SPATIO-TEMPORAL ANALYSIS OF HAZE PROBLEM BY INTEGRATING REMOTE SENSING AND GIS APPLICATION: A CASE STUDY OF THE NORTHERN THAILAND

NION SIRIMONGKONLERTKUN

DOCTOR OF PHILOSOPHY

IN

NATURAL RESOURCES AND ENVIRONMENTAL MANAGEMENT

SCHOOL OF SCIENCE
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ABSTRACT

The aim of this thesis required to test that the regional burning has influence to the increment of PM10 concentration, measured at each station in the Northern Thailand, and the smoke-haze problem in Chiang Rai province is trans-boundary problem. Thailand, Myanmar, and Laos were chosen as case studies. The study is divided into 2 parts, which are the regional burning level and local burning level in case Chiang Rai Province. 2009, 2010, and 2012 were year chosen for case studies. Hotspots detected by the by the MODIS Rapid Response System were used to represent burning in the region. Hotspots were filtered through fire confidence with confidence levels of 80% or more. The spatial analysis by GIS was used as the main tool for analyzing the location of burning at study sites. Simple Regression Analysis was used to determine the correlation between the number of hotspots in the region and PM10 concentration.

The result of this study showed that the regional burning has influence to the increment of PM10 concentration especially at four stations located along the border areas, Mae Sai, Mae Hong Son Chiang Rai and Nan stations. The coefficients of determination (R^2) for these stations were 0.99, 0.92, 0.83 and 8.98 respectively. The result for the local burning level in case Chiang Rai Province showed smoke- haze problem in Chiang Rai was mainly caused by short range transport from open burnings, mostly conducted within the province, in the radius of 50 km from Chiang Rai monitoring station. From the field survey showed the majority of burning conducted in Chiang Rai was concerning agricultural activities special for corn filed in the high land. Local agriculturists generally burn agro-residues in order to prepare lands and the burning activities were conducted many more in March, while the lack of making fire breakers in the areas was resulting in fires spreading and finally becoming major forest fires. The smoke-haze problem was considered as a local impact enhancing by meteorological and topographical factors. The low humidity, high temperature, low dew point temperature and calm wind with the speed of 12.8 – 19.2 km/hr., resulting in stagnant air condition this resulting in inhibiting the vertical dispersion of smoke and pollutants. Besides, Chiang Rai was surrounded by high mountains that were not conducive to emitting of smoke caused by open burnings. As a consequence, the accumulation of PM10 level was gradually higher. Once there was an impact from long range transport from open burning, via southwestern wind which passed by burning areas in neighboring countries and provinces, PM10 level was substantially higher. The daily backward trajectories in March demented impact from long range transport from biomass burning, via southwestern wind which passed by burning areas in neighboring countries and provinces, PM10 level was substantially higher.

Therefore Thailand especially Chiang Rai should be primarily focused in agricultural burning conducted on highlands in the forest areas. First of all, the government may cancel price assurance especially for the corns which harvested from the intentionally burned areas by using hotspots in monitoring process. Secondly, agencies involved in this issue, for instance, Land Development Department should provide agriculturists knowledge for farming in highlands and also alternative solution instead of burning their lands. Additionally, in cooperation with local administration, the make use of agricultural residues should be supported. At the same time, government may offer incentives to local agriculturists who seriously reduce their burnings by continuously providing price insurance for their produces.

Keywords: PM10/Hotspot/Open burning/GIS/Short range transport/Long range transport

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CHAPTER 1

INTRODUCTION

1.1 Background

Haze and smoke problems with adverse socio-economic and health impacts have become emerging new “disaster” issues over the last few years, especially in northern Thailand. The unprecedented smoke- haze that blanketed all areas in the northern highland region of Thailand is a recent problem that the local population must endure every year. The smoke -haze situation directly affects the air quality in many areas, including the provinces of Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Lampun, Phrae, Nan and Phayao.

A report from the Pollution Control Department (The Pollution Control Department [PCD.], 2012) indicates that the level of PM10 measured at stations in northern Thailand shows PM10 levels started to rise above the standard level set by the Pollution Control Department (120 $\mu g/m^3$) from February, with the highest levels of PM10 being reached in March each year. The PM10 situation was especially severe in 2012 when all stations had PM10 values have exceeded standards level continuously over several days, especially at Mae Sai and Mae Hong Son Stations, which had measured PM10 values exceeded standard level over several days and periods.

It was found that the highest 24 hour average PM10 value at Mae Sai Station was 357.46 $\mu g/m^3$on March 19, 2012, and the highest 24 hour average PM10 value at Mae Hong Son Station was 354.79 $\mu g/m^3$on March 20, 2012. PM10 values at both stations are almost 3-4 times of the standard level. This means that the air quality index (AQI) was over 100. When the AQI goes over 100 it means there will be possible direct effects on the health of the local population (The Pollution Control

Department [PCD.], 2011), especially at-risk groups such as children under 5 years old, elderly people over 60 years old, and those who has respiratory problems.

According to Report No. 10 from the Office of Disease Prevention and Control, it was found that from March 15 to March 22, 2007 there were a total of 57,765 patients seeking treatment due to illness related to smoke- haze in 8 provinces, including Chiang Mai, Lampun, Lampang, Mae Hong Son, Phayao, Chiang Rai, Phrae, and Nan. This is a daily average of 7,220 patients during the said period. Over 90% of the cases had general respiratory problems but their symptoms were not severe. The highest number of patients was in Chiang Rai Province for at 18,412 cases. The next highest number of patients was in Lampun province, at 13,936 cases, followed by Chiang Mai Province at 8,399 cases. This is in accordance with a report from the Chiang Rai Provincial Hospital which indicates that, since 2007, the number of patients was very high, with an average of 2,200 cases per day in March of each year (Kasemsan Manomaiphiboon, 2007). It was also found that the number of patients affected by smoke-haze increased in March of each until the present. Reports from 87 hospitals in the northern region of Thailand from March 1-7, 2012 indicates that patients that sought treatment during that period belong to 1 of 4 groups, including 23,685 cardiovascular disease patients, 24,837 respiratory disease patients, 2,265 patients with eye irritation, and 2,610 patients with skin irritation. An average of 20,000 patients sought treatment each day during that period, which is 10 times more than in 2007. The majority of the patients were treated for effects from the smoke-haze that covered the whole province in March. They suffered mainly from respiratory problems and stinging eyes (Health Information System Development Office, 2012). It can be seen that there is an increasing trend in the number of patients affected by smoke- haze each year.

The haze problem is not only affected air quality, but also reduced visibility. Visibility reduction is probably the most apparent symptom of air pollution. Visibility degradation is caused by the absorption and scattering of light by particles and gases in the atmosphere. Absorption of electromagnetic radiation by gases and particles is sometimes the cause of discolorations in the atmosphere but usually does not contribute very significantly to visibility degradation. However, scattering of light by particulates impairs visibility much more readily. Visibility is reduced by significant scattering from particles between an observer and a distant object. The particles scatter light from the sun and the rest of the sky through the line of sight of the observer, thereby decreasing the contrast between the object and the background of the sky. Particles that are the most effective at reducing visibility (per unit aerosol mass) have diameters in the range of 0.1-1.0 µm. The effect of air molecules on visibility is minor for short visual ranges but must be taken into account for ranges above 30 km. Based on a report from the Pollution Control Department, it was found that in the 8 provinces in upper northern of Thailand, the visibility was less than 10 km, especially at Chiang Rai and Mae Hong Son Province (which had visibility of less than 1 km) during the haze episode. This low visibility is greatly affected to traffic and transportation, and may cause influence for the occurrence of traffic accidents. Low visibility also disturbed air transportation and resulting in reducing the number of flights (Wichan Simachaya, 2011). The smoke-haze problem also negatively affected tourism businesses. According to a report from the Kasikorn Research Center, it was indicated that the number of tourists has decreased by 25% during smoke-haze episodes, especially in Mae Hong Son, Chiang Mai, and Chiang Rai Provinces, resulting in losses of almost 2 billion Baht in revenue.

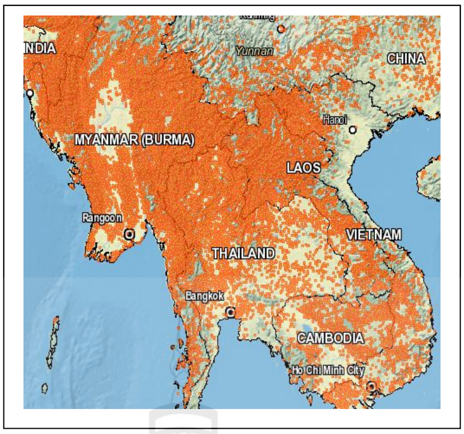
Forest fires and agricultural burning affect the air quality and create smoke, haze and dust particles in the atmosphere. Particular matter less than 10 microns (micrometers) in diameter, or PM10, which are small particles that cause irritation or stinging to the eyes and make breathing difficult, was created during the burning season of the year. In addition, air pollution also affects the business sector; according to the research conducted by Rewadee Jarungrattanapong and Areeya Manasboonpermpoon (2009 quoted in Mongkol Rayanakorn, 2010), it was found that there were fewer tourists in Chiang Mai Province when it experienced air pollution and smoke- haze, which is negatively affects the economy as well.

PM10 is considered the most significant air pollutant that contributes serious air pollution during the dry season, especially in northern Thailand. Major sources of PM10 are open burning (Teerachai Amnauylawjarurn, Jiemjai Kreasuwun, Sripen Towta & Kingkeo Siriwitayakorn, 2010; Kasemsan Manomaiphiboon et al., 2009; Mongkol Rayanakorn, 2010) and internal combustion exhaust from traffic. However, traffic density seems to be constant for the whole year, while open burning is mostly performed during the dry season, which coincides with the peak of the annual haze episode in the upper northern region of Thailand (Somporn Chantara, 2012; Oanh & Ketsiri Leelasakultum, 2011). The open burning in this region consists of forest fires and the burning of agricultural waste. These activities definitely emit a variety of air pollutants in the forms of both particulates and gases. In the case of Chiang Mai Province, according to the research conducted by Mongkol Rayanakorn (2010) and Teerachai Amnauylawjarum et al. (2010), it shown that 50%-70% of PM10 came from forest fires and the agricultural burning, at 10% came from diesel engines, and the remainder came from dust that blew over from another source. This was confirmed by Ketsiri Leelasakultum (2009), who found that the major types of emission sources with high PM10 during the smoke-haze episode were forest fires and agricultural burning.

Northern Thailand's geography is generally mountainous with north-south aligned hill ridges that are parallel from west to east, forming a number of valleys, such as valleys in Chiang Mai, Lampun, Chiang Rai, Lampang, and Mae Hong Son. The ventilation of air pollutants out of valleys is difficult due to the enclosed nature of valleys. In the dry season there is a low level of precipitation with calm winds (Oanh & Ketsiri Leelasakultum, 2011) allowing air pollutants generated from various sources - mostly anthropogenic sources – and then accumulate in the lower atmosphere and to affect human health and the environment. PM10 is considered the most significant air pollutant that contributes to serious air pollution during the dry season of northern Thailand.

Research conducted by Bach and Nion Sirimongkonlertkun (2011) indicated that Thailand is not the only country that conducts burning activities during the dry season (from January to April). Significant burning is also conducted in Laos and Myanmar. According to the available remote-sensed data which were analyzed for better understanding of spatial and temporal distribution patterns of fire occurrences among GMS countries, and also within Thailand, from 2006 to 2010, a significant conclusion was made. Comparative analysis of the magnitude of fire occurrences among GMS countries revealed that the frequency of fires can be ranked in three categories: the highest frequency in Myanmar; moderate frequency in China, Thailand, Cambodia and Laos; and the lowest frequency in Vietnam. Moreover, the frequency of fires in Myanmar alone is approximately equal to the frequency of fires in all other GMS countries combined. However, monthly distribution analysis clearly shows a common peak across these countries during the period from February to April. It is interesting to observe here that a single peak hotspot in March is common for all the five countries (Myanmar, Laos, Vietnam, Thailand and China). There seems to be an additional minor peak in May for China. For Cambodia, the hotspot peak occurs in January. More over the result showed that most GMS countries experience the highest amount of burning during March of each year. This is in accordance with the increasing PM10 values in the upper northern region of Thailand during the same period (PCD., 2012).

Therefore, in order to solve this smoke-haze problem, Thailand has initiated the concept of mutual cooperation to solve trans-boundary haze problems between 5 GMS nations, including Cambodia, Laos, Myanmar, Vietnam, and Thailand. As a result of the cooperation, working teams were established to work in the areas of forest fires and haze pollution for the region. The ASEAN Secretary General's Office is serving as the secretariat of the working teams. The aim to work towards a sub-regional target of (I) controlling the cumulative hotspot count not to exceed 75,000 hotspots (based on 2008 data), which is targeted to be achieved by 2011; and (II) controlling cumulative hotspot count not to exceed 50,000 hotspots (based on 2006 data), which is to be achieved by 2015 (HazeOnline, n.d.). However, it was found that burning still does not show a declining trend (Bach & Nion Sirimongkonlertkul, 2011), which is evident through satellite images, which show that hotspots can still be found among GMS nations during the dry season, as indicated in Figure 1.1.



From NASA. (n.d.b). **Firms web fire mapper.** Retrieved June 22, 2012, from http://firms.modaps.eosdis.nasa.gov/firemap/

Figure 1.1 Hotspot Occurrence in GMS Nations from February 27–March 29, 2012

In addition, the Pollution Control Department of Thailand has publicized about zero burning in order to encourage citizens to reduce burning through support for the utilization or burial of agricultural waste instead of burning (The Pollution Control Department [PCD.], 2003). During the haze crisis of 2012, which was the period when the longest and most severe haze occurred, PM10 reached 479.12 $\mu g/m^3$ on March 21, 2012. At that time, Mae Hong Son and Chiang Rai Province were heavily affected, and PM10 values at these 2 provinces exceeded 120 $\mu g/m^3$ for the longest period (PCD., 2012), and caused health impacts in all areas.

Therefore, the Minister to the Prime Minister's Office, Mr. Worawat Auapinyakul, has instructed all areas in the northern region, especially Chiang Rai Province, to conduct work to reduce haze within 3 days by inspecting all areas to ensure that no burning occurs (in order to prevent risks from haze and particulates). The Governor of Chiang Rai Province, Mr. Thanin Suphasaen, instructed all areas in his province to cease burning from March 12-14. This resulted in all agencies becoming strict in monitoring for burning during 3 days of March. Heavy rain from March 13 to 14 resulted in PM10 over the 2 days reduced less than 120 $\mu g/m^3$.

However, as burning activities has decreased on March 12, but PM10 values still exceeded 120 μg/m^3. It can be seen that, even though burning decreased in the local area, but PM10 values can still exceed standards. The satellite data has detected widespread hotspots in the Greater Mekong Sub-Region, especially in border areas between Thailand, Myanmar, and Laos. Therefore it can be hypothesized that increasing PM10 values in the northern Thailand was influenced by burning in regional level.

The majority of research is focusing on the study related to the results of smoke-haze impacts. These studies also forecast various possible situations. A research conducted by Oanh and Ketsiri Leelasakultum (2011) and Somporn Chantara (2012) also studied the cause of smoke-haze in Chiang Mai Province. Another research by Patipat Wongruang, Prungchan Wongwisad and Sitichai Pimonsree (2012) studied the relationship between burning and changes in PM10 concentration, and obtained to similar conclusion that burning significantly cause PM10, especially from January to April each year. Some research indicates that burning in the long range affects the increasing of PM10 during the haze crisis period also. However both research still need to study the smoke haze problem in Thailand in relations with the burning phenomenon in neighboring counties. Therefore, it can be seen that the study of smoke- haze that occurred in the northern region of Thailand cannot consider only in limited local area, but it should be considered several areas, which has neighborhood with the study area, in particularly the Greater Mekong Sub-Region (Bach & Nion Sirimongkonlerkun, 2011)

However, studying the relationship between variables at the local scale in case of Chiang Mai province also clearly shows that burning is an important influence on increases of PM10. Even though, mostly PM10 increases in some areas in the northern region of Thailand at the period from January to April yearly, there still no clear studies about the changes or forms of changes of PM10 and burning patterns during the burning season. Moreover, it lacks of overall study of the problem at the national level, as well as lack of study on the burning activities in neighboring countries, and the relationship between regional burning in nearby areas and their affect to PM10 in the northern region of Thailand.

That is why we have conducted the research on this topic, which is targeting to determine the regional burning activities influences to the PM10 increment at every station in the Northern Thailand. The countries in the region which are Thailand, Myanmar, and Laos were chosen as study area for case studies, with a focus on the burning season (January to April) of each year. This research aims to study the relationship between regional burning and PM10 concentration during the burning season, using 2009, 2010, and 2012 as case studies based on available PM10 data (except for 2008 and 2011, as the smoke-haze problem was reduced) Thirteen PM10 measuring stations in the northern region of Thailand were selected, including Chiang Mai (2 stations), Chiang Rai (2 Stations), Lampang (4 stations), Mae Hong Son, Nan, Lampun, Phrae, and Phayao. This study has emphasized on Chiang Rai province to be a study area for studying the possible burning activity impact from three neighboring countries which cause the increment of PM10 concentration. This is to prove that, the increased PM10 concentration value beyond the standard level in Chiang Rai province could be cause by neighboring countries or trans-boundary smoke-haze

Therefore the main objective of this research is to investigate on the hypothesis. The study is divided into 2 parts, the first part is to study on the overview of burning situation in three countries in the region which could impact to Thailand's 13 PCD stations or shortly called as regional impact, in which the year 2009, 2010 and 2012 were selected as study period. Hotspots detected by MODIS (Moderate Resolution Imaging Spector radiometer) sensor and provided to the public by Rapid Response System were used to represent burning in the region. Hotspots are filtered through fire confidence with confidence levels of 80% or more. The Spatial data analysis by GIS was used as the main tool for analyzing the location of burning at study sites. Simple Regression Analysis was used to determine the correlation between the number of hotspots in the region and PM10 concentration.

The second part of the study is to focus on the smoke-haze problem in Chiang Rai province. This part is divided into two sections, which are 1) study on the overview of burning activities in three neighboring countries which affect to the increment of PM10 value in Chiang Rai province or "Regional Burning" by considering the relationship between PM10 value and hotspot which occurs in

January to April of year 2009, 2010 and 2012 using buffer zoning with the increment of 10km from the measurement station to check that burning in which distance that has possibility to start the increment of PM10 value in the province. The study on the influence of long range transport which could cause the increment of PM10 value in the province was also taken to account, in which March of 2007, 2009, 2010 and 2012 were considered as the period of severe burning season of the year and selected into investigation to analyze the daily backward trajectories by HYSPLIT model and 2) is related to Local burning impact which is focusing on the study of burning pattern that occurs in the province by using the fire occurrence report within year 2007-2012 compiled by the Protected Area Regional Office 15, Forest Fire Control Division, Department of National Parks Wildlife and Plant Conservation, which were collected from the field survey to study on the pattern and trend of burning activities in the province, also including the study on relationship of burning activities with the increment of PM10 value in the province. Apart of that, the meteorological and topographical factors were also taken into considerations. The results from this study will be used to be a tool for decision-making to solve the smoke-haze problem, in particularly in the province.

1.2 Hypothesis of This Research

The regional burning has influence to the increment of PM10 concentration, measured at each station in the Northern Thailand, and the smoke-haze problem in Chiang Rai province is trans-boundary problem.

1.3 Research Questions

1.3.1 How is the impact of burning activities in three neighboring countries to the increment of PM10 concentration in Northern part of Thailand?

1.3.2 Smoke-haze and the increment of PM10 concentration in Chiang Rai province is trans-boundary problem?

1.4 Research Objectives

1.4.1 To determine that burning activities in three neighboring countries has influence to the increment of PM10 concentration in all 13 measurement stations.

1.4.2 To determine that smoke-haze problem in Chiang Rai province caused by trans-boundary smoke-haze.

1.4.3 To propose the general policies for solving smoke-haze problem.

1.5 Scope

The study sites are in Myanmar, Laos, and Thailand. Eight provinces in northern part of Thailand, including Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Lampun, Phrae, Nan and Phayao. Hotspots were counted using the information obtained from the website of NASA's Earth Observatory (NASA, n.d.a) and Web Fire Mapper (NASA, n.d.b) for the years of 2007-2012 by selecting the fire confidence level equal to 80% or higher. The hotspot or fire data was used to describe the open burning activities in the three neighboring countries. The spatial resolution of hotspot data is 1x1 km^2 as defined in NASA MOD 14 algorithm, which is accepted on regional scale. This study is supported by the Pollution Control Department for the PM10 data obtained from 13 stations in the northern part of Thailand. The study uses linear regression analysis with significance test, where the mark is significant for 99% of confidence level. The study also uses the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) to determine the air mass movement of smoke from biomass burning in the regional level.

1.6 Limitations

1.6.1 PM10 data is not available in other neighboring countries. Some PM10 data sets are not completed for some stations in the northern part of Thailand for some period of time.

1.6.2 Hotspots were counted using the information from the website of NASA's Earth Observatory (NASA, n.d.a) and Web Fire Mapper (NASA, n.d.b). According to NASA algorithm, each fire pixel represents a pixel of 1 x 1 km, which the geographical coordinates is the center of the pixel. MODIS satellite images for Thailand are available 1-2 times per day. Hence, short-lived fires occur in other time period within a day will not be detected by the satellite. In case of cloud cover in the study area, fire occurrence located underneath the clouds is not detected by the satellite. Therefore, the hotspot counting is based on the data availability detected by satellite may not be in consistency with the actual number of fire found in the area.

1.6.3 Fire information collected by the local forest fire stations is limited due to limited number of officers for data collection

1.6.4 This study is focusing on the research of smoke-haze problem that caused by open-space burning which has influence to the increment of PM10 concentration. The study methodology is based on the relationship of two physical parameters (PM10 concentration and hotspots counts) and data analysis of related factors such as meteorological and topographical factors to find out the possibility of the problem that could linked with these factors, without quantitative measurement which need more time and details.

CHAPTER 2

LITERATURE REVIEW

2.1 Haze Problem

2.1.1 Definition of Haze

Many researchers and specialists from different organizations have defined the definition of haze. The Association of Southeast Asian Nations (2002) has defined haze as smoke resulting from land and/or forest fire, which causes deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems and material property, and impair or interfere with amenities and other legitimate uses of the environment. Sun, Zhuang, Tang, Wang and An (2006) defined haze as the weather phenomenon that leads to atmospheric visibility of less than 10km due to moisture, dust, smoke, and vapor in the atmosphere.

Wichan Simachaya (2011), the Director General of the Pollution Control Department, has defined haze as the accumulation of smoke or particles in the air, the majority of which are caused by the burning of agricultural waste and forest fires. Haze is considered one type of air pollution. Haze is comprised of particles less than 10 microns (PM10) in diameter, which have an impact on human health. Therefore, it can be concluded that haze is air pollution that occurs due to the accumulation of PM10 in the atmosphere, resulting in 24 hour average PM10 values exceeding set standards (120 $\mu g/m^3$) and impacting human health.

2.1.2 Haze Episodes in ASEAN

2.1.2.1 Critical Sources of Haze in ASEAN

During the 1982-1983 East Kalimantan fires, the haze also reached as far as peninsular Malaysia and Singapore, lasting an entire month and covered an area of about 35 million ha. In 1997, haze covered about 100 million ha of land and water and lasted as long as six months. From September to November 1997, the dense haze from the Indonesian fires spread over an area the size of Western Europe, affecting some 70 million people in the region, directly or indirectly. This haze was probably the worst on record. The 1998 fires in Indonesia did not affect mainland Asia as much as in 1997. The haze covered the source area of East Kalimantan and spread over to West Kalimantan, southeastern Sarawak, and parts of peninsular Malaysia.

Haze from fires in peat land is estimated to contribute 60 percent, while converted forests contribute 18 percent of the total smoke and haze produced. Instead of stray individual fires, 80 percent of the haze was produced by seven clusters of fires in and around peat forests in Kalimantan and Sumatra. Shifting cultivation accounted for only 1.5 percent of the haze. The thickest haze came from an extensive fire in a 1 million ha area of peat being drained by the government for a massive rice planting project, known as the Grand Million Hectare Peat land Project. During the 1997-1998 fires, more than 700 million mg of carbon dioxide were released into the atmosphere from the burning of the peat.

The smog arising out of the 1997 fires spread to Brunei Darussalam, Indonesia, Malaysia, Philippines, Singapore, and Thailand, affecting a population of 70 million.

1. On September 26, all 234 people on board a jetliner died when it crashed before landing in northwest Indonesia. Visibility was poor due to the haze.

2. An Indian cargo ship collided with a Panamanian vessel in the Strait of Malacca, killing 29 people, due to poor visibility.

3. Seven boat accidents were reported in Kalimantan's Mahakam River. In one, nine students were killed. Doctors point out that the smog (haze) can cause a range of ailments from heart and lung diseases to damage to the nervous system, blood, and kidneys. Experts predict that the impact of the forest fires in Indonesia is potentially more dangerous than that of the oil fires in Kuwait during the 1990 Gulf War.

2.1.2.2 Smoke-haze pollution in Northern Thailand

Thailand recently experienced one of the worst air pollution episodes in recent years, which is the extended elevated haze pollution in northern Thailand during March,

2007. Haze pollution occurs in this region during this period regularly each year because it coincides with the annual drought season when wildfires and agricultural fires occur intensively (Kasemsan Manomaiphiboon, 2007).

The unprecedented smoke-haze that blanketed all areas in northern Thailand is a problem that the local population must endure every year since 2007. The smoke-haze situation directly affects the air quality in many areas, including the provinces of Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Lamphun, Phrae, Nan and Phayao. The poor air quality, in turn, affects the health of the people. The main causes of this smoke-haze are forest fires, open burning and exhaust pollution from vehicles (Mongkol Rayanakorn, 2010; Jiamjai Kreuasuwan et al. [2008 quoted in Mongkol Rayanakorn, 2010]) found that 50% - 70% of small dust particles came from forest fires and burning off at farmlands, 10% came from diesel engines, and the remainder is dust that blown over from another source. In addition, it was found that some areas may have been affected by air pollution from forest fires in neighboring countries (Ketsiri Leelasakutum, 2009; Kasemsan Manomaiphiboon et al., 2009).

Northern Thailand borders eastern Myanmar and northern Laos, and it is a few hundred kilometers away from southern China. Most of northern Thailand is hilly and mountainous. There are north-south aligned hill ridges parallel from west to east, forming a number of valleys. The serious haze problems faced by northern Thailand in early 2007 were likely due to the increase in fine particles (PM10). In Chiang Mai, Since February, 2007, the 24-hour average PM10 value has increased up to 396.4 $\mu g/m^3$. Satellite imagery found heat areas (hotspots) in many parts of Thailand, Myanmar, Laos, Vietnam and Cambodia (Bach & Nion Sirimongkonlerkun, 2011) during the period when cold air mass covered the northern area of Thailand, allowing particle matter to be suspended in the atmosphere for some time. This resulted in poor visibility of less than 1 km in several provinces such as Chiang Mai, Lamphun, Lampang, Mae Hong Son, Chiang Rai, Phayao, Phrae and Nan, etc.

The haze also affected the health of local residents. Haze/smoke not only causes health problems but also low visibility for motorists. It was found that Mae Sai district had low visibility of less than 300 meters, resulting in higher risk for accidents. As a result, the air traffic control was unable to guide aircrafts to land safely, causing flight cancellation, hotel cancellation and downtime in the tourism industry. The financial status report for the northern region in March, 2007, showed that hotel cancellation was at about 20-30%. A report from Kasikorn Bank Research Center pointed out that haze/smoke from March-April, 2007, caused 2 billion baht in losses in tourism cash flow.

Among GMS nations, Thailand is the only nation that conducts monitoring of PM10 values, under the supervision of the Pollution Control Department, Ministry of Natural Resources and Environment. Measurement stations were established at 8 Northern provinces, including Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Lamphun, Phrae, Nan and Phayao. Therefore, Thailand is the only nation among GMS nations that is aware of the PM10 concentration change situation, especially during haze episodes. It was found that, every PM10 measurement station in the northern region of Thailand had 24-hour average PM10 values that exceeded set standards over a period of several days. Therefore, Thailand conducted coordination among 5 GMS nations to solve the problem of trans-boundary smoke- haze. A working team on forestry and haze was also established for the Greater Mekong Sub-Region. The team is comprised of representatives from Cambodia, Laos, Myanmar, Vietnam, and Thailand. Moreover, these GMS nations agreed to work towards achieving the second sub-regional target of hotspot reduction, i.e. reducing cumulative hotspot counts to ensure not to exceed 50,000 hotspots (based on 2006 data) which need to be achieved by 2015.

2.2 Biomass Burning or Open Burning

2.2.1 The Definition of Biomass Burning or Open Burning

Anwar, Juneng, Rozaliothman and Latif (2010) that biomass burning is the burning of living and dead vegetation, predominantly burning of grasslands, forests and agricultural lands after harvest, land clearing and also when land use changes. The ASEAN Agreement on Trans-boundary (Environment Division of ASEAN Secretariat HazeOnline, 2008) defined open burning as any fire, combustion or smoldering that occurs in the open air. Meanwhile, The Pollution Control Department (2011) defines open burning as any fire, burning, or smoldering of material that occurs in an open area, allowing dust, smoke, gas, and toxic substances to spread into the atmosphere. For this research, open burning is defined as the burning of agricultural material leftover after harvests, for the purpose of preparing the land for the next cultivation cycle. This burning may cause forest fires that create dust, smoke, and various gases in the atmosphere.

Open burning, the burning of living and dead vegetation for land-clearing and land use change, has been identified as a significant source of gases and particulates to the regional and global atmosphere. The burning of forest biomass (grass, moss, lichen, shrub and wood) results in atmospheric emissions of large quantities of gases (e.g.CO_2, CO, CH_4, etc.) and smoke particles. Biomass burning associated with human land-use activities, as well as naturally occurring wildfire, has come to be recognized as having an important role in regional and global climate change (Andreae, 1991).

More recently, biomass burning has been found to affect weather on much shorter timescales (Rosenfeld, 1999). With a more variable and changing climate, fire distributions and regimes are likely to change (Kasischke, Christensen & Bourgeau-Chavez, 1995; Weber & Flannigan, 1997). There is consequently a considerable need for long-term global fire information. At present the only practical way to monitor fire activity at a continental or global scale is with sensors on terrestrial satellites (Justice & Korontzi, 2001; Weber & Flannigan, 1997).

Mahmud (2005) estimated the emission and dispersion of pollutants, such as particulates, sulfur dioxide, nitrogen dioxide, carbon monoxide and non-methane hydrocarbons from burning. The emission estimates showed that carbon monoxide ranked as the highest polluter, followed by particulate matter and non-methane hydrocarbons. The spatial distributions of active fires displayed clustering pattern that coincide with paddy and sugarcane vegetation burning, particularly over the states of Perlis, Kedah and Pahang of Malaysia, during early February.

2.2.2 Fire Monitoring

Remote sensing studies have been confirmed as a useful tool for fire monitoring over a global or large scale region. The Moderate Resolution Imaging Spector-radiometer (MODIS) is a multi-temporal remote sensing device. The collected data are available in near real time. It is therefore a promising data source for use in tracking both active fires and burned areas, and can potentially be used to improve management during the forest fire season (Justice et al., 1998) MODIS is one of the sensors in the Earth Observing System (EOS).

It has been shown that the best way to obtain large scale information on forest fires over the past three decades was via satellite remote sensing (Justice et al., 1998; Justice et al., 2002) One of the first systems utilized was the Advanced Very High Resolution Radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) in the Polar Orbiting Environmental Satellites (POES) family. It was originally used for weather monitoring then employed as the main sensor in the detection of active fires, or "hotspots" on the global scale and with relatively high temporal frequency. Other sensors include those in the Geostationary Operational Environmental Satellite (GOES) such as the Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS) (Prins & Menzel, 1992) and the GOES Imager.

However, MODIS is the first sensor specifically designed and developed to include capability for forest fires detection (Justice et al., 2002; Giglio, Descloitres, Justice & Kaufman, 2003). The MODIS active fire product detects fires in 1km pixels that are burning at the time of overpass under relatively cloud-free conditions using a contextual algorithm, where thresholds are first applied to the observed middle -infrared and thermal infrared brightness temperature and then false detections are rejected by examining the brightness temperature relative to neighboring pixels (Giglio et al., 2003).

The active fire map show the spatial distribution of fire spots detected by the MODIS (Moderate Resolution Imaging Spector radiometer) Rapid Response System using a standard MODIS MOD14 Fire and Thermal Anomalies Product algorithm. The individual detection on the map represents the center of a 1 km pixel containing at least a fire within that pixel. A detection confidence is estimated and ranges from 0% to 100% (Giglio et al., 2003). The confidence level is classified into three classes, which are low-confidence (<30%), nominal-confidence (30%-80%), or high-confidence (>80%). Fire data with high confidence levels can be applied to reduce the number of false alarms (errors of commission) at the expense of a lower detection rate (Giglio, Kendall & Tucker, 2010). Therefore this research selected only hotspot data with a confidence level higher than 80%.

Several researches were conducted to validate data on hotspots and burning, for example, Information for Resources Management System at the University of Maryland. Accuracy assessments with independent reference data are crucial to obtain an estimate of the validity of the data. Yet only partial validations exist for active fire data. These include Morisette, Giglio, Csiszar and Justice (2005) in South Africa, and Csiszar, Morisette and Giglio (2006) in Northern Eurasia All these studies assess the accuracy of the MODIS fire hotspots with auxiliary satellite imagery. The results from the validations suggest that omission errors (false non-detection or false negative) are relatively frequent while commission errors (false alarms) are comparatively rare, particularly for smaller fires (Csiszar et al., 2006).

For Thailand, the Department of National Parks, Wildlife and Plant Conservation conducted accuracy assessment of hotspot data by examining ground and aerial data. It was found that data on hotspots and forest fire had 82.3% validity. Therefore, hotspot data obtained from remote sensing has a high level of accuracy (Suchat Podchong, 2010).

Veerachai Tanpipat, Kiyoshi Honda and Prayoonyong Nuchaiya (2009) conducted validation of MODIS hotspot data by examining areas to see whether burning took place or not. Ground and aerial field surveys were conducted in this study by the Forest Fire Control Division, National Park, Wildlife and Plant Conversation Department, Ministry of Natural Resources and Environment, Thailand. A quantitative evaluation of MODIS hotspot products has been carried out since the 2007 forest fire season. The careful selected hotspots were scattered throughout the country and within the protected areas of the National Parks and Wildlife Sanctuaries. A high accuracy of 91.84 %, 95.60% and 97.53% for the 2007, 2008 and 2009 fire seasons were observed, respectively, resulting in increasing for fire detection confidence in the use of MODIS hotspots for forest fire control and management in Thailand. This is in accordance with a study by Yootthapoom Potiracha, Thanwarat Anan and Anusorn Rungsipanich (2007) which validated hotspot data of MOD14 products by comparing it with a 5-km buffer of hotspots extracted from LANDSAT-5. These data were acquired during 2007 in the dry season, which is forest fire season in northern Thailand. The validation of hotspot from MOD14 product with LANDSAT-5 TM yield low accuracy of validation during the beginning of the forest fire season, because only a small number of hotspots occurred at that time. But from late February until early April, which is a peak period of forest fire, a large number of hotspots were detected because of several areas covered with forest fire spots and burn scars, thus yielding a high accuracy of validation.

This study obtained information from the readily available fire data from the Fire Information for Resources Management System (NASA, n.d.b) at the University of Maryland. FIRMS is an information distributor of hotspot information obtained from the MODIS Rapid Response system that is located in the Goddard Space Flight Center (GSFC), National Aeronautics and Space Administration (NASA).

2.3 Particulate Matter Less than 10 Microns (PM10)

2.3.1 Definition of PM10 and the Relationship between PM10 and Open Burning

The Pollution Control Department defines PM10 as particulates with a diameter of less than 10 microns (PCD., 2011).

2.3.2 Source of PM10

Particles in the atmosphere are released from both natural and human activities. The major natural sources of particles are soil dust, sea salt, smoke from forest fire and biomass burning. Man-made sources or anthropogenic sources can be divided into: point sources, such as industrial air pollution emitted from factories; mobile sources, such as automobile air pollution emitted from various vehicles; and non-point sources, such as open burning, forest fires, the burning of rice stubble, the burning of waste, etc.

Each area in the world has different sources of PM. Developed nations (with developed technology and industries) are more likely to have industrial sources of PM10 through the use of fuels such as coal, natural gas, and wood. If these fuels are not completely burned, it will result in PM10. For developing nations, especially nations in Asia, the majority of these nations' populations traditionally practice slash- and-burn agriculture, especially the cultivation of cash crops such as rice, corn, etc.

Therefore, burning in developing nations is aimed at eliminating weeds and preparing the land for the next cultivation session (Qadir, 2001; PCD., 2011). In addition, Qadir (2001) said that humans have used fires as they settled in the forests for thousands of years to practice agriculture and help in hunting. Traditional use of fire is thought to have little long-term ecological impact on the forest; but increased population density, shortened fallow periods, and cash cropping made shifting cultivation an agent of ignition, along with several other factors.

Agriculture is the most important economic sector in GMS countries comprised of Thailand, Laos, Myanmar, Cambodia, and Vietnam. On average 75% of the population of GMS nations engage in agriculture and aquaculture. Shifting cultivation (swidden agriculture) systems are practiced by upland rural communities throughout the world. This is simply for the reason that fire is the most efficient and cheapest way to clear bush or woody vegetation for crop production. The shifting cultivation systems can be divided into two broad categories: pioneering systems and rotational swidden systems. In the pioneering shifting cultivation a plot of forest is cleared and cultivated as long as the soil fertility is adequate to give a satisfactory crop yield. After the fertility declines below a satisfactory level, the farm-family moves to another forested area and abandons the first one. Usually the cultivation period is 3 to 4 years followed by a fallow of 7 to 20 years depending on soil fertility. As economic integration proceeds many mixed cultivation systems have emerged which mix sedentary land use with shifting cultivation. Therefore, it can be seen that open burning, which includes burning of agricultural material, burning to prepare land for cultivation, and forest fires, is linked to changes in PM10 concentration, for example Maharani Pradani and Puju Lestari (2010) applied statistical analysis to obtain the correlation value between the number of hotspots and the concentration of 5 ambient air quality parameters (PM10, SO_2, CO, O_3 and NO_2) taken from the ISPU Palangkaraya City in 2009. The result showed that the most significant correlation between the number of hotspots and the concentration of PM10, SO_2, CO, O_3 and NO_2 is by the correlation value of 0.63, 0.59, 0.65, 0.46 and 0.70, respectively. The best correlation between the number of hotspots and the concentration of pollutants occurred for the parameters PM10, CO and NO_2. The relationship relevance for hotspots and the concentration of SO_2 and O_3 are not as significant as compared to the relationship relevance for PM10, CO and NO_2.The same as with Anwar et al. (2010) determining the concentration of five major pollutants (PM10, SO_2, NO_2, CO and O_3) in Riau, Indonesia, for 2006 and 2007, and also correlated the level of air pollutants to the number of hotspots recorded, using the hotspot information system introduced by the Malaysian Centre for Remote Sensing (MACRES). They concluded that the concentration of air pollutants recorded was found to increase with the number of hotspots. Nevertheless, only the concentration of PM10 during a haze episode is significantly different when compared to its concentration in non-haze conditions. For example, in Thailand Danutawat Tipayarom and Oanh (2007) determined the relationship between monthly average PM10 measurements at Bangkok University (Rangsit) station and hotspot counts from daily MODIS images in Pathumthani (web fire mapper) from April, 2003 to April, 2004. The results showed very strong correlation (R^2= 0.7689) between hotspot counts and PM10 concentration. It means that burning rice straw during the dry season affects air quality in nearby areas, especially in Bangkok.

In the case of the northern region of Thailand, research that studied the relationship between hotspots and PM10 are still limited because the haze problem is still relatively new. The only study of note was by Oanh and Ketsiri Leelasakultum (2011), but the study covered only some areas and focused on meteorology and forecasting more than burning and the main cause of changes in PM10. However, the majority of research concluded that burning significantly affects increases in PM10.

However, studying the relationship between variables at the local scale also clearly shows that burning is an important influence on increases in PM10. Even though the increase in PM10 in some areas in the northern region of Thailand mostly occurred from January to April of each year, there have been no clear studies about changes or forms of changes in PM10 and burning during the burning season. There is also lack of overall studies into the problem at the national level, and lack of studies on the relationship between regional burning in nearby areas and their affect son PM10 in the northern region of Thailand. Therefore, this research studies the relationship between PM10 and burning, using statistical analysis to obtain the correlation as the main tool in analysis. The relationship between PM10 at stations in the northern region of Thailand and regional burning was studied.

2.3.3 Characteristics of PM10

PM10 can remain suspended in the atmosphere for long periods of time unless an external force causes them to move, such as the flow of air or wind (PCD., 2011) While coarse particles flush out of the atmosphere within several hours up to a day, fine particles have the longest residence time (up to weeks) in the atmosphere and travel extensive distances (hundreds to thousands of kilometers). Their elimination out of the atmosphere is mainly due to rain (http://haze.asean.org/info/firehaze). It was also found that the residence time of PM in the atmosphere ranges from 1–2 days to 4–6 days, depending mostly on the size of the particles and their chemical composition. For instance, coarse particles have shorter residence times than fine particles because they are more effectively removed by dry deposition. Typical travel distances are about 500–1000 km (World Health Organization, 2003).

Meteorological factors are the most important parameters that play a leading role in the dispersion of pollutants in the atmosphere. These factors include wind velocity, atmospheric turbulence, stability, temperature, humidity, etc. The pollutants get transported along the direction of wind. But it is the atmospheric turbulence that determines the lateral and vertical spread of the pollutants. Stability assumes a critical role in determining the amount of turbulence in the atmosphere and thus directly affects the level of dispersion. Due to PM10's ability to remain in the air for long periods of time, it has a typical travel distance of about 500–1000 km. This allows PM10 to spread long distances. Therefore studies of PM10 should consider long range transport of air pollutants, which refers to the atmospheric transport of air pollutants within a moving air mass for a distance greater than 100 kilometers. Long range transport of pollutants across national boundaries and continents can carry pollutants far away from their sources. Thus, local air quality can be impacted by pollution generated elsewhere, to the extent that critical levels may be exceeded.

2.4 Long Range Pollutant Transport

Long range transport of air pollutants refers to the atmospheric transport of air pollutant within a moving air mass in a distance greater than 100 kilometers (Glossary of Environment Statistics, 1997)

The air pollutants emitted at a location could circulate the globe within a few days to weeks depending on meteorological conditions. In many cases, air pollutants were found thousands of kilometers away from their emission sources. While air pollutants were traveling around the globe, their impacts on human could be ranged from local to global. Therefore, through the trans-boundary transport phenomena, the air pollutants emitted within a state or country could evidently introduce adverse effects in other states or countries.

PM10 is a type of air pollution that generated by a variety of human activities and can travel long distances in the atmosphere (World Health Organization, 2006). Moreover, it can be transported by winds over distance of thousands of kilometers before being set down (Agren, 2009). PM10 emitted within urban sources could possibly cause the majority of air pollution in the areas. However, long-distance transport of PM10 from man-made sources could also significantly contribute to urban pollution. As a result, long range pollutant transport could be as important as the local sources; it was usually discussed in terms of multistate pollution episodes where emissions in upwind states lead to high pollutant levels in downwind states and the trans-boundary issue (Global Sources of Local Pollution, 2009).

There were concrete evidences to confirm the occurrence of long range transport of pollutants across national boundaries and even continents. The study cases which employed transport models to prove such occurrence were the Arctic pollution episode and the transport of Boreal forest fire emissions from Canada to Europe or called trans-Atlantic transport of air pollution

For the first case, the Arctic pollution episode, high levels of air pollution were measured at Zeppelin Research Station (11.9° E, 78.9° N) located on the western coast of Spitsbergen, Norway in the months of April and May, 2006. Additionally, the most severe episodes were evidenced on April 27 and May 2 and 3. During this period there were a great number of agricultural fires in the Baltic countries, western Russia, Belarus and Ukraine. These were detected by satellites using the MODIS instruments, with more than 300 fires per day spotted between 25 April and 6 May 2006. Therefore, through trajectory model, it clearly showed that the air masses arriving at Zeppelin passed over these regions 2-4 days prior to arrival, bringing biomass burning emissions with them. In this episode, pollutants were transported over several hundred kilometers in only a few days (Bo, Huang, Narayanappa & Mukund, 2009).

In the second case, it was a transport over longer distances, the transport of Boreal forest fire emissions from Canada to Europe. In August 1998, severe forest fires occurred in many parts of Canada, with more than 106 hectares of forest burnt in the week of August 5 to 11. The emissions from these forest fires were transported across the Atlantic to Europe as it could be observed in the FLEXTRA back-trajectories at Leipzig, Germany. Moreover, the vertical aerosol concentration profiles obtained from FLEXPART forward simulations were found to be in good qualitative agreement with lidar measurements at various stations in Germany. For this case, the air masses travelled a distance of more than 5,000 kilometers in about a week.

As a consequence, the two occurrences described earlier could obviously affirm the phenomena of the long range transport of pollutants across national boundaries and continents as well as the transport over longer distances. Apart from analysis of observational data, there are many theoretical tools to study pollutant transport. Some of the simplest are the trajectory models. In such models, a small volume of air, called a particle, is adverted using the mean horizontal and vertical winds from a meteorological model. Examples of such models include HYSPLIT, FLEXTRA, LAGRANTO and TRAJKS. These models are often run backwards in time beginning from a given location, resulting in the so-called 'back-trajectories'. These indicate where the tracer particle came from, and are useful to discern pollution sources and for interpreting in-situ measurements (Bo et al., 2009).

Several authors employed backward trajectory modeling to detect the long range transport of polluted air masses that might have an impact on the change of local PM10 levels. Trajectories arriving at a given site could be analyzed in order to discover the origin of polluted air masses.

Lin et al. (2004) used the Air-mass back trajectory to classify and study the long range transport processes by specifically examining the frontal passages in two representative years. They found that there was about one frontal passage per week in winter and spring that was consistent with the climatological average. They estimated that the contribution of long range transport to PM10 abundance in northern Taiwan during winter and spring were in the range of 50% to 75%.

Chan, Wong, Li, Chan and Zheng (2006) also employed the backward trajectory modeling to detect the long range transport of polluted air masses to demonstrate the increase of PM10 over the Tibetan Plateau in Southwest China. Based on the abundance of O3, the consequence of tracing gases and aerosols (PM10 and PM 2.5) in the atmosphere there showed that pollution transport from Southeast Asia and South Asia had relatively stronger impacts than those from Central and South China.

Sánchez-Ccoyllo, Silva Dias, de Fátima Andrade and Freitas (2006) studied the impact of air pollution created from remote sources on the Metropolitan Area of São Paulo (MASP). Air-mass back trajectories from June to August of the year 1999 were calculated. The air-mass back trajectories in the MASP were originated from all four quadrants: northeast (32%), southeast (12%), southwest (19%) and northwest (37%). Their analysis of back-trajectory clusters in the MASP suggested a transport to ambient air of O3 precursors and O3 from the northeast region, which was related to agricultural activities involving biomass burning.

Riccio, Giunta and Chianese (2007) identified the role exerted by meteorology on air quality over urban area in Naples (Southern Italy). The researchers found that ozone and PM10 profiles shared some similarities since they both loaded high during anti-cyclonic, subsiding conditions, a common situation during the summer months. At that time, stagnation and recirculation effects would enhance the concentration of locally emitted air pollutant.

Sarath Guttikunda (2008) concluded that during the harvest season, the burning of the field residue was a major source of pollution following the long range transport (LRT) of the pollutants. The estimation of 40% of ambient PM was originated outside the city. These LRT sources were both of local and regional scale. Of all the sources, the long range transport between regions and countries was the most difficult to neither investigate nor estimate. The results were taken from the calculation for every four hours of the sampling period, based on receptor modeling of Hien et al., 2004

According to Prapat Pentamwa and Oanh (2008) backward trajectories obtained by HYSPLIT4 model revealed that on the days of peak concentrations of PM10, the air masses that passed over the intensive fire region in Sumatra Island were arriving at Songkhla and Phuket in southern Thailand. The 3-day backward trajectories confirmed that the high level of PM10 issues observed in southern Thailand coincided with the air masses originated from or passed over the intensive fire locations in Sumatra. The transport of haze from the fire region to southern Thailand took approximately 2-3 days.

Li, Huang, Zhu, Li, Song, Cai and Xie (2012) studied the transport pathways and potential sources of PM10 in Shanghai. The result showed that the northerly air flow transported high concentration PM10, emitted from northwestern sources including Hubei, Shandong, Anhui and Jiangsu, to Shanghai in winter and spring. In addition, the relative PM10 originated from northwestern sources contributed to Shanghai was just about twice of those originated from southwestern sources.

It could be concluded that long range transport was practically used by most researchers in order to discover the local impact by burning originated from remote area, or the effects of trans-boundary air pollution. Likewise, this research used the principle of long range transport of air pollutants, which emitted from upwind states but accumulated to high pollutant levels in downwind states. Field surveys were conducted to measure trans-boundary air pollution arriving at Chiang Rai, and its impact. Accordingly, long range transport of air pollutants in this research referred to the atmospheric transport of air pollutants within a moving air mass for a distance greater than 100 kilometers (Glossary of Environment Statistics, 1997). On the contrary, the air pollutants within a moving air mass for a distance less than or equal to 100 kilometers referred to short range transport of air pollutants. The backward trajectory modeling was used to detect the long range transport of air pollutants that might have an impact on the increases of PM10 level in Chiang Rai.

2.5 Trajectory Analysis

To determine the origin of air parcels arriving at particular locations during haze episode and emission transportation, backward trajectories and forward trajectories widely use the Hybrid Single-Partial Lagrangian Integrated Trajectories (HYSPLIT), which is the newest version of a complete system for computing air parcel trajectories as well as dispersion and deposition simulation.

Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model from the Air Resources Laboratory (ARL) of the National Oceanic and Atmospheric Administration (NOAA) (Air Resources Laboratory, n.d.) is one type of dispersion model, which can compute the advection of air parcels, or its trajectories. When a source location emits pollutant parcel into the atmosphere, the trajectories of those can pinpoint how pollutants flow through the atmosphere.

Input data for this model includes start location (defined by latitude/longitude), trajectory direction (forward/ backward), stat time, run time, start height and emission (only for dispersion modeling) and meteorological data. The archived meteorological data is generated by the National Weather Service's National Center for Environmental Prediction: NCEP). They generate forecasts using both the Global Data Assimilation System (GDAS), and the EDAS (Eta Data Assimilation System). Both systems generate basic fields, such as the u- and v- wind components, temperature, and humidity. In principle, the HYSPLIT model is used for long range transport study. The output of this model includes practical parcel, vertical motion and concentration contour.

Anderson and Brode (2006) compared the model performance of four state-of-the practical Lagrangian dispersion models: CALPUFF, SCIPUFF, HYSPLIT, and FLEXPART. They simulated the dispersion of the tracer cloud for the European Tracer Experiment (ETEX) and the Cross-Appalachian Tracer Experiment (CAPTEX). Verification scores show that the NOAA HYSPLIT model performed best overall, followed by the SCIPUFF and FLEXPART models. CALPUFF performance was significantly poorer than the other three models in the ETEX experiment and improved in CAPTEX.

Literature review show that the HYSPLIT model is a popular model for studying the transport of air pollutants at the regional level (Begum, Kim, Jeong, Lee & Ke, 2005; Danutawat Tipayarom & Oanh, 2007; Vanisa Surapipith, 2008; Kasemsan Manomaiphiboon et al., 2009; Juda- Rezler, Reizer & Oudinet, 2011), and at the local level (Danutawat Tipayarom & Oanh, 2007; Prapat Pentamwa & Oanh, 2008; Nuengruthai Yasanga, Pattarinee Traisathit & Sukon Prasitwattanaseree, 2010). The HYSPLIT model is also commonly used to forecast the movement of air masses (Vanisa Surapipith, 2008; Kasemsan Manomaiphiboon et al., 2009; Juda-Rezler et al., 2011), and to categorize transport patterns (Nuengruthai Yasanga et al., 2010), in order to have clear understanding about the movement of air masses and impacts on local air quality to aid in monitoring and preparations to mitigate impacts.

2.6 Linear Regression

Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. Before attempting to fit a linear model to observed data, a modeler should first determine whether or not there is a relationship between the variables of interest. This does not necessarily imply that one variable causes the other, but that there is some significant association between the two variables. A scatterplot can be a helpful tool in determining the strength of the relationship between two variables. If there appears to be no association between the proposed explanatory and dependent, then fitting a linear regression model to the data probably will not provide a useful model. A linear regression line has an equation of the form

$$Y = \beta 0 + \beta 1x \qquad \text{(Eq.1)}$$

Where x is the explanatory variable and y is (the dependent variable), β0 describes where the line crosses the y-axis, and β1 describes the slope of the line. The relationship relevance between 2 variables then states with its coefficient of determinant (R^2), it provides a measure of the goodness of fit for the estimated regression equation. They represent the percentage (%) variation of the data explained by the fitted line; the closer the points to the line, the better the fit.

The coefficient of determinant (R^2) could then be determined using the following equation:

$$R^2 = \beta_1 \frac{* Sxy}{Syy} \text{ ....} \qquad \text{(Eq.2)}$$

$$Syy = \sum Y_i^2 - \frac{(\Sigma Y_i)^2}{n} \text{ ....} \qquad \text{(Eq.3)}$$

$$Sxy = \sum X_i Y_i - \frac{\Sigma X_i \Sigma Y_i}{n} \text{ ....} \qquad \text{(Eq.4)}$$

Where x is the explanatory variable and y is (the dependent variable), and β1 describes the slope of the line.

2.7 Act and Responses

2.7.1 At the Region Level

An environmental crisis hit Southeast Asia in the late 1990s. The crisis was mainly caused by land clearing via open burning in the Indonesian island of Sumatra. Satellite images confirmed the presence of hot spots throughout Borneo, Sumatra, the Malay Peninsula and several other places. Malaysia, Singapore and to a certain extent, Thailand and Brunei were particularly badly affected. From Sumatra, monsoon winds blew the smoke eastward and hence creating negative environmental effects (externalities) on other Southeast Asian nations. Thick haze covered much of Southeast Asia for weeks and caused noticeable and widespread human health problems. This resulted in ASEAN nations signing the ASEAN Agreement on Trans-boundary Haze Pollution, to use the agreement as a framework for inspecting air pollution from trans-boundary haze and to reinforce cooperation between nations to control and solve the problem of air pollution from trans-boundary haze. As of June 2007, eight countries, including Malaysia, Singapore, Brunei, Myanmar, Vietnam, Thailand, Laos and Cambodia have ratified the agreement. The objective of the Agreement is to prevent and monitor trans-boundary haze pollution that resulted from land and/or forest fires, in order to mitigate impacts through concerted national efforts and intensified regional and international co-operation. This should be pursued in the overall context of sustainable development Principles.

The Agreement established the ASEAN Coordinating Centre for Trans-boundary Haze Pollution Control for the purposes of facilitating cooperation and coordination among the Parties in managing the impact of land and/or forest fires in particular haze pollution arising from such fires. A Committee composed of representatives of the national authorities of the Parties shall oversee the operation of the ASEAN Centre .Each Party shall designate one or more Competent Authorities and a Focal Point that shall be authorized to act on its behalf in the performance of the administrative functions required by this Agreement. Each Party shall take appropriate measures to monitor: all fire prone areas, all land and/or forest fires, the environmental conditions conducive to such land and/or forest fires, and haze pollution arising from such land and/or forest fires. It can be concluded that member nations have agreed to monitor the problem of smoke- haze with trans-boundary impacts, with an emphasis on the promotion of zero burning policy to deal with land and or forest fires resulting in trans-boundary haze pollution. The Parties shall, jointly or individually, develop strategies and response plans to identify, manage and control risks to human health and the environment arising from land and/or forest fires and related haze pollution arising from such fires, as appropriate, prepare standard operating procedures for regional co-operation and national action required under this Agreement. Each Party shall ensure that appropriate legislative, administrative and financial measures are taken to mobilize equipment, materials, human and financial resources required to respond to and mitigate the impact of land and/or forest fires and haze pollution arising from such fires and shall forthwith inform other Parties and the ASEAN Centre of such measures. The agreement also promotes technical cooperation and scientific research.

However, it can be seen that the agreement is a general approach to solving problems among member nations. But no detailed plans or policies have been established to handle trans-boundary haze pollution. No presentations of methods to reduce open burning, in accordance with the zero burning policy, have been made, especially for the Greater Mekong Sub-Region Economic Cooperation area, comprised of Thailand, Laos, Cambodia, Vietnam, Myanmar, and Yunnan Province of China. All these nations have a similar culture of burning (Bach & Nion Sirimongkonlerkun, 2011).

2.7.2 At the Sub-Regional Level

Thailand therefore initiated the concept of coordinating to solve trans-boundary haze problems between 5 GMS nations, including Cambodia, Laos, Myanmar, Vietnam, and Thailand. Working teams were established to work in the areas of forest fires and haze pollution for the region. The ASEAN Secretary General's Office is serving as the secretariat of the working teams, while the ASEAN Specialized Meteorological Centre (ASMC) is providing relevant data.

However, the progress of working teams at the national level has been slow due to lack of policy support from governments in applying the research of working teams. Therefore, Cabinet committees are being established to supervise and provide policy support to solve the problem of open burning and air pollution from trans-boundary haze. ASEAN nations approved of this plan on October 13, 2010, during the 6th ASEAN Meeting on Trans-boundary Haze Pollution. The meeting also approved to establish environmental committees for GMS nations at the Cabinet levels.

The responses seem to be rather active recently. For example, the Sub-regional Ministerial Steering Committee on Trans-boundary Haze Pollution in the Mekong Sub-Region (MSC Mekong) convened for the first time on 25 February 2011 in Krabi, Thailand, and was attended by Environment Ministers/representatives from Cambodia, Laos, Myanmar, Thailand and Vietnam. One of the important outcomes from the meeting is endorsement and agreement to work towards a sub-regional target of (1) reducing cumulative hotspot count not to be exceed than 75,000 hotspots (based on 2008 data) to be achieved by 2011; and (2) reducing cumulative hotspot count not to be exceed than 50,000 hotspots (based on 2006 data) to be achieved by 2015.

Individual Mekong countries also agreed to set their respective national targets for hotspot count reduction in order to achieve the regional/sub-regional targets. For the National Target, each member state will set their own targets for hotspot count reduction to be consistent with the regional targets.

The first sub-regional target to be achieved by 2011 has almost been met. The hotspot count has reduced from 87,000 in 2009 to 78,321 in 2011. The low hotspot count in 2011 is partly due to weather condition affected by La Niña. Mekong countries will explore setting national targets in terms of hotspot counts and air quality data such as PM10, and other criteria such as air quality data, actual burned areas, etc. Moreover the meeting agreed to work towards achieving the second sub-regional target of hotspot reduction, i.e. reducing cumulative hotspot counts to be not exceed than 50,000 hotspots (based on 2006 data) to be achieved by 2015.

Mekong nations will also further consider establishing targets based on PM10 data. Among the targets suggested were PM10 concentration data, the level on air quality based on Air Quality Index (for example the number of days when air quality exceeds moderate or unhealthy level), or the number of days where PM10 concentration exceeds national standard.

However, Thailand is the only nation in the Greater Mekong Sub-Region that monitors PM10 values. Other nations do not know the severity of their haze situation, or how much the haze situation affects the health of their population. This has resulted in lack of awareness and motivation to truly handle the problem, resulting in lack of progress in advancing policies related to solving haze problems. Thailand has resolved to support other GMS nations to establish systems to monitor haze situation. Laos and Myanmar have expressed interest in receiving support. In the future, cooperation will be extended to Vietnam and Cambodia.

However in summary, it should be noted that although there is an ASEAN Agreement on Trans-boundary Haze Pollution that was signed several years ago by member countries, its effectiveness to control the pollution is still far from satisfactory because of lack of full understanding of the problem and lacks of specific measures to deal with complicated trans-boundary issues. Locations have not been set for urgent work to solve haze among GMS nations. The target to reduce hotspot count at the sub-regional level has been set, and is to be set at national levels. However an emerging challenge issue of how to achieve such targets has not been addressed in sufficient details. Likewise, no regional cooperation is initiated yet on monitoring of land and forest fires, which are the root cause of air quality problems.

2.7.3 At the National Level in Thailand

Main agencies responsible for handling haze problems include the Pollution Control Department and the Department of National Parks, Wildlife and Plant Conservation, Ministry of Natural Resources and Environment, and the Land Development Department, Ministry of Agriculture and Cooperatives. The Department of National Parks, Wildlife and Plant Conservation is responsible for managing and solving forest fire problems in order to conserve and rehabilitate forest resources. The Pollution Control Department is responsible for controlling, preventing, reducing, and eliminating pollution and conserving and rehabilitating the environment to be conducive for human life.

The Forest Fire Control Division of the Department of National Parks, Wildlife and Plant Conservation is responsible for managing and solving forest fire problems in order to conserve and rehabilitate forest resources. Starting from 2006, with the cooperation of Information for Resources Management System at the University of Maryland, the division compiled forest fire statistics and hotspot data for use in the control of forest fires. The university sent daily hotspot information received from the MODIS Terra and Aqua satellites. The information was divided into hotspots that occurred in protected areas and hotspots that occurred outside protected areas. The information was categorized by provinces, and sent to responsible agencies in each province to allow for inspection and managing of forest fires at the provincial level. Hotspot information was disseminated on the website for public.

From 2003 until the present, the Cabinet has made several important resolutions related to solutions to haze problems and open burning. The Cabinet approved the National Master Plan for Open Burning Control, the Strategic Plan to Solve Forest Fires, measures to urgently solve haze situation in the upper northern region of Thailand, and the Operational Plan to Solve Smoke, Haze, and Forest Fires 2008-2011. In 2009, the Cabinet resolved to conduct work to prevent and solve open burning, and also established urgent measures to solve air pollution and haze in the northern region of Thailand.

The National Master Plan for Open Burning Control is aimed at preparing work plans and measures to accommodate the ASEAN Agreement on Trans-boundary Haze Pollution, and to implement zero burning policies as a strategy for every region to control and reduce open burning and air pollution, and as a framework for agencies to conduct work in the same direction in accordance with the Operational Plan to Solve Smoke, Haze, and Forest Fires 2008-2011, in accordance with the Cabinet's resolution on October 30, 2007. The plan aims to integrate work of relevant agencies, with the Pollution Control Department, Ministry of Natural Resources and Environment, being the main agency. The plan emphasizes 3 important strategies, including control of open burning in communities and agricultural areas, control of forest fires, and campaigns to provide knowledge to help people participate in monitoring burning. The first target of the plan is to ensure that at least 90% of air quality in all locations is not detrimental to health during the period from October to March. The second target of the plan is to reduce forest areas that are burned to less than 300,000 Rai per year.

Other laws related to the control of air pollution in the form of particulates, including the Environmental Committee's National Notification that requires average value of particulates less than 10 microns in diameter over a period of 24 hours shall not exceed 0.12 milligrams per cubic meters. The arithmetic mean of the particulates over a 1 year period shall not exceed 0.05 milligrams per cubic meters.

In addition, measures were established to monitor forest fire and haze situations, to allow for information to be exchanged between central and local agencies. Information will be collected to assess situations, and to create operational measures to issue warnings on haze situations in the northern region. Experimental programs on measures to control open burning in agricultural areas will be conducted in the northern and northeastern regions, in order to spread knowledge about problems and impacts from open burning to members of the public, agriculturists, and local civil servants. Technology and agricultural practices that do not involve open burning was demonstrated to agriculturists, such as burying rice stubble and using organic fertilizers to dissolve leftover agricultural material. Economic measures were also used to promote agriculturists to not conduct open burning, such as the Royal Rain Project to alleviate haze and forest fire situations in the northern region every February 1 to April 30 of each year.

However, work implementation to control open burning in Thailand, including work plans and measures, have not taken clear form and still lacks proper promotion to achieve results. There is no integration of work between relevant agencies. There is no continuity in coordinating and linking solutions to problems. There is also lack of knowledge at the local levels, resulting in the inability to evaluate local burning situations. These obstacles contribute to lack of clear results in Thailand's work to control burning.

2.8 Related Research

2.8.1 Health Impacts of Haze

Pongtape Wiwatanadate (2007) conducted research to examine the number of patients how were affected by smoke-haze in Chiang Mai Province to determine whether they had symptom that could indicate respiratory problems. The findings showed more than 20 out of 25 people had the symptoms.

Tippawan Prapamontol, Tanyapron Kerdnoi and Nisa Pakvilai (2009) collected information among students in municipalities and students outside municipalities, at Ban Pa Tueng School and Mae Ha Pa Rai-Sri Yang Chum School. They conducted urine test to determine whether people came into contact with PAS substances. It was found that students outside municipalities had higher PAS in their urine than students in municipalities. It was also found that communities outside municipalities conducted open air burning, such as burning of wood and agricultural material, more than communities inside municipalities. A significant relationship was found between open air burning and exposure to PAS.

Chingchai Humhong and Chada Narongrid (2010) conducted a study of areas at risk of forest fires in Mae Hong Son Province, using historical data from the Terra and Aqua satellite. They analyzed environmental factors, including altitude, slope and distance from municipalities, distance from villages, distance from roads, distance from sources of water, distance from agricultural areas, and distance from forests. The study found that areas with a history of hotspots were scattered throughout Mae Hong Son Province, but Mae Sariang District had a higher number of hotspots than other districts. Hotspots in the district occurred both inside and outside a national park, with most hotspots occurring near forests, water sources, agricultural areas, and roads, at average distances of 0.009, 0.2, 1.1, and 1.3 kilometers, respectively.

2.8.2 Investigation into the Cause of Smoke -Haze Problem

Ketsiri Leelasakultum (2009) investigated the case of the Chiang Mai haze episode, which occurred in March, 2007, by using GIS technology and hotspot data from MODIS. The results showed that the main cause of the Chiang Mai haze episode is local biomass burning and long range transportation from upwind biomass burning locations.

Teerachai Amnauylawjarurn et al. (2010) investigated the factors affecting dispersion of particulate matter (PM10) released from forest fires in Chiang Mai province from March 9-13, in2007 and 2008. The simulated PM10 concentrations in Chiang Mai were 161-401 $\mu g/m^3$ from March 9-13, 2007, and 32-80 $\mu g/m^3$ from March 9-13, 2008, which are consistent with the observed values. The PM10 affected areas in Chiang Mai were defined according to the concentration of air pollutants.

2.8.3 Areas at Risk of Forest Fires

Anusorn Rungsiapnich and Kampanat Deeudomchan (2006) applied remote sensing data and GIS input for risk areas to conduct forest fire modeling. The model used Landsat-5 TM imagery for Chiang Mai Province from 1999 to 2006. Meanwhile, Xu et al. (2006) integrated forest inventory data with Landsat TM data, and added new data layers for factors that affect forest fire in Jilin Province of China.

Takeuchi, Matsumura, Sawada and Yasuoka. (2008) used hourly MTSAT imagery for evaluation of wildfire duration time over Asia. Fire duration time was detected by comparing the pixel that contains hotspots with non-affected pixels around it. If there is some wildfire at a pixel, the temperature of the pixel become higher than the non-affected pixels. The researchers concluded that hourly monitoring provides sufficient time resolution and plays an important role in monitoring wildfire duration time.

Tran, Dinh, Nguyen and Phonekeo (2008) developed a forest fire risk map for Quang Ninh Province, Vietnam, by using high-resolution satellite imagery with the MODIS Fire Product (MOD14), GIS data, and fire occurrence information collected during field visits. The risk zones were defined using weight overlay analysis, and then the forest fire risk index was generated for reclassifying and validation, prior to the generation of a forest fire risk zone map.

Suchat Podchong (2010) created a forest fire risk map for forest conservation areas in Thailand from 2007-2009. Relevant factors were included in the map, including geographic factors, fuel factors, and human and climate factors. The relationship between these factors was determined. A map was created that showed forests in conservation areas that are at risk of fires. The areas were categorized based on risk: low, moderate, and high.

Xu et al. (2006) studied natural factors that affected forest fires in the Jilin Province of China. They used GIS principles to create 3 maps, including fuel-based fire risk map, topography-based fire risk map, and anthropogenic-factor fire risk map. Data on the 3 maps were synthesized to show areas that area at risk of forest fires. The study found that the factor that greatly influenced the occurrence of forest fires include natural fuel, topographical characteristics, followed by human behavior.

2.8.4 Monitoring and predicting active fire occurrence

Phonekeo, Sann Oo and Samnrakoon (2006) developed the MODIS Fire Information System (FIS), based on the MODIS Active Fire Product (MOD14) Production Code, version 4.3.2, which was developed by NASA. This system automatically generates fire pixels or hot spots information with other physical parameters, which are useful for the study of fire occurrence phenomenon. Meanwhile, Oraprapa Pummakarnchana (2006) developed an Internet GIS system used for acquiring and monitoring real-time air quality levels, and updating information through wireless GIS using Web Map Service.

Kasemsan Manomaiphiboon et al. (2009) conducted an overview of a smoke-haze forecast modeling system recently developed and applied to the smoke-haze problem for Northern Thailand They conducted an experimental forecast operation using the system during March-April, 2008. They used fire hotspots detected by the MODIS sensors on board NASA's satellites to examine the trans-boundary transport of smoke- haze from the neighboring areas of upper northern Thailand.

Veerachai Tanpipat et al. (2009) conducted validation of MODIS hotspot data by examining areas to see whether burning took place or not. Ground and aerial field surveys were conducted in this study by the Forest Fire Control Division, National Park, Wildlife and Plant Conversation Department, Ministry of Natural Resources and Environment, Thailand. A quantitative evaluation of MODIS hotspot products has been carried out since the 2007 forest fire season. The carefully chosen hotspots were scattered throughout the country and within the protected areas of the National Parks and Wildlife Sanctuaries. A high accuracy of 91.84 %, 95.60% and 97.53% for the 2007, 2008 and2009 fire seasons were observed, respectively, resulting increased confidence in the use of MODIS hotspots for forest fire control and management in Thailand. This is in accordance with a study by Yootthapoom Potiracha et al., (2007), which validated hotspot data of MOD14 products by comparing MODIS data with a 5 kilometer buffer of hotspots extracted from LANDSAT-5. These data were acquired during 2007, in the dry season, which is a forest fire season in northern Thailand. The validation of hotspot from MOD14 with LANDSAT-5 TM yield low accuracy of validation during the beginning of the forest fire season, because only a small number of hotspots occurred at that time. But from late February until early April, which is a peak period of forest fire, a large number of hotspots were detected because of several areas covered with forest fire spots and burn scars, thus yielding a high accuracy of validation.

Suchat Podchong (2010) For Thailand, the Department of National Parks, Wildlife and Plant Conservation conducted accuracy assessment of hotspot data by examining ground and aerial data. It was found that data on hotspots and forest fire had 82.3% validity. Therefore, hotspot data obtained from remote sensing has a high level of accuracy.

Nion Sirimongkonlertkun and Phonekeo (2012, January) analyze trends of aerosol optical thickness (AOT) acquired from Terra/ Aqua MODIS and PM10 concentration from 12 PCD air quality ground measurement stations in the period from February to March, from 2007-2010, and determined their relationship to generate estimated PM10 concentration maps for northern Thailand. The results showed that the trends of AOT and PM10 go together in a similar direction. The equation for the relationship between AOT and PM10 is Y = 57.09+ 70.93 (R=0.32)

Chat Phayungwiwatthanakoon and Songkot Dasananda (2012) studied the relationship between PM10 and Aerosol Optical Depth (AOD) in the upper northern region of Thailand from 2010 to 2011. They chose to use AOD values obtained from band 3 of Terra/ Aqua MODIS. The study found strong coefficient (R^2 = 0.77), and the equation for the relationship between AOD and PM10 is Y = 1,627.9 (AOD) - 1,033.

2.8.5 Air Mass Movement

Nuengruthai Yasanga et al. (2010) identified back trajectories of air masses arriving in Chiang Mai and categorized them into distinct transport patterns by cluster analysis. Two-day backward trajectories at an altitude of 500 m in Chiang Mai and Bangkok were calculated between June, 2008 and May, 2009. The results show that the southwesterly transport pattern that passed Bengal Gulf and southern Myanmar occurred most frequently.

Patipat Wongruang, Prungchan Wongwisad and Sittichai Pimonsree (2012) identified back trajectories of air masses arriving in Mae Hong Son on March 18, 2012, which was the date when the highest 24 hour average PM10 value was recorded at 506 $\mu g/m^3$. Two-day backward trajectories at an altitude of 500 m were identified in the province. It was found that air masses began in Myanmar and moved through areas with high concentration of hotspots before passing through Mae Hong Son, Thailand.

Begum et al. (2005) used the HYSPLIT model to identify potential source areas and preferred pathway of pollutants to Philadelphia. The five-day backward trajectories were obtained by fixing the arrival of air parcel an altitude at 500 m. It is mentioned that this height was selected to diminish the effects of surface friction and to represent winds in the lower boundary layer

Prapat Pentamwa and Oanh (2008) also utilized HYSPLIT to assess the potential contribution of long range transport to particulate matter in Bangkok, Thailand. The height above ground level was set at 1000 m to compute the ten-day backward trajectory. This study found that there was no difference between the trajectories for the starting levels of 500m and 1000m.

Chan et al. (2006) used the HYSPLIT model to trace the source regions and transport pathways of pollution, namely ozone, CO, NO_x, PM10 and PM2.5 over the Tibetan Plateau of southwest China. The results showed that pollution transport from Southeast Asia and South Asia had relatively stronger impacts than that from Central and South China on the abundance of O3, trace gases and aerosols in the background of the Tibetan Plateau of Southwest China.

Danutawat Tipayarom and Oanh (2007) used the HYSPLIT model to examine possible transport pathways of smoke emitted from rice straw burning in Pathumthani Province. The results show that during the intensive burning season (November-April) smoke plumes from rice straw burning in Pathumthani can be transported to Bangkok following the northeast monsoon. Emission from open rice straw burning may therefore contribute significantly to air pollution levels in surrounding areas, including Bangkok.

Vanisa Surapipith (2008) concluded in the Report for the 10th Workshop on the Transport of Air Pollutants in Asia that fire emission datasets for HYSPLIT forecasting has become the first priority in dealing with haze early warning. The capacity to run CALPUFF has been implemented and public understanding on the issue is thought to be important to the progress in enforcing policy on air quality control.

Nuengruthai Yasanga et al. (2010) classified backward trajectories of air masses arriving in Chiang Mai and Bangkok into distinct transport patterns by cluster analysis. Two-day backward trajectories at an altitude of 500 m in Chiang Mai and Bangkok were calculated between June, 2008 and May, 2009, using the HYSPLIT Model developed by the Air Resources Laboratory of the United States National Oceanic and Atmospheric Administration (NOAA). The result show 3 transport patterns were detected in Chiang Mai. The southwesterly transport pattern that passed Bengal gulf and southern of Myanmar was found most frequently.

Juda et al. (2011) used the HYSPLIT to generate 3-day backward trajectories for air parcels arriving in six cities situated in northern, central and southern Poland at an altitude of 200, 500 and 700 m. The potential source areas of long range transported pollution were studied using 72-hour backward air mass trajectories with a starting height of 500 and 20 m (March 31–April 2, 2008, April 2 to April 8, 2009) above ground level.

Danutawat Tipayarom and Oanh (2007) determined the impact that burning rice straw hats on air quality in the Bangkok region by studying the relationship between monthly average PM10 measurements at Bangkok University (Rangsit) station and hotspot counts from daily MODIS images in Pathumthani (web fire mapper) from April, 2003 to April, 2004. The results showed very strong correlation (R^2= 0.7689) between hotspot counts and PM10 concentration. It means that burning rice straw during the dry season affects air quality in nearby areas, especially in Bangkok.

Anwar et al. (2010) determining the concentration of five major pollutants (PM10, SO2, NO2, CO and O3) in Riau, Indonesia, for 2006 and 2007, and also correlated the level of air pollutants to the number of hotspots recorded, using the hotspot information system introduced by the Malaysian Centre for Remote Sensing (MACRES). They concluded that the concentration of air pollutants recorded was found to increase with the number of hotspots. Nevertheless, only the concentration of PM10 during a haze episode is significantly different when compared to its concentration in non-haze conditions.

Literature review found that the problem of haze in the upper northern region of Thailand is significantly linked to open burning (Ketsiri Leelasakutum, 2009), and that haze problems have affected air quality and the health of people (Pongtape Wiwatanadate, 2007; Tippawan Prapamontonl et al., 2009). However, at present, the application of remote sensing for monitoring of hotspots in all areas (Phonekeo et al. 2006; Phonekeo, Gunasekara & De Silva, 2009) has allowed all GMS nations to be aware of hotspot situations in near-real time. Maps showing forest fires have also been developed for GMS countries, such as Vietnam (Tran et al., 2008), and Thailand (Anusorn Rungsiapnich & Kampanat Deeudomchan, 2006; Chingchai Humhong & Chada Narongrit, 2010). Research has also been conducted in Thailand on measures to forecast PM10 values (Kasemsan Manomaiphiboon et al., 2009; Nion Sirimongkonlerkun & Phonekeo, 2012, March; Chat Phayungwiwatthanakoon & Songkot Dasananda,

2012) in order to monitor PM10 situations in the upper northern region of Thailand. In addition, studies to identify potential source areas and preferred pathway of pollutants have also been conducted for some areas in northern Thailand. This can be seen that, most of the researches on smoke-haze problem are limited only in Chiang Mai province only.

However, based on the physical characteristics of smoke that, smoke and haze are not reside at particular locations, but always unlimitedly move to any direction under the influence of air flow. Therefore study on smoke-and-haze problem that occurs in Northern Thailand, still need to focus on burning activities of neighboring countries and its possible impact to the increment of PM10 concentration in each location. This is the driving force to setup this study, which need to investigate the relationship between the burning activities occurs in three countries comprise Thailand, Laos and Myanmar, with the smoke-and-haze phenomenon that occurs in Northern Thailand. To investigate this, PM10 concentration data measured at 13 stations in Northern Thailand was used, and apply to understand the same phenomenon which occurs in Chiang Rai province, that could be caused by burning activities from neighboring countries. Moreover, study on the burning patterns in Chiang Rai province also was carried out, with data analysis of related factors such as meteorological and topographical factors to find out the possibility of the problem that could linked with these factors. This will help to the pattern and trend of the problem in the province, and to support decision-making for solving the smoke-haze problem.

CHAPTER 3

METHODOLOGY

3.1 Overall Research Framework

In order to successfully provide comprehensive answers to the research questions that were set earlier. The methodology was designed to be main two parts which related to the research in regional part and local part.

3.1.1 Regional Level

This section will show the research in regional part which is to find the answer to the burning activities in regional level, that covers Thailand, Myanmar and Laos that would has the possible impact to the increasing of the PM10 values measured in 13 stations in the Northern part area of Thailand

3.1.2 Local Level

This is research step to find the answer to the smoke-and-haze problem, which could be from neighboring countries which mean cause by burning activities in regional level.

From the two sections as shown above, the overall research framework can be shown in the in Figure 3.1 as below.

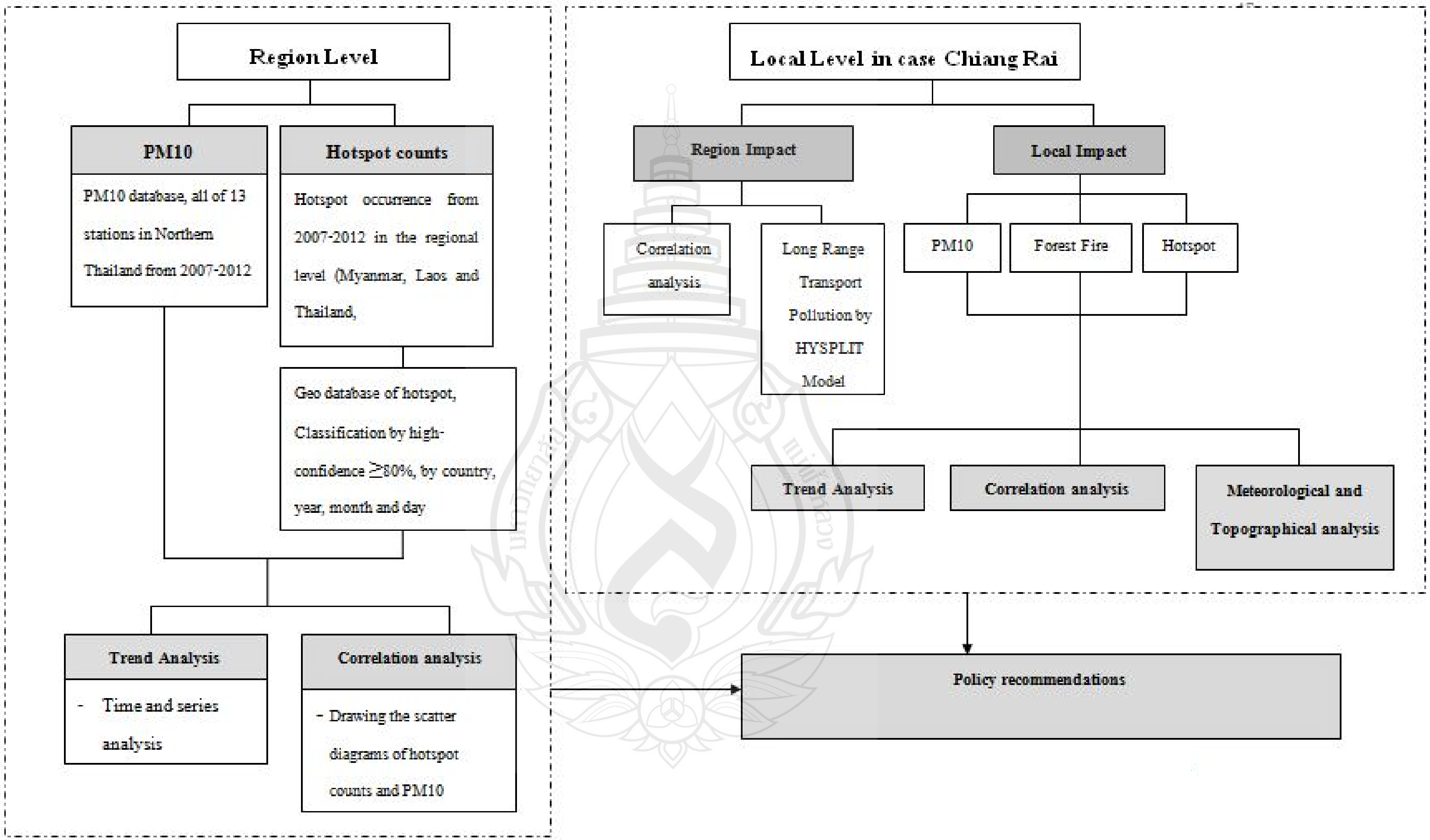


Figure 3.1 Overall Research Framework

3.2 Data Sources

3.2.1 PM10 Concentration

The PM10 concentration in 8 provinces of Northern Thailand, as well as monthly and daily PM10 concentration data for seven years (2007-2012) obtained from selected monitoring stations in Northern Thailand is the main data that used in this study. These PM10 data were recorded by the Pollution Control Department (PCD) of Thailand by the stations as shown in Table 3.1. The locations of ambient air monitoring stations are shown in using the red squared dots in Figure 3.2.

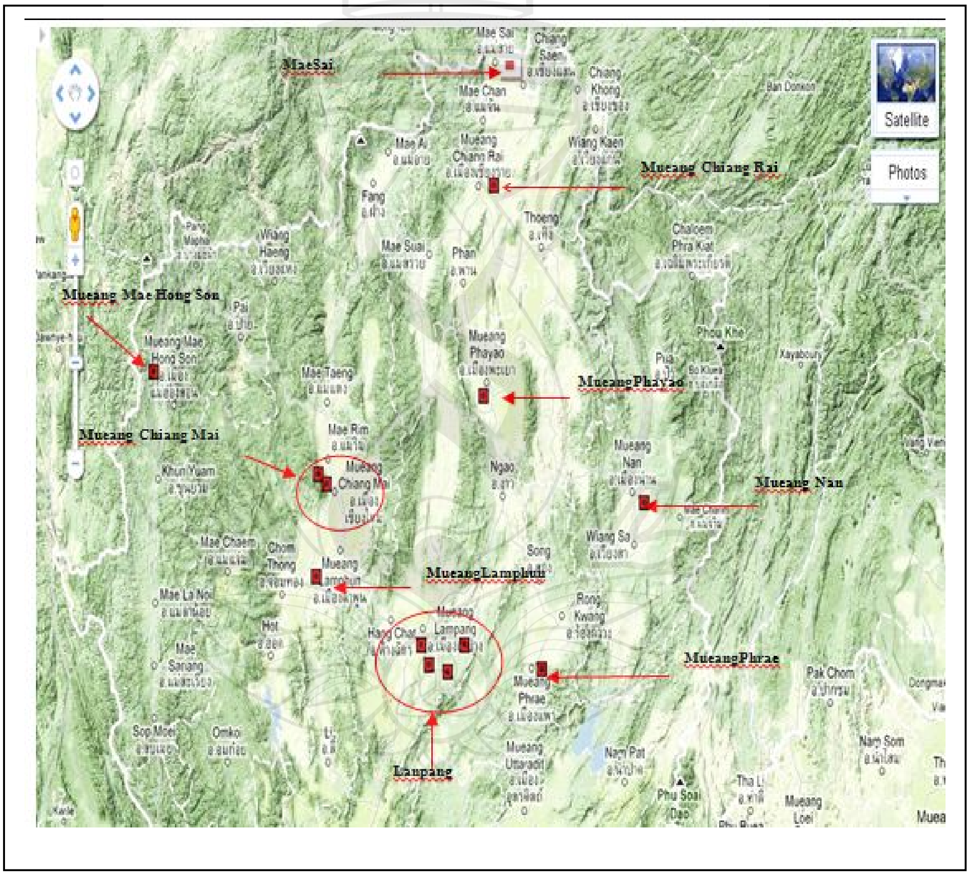


Figure 3.2 Locations of the PCD Air Quality Measurement Stations in Northern Thailand are Marked by Red Squares and Shown on the Google Earth Base map.

Table 3.1 List of PCD Air Quality Measurement Stations in Northern Thailand

No.	Province name	Province code	Station name	Longitude	Latitude	Station code
1	CHIANGMAI	101	ChiangMai1	98.9729	18.8377	T35_CM1
1	CHIANGMAI	102	ChiangMai2	98.9932	18.7883	T36_CM2
2	LAMPANG	201	Lampang1	99.5063	18.2868	T37_LP1
2	LAMPANG	202	Lampang2	99.7669	18.2478	T38_LP2
2	LAMPANG	203	Lampang3	99.7611	18.4242	T39_LP3
2	LAMPANG	204	Lampang4	99.6631	18.2797	T40_LP4
3	CHIANGRAI	301	ChiangRai1	99.8234	19.9092	T65_CR1
3	CHIANGRAI	301	Chiang Rai2	99.8836	20.4280	T73_CR2
4	MAEHONGSON	401	Maehongson1	97.9715	19.3045	T66_MH1
7	PHRAE	701	Phrae1	100.1655	18.1261	T69_PR1
8	PHAYAO	801	Phayao1	99.9000	19.1639	T70_PY1

3.2.2 Active Fire Data

The daily active fire or hotspots data for three countries such as Thailand, Myanmar and Laos was downloaded from the FIRMS website by the URL http://maps.geog.umd.edu/firms. Each active fire pixel represents a pixel of 1 km. by 1 km. pixel that indicates the geographical location in latitude and longitude. The hotspot count is based on the available satellite imagery that passed over the area, where fire occurrence is detected within 1 km. by 1 km. pixels. Therefore due to coarse spatial resolution, the active fire number that counted may be underestimated comparing to the active fire available on the ground at regional level.

Active fire or hotspot data obtained from the website are in the format of spatial data which include several physical parameters designed by NASA, in particularly, latitude, longitude, detection date and time, brightness temperature, fire power and fire detection confidence which range from 0 to 100%. In order to apply the downloaded active fire data, it is necessary to create a spatial database for the data which will be grouped in monthly, yearly for each country and only the data with fire confidence higher or equal 80% will be used. The process of the database development is conducted using GIS tools, which the details can be described as follow.

1. Input hotspot data with fire confidence that higher or equal 80%
2. Input the GIS data of political boundaries for the three countries.
3. Allocate the hotspot data with fire confidence that higher or equal (≥) 80% to be within the political boundaries of each country.
4. The resulted data of the database will be attribute data which consist of geographical location of the fire pixels indicates by latitude, longitude, also detection date and time, fire confidence, country name and administrative names where the hotspot data is located.

The Figure 3.3 below illustrates the process of overlaying the hotspot data with the GIS administrative data to allocate the hotspot data by country.

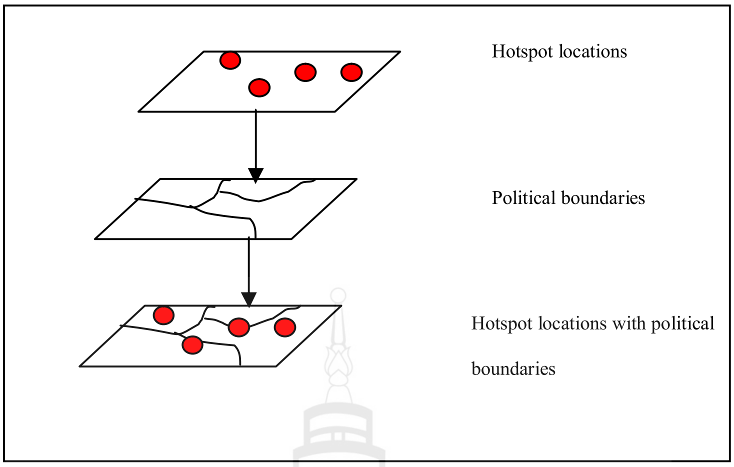


Figure 3.3 Allocation of Hotspot Data Within Specific Country using GIS Overlaying Tools.

Apart of downloaded active fire or hotspot data, the fire occurrence location information collected from the field survey was also applied this study. This data was compiled by the Protected Area Regional Office 15, Forest Fire Control Division, Department of National Parks Wildlife and Plant Conservation, and it is used together for the study in local level.

3.3 Research Step for the Study on the Impact of Regional Burning Activities to the Increasing of PM10 Concentration in Northern Part of Thailand

In this step, it is necessary to investigate the possible impact of the burning activities that could cause increasing of PM10 concentration in selected measurement stations in the Upper Northern Part of Thailand, using the study on the relationship between active fire and PM10 concentration data using statistical Linear Regression Analysis. However, in the beginning of the study, it is necessary to understand the patterns and trends of PM10 concentration values in time and space, including study on the month-by-month change of the both parameters (active fire and PM10 concentration) to have better understanding of their occurrence and change. The study of these parameters will have the following details as shown in the next sections.

3.3.1 Trend Analysis by Time and Space

3.3.1.1 Trend of PM10 concentration in Northern Thailand by time and space

In this section, the study presents the changes of PM10 trends at 8 stations in the Northern region of Thailand, by analyzing the average monthly data from each year to have the change patterns and trends.

3.3.1.2 Trend of hotspot distribution in three countries by time and space. In this section, selection of data from the spatial database developed in in section a is carried out by the conditions, attribute query function, which were defined for data selection for each country (Laos, Myanmar and Thailand) and classified by year and month to generate the maps of hotspot distribution in the burning season of year 2007, 2009, 2010 and 2012. The graphs that represented the trend of hotspot distribution in regional level were also generated.

3.3.2 Analysis on the Month-to-Month Change

PM10 changes for selected stations in Northern part of Thailand and the monthly-to-month change of hotspots at the regional level in 2007, 2009, 2010, and 2012. In order to determine the characteristics of monthly changes in hotspot counts and PM10 concentration, the rate of change between number of hotspots and PM10 concentration were also calculated during the same period. This study also needs to investigate how a hotspot point could affect the PM10 change. In this study, the analysis based on mathematical calculations was conducted.

3.3.3 Correlation Analysis

This process involves analysis of the relationship between hotspot counts in the regional level and PM10 concentration at every station in the Northern Thailand from January to April for each year of 2007, 2009, 2010, and 2012 The correlation analysis is conducted according to the following methods:

3.3.3.1 Draw the scatter diagrams of hotspot counts and PM10 concentration. The diagram could then visually show whether there is any relevant relationship between the variables. The relationship can be represented mathematically as

$$y = \beta_0 + \beta_1 x \qquad \text{(Eq.1)}$$

Where x is hotspot counts (the explanatory variable) and y is PM10 concentration (the dependent variable), β_0 describes where the line crosses the y-axis, and β_1 describes the slope of the line.

3.3.3.2 The relevant relationship between 2 variables can be determined with its determinant coefficient (R^2). The determinant coefficient (R^2) could then be determined using the following equation:

$$R^2 = \beta_1 \frac{*Sxy}{Syy} \qquad \text{(Eq.2)}$$

$$Syy = \sum Y_i^2 - \frac{(\Sigma Y_i)^2}{n} \qquad \text{(Eq.3)}$$

$$Sxy = \sum X_i Y_i - \frac{\Sigma X_i \Sigma Y_i}{n} \qquad \text{(Eq.4)}$$

Where x is hotspot counts (the explanatory variable) and y is PM10 concentration (the dependent variable), β_1 describes the slope of the line.

3.4 Local Level in Case Chiang Rai Province.

The purpose of this study step is to investigate the burning activities in regional level could be the possible factors that cause the increasing of PM10 concentration in Chiang Rai province. In this step, the study on regional and local impacts will be carried out as follow.

3.4.1 Regional Impact.

The study in this part focuses on the regional impact of burning activities in regional level that could be the reason of increasing the PM10 concentration in Chiang Rai province. The idea of this study is based on the relation of the burning activities in three countries during the burning seasons (January to April) for the year 2009, 2010 and 2012, with the increasing of PM10 concentration in the same period. The study in this step also cover the possibility of the movement of air mass that could affect to the PM10 concentration by the wind direction and daily air mass movement in March to measurement station locates in Chiang Rai province. Hence, this main step is divided into two another study steps:

1. Study on relationship between the number of regional hotspots and PM10 level at Chiang Rai station, and
2. Study on Daily backward trajectories in March to Chiang Rai

The details of the two study steps above can be summarized as below:

Relationship between the number of Regional hotspots and PM10 level at Chiang Rai station

1. Select hotspot information for each country from January to April for the years 2009, 2010 and 2012 (based on the conditions that PM10 data is available accordingly)
2. Selection of buffer at distances of 0-10 km. from Chiang Rai stations with the count hotspots within the buffer interval.
3. Select average monthly PM10 at each station from January to April of 2009, 2010 and 2012
4. Analyze the relationship between the hotspot counts and PM10 concentration by simple regression analysis.

Daily backward trajectories in March to Chiang Rai

This step of the study is to investigate the possibility that wind direction to Chiang Rai province could carry PM10 to the province, which will focus on the wind pattern and direction, including for the daily air mass movement for March 2007, 2009, 2010 and 2012. The software that used for this purpose is HYSPLIT model. The model can be run online at http://www.ready.noaa.gov/ready/open/hysplit4.html.

After obtaining the result from this model, the result will be overlaid with the hotpot distribution data that occurred in March of each year

Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) is one type of dispersion models, which can compute the advection of air parcels, or its trajectories. When a source location emits pollutant parcel into the atmosphere, the trajectories of those can pinpoint how pollutants flow through the atmosphere. Input data for this model are following:

1. Meteorological data, which the following parameters are selected:
2. Start location, which is the geographical location of PM10 measurement station (latitude/longitude: 19.9092,99.8234) Trajectory direction, in this case, backward is selected
3. Run time, 24 hours is selected.

3.4.2 Local Impact

The study in this part is to carry on the investigation on the possibility of the burning activities in provincial level could affect to the increasing of PM10 concentration PM10, by starting the study on the increasing of PM10 and burning activities within the province. The data that used in this step is obtained from the forest fire report compiled by Protected Area Regional Office 15, Forest Fire Control Division, Department of National Parks Wildlife and Plant Conservation, that had only 4 forest fire stations in the concerning areas, which include the information of the burning location, date and time from the field survey. However, the report shows only the information of the fire occurrence in the neighboring area with the Office (Pornthep Thedthong, 2012). Therefore, hotspot data downloaded from FIRMS website and only use the hotspot data with fire confidence that equal or higher than 80%, together with other possible factors which related to the local climate and topography that could be taken into account, in which can be considered as below:

1. Trend of PM10 concentration at Chiang Rai station by time and space. In this step, the study on the changes in PM10 concentration trends at Chiang Rai station is carried out by analyzing the average monthly data and trends changes from each year of 2009, 2010 and 2012

2. Trend of forest fire occurrence by time and space.
3. Trend of hotspot distribution in three countries by time and space.

This process involves the data selection of data from the spatial database developed in in section a is carried out by the conditions, attribute query function, which were defined for data selection for each district and classified by year and month to generate the maps of fire occurrence distribution.

3.4.2.1 Correlation analysis

This process involves analysis of the relationship between hotspot counts in the local level or provincial level and PM10 concentration at Chiang Rai's station from January to April for each year of 2007, 2009, 2010, and 2012 by Linear regression.

3.4.2.2 Meteorological and topographical features analysis.

In this step of the study, the meteorological and topological factors were applied to analyze the smoke-and-haze problem in Chiang Rai province. The meteorological data was provided by Thailand Meteorological Department. GIS tools were used in this study step to show the relationship between of the topographical patterns of the province with the wind speed and directions, and the fire occurrence.

CHAPTER 4

RESULTS AND DISCUSSIONS

The main purpose of this chapter is to assess the impacts of burnings activities at both regional and local scales related to PM10 concentrations in the northern region of Thailand and to check the main cause of smoke and haze problem in case study of Chiang Rai Province . In this chapter, we start with both hotspots and PM10 situations separately, following by their relationships at various spatial-temporal scales and daily backward trajectory in March for the case of Chiang Rai Province.

4.1 Regional Level

4.1.1 Trend Analysis

4.1.1.1 PM10 Situation

As the monthly PM10 concentrations data are available mainly for Thailand, these data were downloaded from Thailand's Pollution Control Department for this study. The monthly PM10 data were gathered for the years from 2007 to 2012 at all 11 stations in Northern Thailand (2 stations in Chiang Mai and Chiang Rai Provinces, and 1 station from other provinces including Phrae, Nan, Lampun, Lampang, Phayao, and Mae Hong Son), as shown in Figure 4.1. Note that the two years of 2008 and 2012 experienced frequent rainfalls in the dry season, so these years are excluded from the analysis.

The seasonal characteristics of PM10 in Northern Thailand are seen clearly: the monthly PM10 value remains very low and fairly unchanged (around 30 $\mu g/m^3$) in the rainy season (typically from May to December) in these years. However, the value sharply increases in the burning season (from January to April) to an average value of 93 $\mu g/m^3$, and reaching a peak of about 141 $\mu g/m^3$ in March, which is much more than the standard PM10 level of 120 μg/m^{3}which was defined for Thailand. The spatial variations of mean PM10 concentrations and their standard deviation (SD) are illustrated in Table 4.1. It was found that concentrations of PM10 collected in the burning season (January-April) were significantly higher than non-burning season, while the lower concentration was found during non-burning season (May-December). Average PM10 concentrations at each station were found to be very similar.

Increasing in PM10 in the burning season is about 3 times higher than in the non-burning season in Northern Thailand. The highest PM10 among these stations are seen at three stations of Mae Sai (Chang Rai2), Mae Hong Son, Chiang Rai (Chiang Rai1), which all share borders with Myanmar and Laos, as indicated in Figure 4.1. In addition, the sharp increase is seen from February to March at these stations only, while the other stations tend to indicate an opposite trend (as shown in Figure 4.2). More details are provided in Appendix A. These observations are more comprehensive than previous studies of PM10 which focused mainly on a particular local site such as Chiang Mai.

The increase in PM10 values during the dry season can therefore be considered an abnormal situation. This situation is probably due to the effects from open burning that are part of agricultural activities and forest fire that are mostly performed during the dry season, as well as forest fires. This is in accordance with statistics from the Forest Fire Control Division, Department of National Parks Wildlife and Plant Conservation, which shows that fires commonly occurs during the dry season and peak in March of each year (the graph showing forest fires are shown in the Appendix B). In the rainy season and at the beginning of the dry season each year, PM10 values in the air was generated from other anthropogenic sources, such as traffic that does not change in very year. The statistic information about annual traffic shows on Appendix C.

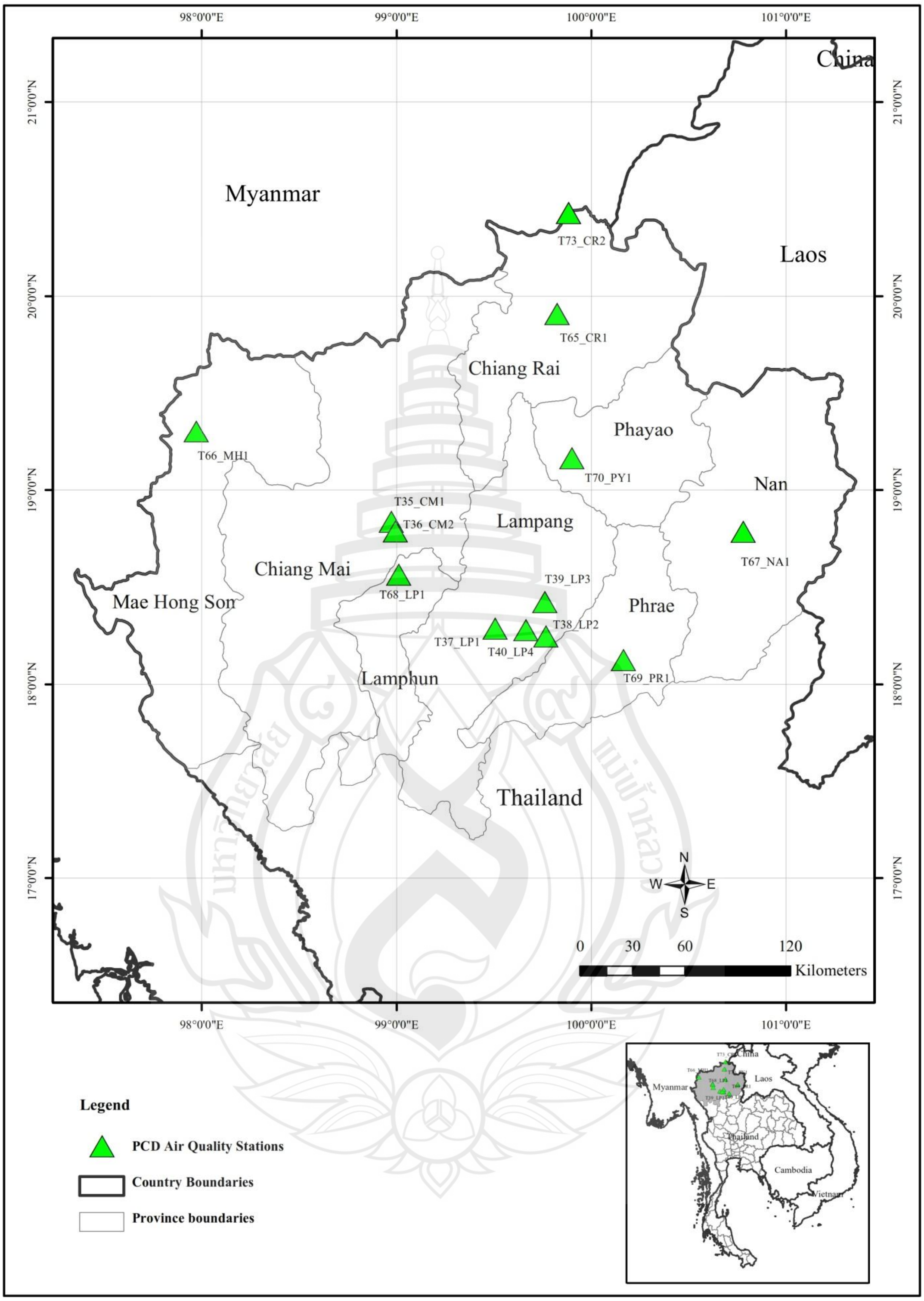


Figure 4.1 The Location of PM10 Stations in Northern Thailand

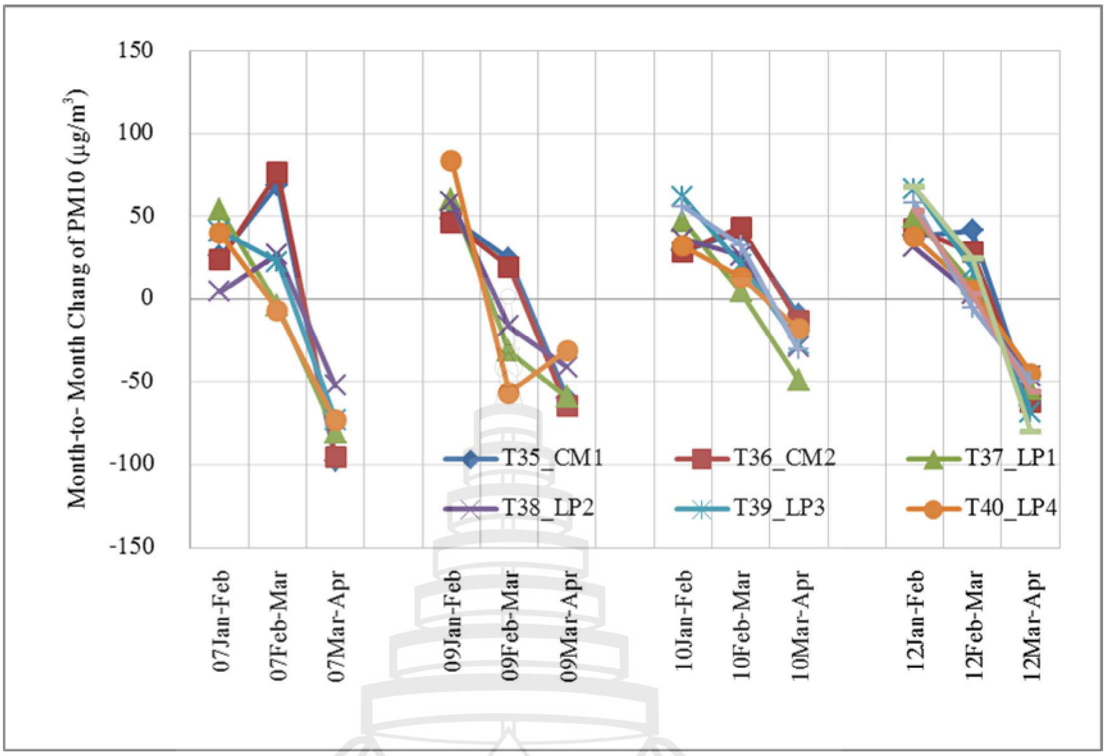
Table 4.1 PM10 Statistics in Northern Thailand, Averaged Over the Four Years (2007, 2009, 2010 and 2012)

PM10 Station	**Burning season**			**Non-burning season**	
	January to April		**March**	**May to December**	
	Average PM10 (µg/m³)	**SD**	**Average PM10 (µg/m³)**	**PM10 (µg/m³)**	**SD**
Chiang Rai2*	151.64	±80.12	262.86	-	-
Mae Hong Son***	99.86	±65.16	187.32	25.74	±8.55
Chiang ai1***	98.57	±49.50	163.15	15.88	±12.20
Nan ***	79.30	±36.015	125.22	26.60	±11.48
Chiang Mai1	80.72	±36.42	126.15	28.25	±9.07
Chiang Mai2	84.61	±36.17	129.25	34.63	±10.49
Lampang1	96.97	±34.42	122.68	31.02	±12.69
Lampang2	76.01	±25.02	99.73	28.21	±9.40
Lampang3	81.28	±36.68	119.82	26.98	±6.32
Lampang4	79.43	±30.06	96.45	26.80	±9.42
Lampun ***	96.41	±34.11	127.53	32.59	±17.14
Phrae**	94.43	±31.73	123.29	30.75	±16.34
Phayao **	93.58	±22.12	143.05	30.30	±28.85
Average	93.29	±39.81	140.50	28.14	±12.66

Note. * data available in 2012 only

** data available in 2010 and 2012

*** data available in 2009, 2010 and 2012.



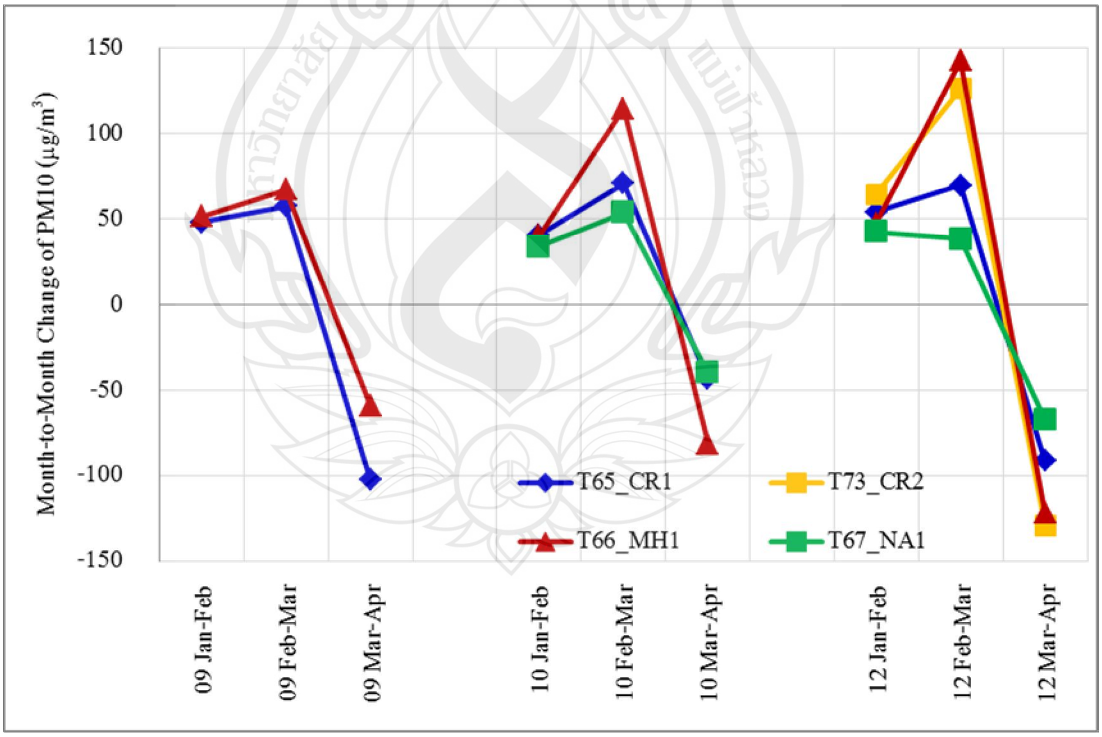


Figure 4.2 Month-to-Month Changes of PM10 in Northern Thailand in Burning Season (2007, 2009, 2010 and 2012)

4.1.1.2 Hotspots Situation

The daily number of hotspots at the regional level was downloaded from the of NASA's Earth Observatory website (NASA, n.d.a) at the Web Fire Mapper (NASA, n.d.b) ,then we have selected for fire confidence of 80% or more, and overlaid with geographic boundaries by GIS to obtain hotspot counts in each country or each zones of interest.

The hotspot counts from 2007, 2009, 2010 and 2012 (from January to April in 2012) at the regional level, including Thailand, Laos, and Myanmar, shows a very high yearly average of 63,795 hotspot, of which about 80% occurs in the burning season (from January to April) with a peak in March (70%) as shown in Figure 4.3 and more detail show in Appendix D. Such a pattern is consistent with other previous studies, but is updated for the year 2012.

The total hotspot counts in the four years (2007, 2009, 2010 and 2012) were 255,177 hotspots. The highest is seen in Myanmar (50 %), followed by Laos (36%) and Thailand (14%). An additional analysis is conducted on hotspot density and hotspot change from a month to following month in the burning season. Hotspot density (per 100 km^2) which is calculated as total hotspot counts divided by the area of interest) for the region (three countries combined together) in the burning season averaged over the three years is about 4 hotspots/100 km^2; it is highest in Laos (10) followed by Myanmar (5) and Thailand (2) For Thailand, the majority of burning occurs in the northern region (64%) with the density of 5 hotspots/100 km^2).

Within the burning season, hotspot count increased sharply from January to February and to March, then decreases in April. An average (over the four years) increasing change is about 7,189 hotspots from January to February, and more than 25,000 from February to March, followed by a decreasing change of 15,817 hotspots from March to April, as shown in Figure 4.4 . However, an average increasing change is 10 times from January to February, and 4 time from February to March, followed by a decreasing change 2 times from March to April as shown in Table 4.2

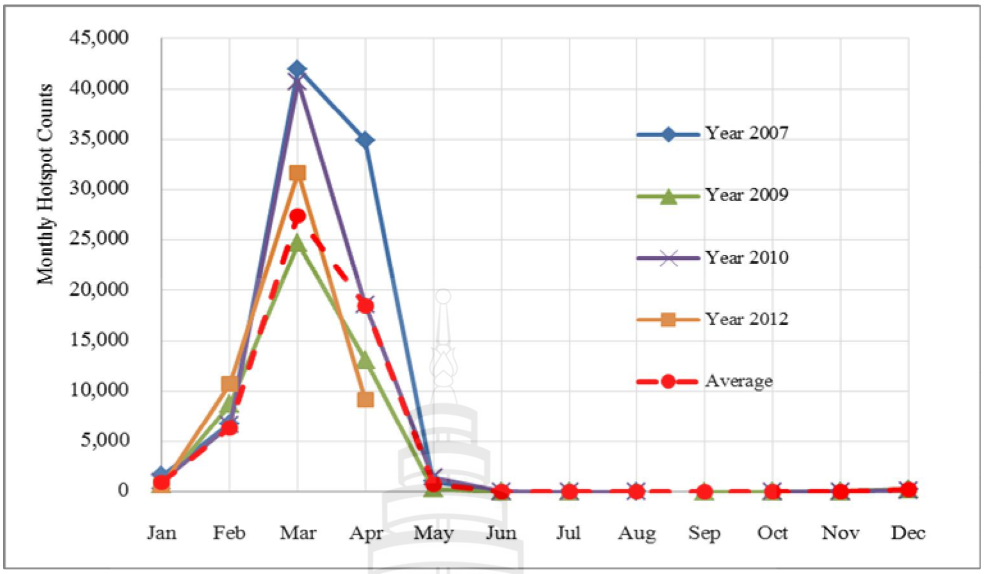


Figure 4.3 Monthly Hotspot Counts Distribution at the Regional Level (2007, 2009, 2010 and 2012)

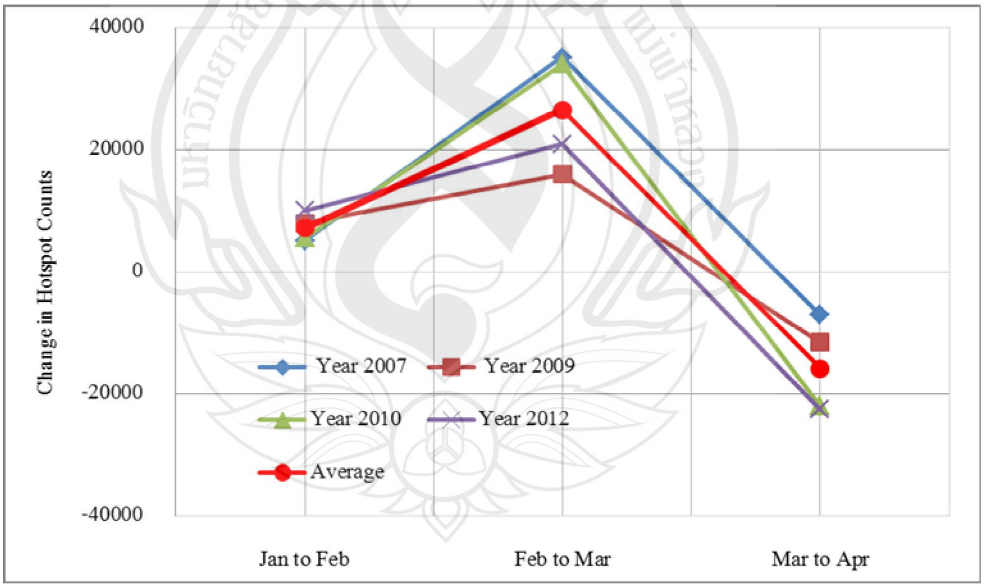


Figure 4.4 Month-to-Month Changes of Hotspot Counts at the Regional Level in the Burning Season (2007, 2009, 2010 and 2012)

Table 4.2 Month-to-Month Changes of Hotspot Counts at the Regional Level in the Burning Season (2007, 2009, 2010 and 2012)

	Average monthly of hotspot counts	**Difference of hotspot for two adjacent months**	**Ratio of hotspot between two adjacent months**
2007-Jan	52.42		
2007-Feb	233.03	180.62	4.45
2007-Mar	1353.48	1120.45	5.81
2007-Apr	1162.80	-190.68	1.16
2009-Jan	22.29		
2009-Feb	299.97	277.68	13.46
2009-Mar	796.19	496.23	2.65
2009-Apr	436.37	-359.83	1.82
2010-Jan	34.55		
2010-Feb	227.93	193.38	6.60
2010-Mar	1312.68	1084.75	5.76
2010-Apr	621.23	-691.44	2.11
2012-Jan	20.29		
2012-Feb	369.069	348.78	18.19
2012-Mar	1022.87	653.80	2.77
2012-Apr	305.36	-717.50	3.35

When considering locations of hotspots in the burning season (in 2007, 2009, 2010 and 2012), we can see clearly the 3 dense hotspots clusters as shown in Figure 4.5. The density is highest in in the Eastern Myanmar cluster (14 hotspots/100 km^2), followed by the Western Laos cluster (13 hotspots/100 km^2), and Northern Thailand cluster (7 hotspots/100 km^2). These densities in clusters are obviously higher than the density for each own country respectively, which the highest is in Myanmar (5) followed by Thailand (2) and Laos (10), as shown in Table 4.3

Table 4.3 The Regional and Cluster Hotspot Statistics

	Myanmar	Laos	Thailand
Regional Level			
Yearly Average Hotspot Counts	31274	22456	9170
Area	676,578	236,880	513,115
Density (hotspot/100 km^2/ year)	4.6	9.5	1.8
Cluster			
Yearly Average Hotspot Counts	8288	8924	2715
Area	81214	61409	36694
Density(hotspot/100 km^2/ year)	10.27	14.35	7.38

When consider the hotspot locations for each country, the locations with the highest hotspot counts and hotspot density per 100 km^2 in each nation remained mostly the same each year, as provided in Figure 4.6-4.8 An example is that the high hotspot counts in Myanmar is often found at Ching Karen and Shan State and the high density always found in the area as indicated in Figure 4.6, the high hotspot counts in Laos is often found at Vientiane, Oudomxai and Louang Prabang Province as showed in Figure 4.7, and the high hotspot counts in Thailand is often found at Nan, Mae Hong Son and Tak Province as province in Figure 4.8.

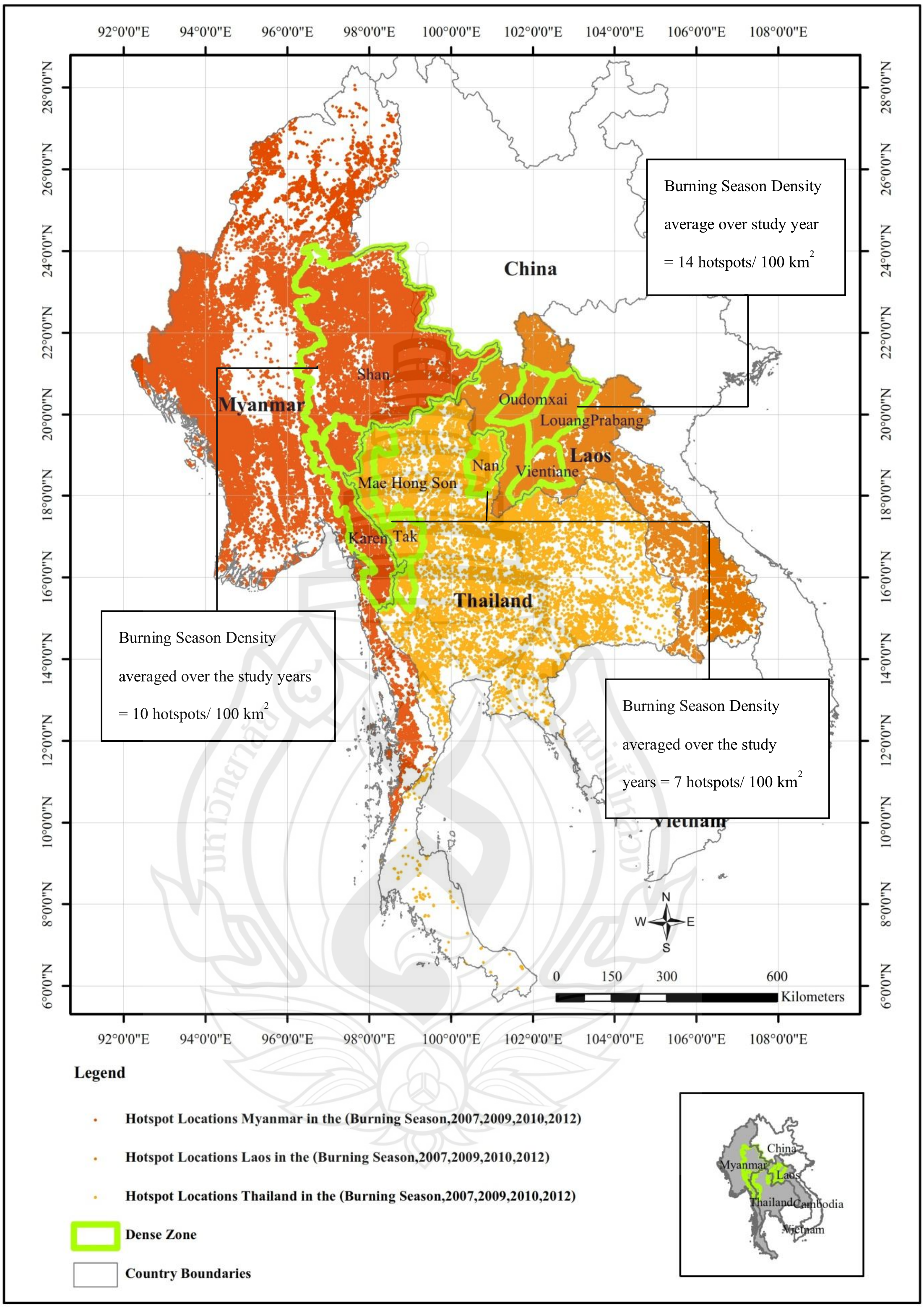


Figure 4.5 The Hotspot Locations and Density for Three Countries (Burning Season, 2009, 2010 and 2012)

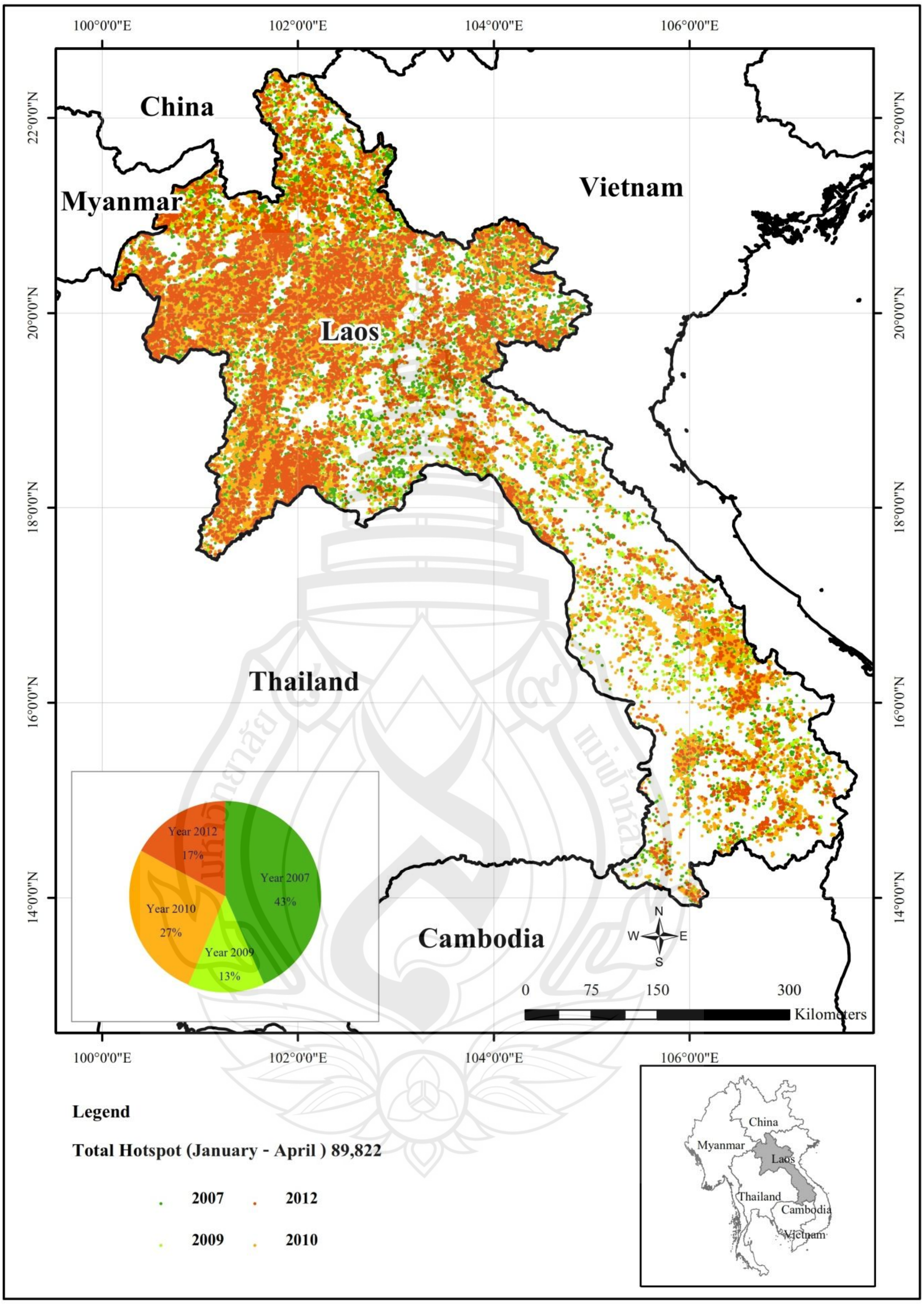


Figure 4.6 Hotspot Locations in Laos in the Burning Season (2009, 2010 and 2012)

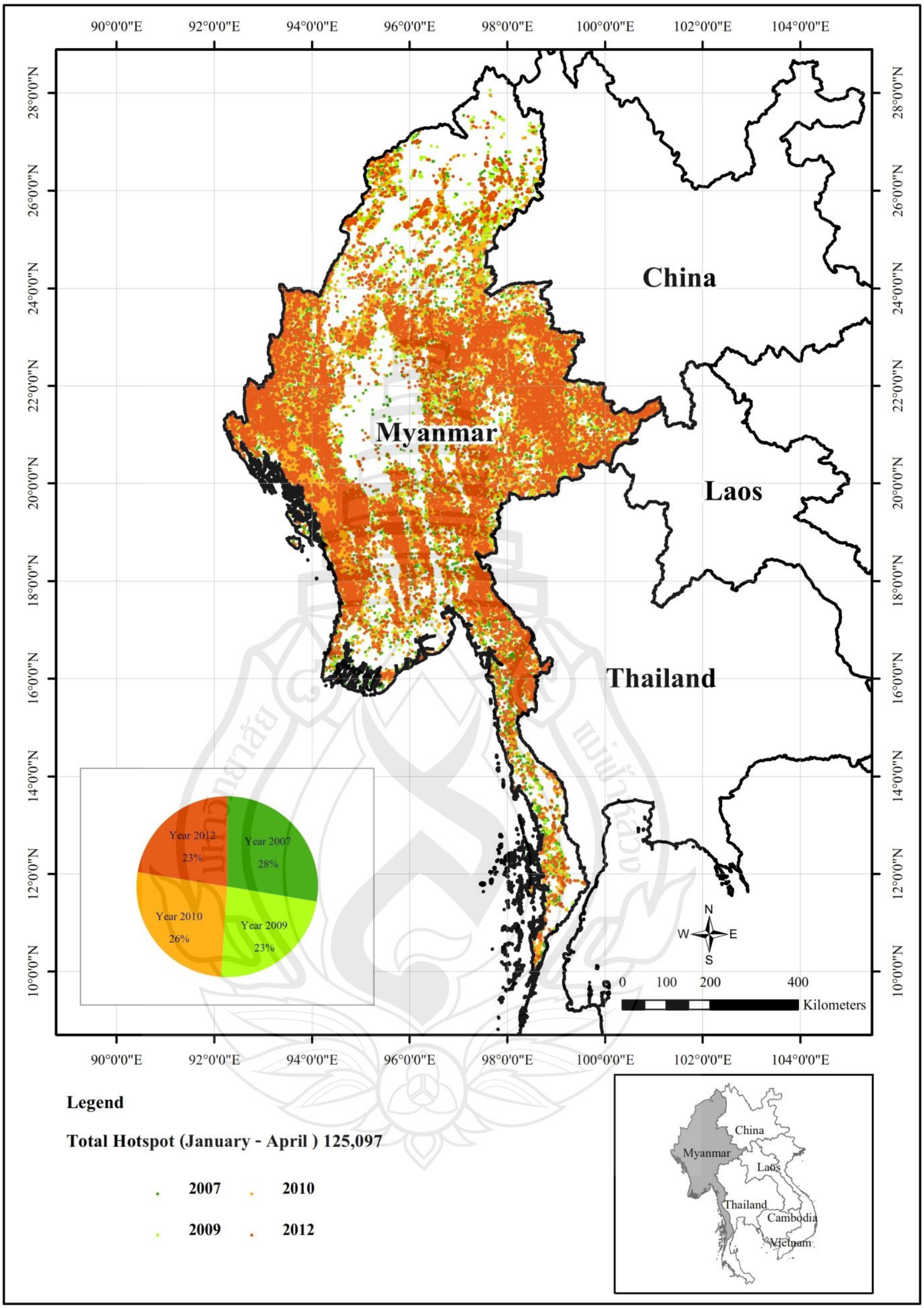


Figure 4.7 Hotspot Locations in Myanmar in the Burning Season (2009, 2010 and 2012)

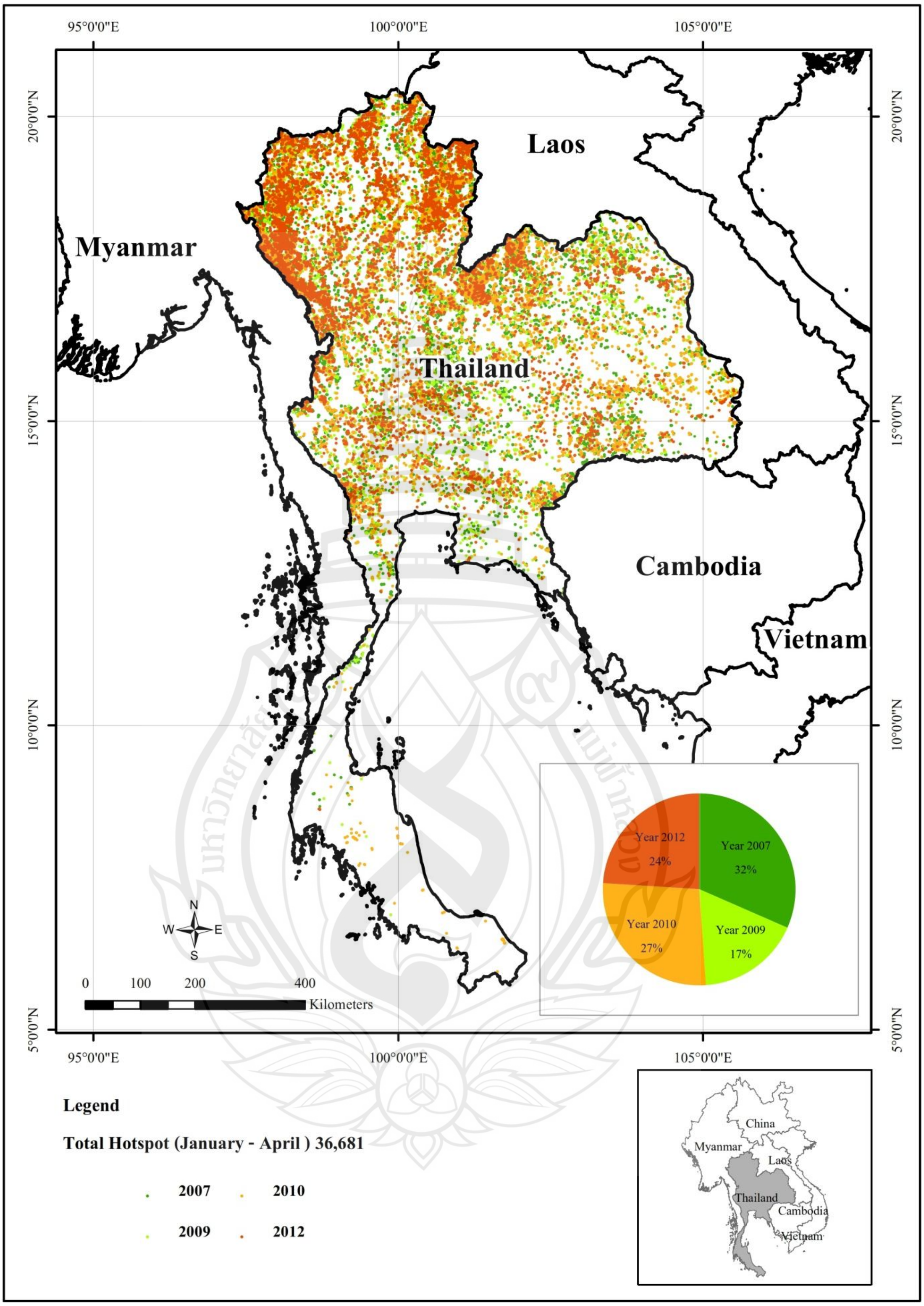


Figure 4.8 Hotspot Locations in Thailand in the Burning Season (2009, 2010 and 2012)

In summary, we can conclude that, the regional hotspot counts has high yearly average of 63,795 hotspot, of which about 80% occurs in the burning season (from January to April) with a peak in March (70%). The highest count is seen in Myanmar (50 %), followed by Laos (36%) and Thailand (14%). The locations with the highest hotspot number in each nation remained mostly the same each year. The regional hotspot density (per 100 km^2) in the burning season averaged over the three years is about 4 hotspots/100 km^2; it is highest in Laos (10) followed by Myanmar (5) and Thailand (2). For Thailand, the majority of burning occurs in the northern region (64%) with the density of 5 hotspots/100 km^2. The locations of hotspots in the burning season (in 2007, 2009, 2010 and 2012) show clearly the 3 dense hotspots clusters in which the density is highest in the Eastern Myanmar cluster (10 hotspots/100 km^2), followed by the Western Laos cluster (14 hotspots/100 km^2), and Northern Thailand cluster (7 hotspots/100 km^2). These densities in clusters are obviously higher than the density for each own country respectively, which is highest Myanmar (5) followed by Thailand (2) and Laos (10). Within the burning season, hotspot count increased sharply from January to February and to March, then decreases in April. An average (over the three years) increasing change is 10 times from January to February, and 4 time from February to March, followed by a decreasing change of 2 times from March to April.

4.1.2 Correlation Analysis

The purpose of this step is to check the hypothesis that burning in the regional level influenced increasing to the PM10 concentration in Northern Thailand, the distribution and trend of average monthly PM10 concentration for each station in northern Thailand by month and average monthly hotspot counts in three countries were studied.

The result on the overall monthly patterns of PM10 concentrations at all the stations fit well with hotspot counts at the regional level in the years of 2007, 2009, 2010 and 2012, as shown in Figure 4.9. The burning season is shown to have sharp increase in both PM10 and hotspot counts with a common peak in March.

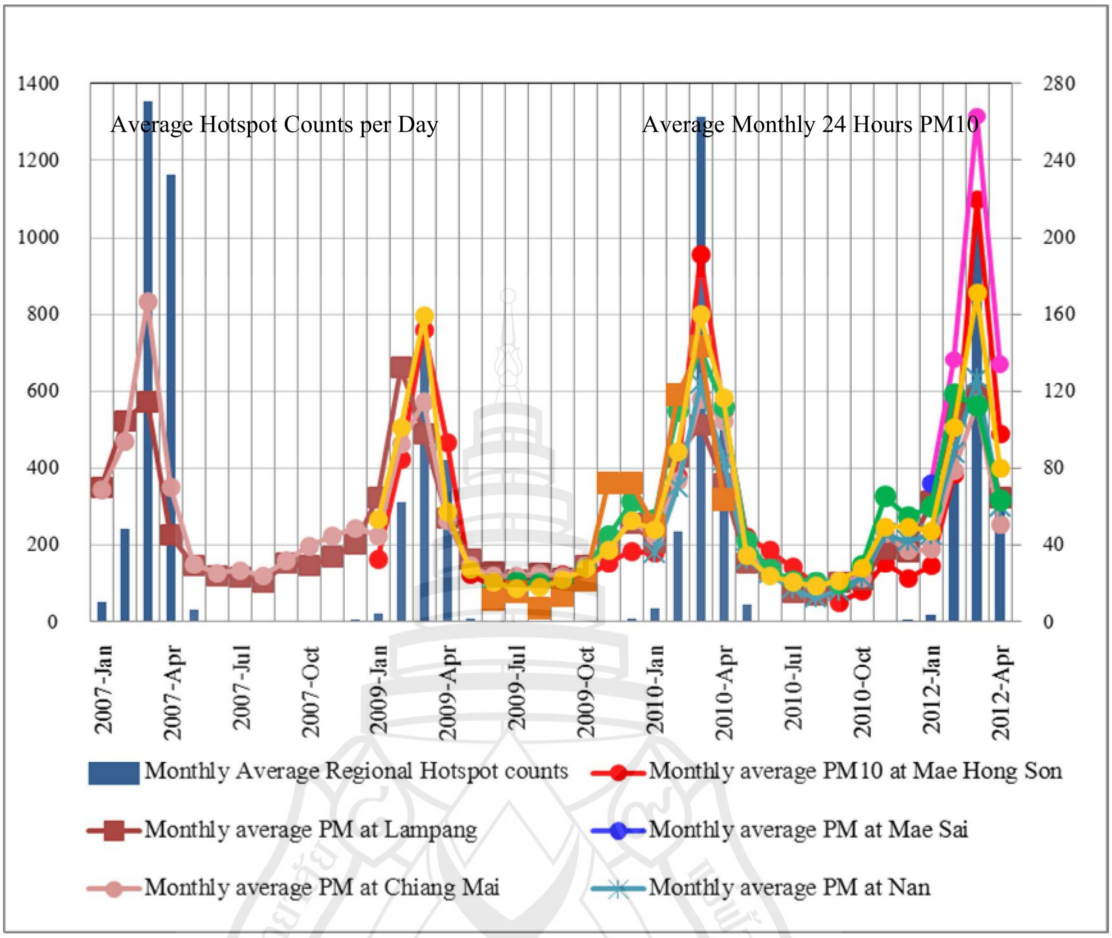


Figure 4.9 The Overall Monthly Patterns of the Regional Hotspot Counts and PM10 Concentrations at All the Stations (2007, 2009 2010 and 2012)

So it can initially be concluded that both variables are related. Further analysis was conducted for the relationship between regional hotspots and PM10 concentration at each station for the period from January to April to confirm this related.

Analysis of the relationship between hotspots in the regional level and PM10 concentration at each station found that the majority of burning is significantly related to changes in PM10, except for the case of Lampang, Phayao, and Phrae Stations where there was very weak correlation coefficient ($0.19 \leq R^2 \leq 0.56$) between PM10 and regional burning. This is because that the PM10 measuring station in Lampang Province is located at the center of Lampang City. It is a residential area surrounded by government buildings, schools and temples with quite high traffic density, and is a densely populated commercial area. This area was reported to possess particulate concentrations exceeding standards throughout the year. Therefore, changes in PM10 in Lampang Province is influenced by traffic, construction, mining activity at Mae Mo Power Plant, and local burning more than burning at the regional level. This is consistent with research by Patipat Wongruang et al. (2012), which studied the relationship between changes in daily PM10 at Lampang and Chiang Mai Station and the number of hotspots at Lampang and Chiang Mai Provinces. It was found that the R^2 value at Lampang Station ranged from 0.33-4.45. The PM10 problem at Lampang Station may be due to other sources, such as mining activity or dust problems more than local burning (Somphon Chantara, 2012). For Phayao and Phrae Province, it was found that the provinces have a moderate coefficient of determinants ($R^2 \geq 0.5$). But there is no statistically significant finding for these two provinces. However, it was found that stations along border areas have very high coefficient of determinants ($R^2 \geq 0.9$). These include Mae Sai, Mae Hong Son, Chiang Rai and Nan Stations. The coefficients of determinant for these stations are as follows: 0.99, 0.92, 0.83 and 0.89, respectively. According to the significant test, this mark is significant for 99% and 95% of confidence level.

Therefore, from statistical analysis, there is a correlation between average monthly PM10 concentration and average monthly hotspots counts for all 3 nations, and the correlation is very significant. The coefficient of determinant is also very high. It means that the average monthly hotspot counts for each case accounts for 83-99% of the variation in average monthly PM10 concentration. The details of this relationship are shown in Table 4.4 below. The scatter plot for each relationship as provide in Figure 4.10 and 4.11

Table 4.4 The Statistical Analysis of the Relationship During Burning Season between Average Monthly Hotspots and PM10 at the Regional Level (For all Data Available)

PM10 Station	**R^2**	**Standard Error**	**Significant**	**Number of Data**	**Regression Equation: $y=\beta_0+\beta_1x$**	
					β_0	**β**
Very High correlation, $R^2 \geq 0.79$ (group I)						
Mae Sai	0.99	6.15	<0.05	4	69.57	0.20
Mae Hong Son	0.92	18.50	<0.01	12	35.16	0.14
Nan	0.89	11.57	<0.01	8	45.91	0.07
Chiang Rai	0.83	19.49	<0.01	12	52.71	0.10
Medium -Low correlation, $0.15 \leq R^2 \leq 0.78$ (group II)						
Lampang1	0.15	30.53	>0.05	16	84.11	0.03
Lampang2	0.37	21.62	>0.05	16	59.50	0.04
Lampang3	0.61	23.83	>0.05	12	52.67	0.06
Lampang4	0.14	27.14	>0.05	16	64.75	0.03
Chiang Mai1	0.78	15.00	<0.01	16	45.84	0.07
Chiang Mai2	0.68	18.44	<0.01	16	49.19	0.06
Phayao	0.70	25.18	>0.05	4	61.62	0.07
Phrae	0.58	25.26	>0.05	4	69.76	0.06
Lampun	0.64	21.21	<0.05	8	68.65	0.06

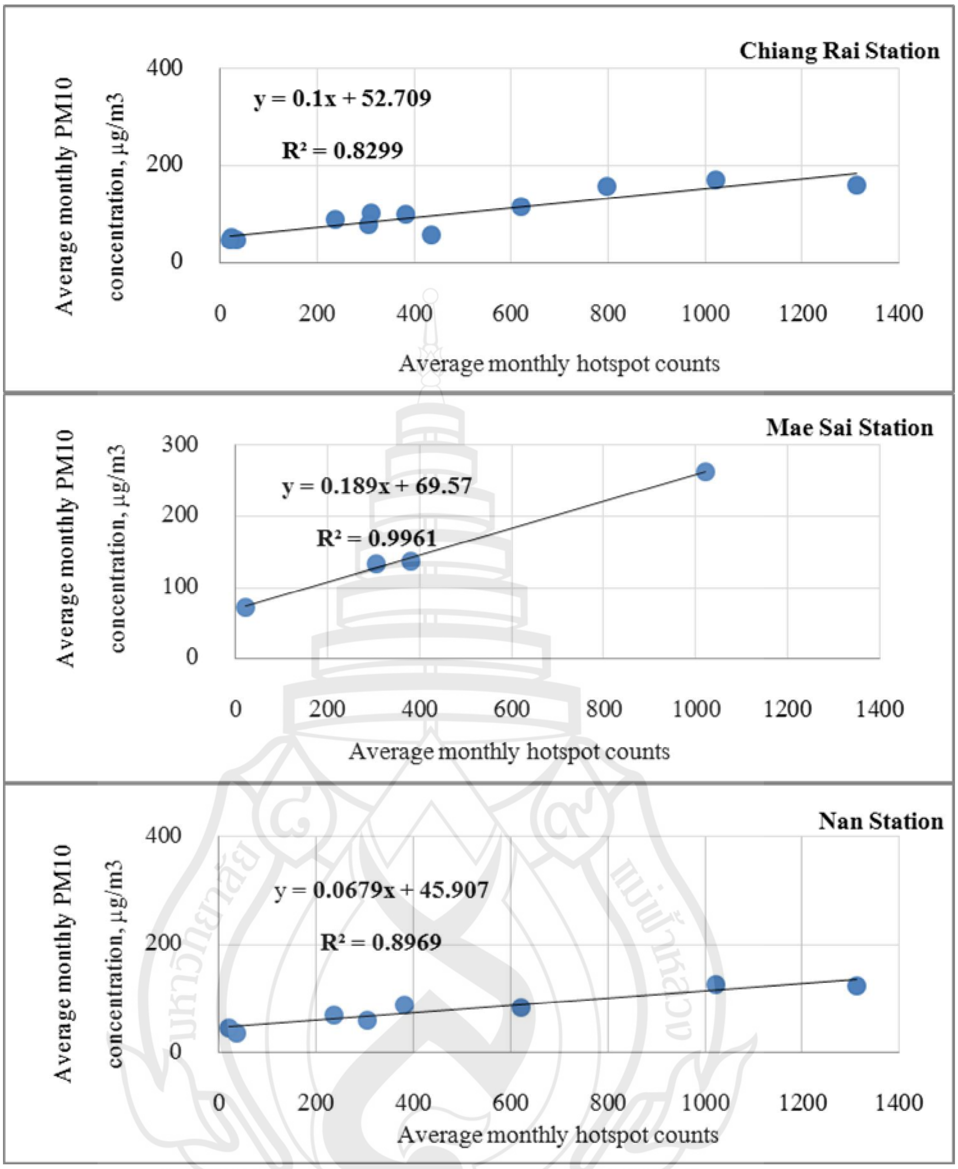


Figure 4.10 The Scatter Plot between Hotspots and High PM10 Stations (Burning Season 2009, 2010 and 2012, Note Mai Sai Station Only Year

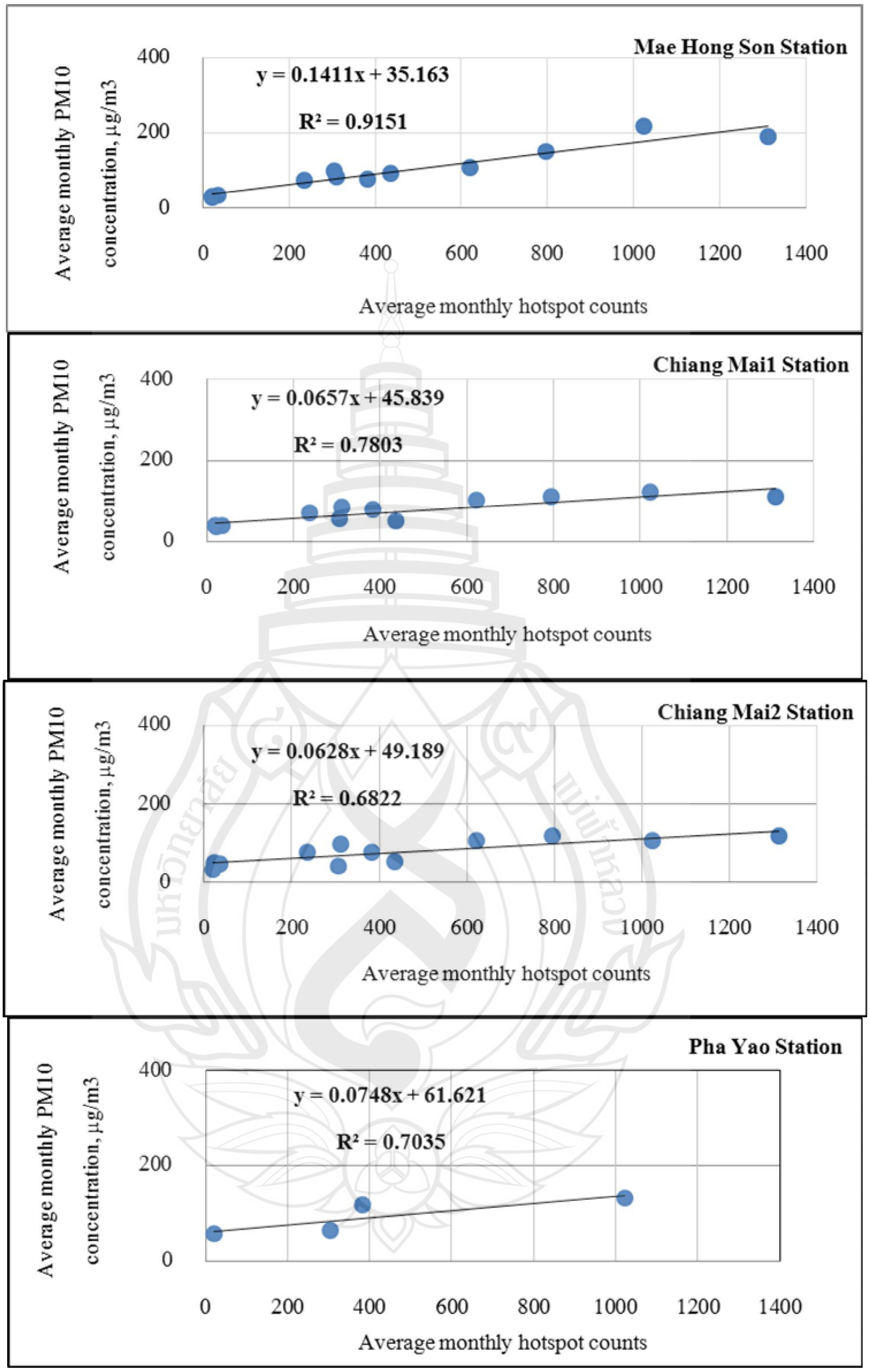


Figure 4.11 The Scatter Plot between Hotspots and PM10 Stations (Burning Season 2009, 2010 and 2012)

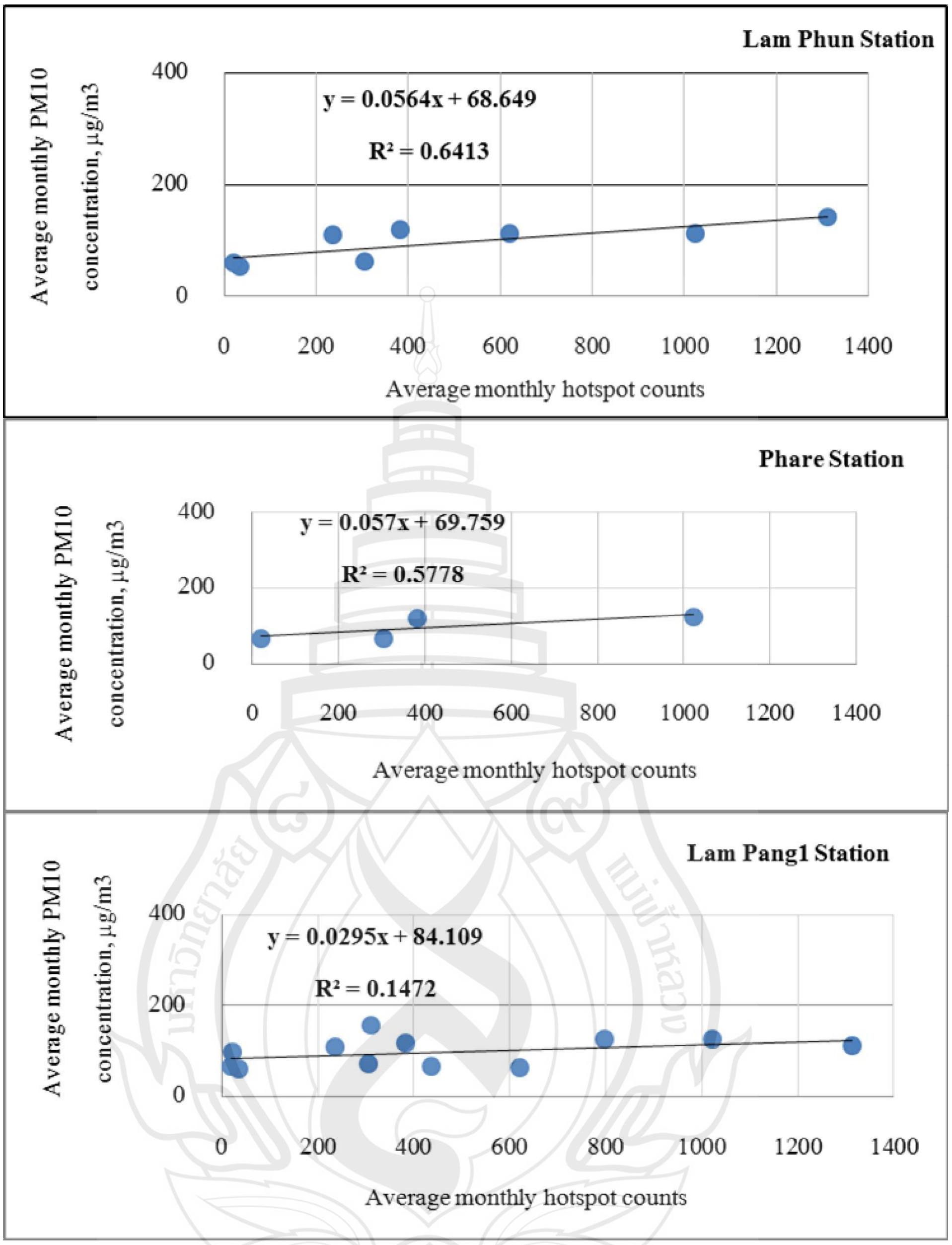


Figure 4.11 (Continued)

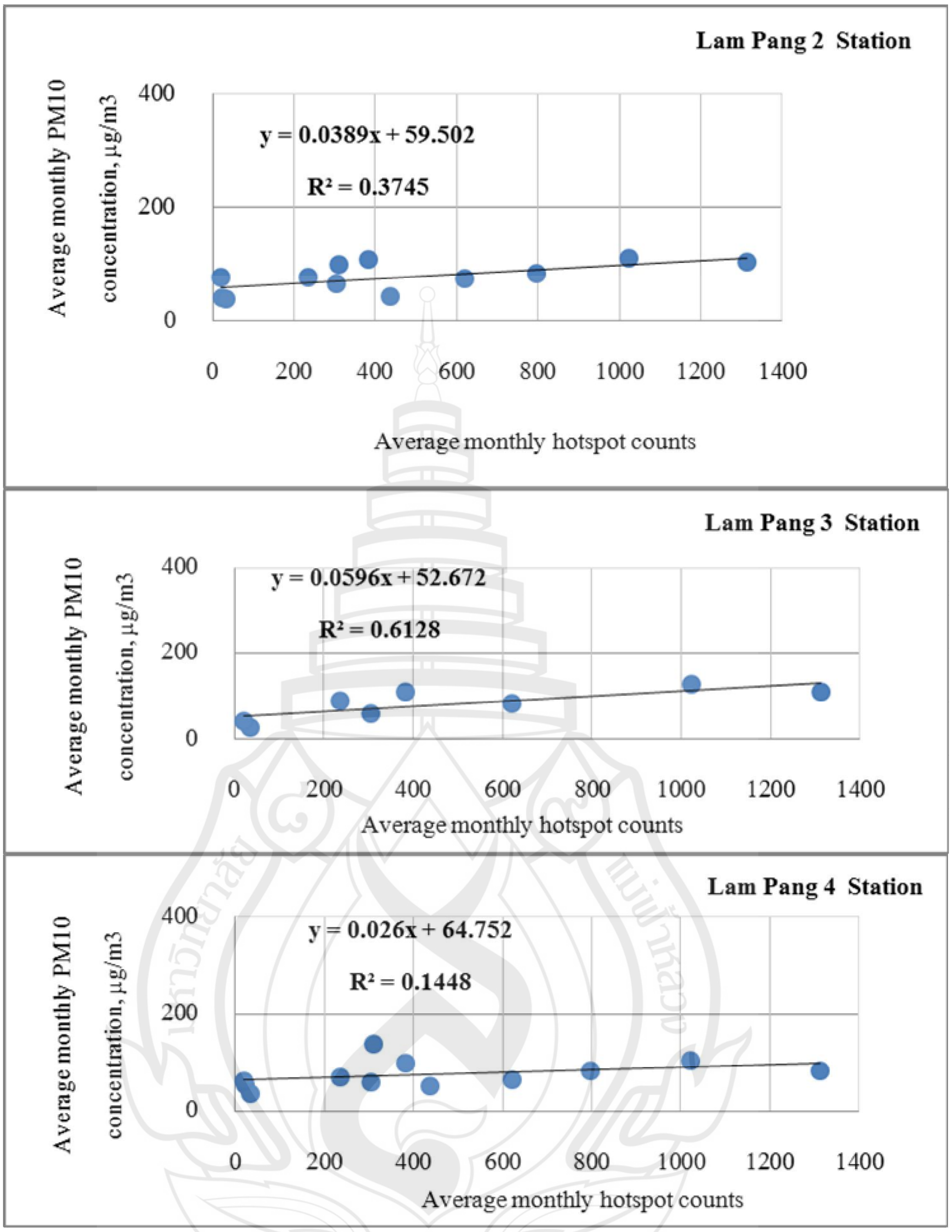


Figure 4.11 (Continued)

From the Table 4.4 and Figure 4.10 and 4.11, based on the considered PM10 monitoring sites, the most affected areas by the regional burning are seen in the border areas (Mae Sai, Mae Hong Son, Chiang Rai and Nan Stations). Further analysis on the month-to-month PM10 changes for all stations in Northern Thailand, the result is shown in three stations (Mae Sai, Mae Hong Son and Chiang Rai) and the information on month-to-month change of hotspots at the regional level can be confirmed for this relationship. The result showed in the same change direction between the month-to-month change in hotspots at the regional level and the month-to-month PM10 changes in three stations as indicated in Figure 4.12. For other stations the relationship was indicated in Figure 4.13. Moreover the correlations between these two changes are quite high (R^2>0.8), as indicated in Figure 4.14. The highest correlation is at Mae Hong Son, following by Chiang Rai stations. The detail of the month-to-month PM10 changes at Mae Hong Son and Chiang Rai Stations are illustrated in Table 4.5

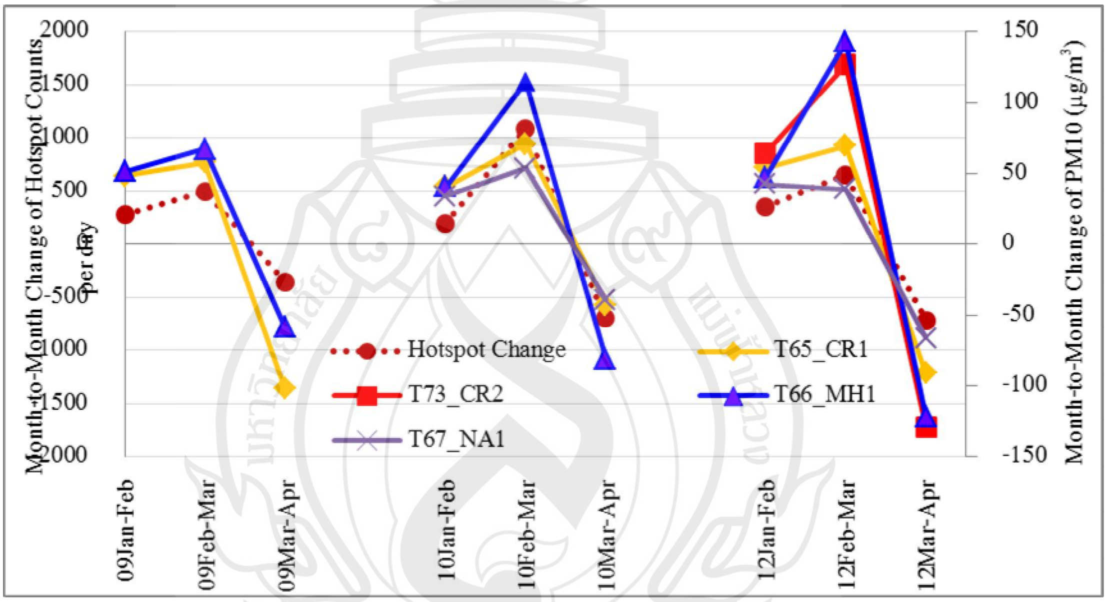


Figure 4.12 The Month-to-Month Rate of Change in Hotspots and PM10 from 4 Stations (Mae Hong Son, Chiang Rai, Mae Sai and Nan Station) from January to April 2009, 2010, 2012

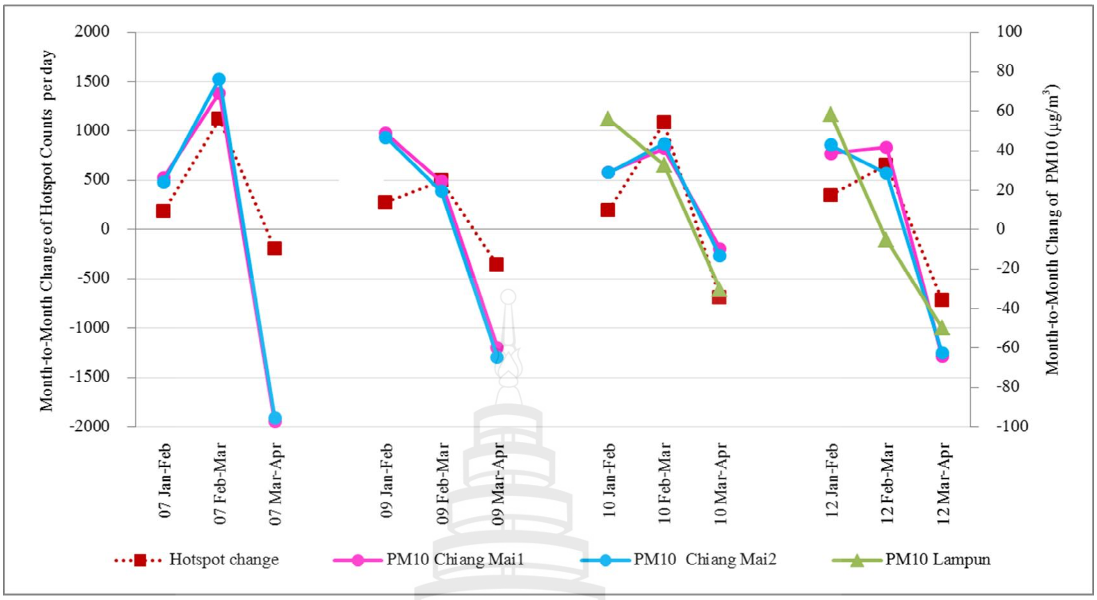


Figure 4.13 The Monthly Rate of Change in Hotspots and PM10 from 3 Stations (Chiang Mai and Lampun) from January to April 2007, 2009, 2010 and 2012

Table 4.5 Month-to-Month Changes of PM10 and Regional Hotspot Counts, Season Burning (2009, 2010 and 2012)

		PM10 change		**PM10 Change/ Hotspot Change**	
	Hotspot change	**Mae Hong Son**	**Chiang Rai**	**Mae Hong Son**	**Chiang Rai**
2009 J-F	277.68	51.47	48.20	0.19	0.17
2009 F-M	496.23	67.34	57.56	0.14	0.16
2009 M-A	359.83	-58.5	101.74	0.16	0.28
2010 J-F	193.38	40.42	40.58	0.21	0.21
2010 F-M	1084.75	114.55	70.80	0.11	0.07
2010 M-A	-691.44	-81.00	-43.15	0.12	0.06
2012 J-F	348.78	47.57	54.05	0.14	0.15

Table 4.5 (Continued)

		PM10 change		PM10 Change/ Hotspot Change	
	Hotspot change	**Mae Hong Son**	**Chiang Rai**	**Mae Hong Son**	**Chiang Rai**
2012 F-M	653.80	142.70	69.65	0.22	0.11
2012 M-A	717.50	-121.40	-91.23	0.17	0.13
	Average each station			**0.16**	**0.15**

Average two stations = 0.16

Form the Table 4.5, there are also new findings that the contribution from one unit of hotspot change to PM10 concentration change is almost the same for each month in every year. These numbers are from 0.06 to 0.28. Some deviations may come from other deviations to PM10 such as amount of traffic that varies from year to year. It may deviate from one month to another. The yearly averages are quite the same (around 0.16) for every year. That means that the rate of increase of hotspot related to PM10 concentration is almost the same.

Therefore, it can be concluded that increased regional burning causes PM10 values to increase as well, especially in the border areas, Mae Sai, Mae Hong Son and Chiang Rai Stations. Moreover the correlation analysis between month-to-month change of average daily regional hotspot counts and month-to-month change of PM10 concentration (in the burning season, 2009, 2010 and 2012), showed very strong coefficients of determinant for two changes (R^2>0.7). The highest correlation is at Mae Hong Son followed by Chiang Rai stations. It will be used as evidence to confirm the aforementioned relationship, as provided in Figure 4.14

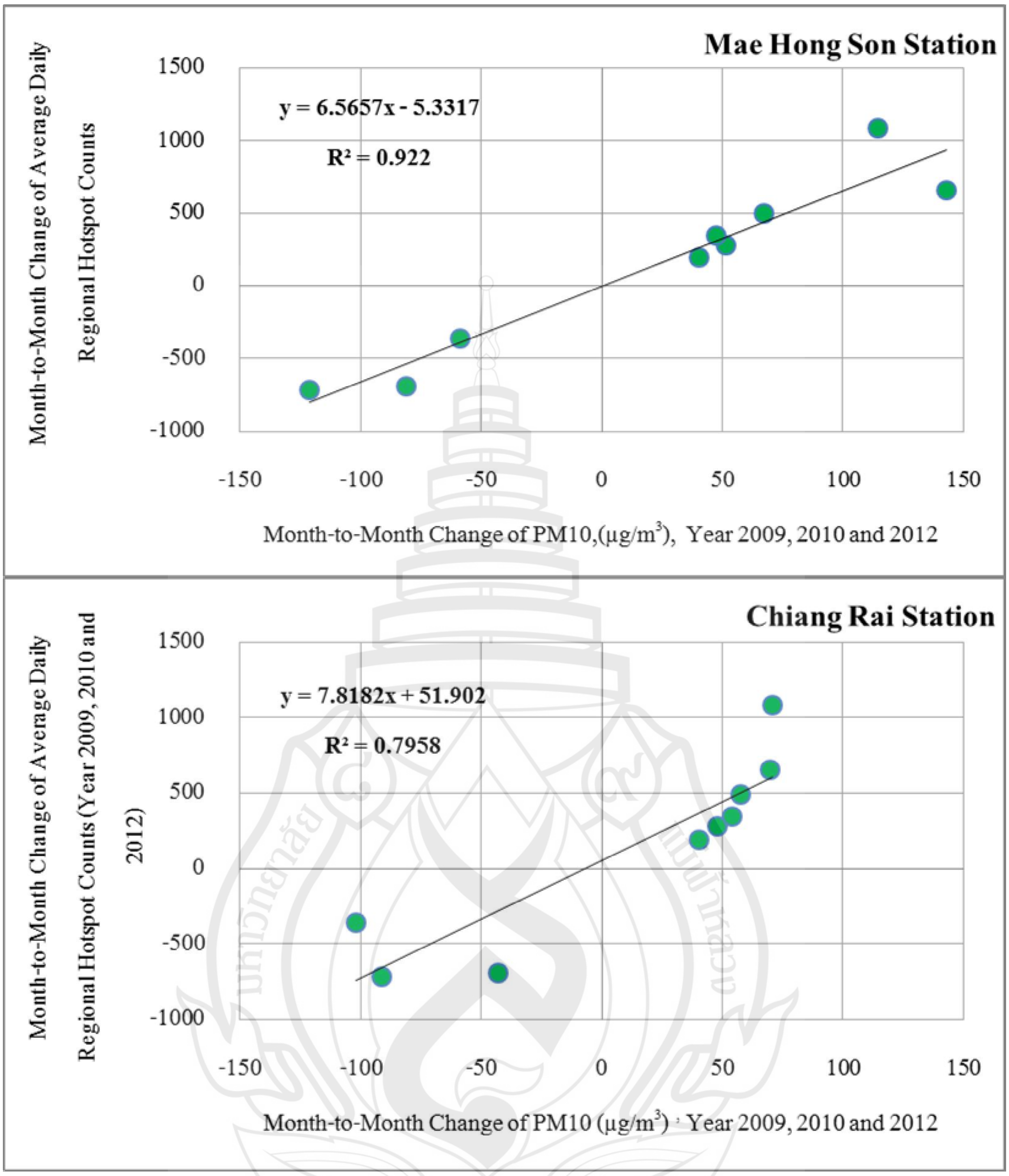


Figure 4.14 The Correlation between Regional Monthly Hotspot Change and Monthly PM Change at High PM10 Stations (Burning Season)

In summary, the increased regional burning affects changes in PM10, especially during the burning season (from January to April) of each year. This is in consistency with the hypothesis of this study. However this trend does not occur at all stations. Burning phenomenon contributes increasing of PM10 in each area and each nation. Stations that are far away from border areas are the least affected by regional burning, and therefore experienced less increase in PM10. At the same time, the most affected areas are Mae Hong Son followed by Chiang Rai. These areas share borders with Myanmar and Laos. The sharp increase in PM10 from one month to another month is contributed from the corresponding sharp increase in hotspot counts of the regional level, and that the contribution from one unit of hotspot change to PM10 concentration change is about 0.16.

As a result of the topic 4.2, open burnings in three countries significantly impacted on the increasing of PM10 at the monitoring stations located in border areas, Chiang Rai, Mae Hong Son, and Nan. In this research, Chiang Rai was chosen as a case study in order to test if smoke- haze problem was mainly caused by open burning in the local area. Additionally, the impacts from open burning that divided into two levels, Regional Impacts and Local Impacts were focused.

4.2 Local Level in Case Chiang Rai Province

4.2.1 Regional Burning Impacts

From the Section 4.1, it could be concluded that open burning performed in three countries significantly impacted on the increasing of PM10 at Chiang Rai monitoring station. However, there was still no information on the range from burning location that affected the increasing of PM10 at Chiang Rai monitoring station the most. This step will involve a study of spatial data distribution of hotspots and a study of the occurrence of hotspots during the burning season each year by using GIS analysis of hotspot counts at 10 km intervals from Chiang Rai station. The testing procedure was run by varying the buffer distance by 10 km at a time in the burning season in 2009, 2010 and 2012. Moreover, the researcher also studied about Long Range Transport which might affect the increasing of PM10 at Chiang Rai station. The 24-hour back-trajectories and one trajectory of each 6 hours back in time at an altitude of 500 m Above Ground Level (AGL) was calculated by using HYSPLIT model. The results of these studies were described in the following sections.

4.2.1.1 The relationship between the number of Regional hotspots and PM10 level at Chiang Rai station.

From the study, at the radius of every 10 km interval from monitoring station, it was found that coefficient of determination (R^2) started to noticeably rise up ($R^2 \geq 0.85$) at the radius of 50 km. This implied that the hotspots occurred in such range could account for 85% of variation of surface PM10 concentrations which shown in the grey area of Figure 4.15 Plus, coefficient of determination (R^2) at the radius of every 10 km interval from Chiang Rai station is displayed in Table 4.6

As a consequence, it could be said that the most effective area was at the radius of 50 km from PM10 Chiang Rai station, which could be called as Short Range Impact. When considering the number of hotspots in this range, as shown in grey area, there were 781 hotspots. From this total amount, the hotspots were found in Thailand the most (96%) followed by Myanmar (3.7%) and Laos (0.3%). In the Table 4.6, it was noticeable that the coefficient of determination was quite high ($R^2 \geq 0.8$) started at the radius of 40 km from Chiang Rai station. Moreover, at this range, hotspots were found in Thailand only. Thus, if focusing only on hotspots occurrence or open burning in this most effective area, there was a high possibility that smoke- haze problem in Chiang Rai was mainly caused by open burning in Thailand or Chiang Rai itself.

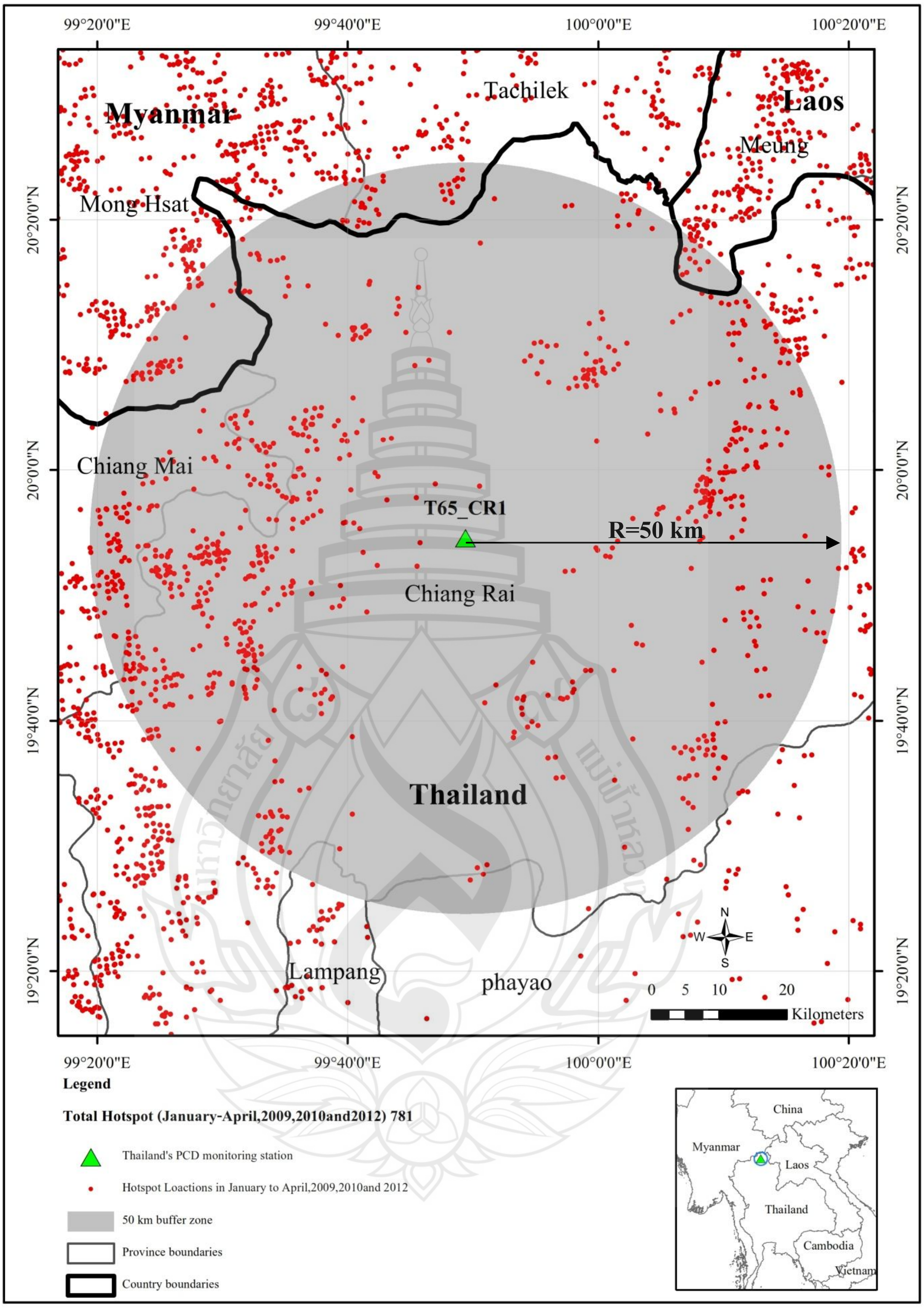


Figure 4.15 Hotspot in the 50 km Buffer Zone from Chiang Rai Station in Burning Season (year 2009, 2010 and 2012)

Table 4.6 The Relationship between Hotspot Counts at Chiang Rai in Season Burning, 2009, 2010 and 2012

Distance form station (km.)	R	R^2	Std. Error.	Sig	Equation y=y0 + a*x		Hotspot			
					a	b	Thailand	Myanmar	Laos	Total
10	0.51	0.26	± 40.66	0.091	84.05	1030.58	5	0	0	5
20	0.74	0.55	± 31.58	0.006	68.14	423.52	26	0	0	26
30	0.86	0.75	± 23.58	0.000	61.81	68.50	194	0	0	194
40	0.91	0.84	± 18.91	0.000	58.63	30.51	475	0	0	475
50	0.92	0.85	± 18.18	0.000	56.89	19.36	749	29	3	781
60	0.94	0.89	± 15.15	0.000	55.05	11.74	1097	209	40	1346
70	0.95	0.91	± 13.51	0.000	52.45	8.67	1408	415	109	1932
80	0.96	0.92	± 13.27	0.000	51.92	5.98	1587	705	544	2836
90	0.94	0.88	± 15.78	0.000	51.95	3.99	1816	1131	1296	4243
100	0.93	0.87	± 16.91	0.000	50.52	3.05	2005	1763	1955	5723

4.2.1.2 Daily backward trajectories in March 2009, 2010 and 2012 to Chiang Rai.

In order to assess the influence of Long range transport on the PM10 levels in March for each year, the transport of air mass to Chiang Rai station was investigated by daily back-trajectories. It was found that the main of the backward trajectories patterns were southwesterly moved pass the Southern Myanmar, Mae Hong Son and Chiang Mai where hotspots were frequently and mostly found as indicated in Figure 4.16.

In Figure 4.16, daily air mass movement or wind direction in March 2009, 2010 and 2012 were demonstrated by using HYSPLIT model. It clearly showed that movement direction of more than 70% of all air mass was Southwestern direction. In addition, most of air mass was originated in Myanmar and then moved into Thailand at Mae Hong Son and Chiang Mai before reaching Chiang Rai. The Figure 4.16 showed that the path way of air mass movement was passed into the areas which dense hotspots were found before arriving at Chiang Rai station. So, this air mass probably brought PM10 into Chiang Rai. Accordingly, there were studies done by Nuengruthai Yasanga et al. (2010) and Oanh and Ketsiri Leelasakultum (2011) who focused on air mass which moved to Chiang Mai during haze episode. They found that air mass moved into Chiang Mai was Southwestern direction and also passed the area of high hotspot numbers. Therefore, when considering open burning at upwind regions, it could be concluded that Chiang Rai was influenced by open burning from the long range regions as well. The air mass trajectory or movement could be used to explain the long range transport of PM10 emission from the burning area to Chiang Rai. Although the air mass traveled from the location where highest number of hotspots occurred, especially Myanmar, before arriving at Chiang Rai, the concentration of PM10 at Chiang Rai station would be already reduced by long distance route from the haze and smoke sources (PCD., 2010). Due to Southwestern direction air mass movement, Chiang Rai was likely influenced by open burning originated in Chiang Mai the most, following by Mae Hong Son and Myanmar respectively.

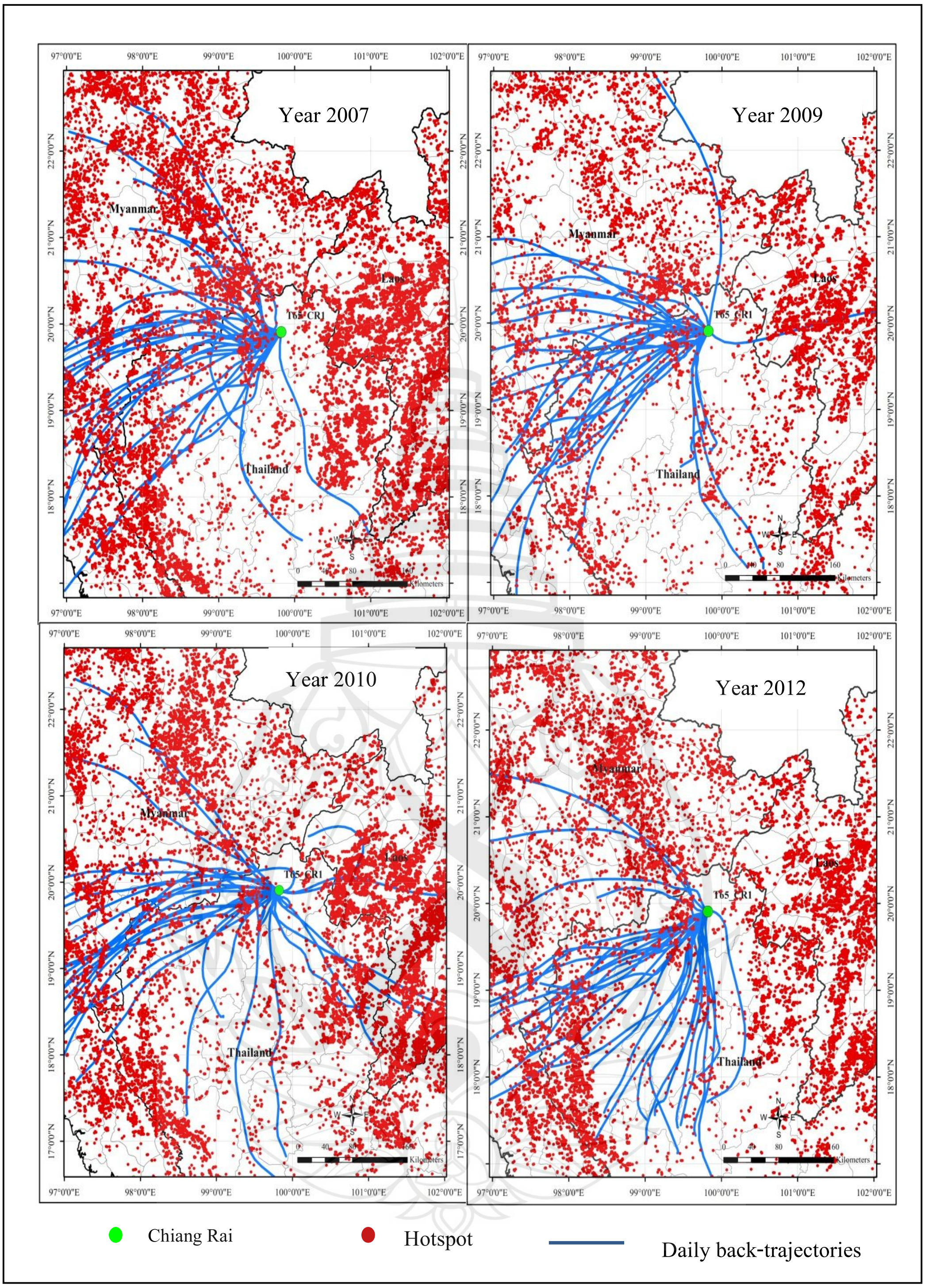


Figure 4.16 Daily Air Mass Movement or Wind Direction in March 2009, 2010 and 2012

However, although smoke-haze problem in Chiang Rai might be influenced by open burning from the long range upwind regions or long range transport of air pollution, it was possible that PM10 traveled with air mass would have less concentration when arriving at Chiang Rai. So, long range transport of air pollution probably caused only low impact on the increasing of PM10 in Chiang Rai.

In March of every year, Northern area of Thailand generally has dry weather, low wind speed and high air pressure which indicate stable weather condition. As a result, air mass cannot spread out of the area easily, but enhance the build-up of high air pollution levels (Oanh & Ketsiri Leelasakultum, 2011; Thai Meteorological Department [TMD.], 2008).

Furthermore, most of the areas in the North are high mountains and plateaus which enhanced the difficulty in dispersing smoke, caused by local burning, out of the areas. Accordingly, PM10 was being accumulated higher and higher. So, because of stable weather condition and such the topography and landscape of Chiang Rai, it was likely that the significant increasing of PM10 in March was mainly due to open burning performed within the province itself.

In order to prove that smoke-haze problem in Chiang Rai might cause by local open burning, the researcher chose to study about PM10 situation, open burning situation, and the relationship between them in details. Climate and terrain factors were also brought in the analysis as shown in next Section.

4.2.2 Local Impacts

4.2.2.1 Trend analysis

1. PM10 situation in Chiang Rai since 2009-2012

In this step, the researcher aimed to study about the overview of PM10 situation in Chiang Rai. As the Pollution Control Department had monitored and documented PM10 levels at Chiang Rai station since January 2009, all of the data until those of April 2012 were used in analysis. Consequently, the researcher found that PM10 levels in Chiang Rai tended to be increased with certain pattern in every year, except 2011. In January to October, PM10 levels were found moderately stable, not exceed 30 $\mu g/m^3$, and then slightly changed in November to January, with monthly average of 30 $\mu g/m^3$ or less. After that, PM10 levels started to be increased in February to April, with monthly average of 80-120 µg/m^3. Moreover, it was obvious that PM10 levels peaked in March every year as indicated in Figure 4.17

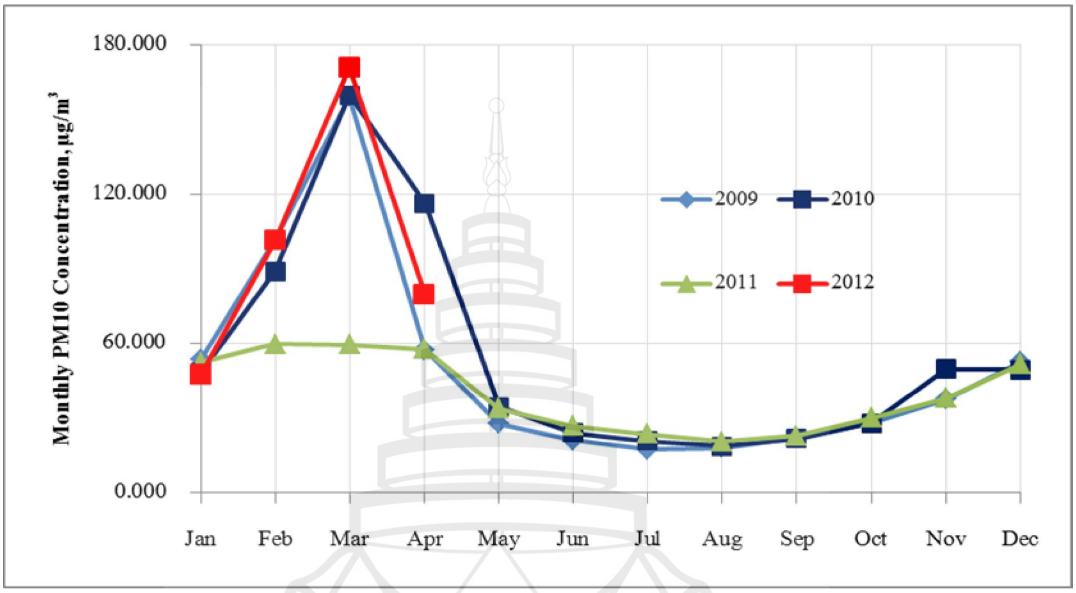


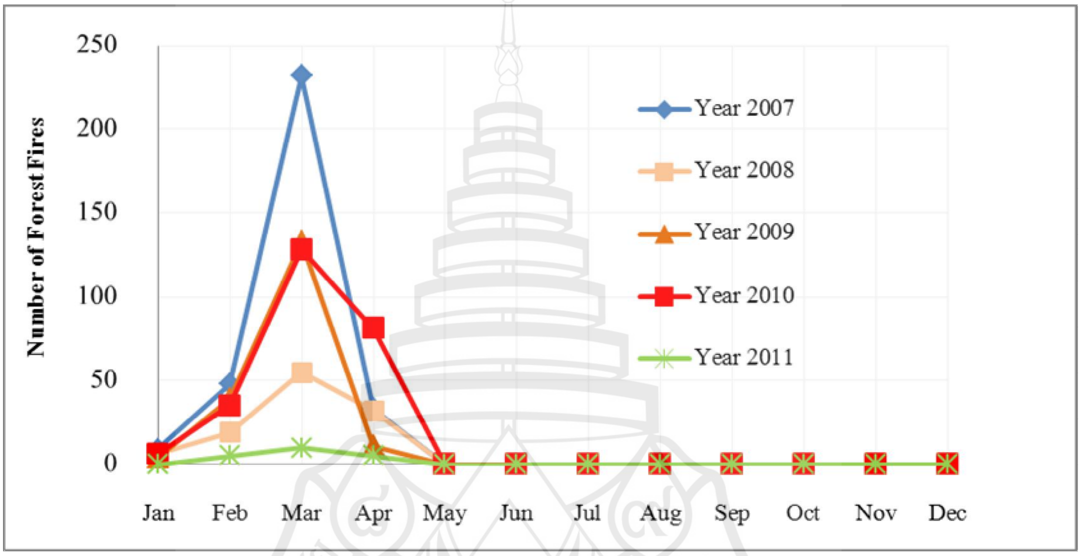
Figure 4.17 Monthly Average of PM10 by 2009-2012 (The Data of 2012 are Available for January to April)

As shown in the Figure 4.17, the increasing of PM10 in February to April or during dry season was considered as an unusual situation. It was probably due to the result of open burnings that were parts of agricultural activities and forest fires mostly performed during the dry season (Somporn Chantara, 2012). This was in consistency with statistics from the Forest Fire Control Division, Department of National Parks Wildlife and Plant Conservation, which showed that fires commonly occurred during the dry season and peaked in March of each year.

2. Forest fires and hotspots situation in Chiang Rai by 2007-2012

The data used in this step were taken from Forest Fire Statistics made by Protected Area Regional Office 15, Forest Fire Control Division, Department of National Parks Wildlife and Plant Conservation, that had only 4 forest fire stations in the concerning areas. However, it found that the fire occurrence statistics provided by Protected Area Regional Office 15 contains only for the area close to the Office

(Pornthep Thesthong, 2012). Therefore, hotspots data downloaded from NASA's website were additionally used in the study. From these data, the researcher found that forest fires and hotspots occurrence pattern were alike, which tended to be declining as indicated in Figure4.18 and Figure 4.19



Note. Protected Area Regional Office 15, Chiang Rai Province

Figure 4.18 Forest Fire Statistics During 2007-2011

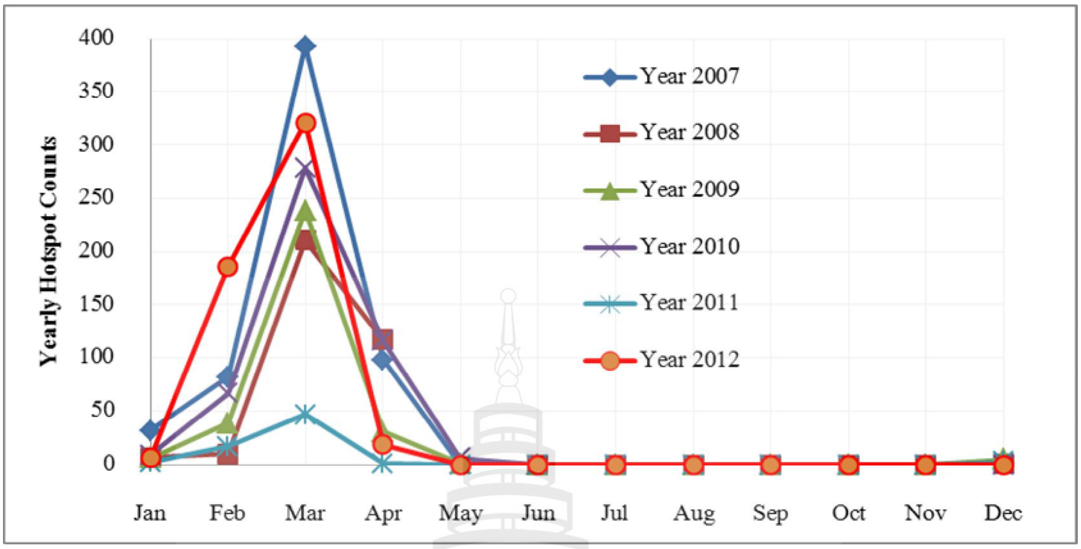


Figure 4.19 Monthly Numbers of Hotspots During 2007-2012

As a result, forest fires in Chiang Rai were found in the same pattern, started in February and ended in April, every year except only in 2011 whereas hotspots were found starting in November. However, they both found peak in March annually.

In 2011, as specified in Figure 4.19, only minimum hotspots were found since there was fluctuation of climate caused by La Niña, resulting in the increase of rain especially in March (Suthinee Dontree, Sunya Thumtakhop, Pipop Chamniwikaiyapong & Suphaluk Noisuya, 2012; National Park, Wildlife and Plant Conservation Department, 2012). The additional analysis showed that an average of 218 forest fires and 457 hotspots occurred annually in Chiang Rai. However, number of hotspots in 2012 was obviously higher than those in previous years, except 2007. This pointed out that if there is no fluctuation of climate in 2013, number of hotspots in this area will likely be increasing. Annual number of hotspots was indicated in Figure 4.20

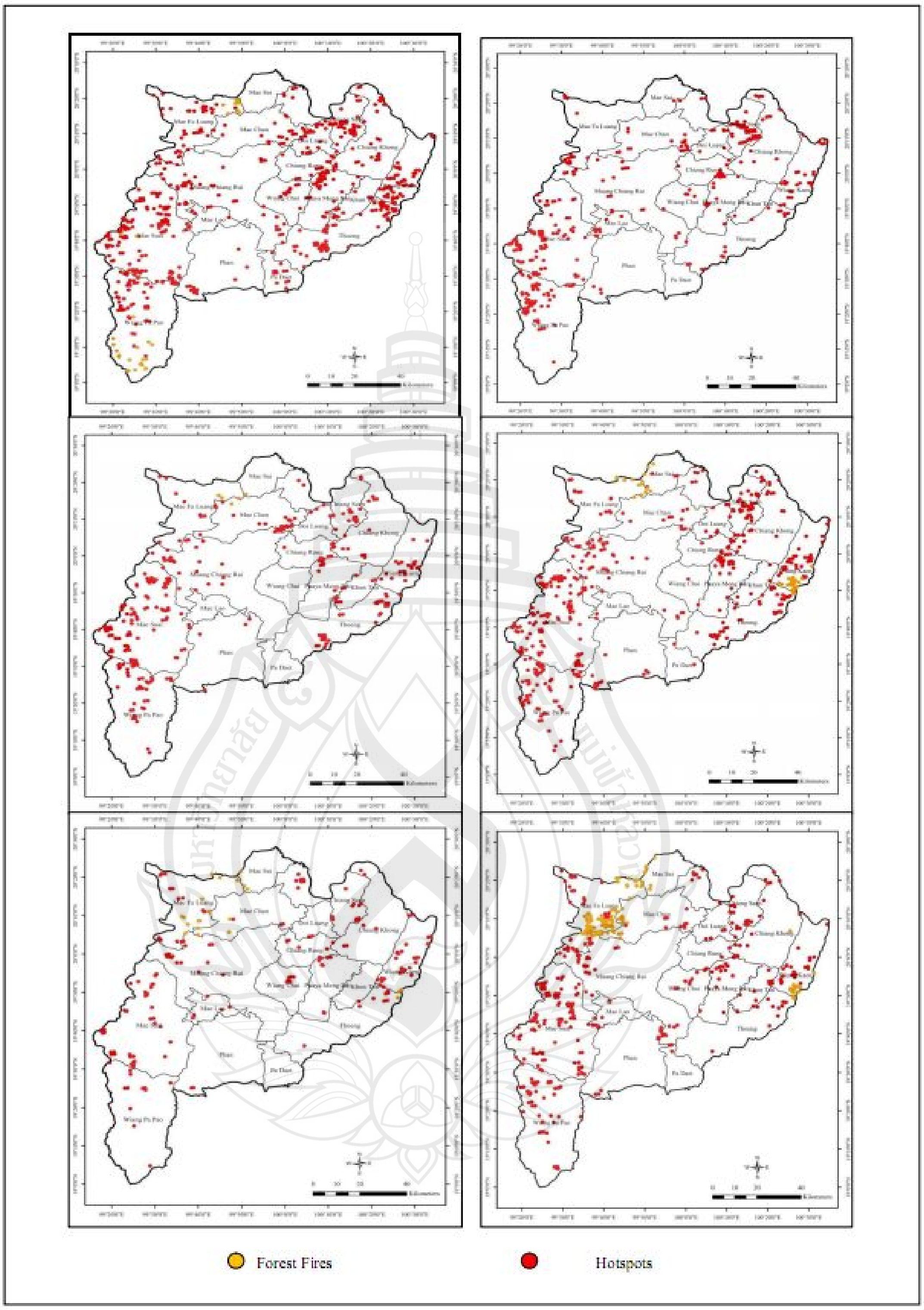


Figure 4.20 The Distribution of Forest Fires and Hotspot, Year 2007-2012

Nevertheless, number of hotspots was found highest in Mae Suai district, Muang district, and Chiang Khong district respectively. After conducting field survey aiming to trace the forest fires in Chiang Rai in March of 2012, the researcher found that majority of hotspots occurred in this month was located in highlands and forest areas, with 400-600 meters above sea level, and generally caused by agricultural burning as showed in Figure 4.21 Local residents often conduct agricultural burning in order to prepare land for next cultivation especially rice and corn (Nion Sirimongkonlerkun & Phonekeo, 2012, January). Normally, burning would begin in February, so the rate of change of hotspots from January to February would be higher comparing with other months during the burning season. Burning activities were conducted many more in March, while the lack of making fire breakers in the areas was resulting in fires spreading and finally becoming major forest fires (Suthinee et al., 2012). Accordingly, the highest number of hotspots was found in this month each year.

Figure 4.21 Burned and Burning Areas Located on Highlands, Chiang Rai (Pictures Taken in March, 2012, Mae Suai Sub District)

3. The relationship between PM10 and forest fire and hotspot occurrences

In this step, the objective was to study the relationship between PM10 levels and open burning conducted in Chiang Rai. To test if local burning significantly related to the increasing of PM10, information on number of forest fire prepared by Protected Area Regional Office 15, Forest Fire Control Division, Department of National Parks Wildlife and Plant Conservation, and hotspots data downloaded from NASA's website were used in the study.

As a consequence, the overall monthly pattern of PM10 levels at Chiang Rai station was found significantly relevant with forest fire occurred in the year 2009 to 2012, as shown in Figure 4.22. In the burning season, there was a sharp increase in both PM10 and hotspot counts added with a regular peak in March of each year. Moreover, the coefficient of determination (R^2) of relationship between PM10 and number of forest fire and also hotspots occurred in the area were very high, 0.9 and 0.85 respectively as specified in Figure 4.23. More detail of the PM10, number of forest fires by Protected Area Regional Office 15, Forest Fire Control Division and hotspot counts as show in Table 4.7.

This could be likely concluded that forest fires and hotspots occurred in Chiang Rai were significantly related to changes in PM10. Therefore, smoke-haze problem in Chiang Rai was generally caused by open burning performed in the province itself.

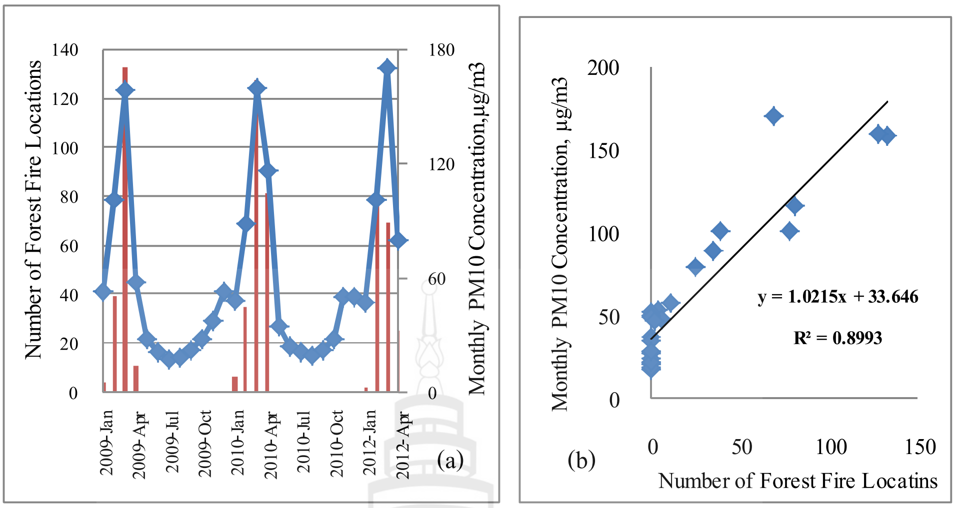


Figure 4.22 (a) The Relationship between the Monthly PM10 Concentration and Number of Forest Fire Occurrence

(b) The Scatter Plot between the Monthly PM10 Concentration and Forest Fire Occurrence Statistics

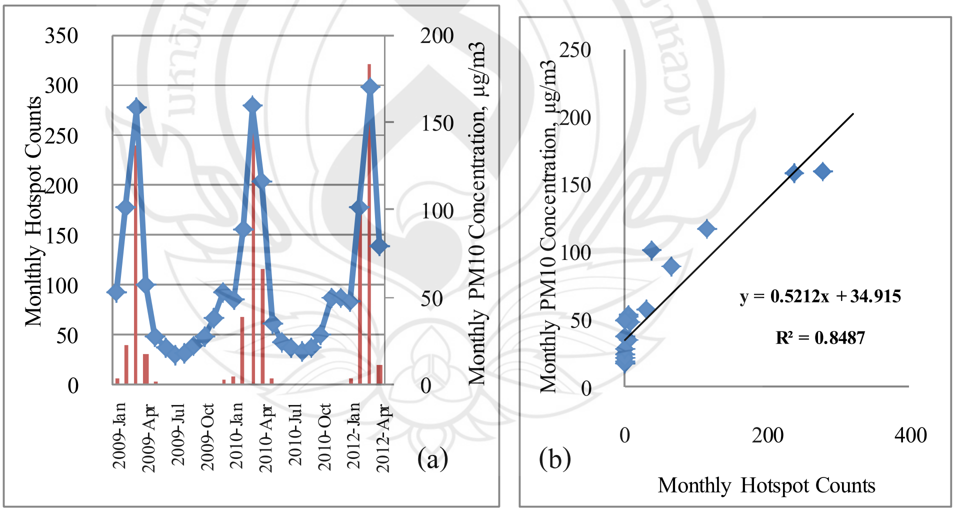


Figure 4.23 (a) The Relationship between the Monthly PM10 Concentration and Hotspot Counts

(b) The Scatter Plot between the Monthly PM10 Concentration and Hotspot Counts

Table 4.7 Detail of the Monthly PM10 Concentration, Number of Forest Firesprovided by Protected Area Regional Office 15, Forest Fire Control Division and Hotspot Counts (Year 2009, 2010 and 2012*)

Year-Month	Monthly PM10	Number Forest Fires	Monthly Hotspot Counts
	(μg/m^3)	(from Protected Area Regional Office 15)	(From NASA's website)
2009-Jan	53.2	4	6
2009-Feb	101.4	39	39
2009-Mar	158.96	133	239
2009-Apr	57.22	11	31
2009-May	27.60	0	1
2009-Jun	21.00	0	0
2009-Jul	17.20	0	0
2009-Aug	18.00	0	0
2009-Set	22.00	0	0
2009-Oct	27.90	0	0
2009-Nov	37.50	0	0
2009-Dec	52.40	0	5
2010-Jan	48.21	6	9
2010-Feb	88.79	35	67
2010-Mar	159.59	128	279
2010-Apr	116.44	81	116
2010-May	34.40	0	6
2010-Jun	24.00	0	0
2010-Jul	20.80	0	0
2010-Aug	18.70	0	0
2010-Set	21.60	0	0
2010-Oct	28.00	0	0
2010-Nov	49.60	0	0
2010-Dec	49.40	0	0
2012-Jan	47.20	0	6
2012-Feb	101.25	0	186
2012-Mar	170.9	0	321
2012-Apr	79.67	0	19

4. Meteorological and topographical features analysis.

Meteorological and topographical features can give influence to keep the smoke near the surface and transport it along drainages. Thus, these factors were additionally brought into the analysis. Since 2008-2012, burning season in Chiang Rai was considered the period of January to April, which was also summer time, with average temperature of 20.16-21.69 degree Celsius. In addition, an average rainfall was 0.7-2.70 mm and average wind speed was 14.59-15.79 km/h while the most prevailing direction of winds was the Northeast, as indicated in Table 4.8.

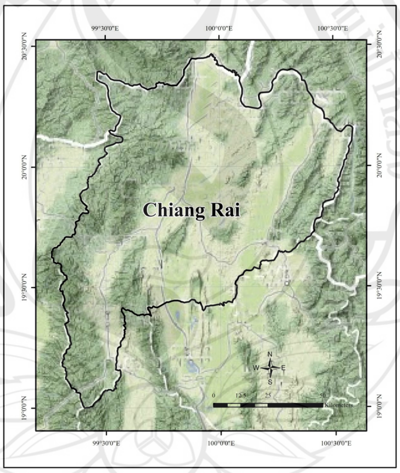
Table 4.8 Climatologically Data for the Period 2008-2012 of Chiang Rai Province (Extracted from Thai Meteorological Department, 2012)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Rainfall (mm)	0.70	0.33	1.46	2.70	6.49	5.26	8.03	10.65	8.09	3.31	0.65	0.07
Mean Temperature (Celsius)	20.61	22.33	24.42	21.69	21.95	22.03	21.64	21.25	21.47	20.75	18.01	16.34
Prevailing direction	NE	NE	NE	SW	SW	SW	SW	E,SE	N,NW	E	SE	NE
Mean Speed (km/hr.)	14.59	15.50	19.31	15.79	17.76	16.93	16.33	15.00	14.41	14.33	13.70	11.85

In the period from January to April or so-called as burning season, the air condition included low humidity, high temperature, and calm wind with the speed of 12.8 – 19.2 km/hr., resulting in stagnant air condition (TMD, 2012). Consequently, PM10 could be suspended in the air for a long time (Bonnet & Guieu, 2004). At the same time, high air pressure from China had also spread over the area of Chiang Rai (TMD, 2012), enhancing the gradually sinking of the air mass. Thus, gases and residues caused by burning could hardly be spread out from the area, which cause PM10 levels would be highly accumulated, especially in March when hotspots were found in the biggest number comparing with those in the other months.

The meteorological analysis of Northern Thailand, made by Oanh and Ketsiri Leelasakultum, 2011, showed that in March, there was a low pressure covering Northern Thailand with clear sky, light wind, and low dew point temperature resulting in both subsidence and temperature inversion or the phenomena called "stagnant meteorological conditions". Such inversion could inhibit the vertical dispersion of emitted pollutants which was consistence with the studies made by Agapol Junpen, Savitri Garivait, Sebestien Bonnet and Adisak Pongpullponsak (2011) and Prapat Pentamwa and Oanh (2008).

Besides climate condition factor as described earlier, topographical feature was also a factor affecting the accumulation of PM10 in the area. Chiang Rai was considered as the North Continental Highland. As indicated in Figure 4.24, there were patches of plateau in Mae Suai, Wiang Pa Pao, and Chiang Khong districts. Mountain ranges were approximately 1,500-2,000 m of height above sea level whereas the plain areas, with approximately 410-580 m above sea level were located along the rivers in many districts which were Phan, Muang, Mae Chan, Mae Sai, Chiang Saen, and Chiang Khong.



From Tala Atlas. (n.d.). **Google Map**. Retrieved August 22, 2012, from https://maps.google.co.th/

Figure 4.24 Basin Area Covers Chiang Rai Province

Chiang Rai was surrounded by mountains, with the presence of valley inversion that would certainly limit the dispersion of smoke, air pollutants, and PM10 caused by local open burning. Furthermore, especially in March of every year, Chiang Rai was influenced by Northeast monsoon (TMD, 2008) resulting in a high air pressure prevailed over the region. The result was a subsidence inversion, which trapped smoke in the mountain valleys.

According to a specific topography of Chiang Rai, including valleys and plain areas, even there was only a small number of burning conducted in the local areas each day, smoke and air pollutants were still being gradually accumulated until reaching critical level. Because of the mountain-valley in the topography of the province, it is a major factor that enhanced smoke-haze condition in Chiang Rai (Protected Area Regional Office 15). Another reason is because of the limit of dispersion of air pollution. Plus, the climate in March included stagnant condition and low-speed wind which resulted in long suspension of PM10 in the air. At the meantime, even there was no increase of burning activities; PM10 accumulation level could still be higher for the whole month as indicated in Figure 4.25.

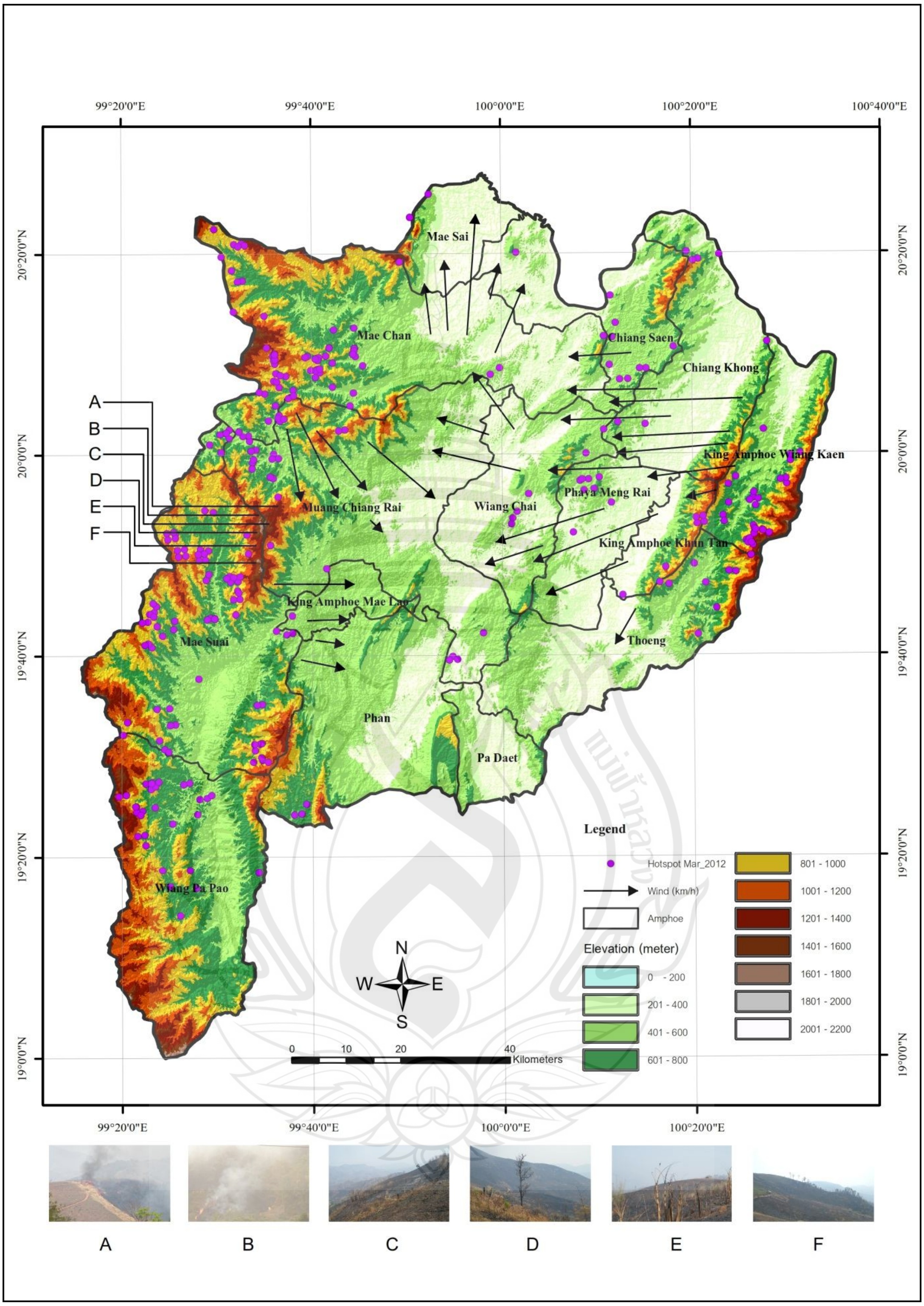


Figure 4.25 The Relationship between Hotpot Occurrence, Topographical Features and Wind Direction, in March 2012

From the Local Impact analysis, both numbers of hotspots obtained from remote sensing

From the Local Impact analysis, both numbers of hotspots obtained from remote sensing data and forest fires from ground field survey were found highest in March of every year. They mostly were the results from agricultural burnings conducted in the forest areas in order to prepare lands for next cultivation, especially corns since they were easily grown and also assured by government for a rather high selling price. From the statistics, open burnings was found in Mae Sai district the most. Moreover, local people generally began to burn agricultural residues by the end of February and then peaked in March of each year. During these months, the air condition was quite dry so that people needed to conduct burning only once. In contrast, prior to these months, the air condition was humid which enhanced the growth of weeds after the first or second burning, giving people difficulty in conducting burning more than once.

In addition, burning activities conducted in the radius of 50 km from Chiang Rai station was found the most significant for the increase in PM10 concentration. Within this range, a half of total hotspots were located in Thailand. According to this half of total hotspots, 80% was detected in Chiang Rai while 15% and 5% were detected in neighboring provinces which were Mae Hong Son and Chiang Mai respectively. Therefore, the over standard of PM10 level in Chiang Rai that was detected in March of each year mainly caused by open burnings conducted within the province. There were other two factors that enhanced the accumulation of PM10 in Chiang Rai. The first was mountain-valley topographical factor that terribly limited the dispersion of smoke and air pollutants. The second was meteorological factor, especially in March when there were calm winds, low humidity, and high temperature making smoke float vertically (PCD., 2011). At the same time, the phenomenon of subsidence inversion that caused stagnant condition was associated with the smoke-haze problem as well. In conclusion, the significant increasing of PM10 especially in March of each year was primarily caused by agricultural burning in the forest areas in Chiang Rai itself.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Regional Impacts

5.1.1.1 The pattern of hotspots occurrence likely caused by open burning in regional level, which included Thailand, Myanmar and Laos, was quite the same. In these three countries, hotspots were found starting from December and gradually increasing until May of each year and the highest numbers of hotspots were always detected in March. In 2007, 2009, 2010 and 2012, the annual average of regional hotspot counts was 63,795. Eighty percent of the average or 51,036 hotspots were occurred in burning season, or January to April, and 70% of this number was detected in March which was the peak month. The countries with highest hotspot counts were Myanmar (50%), Laos (36%), and Thailand (14%) respectively.

5.1.1.2 Since 2007-2012, the increase of PM10 levels during the burning season (January to April) in Northern Thailand was three times higher than those in non-burning season. The highest PM10 levels were detected at three stations, located at Mae Sai (Chiang Rai2), Mae Hong Son, and Chiang Rai (Chiang Rai1). In addition, sharp increases could be observed from February to March at all these three stations.

5.1.1.3 Regional burnings, conducted in Myanmar, Laos and Thailand, significantly resulted in the increasing of PM10 only at the monitoring stations located along the border areas, Mae Sai, Mae Hong Son Chiang Rai and Nan stations. It meant that regional hotspot counts practically correlated with PM10 concentration especially at these four stations. The coefficients of determination for these stations were 0.99, 0.92, 0.83 and 8.98 respectively. Moreover, the month-to-month changes of hotspots at the regional level reasonably correlated with the month-to-month PM10 changes at these four stations. The coefficients of determination for the changes were quite high (R^2>0.8). The highest correlation was at Mae Sai followed by Mae Hong Son and Chiang Rai stations.

5.1.1.4 Open burnings conducted within the radius of 50 km from Chiang Rai monitoring station significantly affected the increasing of PM10 detected at Chiang Rai station the most, with the coefficients of determination of 0.85. In addition, 96% of hotspots occurred within this range was located in Thailand while 4% was in Myanmar. It could be said that the increases in PM10 at Chiang Rai station was influenced by short range transport from biomass burning the most.

5.1.1.5 In March of each year, Chiang Rai was affected by long range transport from biomass burning, which carried by southeastern wind typically originated in Myanmar then passed through Mae Hong Son and Chiang Mai before arriving at Chiang Rai.

5.1.2 Local Impacts

5.1.2.1 The pattern of changes in PM10 levels was relatively constant, that was less than 30 μg/m^3 during April to October and then slightly increased with monthly average of 60 μg/m^3 during November to January. After that, from February to April, monthly average of PM10 levels was higher to 80-120 μg/m^3. It was obvious that the highest level was detected in March of every year.

5.1.2.2 The patterns of both forest fires and hotspots occurrences were the same in every year, except only in 2011. Forest fires would obviously be happened in February and ended in April of each year. From statistics, the number of forest fires was yearly recorded highest in March which was in consistence with hotspots occurrence. However, hotspots were started to be detected in November onwards.

5.1.2.3 During January to April, hotspots and fire forests occurrences in Chiang Rai were significantly correlated with the increasing of PM10 as the coefficient of determination (R^2) was 0.85 and 0.90 respectively.

5.1.2.4 The majority of burning conducted in Chiang Rai was concerning agricultural activities. Local agriculturists generally burn agro-residues in order to prepare lands, regularly located in forest areas with 400-500 m above sea level, for next cultivation especially corn. Theses burnings were usually conducted or peaked at the same period of time during March of every year.

5.1.2.5 Meteorology and topography of Chiang Rai were also main factors that limited the dispersion of PM10, resulting in gradually accumulating of PM10 within the areas.

Therefore, it could be concluded that smoke- haze problem in Chiang Rai was mainly caused by short range transport from biomass burnings, mostly conducted within the province, in the radius of 50 km. from Chiang Rai monitoring station. This problem was considered as a local impact enhancing by meteorological and topographical factors. Meteorological factors included light wind, high pressure and low dew point temperature that generated both subsidence and radiation inversion or called "stagnant meteorological conditions" resulting in inhibiting the vertical dispersion of smoke and pollutants. Besides, Chiang Rai was surrounded by high mountains that were not conducive to emitting of smoke caused by open burnings. As a consequence, the accumulation of PM10 level was gradually higher. Once there was an impact from long range transport from biomass burning, via southwestern wind which passed by burning areas in neighboring countries and provinces, PM10 level was substantially higher.

5.2 Recommendations

5.2.1 Recommendation for Policy

Thailand especially Chiang Rai should be primarily focused in agricultural burning conducted on highlands in the forest areas. First of all, the government may cancel price assurance especially for the corns which harvested from the intentionally burned areas by using hotspots in monitoring process. Secondly, agencies involved in this issue, for instance, Land Development Department should provide agriculturists knowledge for farming in highlands and also alternative solution instead of burning their lands. Additionally, in cooperation with local administration, the make use of agricultural residues should be supported. These residues can be transformed to natural fertilization, biomass power generation and etc. At the same time, government may offer incentives to local agriculturists who seriously reduce their burnings by continuously providing price insurance for their produces. Furthermore, there should be Land Used Planning for Chiang Rai, particularly for the highlands in the forest, by creating specific map clearly illustrates border lines of granted areas for agriculture. Plus, the laws must be strictly enforced to forest encroachers who claim to use the lands for agricultural purpose. This defensive measure can be primarily launched in sub-district level choosing Wawee, located in Mae Soui district, as a model managed by local administration under a full support from government. The government may also use incentive based policy as a main driving mechanism for burning reduction. For instance, the award, which may be in the form of budget support, will be given to local administration for successful practice in reducing the number of hotspots in their own areas.

However, the central government should not drive the Burning Reduction Policy in the form of top-to-bottom as usual, as it has been evidenced that Stop Burning orders can never solve smoke-haze problem but create conflicts between local people and government officials in the area. Therefore, local people should be allowed to take part in giving opinions and suggestions which is the bottom-to-top policy forming. For example, at Doi Tung district, Chiang Rai, the regulations and burning quotas are set under the direction of Huay Krai sub-district municipal. There, registration system is used; people have to inform their intention of agricultural burning to village headman while representatives from sub-district municipal will take responsible in managing the number of burnings per day. This should be recognized as the Best Practice which recommended to related agencies to do so. On the other hand, Thailand especially Chiang Rai should have close cooperation with neighboring countries to seriously work on trans-boundary impact concerning smoke-haze problem. At the present, Thailand has initiated the concept of coordinating to solve trans-boundary haze problems between 5 GMS countries, Cambodia, Laos, Myanmar, Vietnam, and Thailand. Working teams were established to work in the areas of forest fires and haze pollution. The ASEAN Secretary General's Office is serving as the secretariat of the working teams, while the ASEAN Specialized Meteorological Centre (ASMC) is providing relevant data. Recently, the responses seem to be rather active. For example, the Sub-regional Ministerial Steering Committee on Trans-boundary Haze Pollution in the Mekong Sub-Region (MSC Mekong) convened for the first time on 25 February 2011 in Krabi, Thailand, and was attended by Environment Ministers/representatives from Cambodia, Laos, Myanmar, Thailand and Vietnam. Then, they announced a goal on reducing cumulative hotspot counts not to be exceeded 50,000 hotspots (based on 2006 data) by 2015. In order to achieve this goal, each member has to take control of open burning in their own country. However, this goal is still the general idea since there are no operational details for each member, such as the number of hotspots that must be reduced and burning quotas. In the study, it was found that the range which significantly affected the increasing of PM10 was at the radius of 50 km. Thus, Thailand, Myanmar, and Laos should set Green Zone with at least 50 km. from their border areas as Buffer Zone to block smoke caused by long range impact. To solve smoke-haze problem which caused by open burning conducted within Thailand and also neighboring countries, the real source of problem should be critically focused. Since agricultural burning has become a culture among agriculturists for a long time so, the most practical solution is to reduce burning by local agriculturists themselves. Sustainable solutions may take time since they have to change and adapt themselves to a new agricultural lifestyle. Providing incentives to people who cooperate in this campaign in local, national, and regional levels will be a key factor that helps driving the regarding policies success. Therefore, for sustainable solutions, it is necessary to clearly understand the sources of problem and be able to approach local people.

5.2.2 Recommendation for Future Study

Field surveys and serious study on open burning matter should be additionally conducted both in Thailand and neighboring countries to find out the causes behind burnings in other areas. These causes will be used as empirical data in planning and setting policies against smoke-haze problem in these three countries.

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APPENDICES

APPENDIX A

The List of PM10 in Northern Thailand, Year 2007, 2009, 2010 and 2012

Table A1 Monthly Average of PM10 in Burning Season (2007, 2009, 2010 and 2012)

	T35_ CM1	**T36_ CM2**	**T37_ LP1**	**T38_ LP2**	**T39_ LP3**	**T40_ LP4**	**T65_ CR1**	**T73_ CR2**	**T66_ MH1**	**T67_ NA1**
Jan-07	65.04	72.15	76.64	68.21	55.78	79.44				
Feb-07	91.33	96.05	130.5	72.52	96.96	119.4				
Mar-07	160.55	172.54	126.6	99.79	119.6	112.5				
Apr-07	63.15	77.24	46.24	47.75	46.96	39.6				
Jan-09	37.48	52.28	96.62	41.42		56.12	53.2		33.02	
Feb-09	86.31	98.92	157.2	99.98		140.2	101.4		84.49	
Mar-09	110.73	118.44	125.9	83.47		83.75	158.9		151.8	
Apr-09	51.11	53.82	66.81	42.72		52.76	57.22		93.33	
Jan-10	41.35	47.69	60.62	40.28	27.39	38.04	48.21		35.82	36
Feb-10	70.55	76.6	108.0	77.05	89.27	70.56	88.79		76.24	69.94
Mar-10	111.61	120.18	112.6	103.8	110.3	83.93	159.6		190.8	123.7
Apr-10	101.96	106.65	64	75.25	83.48	66	116.4		109.8	84.1
Jan-12	41.24	34.48	66.56	77.6	43.95	62.17	47.2	71.95	29.06	45.62
Feb-12	79.94	77.4	116.8	109.2	110.7	99.94	101.3	136.5	76.63	88.2
Mar-12	121.7	105.82	125.5	111.9	129.6	105.7	170.9	262.9	219.3	126.8
Apr-12	57.49	43.42	71.09	65.22	61.4	60.75	79.67	134.0	97.93	60.1

Table A2 Month-to-Month Change of PM10 in Burning Season

	T35_ CM1	T36_ CM2	T37_ LP1	T38_ LP2	T39_ LP3	T40_ LP4	T65_ CR1	T73_ CR2	T66_ MH1	T67_ NA1
07Jan-Feb	26.29	23.9	53.87	4.31	41.18	40				
07Feb-Mar	69.22	76.49	3.91	27.27	22.6	6.97				
07Mar-Apr	97.4	95.3	80.36	52.04	72.6	72.87				
09Jan-Feb	48.83	46.64	60.54	58.56		84.04	48.2		51.47	
09Feb-Mar	24.42	19.52	31.17	16.51		56.41	57.56		67.34	
09Mar-Apr	59.62	64.62	59.18	40.75		30.99	101.7		58.5	
10Jan-Feb	29.2	28.91	47.39	36.77	61.88	32.52	40.58		40.42	33.94
10Feb-Mar	41.06	43.58	4.63	26.7	20.98	13.37	70.8		114.6	53.71
10Mar-Apr	-9.65	13.53	48.64	-28.5	26.77	17.93	43.15		81	39.55
12Jan-Feb	38.7	42.92	49.92	31.59	66.76	37.77	54.05	64.57	47.57	42.58
12Feb-Mar	41.76	28.42	8.99	2.73	18.93	5.71	69.65	126.3	142.7	38.59
12Mar-Apr	64.21	62.4	54.38	46.7	68.24	44.9	91.23	128.8	121.4	66.69

APPENDIX B

Thailand Ground Recording Data of Forest Fire between Year 2007-2012

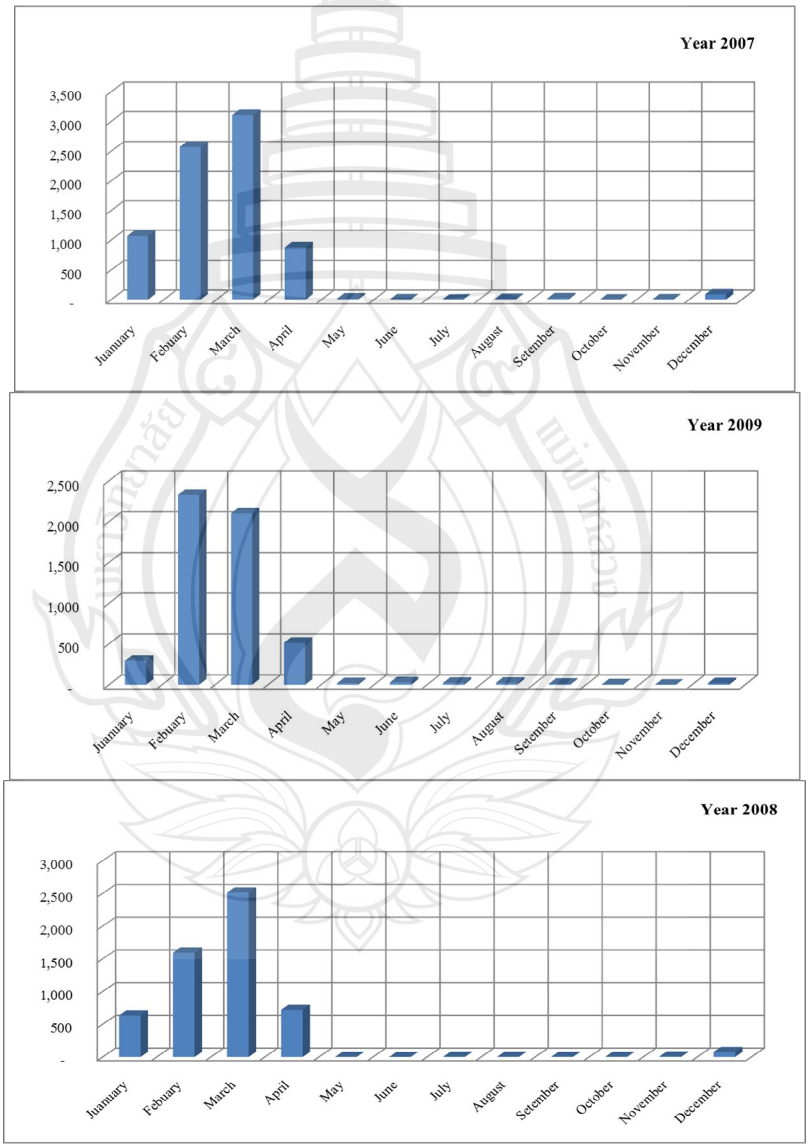
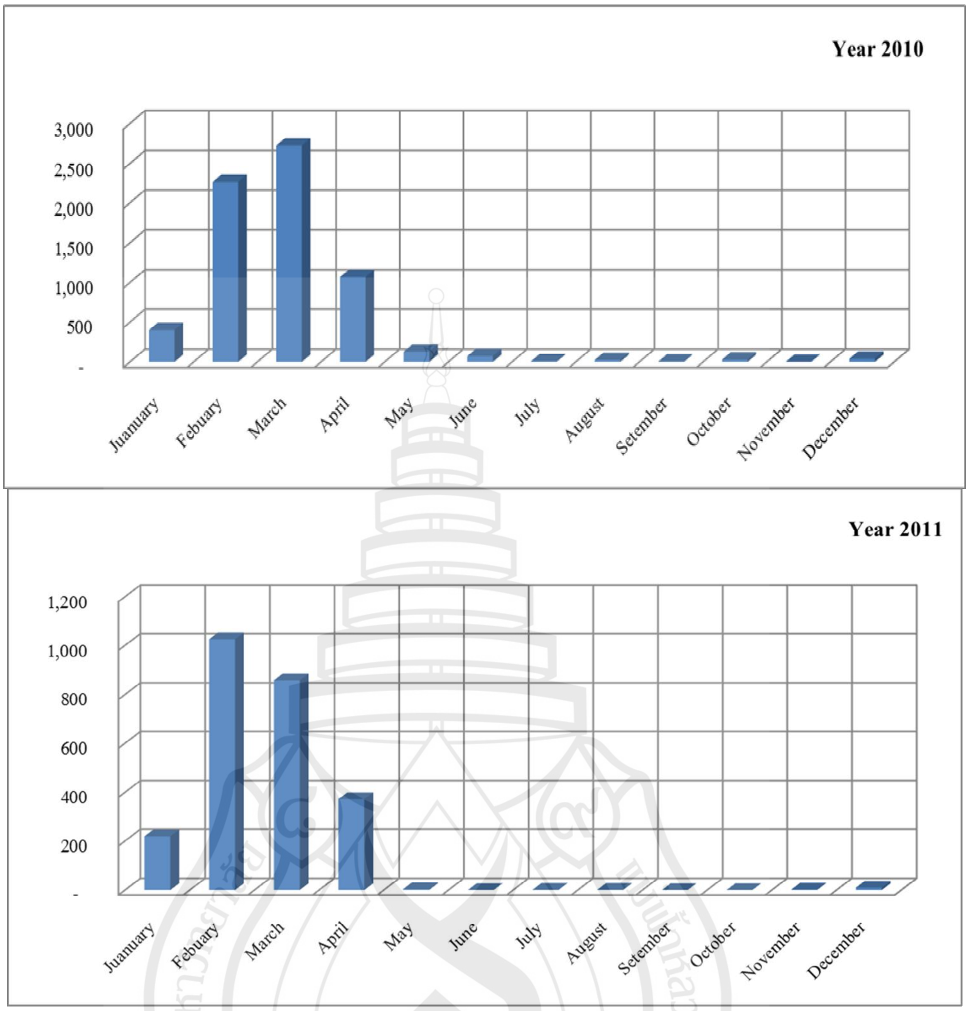


Figure B1 Thailand Ground Recording Data of Forest Fire between Years 2007-2008

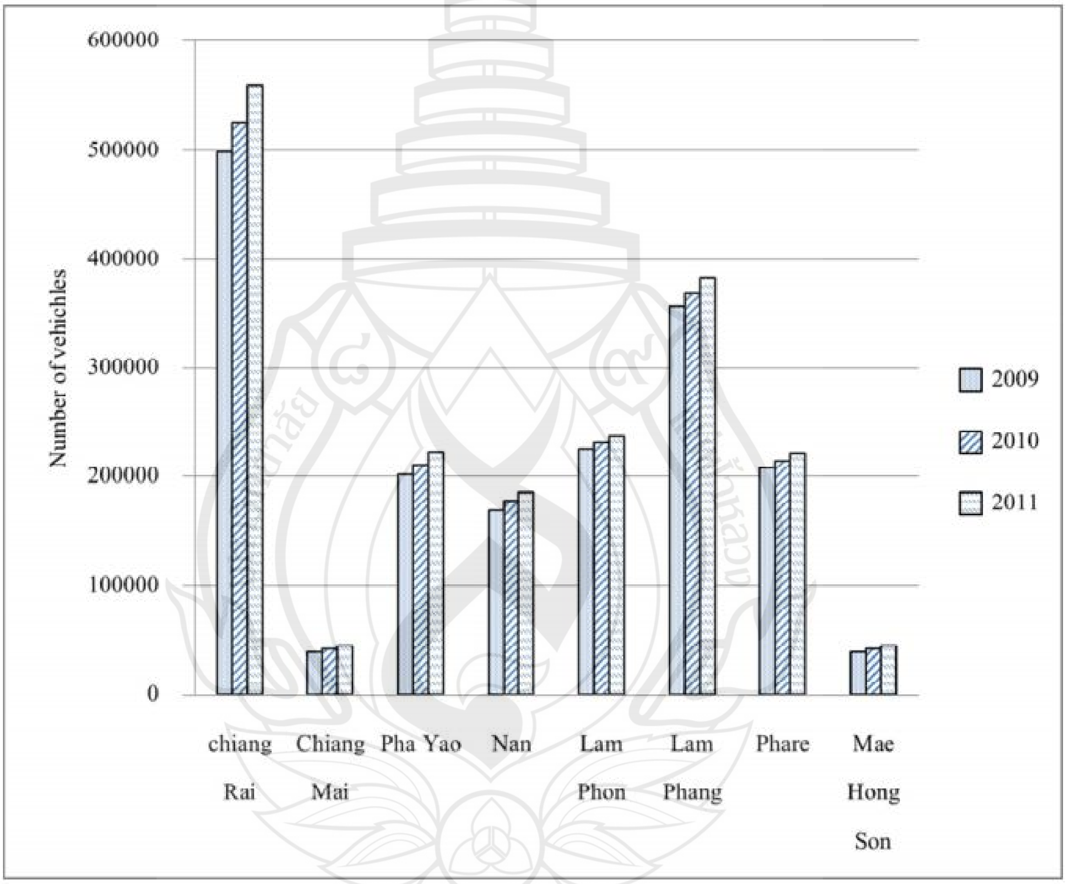


From National Park, Wildlife and Plant Conservation Department. (2012). **Forest Fire Control Division.** Retrieve January 5, 2010, from http://www.dnp.go.th/forestfire/Eng/indexeng.htm

Figure B2 Thailand Ground Recording Data of Forest Fire between Years 2010-2011

APPENDIX C

Traffic Volumes on Highways of Eight Northern Provinces in Years 2009-2011



Note. Department of High Way

Figure C1 Traffic Volumes on Highways of Eight Northern Provinces in 2009-2011

APPENDIX D

The Monthly Hotspot Counts Each Year, 2007, 2009, 2010 and 2012

Table D1 Monthly Hotspot Counts at Regional Level for Each Year

Year Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2007	1,625	6,758	41,958	34,884	1,042	4	4	5	0	2	20	211	86,513
2009	691	8,699	24,682	13,091	304	10	5	0	1	3	37	249	47,772
2010	1,071	6,609	40,693	18,637	1,459	23	9	3	0	1	28	157	68,690
2012	629	10,703	31,709	9,161	-	0	0	0	0	0	0	0	52,202
Total	4,016	32,769	139,042	75,773	2,805	37	18	8	1	6	85	617	255,177

Note. Yearly average = (86,513+ 47,772+68,690+52,202)/ 5
= 63,795 hotspots/ year
= 177 hotspots/ day

Table D2 Monthly Hotspot Counts for Each Country (2007, 2009, 2010 and 2012)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year 2007												
Laos	239	1,198	13,708	23,888	372	3	0	0	0	0	8	43
Myanmar	376	2,773	21,429	10,037	664	0	0	0	0	0	0	33
Thailand	1010	2,787	6,821	959	6	1	4	5	0	2	12	135
Total	1625	6,758	41,958	34,884	1,042	4	4	5	0	2	20	211
Monthly avg.	542	2,253	13,986	11,628	347	1	1	2	0	1	7	70
Year 2009												
Laos	112	1057	7173	3168	78	2	0	0	0	1	15	61
Myanmar	200	5889	14331	8885	203	2	0	0	0	2	7	37
Thailand	379	1753	3178	1038	23	6	5	0	1	0	15	151
Total	691	8,699	24,682	13,091	304	10	5	-	1	3	37	249
Monthly avg.	230	2,900	8,227	4,364	101	3	2	-	0	1	12	83

Table D2 (cont.)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year 2010												
Laos	217	1328	13434	9015	297	5	2	0	0	1	15	41
Myanmar	496	3712	20998	7856	1041	1	0	0	0	0	6	15
Thailand	358	1569	6261	1766	121	17	7	3	0	0	7	101
Total	1,071	6,609	40,693	18,637	1,459	23	9	3	-	1	28	157
Monthly avg.	357	2,203	13,564	6,212	486	8	3	1	-	0	9	52
Year 2012												
Laos	92	1217	9100	4876	0	0	0	0	0	0	0	0
Myanmar	243	5568	18375	3929	0	0	0	0	0	0	0	0
Thailand	294	3918	4234	356	0	0	0	0	0	0	0	0
Total	629	10,703	31,709	9,161	-	-	-	-	-	-	-	-
Monthly avg.	210	3,568	10,570	3,054	-	-	-	-	-	-	-	-

Table D3 Hotspot Counts in Burning Season, 2012

	January	February	March	April	Total	(%)	density of hotspot counts / 100 km^2
Laos	92	1217	9100	4876	15285	29	6
Myanmar	243	5568	18375	3929	28115	54	4
Thailand	294	3918	4234	356	8802	17	2
Total	629	10703	31709	9161	52202	100	4

Note. Total area of Laos = 236,880 km^2

Total area of Myanmar = 676578 km^2

Total area of Thailand = 513,115 km^2

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RESEARCHES AND PUBLICATIONS

Nion Sirimongkonlertkun. (2012, March). **Open burning cause study Chiang Rai Province**. Paper present at the 11th National Environmental Conference, Chiang Rai, Thailand.

Nion Sirimongkonlerkun, & Phonekeo, V. (2012, March). **Remote sensing and GIS for Estimated PM10 in The North of Thailand.** Paper presented at the 1st International Conference on Environmental Science, Engineering and Management, Chiang Rai, Thailand.

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