approximately at 10:30 AM/ PM for terra and 1:30PM/ AM for aqua [16].

3.1.1 Active fire data

This study used MODIS monthly active fire standard data product (MCD14ML) for the period 2006–2017. MCD14ML is a global monthly fire location standard product which is more appropriate to be used for time series analyses or long– term studies. The fire product is processed through the MODIS Adaptive Processing System (MODAPS) using the contextual fire detection algorithm into the collection 6 active fire product [17]. This algorithm used brightness temperature from the middle and shortwave infrared channels of the MODIS instruments to detect fire [18].

The monthly fire location product contains the geographic location, date, scan, track, brightness temperature, detection confidence, version, FRP (fire radiative value) and some additional information for each fire pixel detected by the Terra and Aqua MODIS sensors on a monthly basis [17]. As mentioned earlier, data can be obtained through the MODIS Fire Archive Download Tool via the FIRMS website. The data are available in the following formats: shapefiles (.shp), comma–separated text files (.csv) and JSON files (.json). The spatial resolution of this active fire product (MCD14ML) is one kilometer and the projection is Geographic WGS 84 projection. [15].

3.1.2 Detection confidence of active fire data

The detection confidence value ranges from 0% to 100%. The confidence level is used to assign the classes of low–confidence [<30%], nominal–confidence [30–80%], and high–confidence [>80%] to all fire pixels [15, 17]. This study focused on assessing the status and trend of vegetation fires in Myanmar over 2006–2017. That is

why this study used three classes of fire confidence in order to investigate maximum fire detection in Myanmar.

3.2 Land Cover Data

In this study, the administrative boundary map and the national land use map from the Forest Department, Ministry of Natural Resources and Environmental Conservation, Myanmar were used. The national land use map was produced using data Landsat 7 ETM+ (30 m resolution) and is based on Rapideye Five Constellation Satellites (6.5 m resolution), and IRS Liss 3 Satellite (23.5 m resolution) as reference data to identify land use types. This land cover map was produced based on data from the year 2010 and has a 30 m spatial resolution. It includes 11 land cover classes that are: closed forest, open forest, mangrove forest, other wooded land, cropland, other land, settlements, wetland, grassland, snow and water. A canopy cover greater than 40% refers to closed forest; 10–40% is open forest (normally degraded forest); 5–10% represents other wooded land that does not include land that is predominantly under agricultural or urban land use and other land that includes meadows and pastures, built up areas, and barren land [13]. In terms of land surface, forest, other wooded land, crop land, and other land cover 298,657 km^2, 186,860 km^2 164,075 km^2 and 27,125 km^2. The percentage of map classes were 44% of forest land, 28% of other wooded land, 24% of crop land and 4% of other land respectively. The land cover map of Myanmar is shown in figure 2.

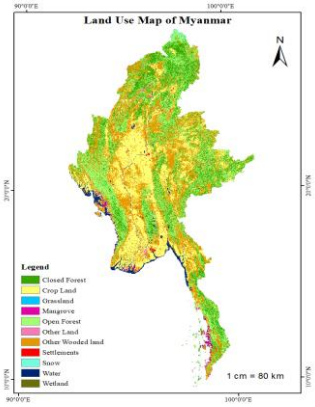


Figure 2. Land cover map of Myanmar (2010)

Source: Forest Department, Myanmar (2015)

3.3 Data Analysis

As stated earlier, this study focused on investigating the spatiotemporal distribution of fires and identifying the land cover types mostly impacted by fires in Myanmar. To this end, active fire data from MODIS were overlaid with the land use map of Myanmar to classify the fire hotspots at the national level and then with the administrative boundary map for each state and region of Myanmar at the regional level accordingly. Data processing was performed using data management, and analysis tools and techniques available within the geographic information system (GIS) software QGIS 2.18.15 version.

To characterize the temporal extent of fire hotspots, this study assessed the total and mean fire counts on a monthly and annual scale over the period 2006–2017. To study the influence of fire hotspots on a land cover type, this study extracted the dominant land cover class for each hotspot. To assess the percentage of hotspots belonging to each land cover class and by extension each state and region of Myanmar, Equation (1) was used. To determine fire density, Equation (2) was used.

$$\%\ of\ hotspots = \frac{\text{Number of hotspots in a particular land cover class}}{\text{Total number of hotspots}} \times 100 \qquad (1)$$

$$\text{Fire Density} = \frac{\text{Number of Fire Hotspots (FHS)}}{\text{Land Area (km2)}} \qquad (2)$$

Following the above assessments, risk area maps were produced based on fire density, with different range of color for each land use type to identify regions and types of vegetation prone to open burning in Myanmar over the study period. In all risk area maps, green color shows the low range of fire density, yellow color for medium range and red color represents the high range of fire density.

3.4 Expert Judgement for the Causes of Vegetation Fires

In order to assess the causes of vegetation fires in Myanmar, this study conducted the online interview to the experts who are responsible of vegetation fires control in Myanmar. This was the best possible way to know the causes of fires in Myanmar and identify the possible solutions to control fires in Myanmar during the short–term study period when this study could not approach the on–ground assessment of vegetation fires in Myanmar.

4. Results and Discussion

4.1 Monthly and Yearly Distribution of Fire Hotspots

As detailed in Table 1, the cumulative number of fire hotspots based on MODIS and NOAA data were found to amount to 811,143 and 369,690 respectively over the period 2006–2017. These results show that there is a large difference between MODIS and NOAA data. This is due to the different sensors and spectral bands of the two satellites to detect fires on the ground as well as timing of overpass. Also, MODIS can detect hotter and larger fires than NOAA (where the AVHRR channels already saturate). However, in either case, the results show a similar pattern regarding the spatiotemporal distribution of fires in Myanmar.

Table 1. MODIS and NOAA Fire Hotspots in Myanmar during 2006–2017

Year	MODIS (FIRMS)	NOAA (ASMC)	Ratio
2006	61,182	18,751	3:1
2007	95,260	33,468	3:1
2008	57,282	27,740	2:1
2009	82,915	34,871	2:1
2010	90,754	38,359	2:1
2011	50,498	27,976	2:1

2012	80,127	52,042	2:1
2013	69,253	44,397	2:1
2014	67,533	37,926	1:1
2015	58,023	26,657	2:1
2016	51,147	16,158	3:1
2017	47,169	11,345	4:1
Annual Average	**67,959**	**30,808**	**2:1**

Source: Data from ASMC website and FIRMS website using MCD14ML product

According to MODIS data, the highest number of FHS occurred in 2007 with 95,260 counts and the lowest in 2017 with 47,169 counts. The annual average number of fire hotspots amounts to 67,959 and it can be assumed that about 10% of the total land area of Myanmar is annually exposed to fire. About 77% of the fires were found to occur in the afternoon (Aqua satellite) and 23% in the morning (Terra satellite). Approximately 99% of the fires were observed to occur during the dry season (from January to May). March and April are the months where the number of fire hotspots culminate with nearly 80% of the total number of fire hotspots recorded during that time in each year. These are the hottest months of the year and a time during which the amount of biomass in forested areas is the highest as trees shed their leaves during that time [19]. Also, it is a period during which the harvesting of crops takes place, including land clearance and preparation for a next cycle of production [20].

4.2 Hotspots Distribution in relation to Land Cover in Myanmar

Looking at confidence levels of fire hotspots, it was found that 66% were assigned to the medium confidence class, 30% to the high confidence class and 4% to the low confidence class. With regard to the land cover and vegetation types mainly

exposed to fire, (see Table 2), over the period 2006–2017, on annual average basis, it was found that about 46% of the fire hotspots were detected on forest land, followed by other wooded land with 37%, cropland with 16%, and other land with 1%. In terms of burned area, this translates into 31,315 km^2 of forest land, 25,157 km^2 of other wooded land, 10,658 km^2 of crop land and 466 km^2 of other land annually. This shows that about 10% of forest land, 13% of other wooded land, 6% of crop land and 2% of other land are affected by fire on an annual basis.

Table 2. Fire Hotspots Distribution in Relation to Land Cover in Myanmar (2006– 2017)

Hotspot Counts (Years)	Forest Land			Other Wooded Land	Crop Land	Other Land	Total
	Closed Forest	Open Forest	Mangrove				
2006	9,286	17,586	67	23,924	9,889	430	**61,182**
2007	15,291	31,867	99	33,607	13,811	585	**95,260**
2008	8,478	18,656	48	21,040	8,659	401	**57,282**
2009	12,794	29,956	53	28,185	11,387	540	**82,915**
2010	15,081	30,673	88	31,438	12,895	579	**90,754**
2011	6,497	16,527	34	19,019	8,092	329	**50,498**
2012	13,168	25,953	69	29,094	11,338	505	**80,127**
2013	10,456	20,961	56	26,686	10,633	461	**69,253**

2014	9,905	18,575	86	26,831	11,552	584	**67,533**
2015	7,869	14,718	47	23,948	10,984	457	**58,023**
2016	7,851	14,853	44	19,402	8,638	359	**51,147**
2017	6,298	11,761	26	18,713	10,012	359	**47,169**
Total %	**15%**	**31%**	**< 1%**	**37%**	**16%**	**< 1%**	**100%**
Annual Average	**10248**	**21007**	**60**	**25157**	**10658**	**466**	**67595**
Annual Average %	**15%**	**31%**	**< 1%**	**37%**	**16%**	**< 1%**	**100%**

Note: Based on data from MCD14ML Product by using MODIS Aqua and Terra Satellites

The highest number of fire hotspots for all land cover types occurred in 2007. This can be partly explained by the fact that it corresponded to an El Nino year [19]. The total number of fire hotspots detected in 2017 is about 50% lower than that in 2007. In 2007, about 50% of the total number of fires were detected on forest land, followed by other wooded land with 35%, cropland with 14%, and other land with 1%. In 2017, as compared to 2007, the number of fire hotspots was found to have decreased by 62% on forest land, and to have increased by 44% on other wooded land and 28% on crop land. These results may be explained in parts by the practices of shifting cultivation followed by farmers, which encroach on forest areas, and by the control measures set in place to prevent illegal logging as well as by the banning of timber export (since 2016) for forest land, land clearance for agricultural expansion, urban development for other wooded land and the removal of agricultural residues and the unreasonable practices for crop growing in cropland [21].

4.3 Hotspots Distribution over States and Regions of Myanmar

Regarding the distribution of fire hotspots in various states and regions of Myanmar, it was found that they mostly occur in inland areas of Myanmar (rather than in coastal areas and the Delta region). As a general result, fires hotspots are mostly found in States rather than Regions in Myanmar. About 70% of fires hotspots were found in States. Based on land cover type, approximately 81% (84% in closed forest, 79% in open forest and 27% in mangrove forest) of fires in forest land were found to be in states, followed by 63% in other wooded land, 58% in crop land and 48% in other land. This observation can be explained by the difference in slopes and elevations between States and Regions, and land cover. All States in Myanmar are located in hilly regions and mainly covered by forest, followed by other wooded land while all regions in Myanmar are located in central plain areas, coastal areas and delta region.

As illustrated in figures 3 and 4, the largest share of fire hotspots occurs in the Shan State in the eastern part of the country with 35% of the total number of fire hotspots, out of which 49% fall on forest land, 34% on other wooded land (34%) and 17% on cropland. This is followed by the Chin State in the upper western part of Myanmar with 10%, out of which 66% are on forest land, 31% on otherwooded land and 3% on cropland. Next are the Magway Region in the central area of Myanmar and the Rakhine State in the lower western part of the country with 8% each of the total number of fire hotspots. For the Magway Region 55% of the fire hotspots occur on wooded land, 24% on cropland, 20% on forest land and 1% on other land. In the Rakhine State 76% of the fire hotspots are on forest land, 20% on other wooded land, 3% on cropland and 1% on other land. It was also found that the lowest number of fire hotspots is in the Yangon region with only 1% of total number of fire hotspots in Myanmar out of which 62% occur on crop land, 26% on other wooded land, 8% on forest land and 3% on other land.

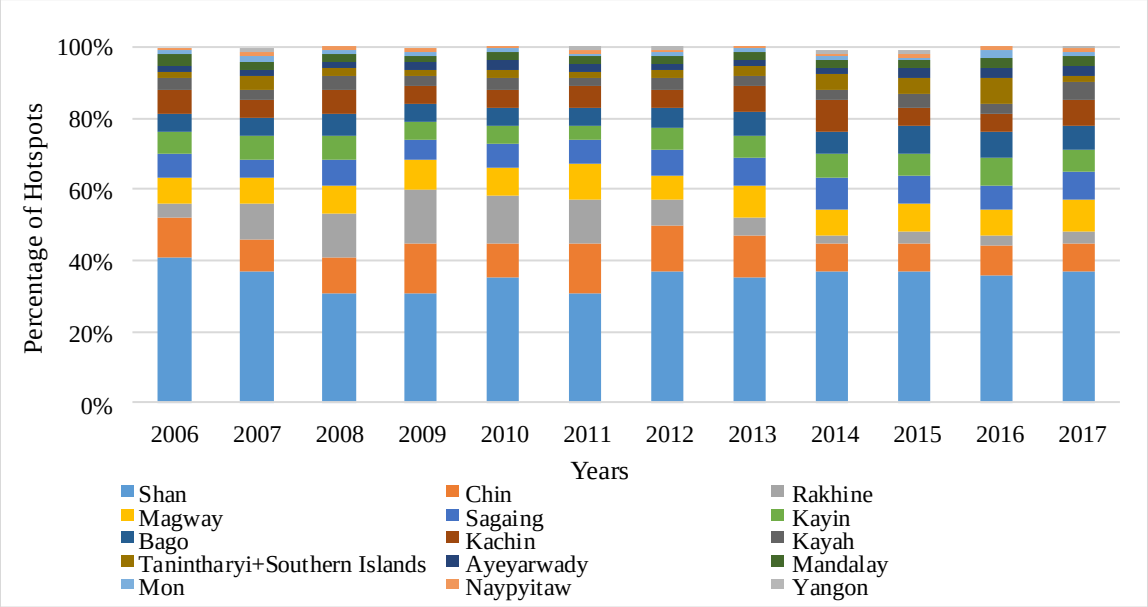


Figure 3. Fire Hotspots Distribution over States and Regions in Myanmar (2006–2017)

Note: Based on data from MCD14ML Product by using MODIS Aqua and Terra Satellites

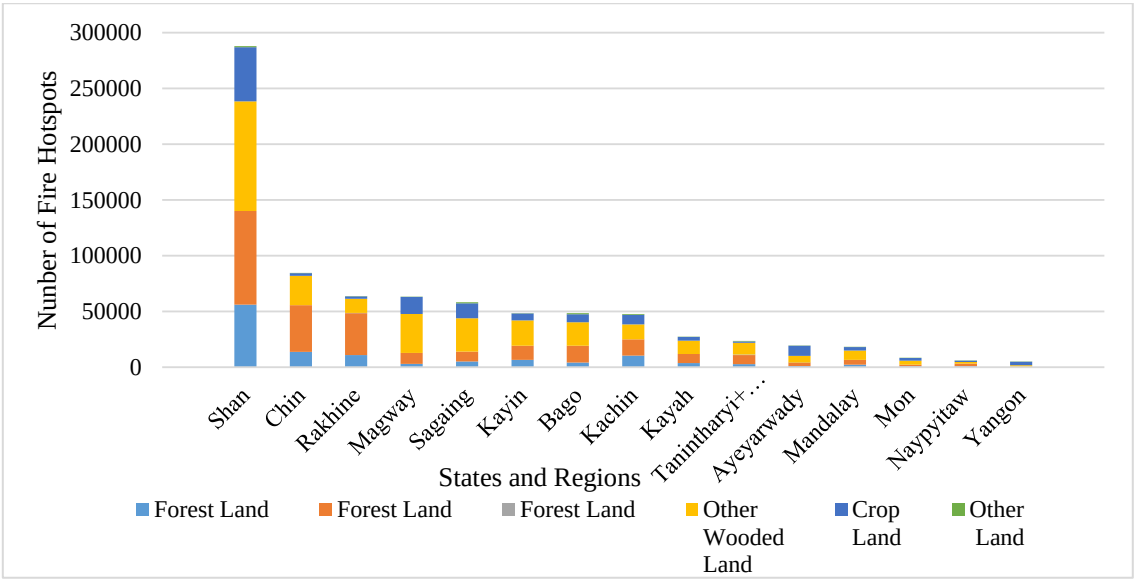


Figure 4. Fire Hotspots Distribution in Relation to Land Cover in States and Regions of Myanmar (2006–2017)

Note: Based on data from MCD14ML Product by using MODIS Aqua and Terra Satellites

4.4 Fire Density Distribition

Fire density is directly proportional to the number of fire hotspots and land cover area. Similarly, to the situation with the number of fire hotspots, fire density in Myanmar peaks in March and April (during the dry season) for all land use types in each state and region. The highest fire density was found in March for all land use types except other land. Averaged over the period 2006–2017, the fire density for the month of March for all land use types was estimated to be about 0.05 FHS/ km^2 (number of fire hotspots (FHS) per unit area (km^2). By type of land use, it was estimated to be about 0.05 FHS/km^2 for forest land, 0.07 FHS/ km^2 for other wooded land, 0.03 FHS/ km^2 for crop land (and 0.0072 FHS/ km^2 for other land for the month of April). The highest fire density was found in March 2007 for other wooded land and crop land, in March 2010 for forest land, and in April 2010 for other land.

As detailed in table 3, the overall fire density for all land use types was estimated to be about 0.10 FHS/km^2 (number of fire hotspots per unit area (km^2). Based on land use types, the density was estimated to be 0.11 FHS/km^2 for forest land, 0.14 FHS/km^2 for other wooded land, 0.07 FHS/km^2 for crop land and 0.02 FHS/km^2 for other land. It was found that that the highest fire density occurs in other wooded land, followed by forest land, crop land and other land. According to table 4, for all land use types, Chin and Kayah are the states with the highest fire density, i.e. 0.19 FHS/km^2. This is followed by the Shan state with 0.15 FHS/km^2, and Rakhine and Kayin states with 0.13 FHS/km^2 each. The lowest fire density occurs in both the Ayeyarwaddy and Yangon regions with 0.04 FHS/km^2. The annual fire density distribution for all land use types in Myanmar from 2006 to 2017 is illustrated in figure 5.

Based on Land use types, it was found that for forest land, the highest fire density occurs in the Rakhine state with 0.21 FHS/km^2 and the lowest in the Kachin state with 0.03 FHS/km^2. For other wooded land, the highest fire density occurs in Kayah state with 0.24 FHS/km^2 and the lowest in the Yangon region with 0.06 FHS/$km^{2.}$ In crop land, the highest fire density occurs in Chin state with 0.24 FHS/km^2 and the lowest in the Mandalay region with 0.0165 FHS/km^2. With regard to other land, the highest fire density occurs in the Chin state with 0.23 FHS/km^2, while the lowest fire density occurs in the Mon state with 0.0007 FHS/km^2 overall.

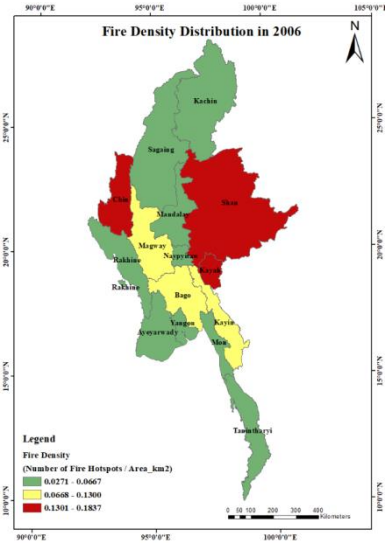
Table 3. Annual fire density for different land use types in Myanmar (2006–2017)

Years	Fire Density per unit area (Number of hotspots/ km^2)				
	Forest Land	Other wooded Land	Crop Land	Other Land	Total
2006	0.0907	0.1282	0.0603	0.0163	0.0908
2007	0.1591	0.1801	0.0842	0.0222	0.1413
2008	0.0915	0.1128	0.0528	0.0152	0.0850
2009	0.1441	0.1510	0.0694	0.0205	0.1230
2010	0.1543	0.1685	0.0786	0.0219	0.1346
2011	0.0776	0.1019	0.0493	0.0125	0.0749
2012	0.1319	0.1559	0.0691	0.0191	0.1189
2013	0.1060	0.1430	0.0648	0.0175	0.1027
2014	0.0962	0.1438	0.0704	0.0221	0.1002
2015	0.0762	0.1283	0.0670	0.0173	0.0861
2016	0.0766	0.1040	0.0527	0.0136	0.0759
2017	0.0609	0.1003	0.0610	0.0136	0.0700
Average	0.1054	0.1348	0.0650	0.0177	0.1003

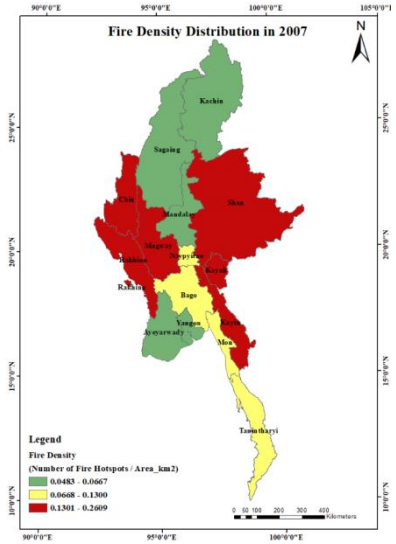
Table 4. Annual average fire density in each state and region of Myanmar (2006–2017)

State and Regions	Fire Density per unit area (Number of hotspots/ km^2)				
	Forest Land	Other wooded Land	Crop Land	Other Land	Total
Ayeyarwaddy	0.0956	0.0628	0.0377	0.0055	0.0449
Bago	0.1213	0.1827	0.0430	0.0332	0.1037
Chin	0.1890	0.2143	0.2418	0.2293	0.1974
Kachin	0.0330	0.0734	0.0999	0.0224	0.0451
Kayah	0.1730	0.2376	0.1756	0.0856	0.1954
Kayin	0.1201	0.1679	0.1025	0.0583	0.1340
Magway	0.1735	0.1797	0.0607	0.0186	0.1187
Mandalay	0.1064	0.0851	0.0165	0.0172	0.0500
Mon	0.0742	0.0710	0.0451	0.0007	0.0489
Naypyitaw	0.0854	0.1045	0.0373	0.0199	0.0703
Rakhine	0.2121	0.1307	0.0280	0.0042	0.1369
Sagaing	0.0348	0.0820	0.0427	0.0267	0.0523
Shan	0.1566	0.1671	0.1321	0.0883	0.1546
Tanintharyi	0.0347	0.0922	0.0806	0.0248	0.0497
Yangon	0.0399	0.0556	0.0471	0.0108	0.0433
Average	0.1054	0.1348	0.0650	0.0177	0.1003

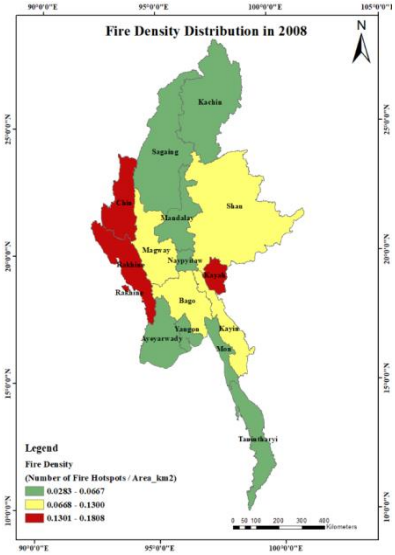
(a)


Fire Density Distribution in 2006
Legend
Fire Density
(Number of Fire Hotspots / Area_km2)
0.0271 - 0.0667
0.0668 - 0.1300
0.1301 - 0.1837

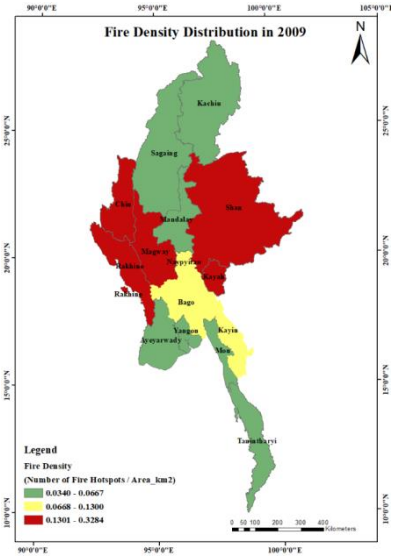
(a)


Fire Density Distribution in 2007
Legend
Fire Density
(Number of Fire Hotspots / Area_km2)
0.0483 - 0.0667
0.0668 - 0.1300
0.1301 - 0.2609

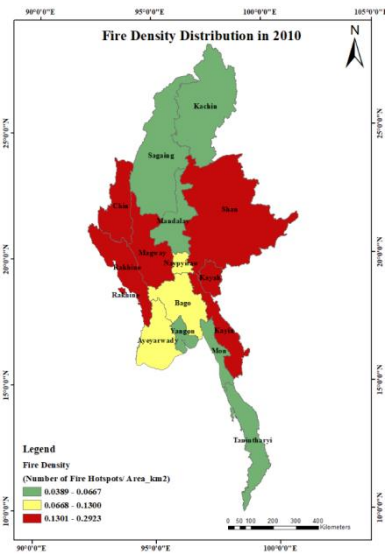
(b)


Fire Density Distribution in 2008
Legend
Fire Density
(Number of Fire Hotspots / Area_km2)
0.0283 - 0.0667
0.0668 - 0.1300
0.1301 - 0.1808

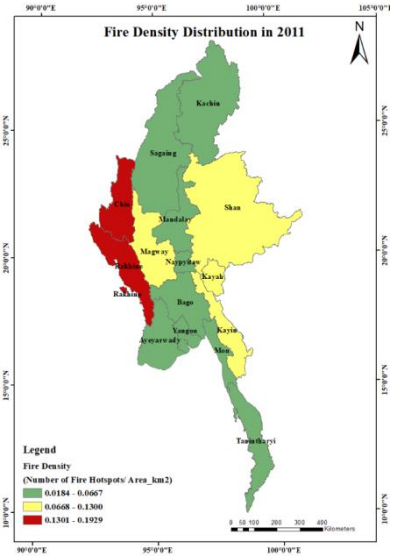
(c)


Fire Density Distribution in 2009
Legend
Fire Density
(Number of Fire Hotspots / Area_km2)
0.0340 - 0.0667
0.0668 - 0.1300
0.1301 - 0.3284

(d)


Fire Density Distribution in 2010
Legend
Fire Density
(Number of Fire Hotspots/ Area_km2)
0.0389 - 0.0667
0.0668 - 0.1300
0.1301 - 0.2923

(e)


Fire Density Distribution in 2011
Legend
Fire Density
(Number of Fire Hotspots/ Area_km2)
0.0184 - 0.0667
0.0668 - 0.1300
0.1301 - 0.1929

(f)

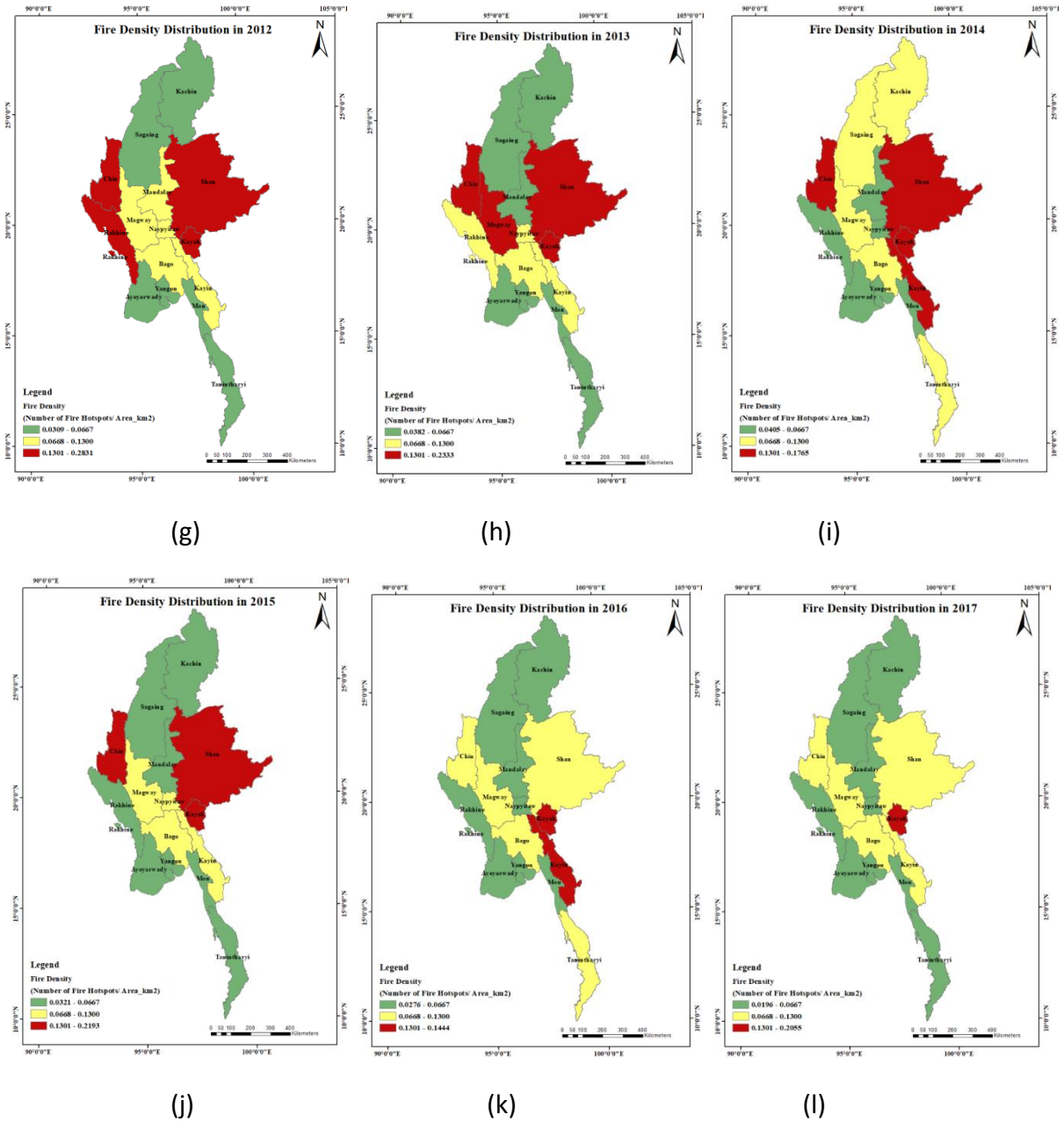


Figure 5. Fire Density Distribution for all land use types in Myanmar for (a) 2006, (b) 2007, (c) 2008, (d) 2009, (e) 2010, (f) 2011, (g) 2012, (h) 2013, (i) 2014, (j) 2015, (k) 2016 and (l) 2017

4.5 Identification of Priority Areas and Main Drivers of Vegetation Fires in Myanmar

This study considered three indicators such as the number of fire hotspots, land cover areas and fire density to identify the priority areas to control fires, as details in table 5. According to this information, this study found that 9 states and regions including Shan, Chin, Sagaing, Rakhine, Magway, Kachin, Bago, Kayah and Kayin out of

15 states and regions in Myanmar as priority areas to control fires. The locations of the priority areas are illustrated in the risk area map shown in figure 6. Furthermore, according to the data analysis reported in sections 4.3 and 4.4, priority areas to control fires in Myanmar for all land use types, should focus on 7 states and regions. From this number, focus should first be on the states of Shan, Chin and Kayah where fire density and fire hotspot counts were found to dominate. Based on fire density data alone, this is followed by the states of Rakhine and Kayin, and the regions of Magway and Bago.

Based on land use types, for forest land, the states and regions of Shan, Chin, Rakhine, Kachin and Magway are identified as priority areas to control fires. For other wooded land, the states and regions of Shan, Chin, Sagaing, Magway and Kayin are priority areas and for crop land, the states and regions of Shan, Sagaing, Magway, Chin and Kayah are notorious to control fires in Myanmar.

To investigate the causes of vegetation fires in Myanmar, representatives from governmental organizations in the country-which are involved in vegetation fire control activities, including the Environmental Conservation Department, the Forest Department and the Department of Agriculture in seven states and regions out of nine priority areas, i.e Shan, Chin, Rakhine, Kayin, Kayah, Magway and Bago, were interviewed. Based on these interviews, the main drivers of vegetation fires in Myanmar were reported to include: (1) burning for land clearance (agricultural expansion, shifting cultivation practices, plantations, urban development, fire prevention in the forest areas and grazing), (2) burning for collection of wood and non-wood forest products, (3) careless and accidental fires (camping, logging and illegal logging), (4) burning for hunting and (5) burning for the removal of agricultural residues. Fire due to prolonged drought was not reported as a major issue in Myanmar.

Based on land use types, In the case of forest fire, the states and regions of Shan, Chin, Rakhine, Kachin and Magway were identified as the priority areas for fire control and the main drivers identified to include: (1) burning for land clearance (mainly for plantations, shifting cultivation practices, and fire prevention in the forest areas), (2) burning for collection of wood and non-wood forest products (3) burning for hunting, and (4) careless and accidental fires. For fire in other wooded land, the states and regions of Shan, Chin, Sagaing, Magway and Kayin were identified as the priority areas

for fire control and the main drivers identified to include: (1) burning for land clearance (mainly for agricultural expansion, shifting cultivation practices and grazing), (2) careless and accidental fires (smoking and cooking), and (3) burning for hunting. For crop land, the states and regions of Shan, Sagaing, Magway, Chin and Kayah were identified as the key areas for fire control and the main drivers to include: (1) agricultural residues burning, (2) land clearance and preparation for crops cultivation, and (3) shifting cultivation practices.

Table 5. Number of fire hotspots (FHS), land cover areas and fire density for all states and regions in Myanmar (2006–2017)

State/ Region	Average Number of Fire Hotspots (FHS) (2006–2017)					Land Cover Areas (km2)					Annual Average Fire Density (Number of FHS per unit area) (2006–2017)				
	Forest Land	Other Wooded Land	Crop Land	Other Land	Total	Forest Land	Other Wooded Land	Crop Land	Other Land	Total	Forest Land	Other Wooded Land	Crop Land	Other Land	Total
Shan	11667.08	8197.17	4042.17	88.75	23995.17	74481.66	49064.35	30610.02	1005.15	155161.18	0.16	0.17	0.13	0.09	0.15
Chin	4640.67	2194.83	187.33	11.58	7034.42	24560.26	10242.09	774.78	50.51	35627.64	0.19	0.21	0.24	0.23	0.20
Rakhine	4067.00	1052.75	183.83	21.42	5325.00	19172.26	8056.34	6557.39	5124.85	38910.85	0.21	0.13	0.03	0.00	0.14
Magway	1067.08	2910.42	1273.50	20.17	5271.17	6150.96	16195.87	20973.25	1085.52	44405.59	0.17	0.18	0.06	0.02	0.12
Kayin	1619.50	1876.75	533.58	21.00	4050.83	13485.50	11176.44	5203.15	360.24	30225.33	0.12	0.17	0.10	0.06	0.13
Bago	1615.33	1753.75	600.83	67.50	4037.42	13318.43	9599.95	13981.06	2034.29	38933.73	0.12	0.18	0.04	0.03	0.10

Kayah	990.33	1000.67	277.58	14.08	2282.67	5723.75	4212.41	1580.55	164.49	11681.21	0.17	0.24	0.18	0.09	0.20
Sagaing	1169.08	2496.17	1122.58	66.08	4853.92	33578.83	30458.06	26268.28	2471.98	92777.16	0.03	0.08	0.04	0.03	0.05
Kachin	2086.25	1111.75	730.00	63.67	3991.67	63141.18	15142.81	7304.67	2845.27	88433.93	0.03	0.07	0.10	0.02	0.05
Tanintharyi	957.00	871.17	104.83	30.83	1963.83	27541.96	9452.49	1300.29	1244.95	39539.69	0.03	0.09	0.08	0.02	0.05
Ayeyarwady	365.67	479.69	767.00	26.08	1638.42	3824.32	7636.88	20347.56	4699.12	36507.88	0.10	0.06	0.04	0.01	0.04
Mandalay	558.25	687.33	272.92	14.83	1533.33	5247.82	8074.52	16509.47	861.98	30693.79	0.11	0.09	0.02	0.02	0.05
Mon	199.67	289.92	201.00	2.08	692.67	2690.58	4082.52	4453.02	2934.48	14160.60	0.07	0.07	0.05	0.00	0.05
Naypyitaw	277.17	120.67	90.58	3.17	491.58	3246.02	1154.85	2429.71	159.24	6989.83	0.09	0.10	0.04	0.02	0.07
Yangon	34.67	114.25	269.97	14.50	433.17	868.02	2056.10	5729.00	1339.50	9992.62	0.04	0.06	0.05	0.01	0.04

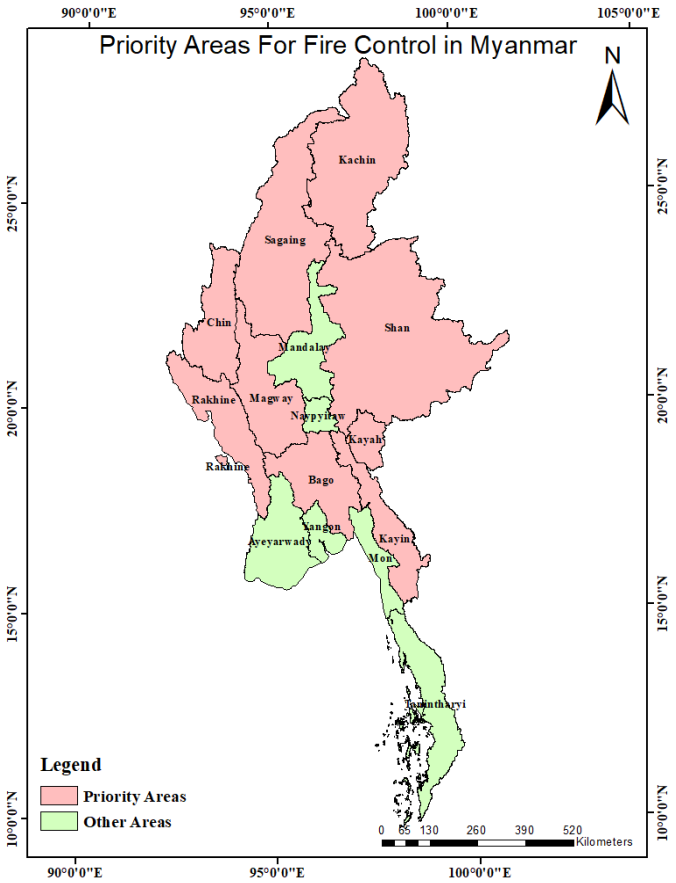


Figure 6. Risk area map for fire control in Myanmar

4.6 Discussion and Recommendations

The review of a country report (*Update on National Action Plan for Haze Control in the Dry Season in Myanmar*, Environmental Conservation Department (ECD)) pointed out that about 95% of vegetation fires in Myanmar are due to anthropogenic actions [9]. The main drivers of these fires are identified to be:

(1) Burning for shifting cultivation;

(2) Burning of agricultural residues;

(3) Burning for hunting; and

(4) Burning for honey collection

It is indicated that most vegetation fires in Myanmar are from shifting practices in mountainous region. In that case, especially with regard to forest fires, shifting (slash

and burn) cultivation, prolonged drought, deliberate burning of the forest for hunting purposes, careless use of fire (smoking or cooking) in the forest, intentional blazing of tree trunk for collection of lacquer and purposeful burning of fodder on the ground to make room for the growth of new grass (grazing) are identified as major drivers [9, 10]. With regard to other wooded land, shifting cultivation practices, land clearance for large scale industrial plantations (e.g. oil palm, rubber), expansion of agricultural land and infrastructure developments are indicated as the main drivers for vegetation fires. On crop land, the two main drivers are reported to include the removal of crop residues via open burning to clear the land for a next cycle of production and for soil fertilization [10, 14]. This published information appears to be in line with the results from the online interview reported above.

According to the investigations performed in this study based on fire hotspot data analysis from MODIS, 46% of all vegetation fires in Myanmar are forest fires. About 67% of these fires occur in open forests. This indicates that fires dominate in degraded forests where agricultural expansion usually occurs through the burning method. Open canopy forests are more prone to fire than closed forests as the floor is drier due to a greater degree of sunlight penetration. As the information s reported in [14, 19], open forests are usually adjacent to land areas that are influenced or cleared by fires as a result of human activities, including, shifting cultivation, crop production, and development of settlements and roads for transportation then. The clearance of forest for large scale industrial agriculture, infrastructure developments, and uncontrolled exploitation of natural resources is performed using fires [1].

About 8.70% of the total land area in Myanmar falls in protected areas (PAs). About 73% of this area is terrestrial land and 27% is marine area [22]. Approximately 3% of all the fire hotspots (FHS) detected in Myanmar during 2006–2017 fall in protected areas (PAs) and 97% in non–protected areas. This study found that the states and regions which include most of the protected areas in the country are not in the regions and states selected for fire control. PAs are mostly found in the Kachin state and the regions of Tanintharyi and Sagaing. Vegetation fires can therefore be effectively controlled if every state and region of Myanmar implement laws and regulations restricting the use of fire as tool for land development and clearance.

According to the information reported in [23], local populations have always used fire in slash and burn agriculture to fertilize their fields with ashes although Southeast Asia's vegetation is not adapted to fire and forest fires are always destructive. The pressure on causing fires is increasing however due to population growth who depend on forests as their livelihoods mainly focus on forests such as hunting, collection of NWFPs and is intensified as conversion of forested areas to other land use types for the cultivation of cheap resources like palm oil or pulpwood.

According to the information reported in [24], overlapping and conflicting priorities and agendas by the forestry and agriculture sectors are major concerns for causing fires in Myanmar for land clearance for agricultural expansion. Measures are recommended to be implemented involving awareness raising to local communities to avoid the use of fire. Law enforcement is also required to control burning from logging/ illegal logging, camping, hunting, collection of woods and non–wood forest products, grazing, removal of residues, etc. Also, powerful land use policies are needed to control the issue of land clearance for agricultural expansion and urban development using fire.

The findings of this study are timely and should contribute guiding policy makers in developing plans and measures for effective control of vegetation fires. The collection of ground–based data on vegetation fires is also imperative and should be implemented to complement and verify the information obtained from satellite data. This would enable Myanmar to develop adequate records of vegetation fires in the form of databases and support the country in its efforts to effectively manage vegetation fires and mitigate haze pollution.

5. Conclusion

In this study, vegetation fires in Myanmar were investigated over the period 2006–2017 based on satellite data and GIS techniques. The highest number of FHS was observed in 2007 and the lowest in 2017. The maximum number of FHS was found to occur in March and April, accounting for more than 80% of the total number of FHS detected each year. The annual average burned areas were 31,315 km^2 for forest land, 25,157 km^2 for other wooded land, 10,658 km^2 for crop land and 466 km^2 for other land

correspondingly. Approximately 10% of total land areas in Myanmar are annually exposed to fires.

Most of the FHS were found to occur on forest land (46%), followed by other wooded land (37%), crop land (16%), and other land including wetland and grassland (1%) respectively. Otherwise, the highest fire density was found to dominate in other wooded land (0.14 FHS/km^2), followed by forest land (0.11 FHS/km^2), crop land (0.07 FHS/km^2) and other land (0.02 FHS/km^2) overall.

Regarding the distribution of fire hotspots in various states and regions of Myanmar, it was found that they mostly occur in inland areas of Myanmar (rather than in coastal areas and the Delta region). About 70% of fire hotspots was found in states rather than regions of Myanmar. The largest share of fire hotspots occurs in the Shan State in the eastern part of the country with 35%, followed by the Chin State in the upper western part of Myanmar with 10%, and the Magway Region in the central area of Myanmar and the Rakhine State in the lower western part of the country with 8% each of the total number of fire hotspots.

In the case of fire density, Chin and Kayah are the states with the highest fire density, i.e. 0.19 FHS/km^2. This is followed by the Shan state with 0.15 FHS/km^2, and Rakhine and Kayin states with 0.13 FHS/km^2 each. The lowest fire density occurs in both the Ayeyarwaddy and Yangon regions with 0.04 FHS/km^2. Rakhine State is the highest hotspot which is affected by fires for forest land, Kayah State is the largest hotspot which exposed to fires for other wooded land and Chin State is the first hotspot which is impacted by fires for crop land and other land significantly.

This study concluded that 9 states and regions out of a total of 15 are priority areas to control fires in Myanmar for all land use types based on both analysis from fire hotspots and fire density. Among them, the states of Shan, Chin and Kayah where fire density and fire hotspot counts were found to dominate are the first attentions. Based on fire density data alone, this is followed by the states of Rakhine and Kayin, and the regions of Magway and Bago.

As a result of the causes of fires in Myanmar from expert judgement, the sources of vegetation fires are mostly due to anthropogenic activities. The main drivers of

vegetation fires include in decreasing order of importance: (1) burning for land clearance (agricultural expansion, shifting cultivation practices, plantations, urban development, fire prevention in the forest areas and grazing), (2) burning for collection of wood and non–wood forest products, (3) careless and accidental fires (camping, logging and illegal logging), (4) burning for hunting and (5) burning for the removal of agricultural residues.

In conclusion, it is observed that since 2012, the number of FHS in Myanmar has been decreasing, particularly on forest land. Over the period 2007–2017, the total number of FHS detected in 2017 is about 50% lower than that in 2007. In 2007, about 50% of the total number of fires was detected on forest land, followed by other wooded land with 35%, cropland with 14%, and other land with 1%. In 2017 (as compared to 2007), the number of FHS was found to have decreased by 62% on forest land, and to have increased by 44% on other wooded land and 28% on crop land.

The contributing factors to the decrease include control measures to prevent illegal logging, the banning of timber export, reforestation such as community forestry, expansion of protected areas and decreased areas of shifting cultivation practices in forest land. The contribution factors to the increase in other wooded land and crop land consist of the expansion of industrial plantation and agricultural areas, urban development, increased population who rely on wood and non–wood forest products for their livelihoods and unsystematic practices for crop growing.

The decrease in the number of FHS in Myanmar is a positive result for the mitigation of transboundary haze pollution in the ASEAN region, especially in the northern ASEAN region. However, ground–based observations of vegetation fires in Myanmar are much needed to better understand the situation of vegetation fires in Myanmar and be able to control haze pollution more effectively in accordance with the ASEAN Agreement on Transboundary Haze Pollution and the Roadmap on ASEAN Cooperation towards Transboundary Haze Pollution Control.

According to these findings, this study would like to suggest the followings for future work to control fires and its relation to haze pollution:

- Fire prevention should receive highest priority in order to reduce vegetation fire r

isk and resulting damage;

- The determination of root causes of fires is necessary for each state and region a nd requires an appropriate statistical data basis;
- Intercommunity cooperation is needed for effective fire management when most of fires were done by rural communities;
- Sustainable management of agricultural land and forest for large scale forest and/or land fires Prevention;
- To develop regionally adapted and cause–specific, effective and efficient strategi es for fire management based on these findings;
- Strengthening policies, laws, regulations and their implementations for fire contr ol and haze pollution;
- Enhancing public awareness and cross–sectoral and stakeholders' participation a nd securing adequate resources from multi–stakeholders for transboundary haze prevention;
- The last but not the least is that to control and maintain shifting cultivation and traditional practices of burning for land clearance and preparation.

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