ENVIRONMENTAL HEALTH BURDEN OF OPEN BURNING IN NORTHERN THAILAND: A REVIEW

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Abstract

Air pollution arising from various sources including open burning and forest fires is a major the risk of public health problem. Open burning for agricultural purposes is a common practice in many Asian countries. Air pollution is a impactful problem in Thailand which makes many Thai people sick, harms the environment, and also affects the tourism industry. PM10 is the most important air pollutant in urban and rural areas of Thailand and has increased to the critical levels since 2006 (250 μg/m^3, 300 μg/m^3, 175 μg/m^3 and 220 μg/m^3 in 2006, 2007, 2008 and 2009 respectively). In 2016, the level of PM10 in the nine regions Chiang Rai, Chiang Mai, Lampang, Lamphun, Mae Hong Son, Nan, Phrae, Phayao and Tak were measured at between 68 to 160. The incidence rates of respiratory diseases and allergic rhinitis grew many times compared to those over some years. Health statistics indicated that respiratory diseases rank 5^{th} in the top ten leading causes of death in Thailand in 2005 with 40.1 per 100,000 populations. In order to reduce the public health challenges, several efforts have been made via public and private partnerships, policy formulation and implementation and awareness campaigns. However, even in 2016, open burning is still the most common method of managing agricultural wastes regardless of the accompanying public and environmental health impacts. This review paper draws attention to and presents an overview of the state of open burning of agricultural residues and the public health burden in Northern Thailand where the most common way of managing agricultural residues is through open burning. Furthermore, the transboundary haze pollution in the Northern Thailand requires collaborative actions by various agencies.

Keywords: open burning, environmental health, burden, northern Thailand

INTRODUCTION

Air pollution arising from various sources including open burning and forest fires considerably causes the public health problem (WHO, 2013). Also, it is becoming a frequent health management problem (Johnston et al., 2014). Environmental health problems that the world currently faces such as, air pollution generated from man–made sources like open burning and industrial emissions directly impacts our ability to develop economically while at the same time affecting the health of people as well as plants and animals (Kibert, 2000). An obvious indicator of incomplete combustion is the formation of black smoke, which consists of small particulate materials. Leaving the fire to burn and smolder for hours or days is not environmentally sound and can be detrimental to health (McCoy and Garthe 1996). Biomass burning is responsible for producing the main toxic gas, particulate matter and greenhouse–effect gases in the planet (Crutzen and Andreae, 1990). Globally, 3.7 million deaths were attributed to ambient air pollution in 2012. At 88.0%, low and middle income countries had the highest number of deaths. In a regional breakdown, it was found that the Western Pacific Region had the highest number of deaths (1,670,000) while the Southeast Asian Regions was the second highest with 936,000 deaths (WHO, 2013).

Air pollutants which are the cause of major health problems, and below standards in Thailand include dust and carbon monoxide. Dust is a serious problem especially in crowded communities with traffic congestion, being 3 to 5 times greater than standards. Other pollutants are lead, sulfur dioxide and nitrogen dioxide (PCD, 2012). According to the ministry of public health, major air pollutants include particulate matter, ozone, carbon monoxide, sulfur dioxide, nitrogen, lead and air toxics (Ministry of Public Health, Thailand, 2011). Air quality data from the pollution control department showed that PM10 is the most important air pollutant in urban and rural areas of Thailand has increased to the critical levels since 2006 (250 $\mu g/m^3$, 300 $\mu g/m^3$, 175 $\mu g/m^3$, and 220 $\mu g/m^3$ in 2006, 2007, 2008 and 2009, respectively) (PCD, 2012). Similarly, MOPH reported in 2011 that PM10 exceeded the standard in many areas.

Open burning is any open flame exposed to the environment, where air pollutants produced from the fire are emitted directly into the surrounding air. This includes the burning of leaves, wood and trash. It encompasses a wide variety of activities including burning of crop residues in agricultural areas. Open burning also includes the burning of any matter in

such a manner that products of combustion resulting from the burning are emitted directly into the ambient (surrounding outside) air without passing through an adequate stack, duct or chimney (North Dakota Department of Health Division of Air Quality, 2015). Open burning of agricultural residues is a human initiated activity to prepare the field for next crop, remove residues, control weeds and release nutrients for the next crop cycle (Gadde et al., 2009). Open burning is very common, yet very unhealthy method of garbage and agricultural waste disposal, and it can lead to forest fires (Sirimongkonlertkun, 2014).

Open burning for agricultural purposes is a common practice in many Asian countries (Tipayarom and Oanh, 2007). Smoke from field clearing fires and big forest fire events in Southeast Asian countries has continued to cause hazardous haze pollution in the region every year (Koe et al., 2001; Stratieva, 2014). Open burning of agricultural residues is one of the major sources of aerosol emission. It is a common way of eliminating agricultural residues after harvesting (Kanokkanjana, 2011). In June 2013, Southeast Asia was said to have faced a serious cloud of record–breaking haze pollution. The smoke from open field burning does not only produce smokes that affect health but also impacts climate change (Stratieva, 2014).

Biomass burning is one of the major sources of air pollution in Thailand which provokes many environmental problems, particularly air pollution resulting in adverse health effects (Vadakan and Vajanapoom, 2011). Thailand is a world player in terms of sugarcane, rice and corn production. As the fourth producer of sugarcane in the world, open burning of sugarcane residues which is a major source of air pollution in Thailand is in on the increase (Sornpoon et al., 2014). Open burning is a common method of managing rice residue and control of weeds in Thailand. Thailand is bordered by Myanmar in the north and west, and people suffer from smoke filled haze caused by burning of forest and agricultural waste from within and neighboring countries. During the period of burning, large areas of land can be enveloped in smoke (Pramuansup, 2013). Most of the farmers in Northern Thailand usually dispose of agricultural waste by open burning rather than plowing since it is an easy, convenient and faster way to prepare land for the next cultivation (Sirimongkonlertkun, 2014). Air pollution in Northern Thailand has been recognized as smog crisis from January to April every year since 2007 (Wiwatanadate, 2013). February and March have been reported

as the two months when conditions of forest fires are at their worst (Forest Fire Control Division, Thailand, 2003).

OPEN BURNING IN NOTHERN THAILAND

The releases of harmful air pollutants from open burning activities have been being an environmental problem of Asia especially Southeast Asia. Field measurements found the particulate emissions and trace gas emissions, including CO_2, CO, CH_4, NO_x, NH_3, N_2O and SO_2, from open burning of wheat straw and maize stover which are two major agricultural residues in China (Li et al., 2007). Corn stover also presents the highest emission factors of NO, NO_x and CO_2, whereas, wheat straw, rice straw, and cotton stalk had the highest emission factors of NO_2, SO_2 and CO, respectively (Cao et al., 2008). The annual emissions from crop residue open burning in Southeast Asia between 2010 to 2015 found the different emission rates in Tg yr^{-1} (1 Tg=1 million tons), which were 12.5 CO; 0.36 NO_x; 0.03 SO_2; 1.0 NMVOC; 0.5 NH_3; 2.0 PM10; 1.8 $PM_{2.5}$; 0.08 BC; 0.8 OC; 190 CO_2; 0.56 CH_4 and 0.015 N_2O (Nguyen et al., 2018). In term of health effect, crop residue open burning was relatively more significant with more than 30% for toxic pollutants of $PM_{2.5}$, OC and NH_3 and less significant at 14–21% for GHGs and the least at 10% for SO_2 (Nguyen et al., 2018). Moreover, there were 8% of PM2.5 emissions over the year and 26% of PM2.5 during harvest seasons from agricultural burning (Zhang et al., 2016). Rice straw burning showed the increase in the concentration of PM2.5 from the observed during this period which reaching up to PM2.5/PM10 ratio of 0.79 (Cheng et al., (2009).

Despite having 13 monitoring stations in Northern Thailand (Thongboonchoo, 2013), PM10 which is generated from open burning is still a major pollutant in the Northern region (Manomaiphiboon et al., 2009 in Sirmongkonlertkun, 2014). In 2016, the Pollution Control Department reported that the levels of dust particles with a diameter smaller than 10 micrometres known as PM10 had crossed the prescribed safe threshold of 120 in four out of nine provinces where monitoring was conducted. The level of PM10 in the nine regions Chiang Rai, Chiang Mai, Lampang, Lamphun, Mae Hong Son, Nan, Phrae, Phayao and Tak were measured at between 68 to 160 μg/m^3.

Chiang Rai is a province in Northern Thailand facing the air pollution problem from crop residue open burning, the monthly averages for PM10 concentrations from the years

2011 to 2014 showed the average of PM10 concentration started to rise during the period from December to April and peaked during the hot season (summer) (February to April) every year at the same time as the open burning season after harvesting. It is also the time when PM10 concentrations usually exceed the Thai national ambient air quality standards of 120 μg/m3 (Hongthong et al., 2017) (Fig.1). Similarly, GIS–based map of PM10 concentrations in Northern Thailand including Chiang Rai in Fig. 2 reveals the high concentration of PM10 during summer from 2011 to 2015.

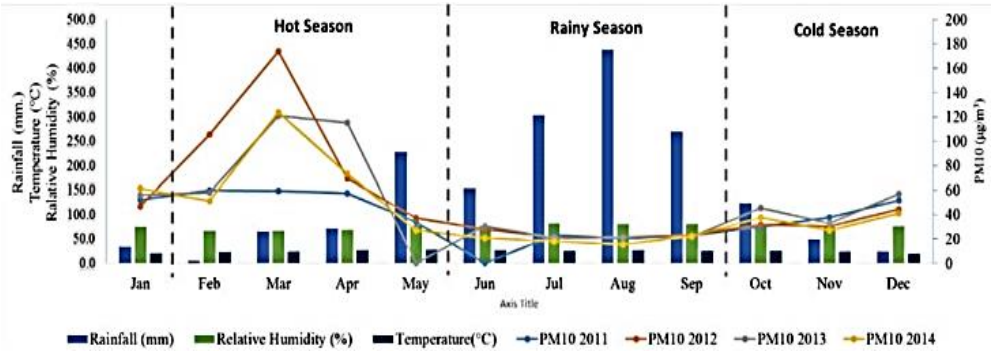


Figure 1. Quantity of PM10 with average rainfall, temperature and relative humidity on a monthly basis during the years 2011 to 2014 (Hongthong et al., 2017)

The current environmental problems in Thailand are not only ones from within the country but also from trans–boundary pollution problems such as smoke or haze due to forest fires in neighboring countries (Ministry of Public Health, Thailand, 2011). All pollutants in March (with fire) were found higher than in October (without fire). This is the implication of bush fire effect to the air quality in Northern Thailand (Pungkhom and Jinsart, 2014). Wildfires in Myanmar and Thailand was involved in the dangerous levels of air pollution in Northern Thailand (Fernquest, 2013). In the rural and border areas, agricultural burning and forest fires including trans–boundary haze from Myanmar have contributed to high levels of PM10. A three–day backward trajectory (BWT) analysis of air mass movements at the Chiang Mai Air Quality Monitoring (CM–AQM) station in the dry season (February–April) from 2010 to 2015 noticed that the air emissions were transboundary from Myanmar by 73.2% and within Thailand by 26.8% (Punsomponga and Chantara, 2018). This finding is in accordance with the scenario of hotspot occurrence in three countries; Thailand, Lao and Myanmar. These countries have similar occurrence pattern in term of hotspot number

however, the lowest number of hotspot was found in Thailand (Sirimongkonlertkun, 2018) (Fig.3).

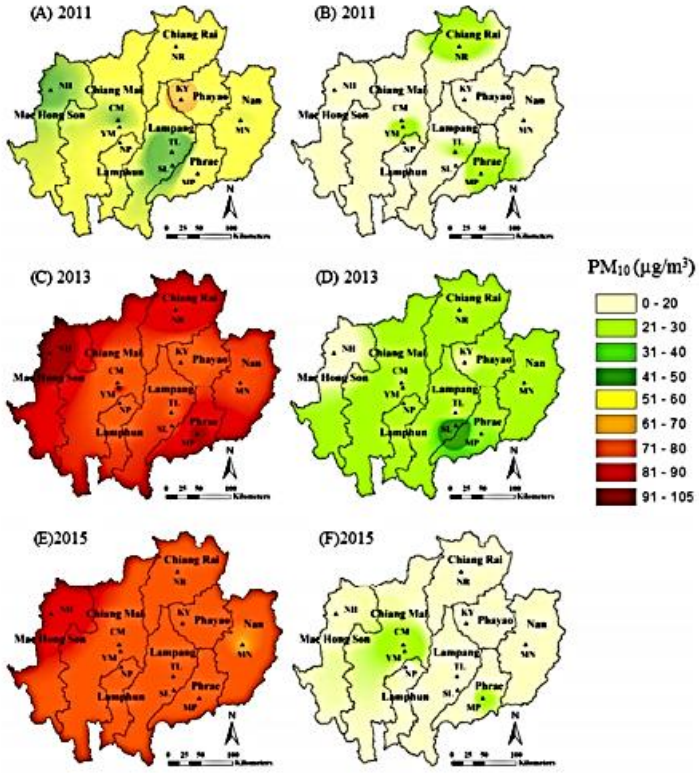
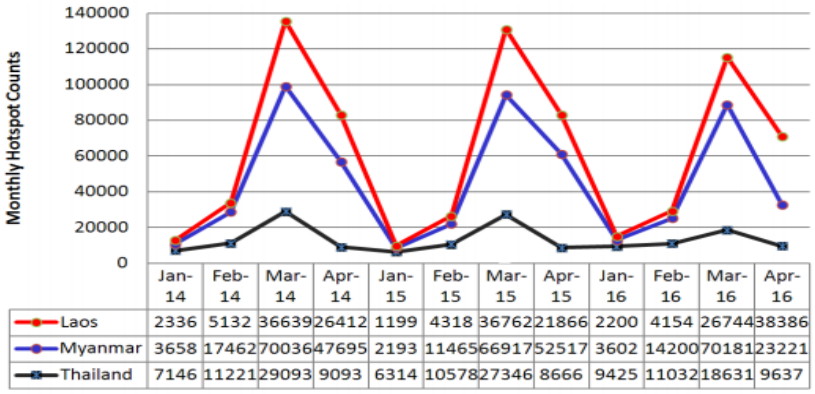


Figure 2. GIS–based map of PM10 concentrations in Northern Thailand (A) 2011 dry season, (B) 2011 wet season, (C) 2013 dry season, (D) 2013 wet season, (E) 2015 dry season and (F) 2015 wet season. (Mitmark and Jinsart, 2017).



	Jan-14	Feb-14	Mar-14	Apr-14	Jan-15	Feb-15	Mar-15	Apr-15	Jan-16	Feb-16	Mar-16	Apr-16
Laos	2336	5132	36639	26412	1199	4318	36762	21866	2200	4154	26744	38386
Myanmar	3658	17462	70036	47695	2193	11465	66917	52517	3602	14200	70181	23221
Thailand	7146	11221	29093	9093	6314	10578	27346	8666	9425	11032	18631	9637

Figure 3. Hotspot occurrence number in Thailand, Laos and Myanmar in the period of January– April of 2014–2016 (Sirimongkonlertkun, 2018).

Northern Thailand, consists of mostly highlands and forest areas where local people often conduct agriculture, especially corn (Sirimongkonlertkun, 2018); therefore, burning activities are performed regularly in March when the highest number of hotspots is found. Furthermore, the majority of lowland is rice fields where farmers can plant rice twice a year, starting in May to August and continuing until the harvest season in November and December (Sirimongkonlertkun, 2104). Farmers usually dispose of agricultural waste by burning rather than plowing since it is an easy, convenient and faster way to prepare land for the next cultivation. In addition, they believe that burning agricultural waste can best increase fertility despite treating the soil and killing pests (Sirimongkonlertkun, 2104). In Chiang Rai, Northern Thailand, there are findings of the association between open burning behavior and level of environmental health knowledge, attitude and practices; people with low knowledge levels were more likely to engage in open burning than those who have average and high knowledge levels and among other factors like culture, finance, large scale commercial farming (Adeleke et al., 2017; Adeleke et al., 2017). Therefore, the crop residue field burning should be of concern and be the point of raising environmental health, waste management technology and awareness to stop crop residue open burning activity.

PUBLIC HEALTH CONCERNS OF OPEN BURNING

As mentioned earlier, open burning contributes to air pollution which comes with various health implications, it affects human and animal life, insects below the earth surface and sometimes causes poor visibility (Kumar and Kumar, 2012). Air pollution is a big problem in Thailand which makes many Thai people sick, harms the environment, and also affects the tourism industry (Ping, 2011). Exposure to air pollutants is dangerous to the health of humans as it has been revealed by various studies to be associated with different respiratory problems, heart disease and stroke. For example, WHO reported that Ozone is a major factor in asthma morbidity and mortality. Air pollution caused deaths–breakdown by disease revealed the following results: 40.0% ischemic heart disease, 40.0% stroke, 11.0% COPD, 6.0% lung cancer and 3.0% stroke (WHO, 2012). Mortality from ischemic heart disease and stroke are affected by risk factors such as high blood pressure, unhealthy diet, lack of physical activity, smoking and household pollution. Some other risk factors for childhood pneumonia include smoking and air pollutions. One of the risk factors which may contribute

to deaths is ambient air pollution (WHO, 2013). Similarly, a 2007 review of evidence found ambient air pollution exposure is a risk factor correlating with increased total mortality from cardiovascular events (range: 12% to 14% per 10 μ/m^3 increase) (Chen et al., 2008).

The human respiratory system has a way of protecting against air pollution. For example, the hair in the nose helps to filter out particles. Sneezing and coughing expel contaminated air and mucus when pollutants irritate one's respiratory system. However, prolonged or acute exposures to air pollutants can over load or breakdown these natural defenses (Spoolman and Miller, 2013). Health effects related to air pollution include some forms of cancer such as lung cancer and skin cancer, damage to vital tissues and organs such as the nervous system, impairment of lung and breathing function (Friis, 2012). Exposure of pregnant women to air pollution was linked with fetal growth retardation, low birth weight, preterm birth and neonatal mortality (Marshall et al., 2010). Even in the areas with relatively low levels of air pollution; public health effects can be significant and costly since a large number of people breath in such pollutants. Particle inhalation may lead to death (AbdoArbex et al., 2004) as shown in Fig.4.

Forest fires release pollutants and a range of toxic gases, carbon monoxide, particulate matter and volatile organic compounds that affect human health (Sukitpaneenit and Oanh, 2013). Carbon monoxide reacts with hemoglobin in red blood cells and reduces the ability of blood to transport oxygen to body cells and tissues. Chronic exposure can trigger heart attacks and aggravate lung diseases such as asthma and emphysema. At high levels, carbon monoxide can cause headache, nausea, drowsiness, mental impairment, collapse, coma and death (Spoolman and Miller, 2013). At high levels, nitrogen oxide can irritate the eyes, noses and throat; aggravate lung ailments and suppress plant growth (Spoolman and Miller, 2013). Nitrogen dioxide and sulfur dioxide can also play a role in asthma, bronchial symptoms, lung inflammation and reduced lung function (WHO, 2013). Particulate matter affects more people than any other pollutant (WHO, 2013). The most health–damaging particles are those with a diameter of 10 microns or less, (≤ PM10), which can penetrate and lodge deep inside the lungs. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer. There is a close, quantitative relationship between exposure to high concentrations of small particulates (PM10 and PM2.5) and increase of mortality or morbidity, both daily and over

time (WHO, 2013). Ultra–fine particles can settle deep in the lungs and lead to cancer, heart attack and stroke, can irritate the nose and throat, damage the lungs, aggravate asthma and shorten life. Particulates also reduce visibility; 62.0% comes from natural sources like wildfire and dust while the remaining 38.0% comes from human sources like burning, motor vehicles and tobacco smoke (Spoolman and Miller, 2013).

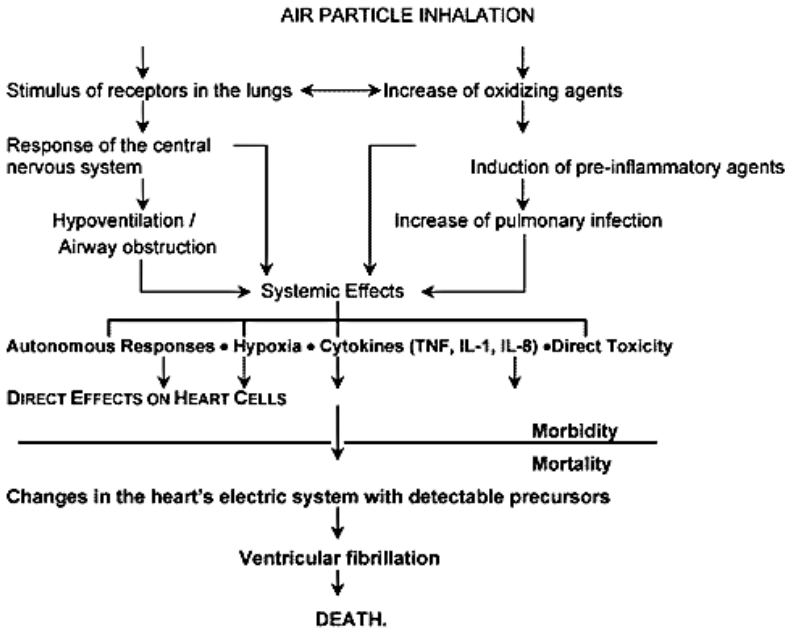


Figure 4. Hypothetical mechanisms through which particle inhalation may lead to death. (AbdoArbex et al., 2004).

Moreover, short term exposure to smoke is associated with acute physical symptoms and mild psychological disturbances in healthy individuals according to Ho et al., (2014). The findings showed that the higher number of physical symptoms were link to the greater psychological stress (Ho et al., 2014). A negative impacts from smoke haze is the increase of respiratory tract symptoms. High levels of air pollution can endanger our health and can kill people as well, especially when reactive gases are discharged into the atmosphere and vulnerable persons are exposed to them (Friis, 2012). Smoke from open burning has negative impact on air quality and health of people (Rayanakorn, 2010).

The incidence rates of respiratory diseases and allergic rhinitis have increased many times compared to those over some years ago as shownin Fig.5. Health statistics also indicated that respiratory diseases rank the fifth in the top ten leading causes of death in

Thailand in 2005 with 40.1 per 100,000 populations. Regarding the situation of air quality problems within and outside homes, the important indicators of health and air quality were respiratory diseases (MOPH, Thailand, 2012). The findings of other studies equally show the relationship between PM10, PM2.5 and chronic pulmonary disease, respiratory and cardiovascular illnesses (Pramuansup, 2013; Moeltner et al., 2013). According to Pramuansup, the relationship between COPD and PM10 was found to be statistically significant at 6.03 times comparing between exposure and non–exposure periods. The study showed that PM10 concentration in March (a typical burning period) was higher than that of September in 2011. In March 2016, Mae Sai District of Chiang Rai Province had a record 410 micrograms per cubic metre (u/cg) of harmful air particles.

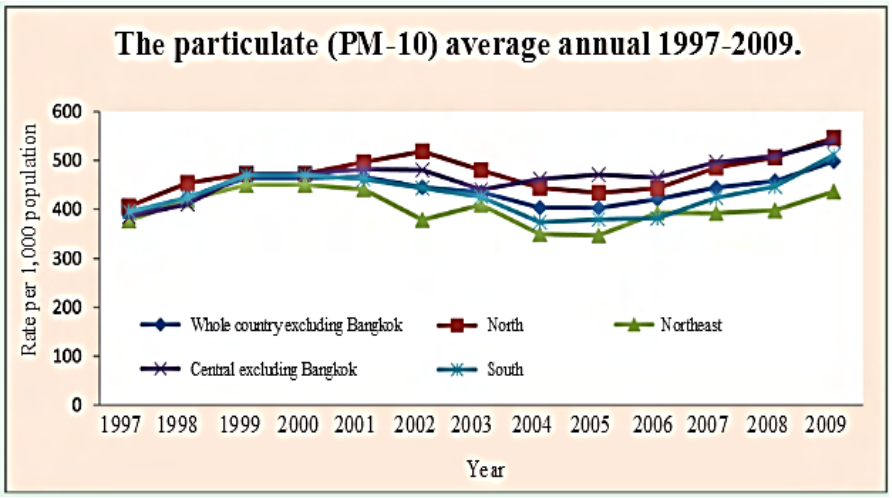
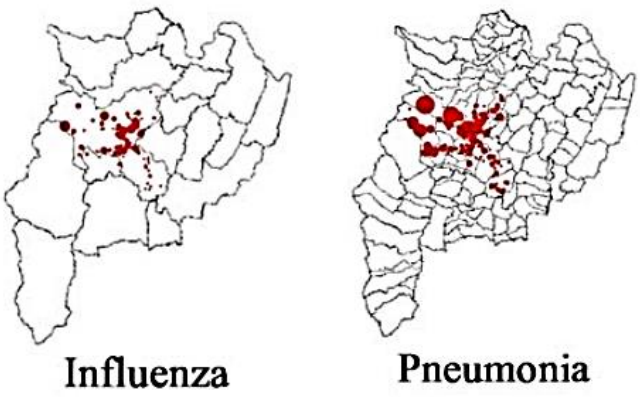


Figure 5. Morbidity rate of respiration disease among outpatients by region, Thailand 1997–2009 (Ministry of Public Health and Ministry of Natural Resources and Environment, 2011).

Fig. 6 shows the spatial temperature distribution map revealed higher incidence of cases of influenza and pneumonia throughout the lower temperature area of Chiangrai city centre. Influenza was affected by PM10, rainfall, relative humidity, and temperature, according to the following correlation ratios: 0.8217, 0.8842, 0.9375 and 0.8775, respectively. The incidence of pneumonia was affected by rainfall, relative humidity and temperature following the correlation ratios 0.7746, 0.7621 and 0.9684, respectively. Whereas PM10 was modestly associated with pneumonia as a significant ratio was 0.6079. (Hongthong et al., 2017). This similar to another finding of the strongly association between PM10 and

severity of COPD with statistical significance of 5.85 times comparing between exposure and un–exposure periods (Pramuansup et al, 2013).



Disease	Correlation coefficient (R^2)			
	PM10	Rainfall	Relative humidity	Temperature
Influenza	0.8217 (-)	0.8842 (-)	0.9375 (+)	0.8775 (-)
Pneumonia	0.6079 (-)	0.7746 (-)	0.7621 (+)	0.9684 (-)

Note: (+) mean disease increase when air parameter increased
(-) mean disease decrease when air parameter decreased

Figure 6. Distribution of cases and relationship between respiratory diseases and air parameters in Chiangrai, Northern Thailand (Hongthong et al., 2017)

Moreover, PM10 and PM2.5 emissions from forest fires were related to visibility reduction in Chiangmai This could be applied in epidemiological assessments of population exposure to airborne particles where measurements of fine particle mass are not available. A wildfire controlprogram should be seriously concerned to mitigate the visibility effect and public health impacts (Jeensorn et al., 2018). The annual quantity of rice straw residues that are subject to open burning in Thailand is 10.5 Tg and the percentage of rice straw open burnt in Thailand is counted as 48% of Southeast Asia, (Gadde et al., 2009), therefore, there should be more concern on local effects on health and the environment from PM2.5 in Thailand.

EFFORTS TO SOLVE THE PROBLEM OF AIR POLLUTION

Thailand has general and specific laws and regulations for preventing and mitigating forest fires and air pollution to protect public health and environment from the impacts arising from both domestic and transboundary sources (Tiyapairat, 2012).

Engagement concerning regional pollution problems dates back to 1977. Trans–boundary pollution was taken up at the official ASEAN level with Kuala Lumpur Accord on environment and development in 1990 and the ASEAN Singapore summit of 1992. However, these declarations were limited in scope and it took about serious levels of intense haze in 1994 to trigger the ASEAN cooperation plan on trans–boundary pollution to finally put this issue firmly on the regional security map (Roberts, 2012).

More recently, ASEAN has introduced management strategies, and zero–burning best practices. Nevertheless, despite the international effort, local efforts in northern Thailand have proven difficult to coordinate. Attempts to impose 90–day burning bans, or even offers of 5000THB reward to those willing to divulge information about outdoor burning, have not yielded results (Gebhart, 2013). The provincial office for Natural Resources and Environment of Chiangrai (2011) reported partnership between private and public sectors in solving the issue of air pollution in Chiang Rai province, but due to the lack of substantial cooperation, there is still not a strong operational plan, as such, the problem persists.

Pollution Prevention and Mitigation Policy (1997–2016)

Policy:

1. Accelerate the reduction of air pollution initially from vehicles, industry, construction, and transportation.
2. Maintain air quality in areas that have air quality that is within designated standards, not allowing it to be degraded below designated standards.
3. Promote and support utilization of low pollution transportation systems.
4. Promote participation among the government, private sectors and the general public, including both polluters and affected people, for the conservation of air quality.

The goals of this policy include: air quality in pollution control zones and urban areas, particularly dust level, will be within designated ambient air quality standards, other pollutants in ambient air will remain within designated standards, particularly carbon

monoxide, beginning in 1997, the concentration of air pollutants in industrial zones and general communities, particularly sulfur dioxide and nitrogen oxide level will be within designated standards.

The second National Environmental Health Strategic Action Plan 2012–2016

The past performance and situation review revealed that after the Cabinet had assigned relevant state agencies to implement the first National Strategic Plan for Environmental Health (2009–2011), in 2010, Ministry Of Public Health conducted the programmer for monitoring and evaluation and found that 60% of the relevant agencies had implemented the plan. Such a low level of plan implementation might be due to the lack of understanding and perception of the Strategic Plan and inadequate budget and personnel (in terms of both quantity and quality). It was discovered that the time frame (2 years) was low, and the announcement time (December) had already exceeded the budget period (May–August). Additionally, government officials have limited knowledge, understanding and experience on operation in the field of environmental health. However, it was equitably reported that factors that can make this plan successful are raising awareness in every sector (both government and private) of environmental health problems, participating of Thai people, and the potential and capacity of the government sector (MOPH and MNRE, 2012).

CONCLUSION AND FUTURE DIRECTIONS

Reviewed literature revealed that open burning of agricultural residues is a major contributor to air pollution which generates toxic substances, hence affecting human and animal health. Air pollution is a worldwide public health challenge. It had been linked to various chronic diseases and death in millions. In order to prepare land for a new planting season, open burning of agricultural residues is a common way of managing farm wastes in Northern Thailand where a lot of farming activities take place. This practice leads to the emission of toxic substances and pollutants with PM10 being the most common. These pollutants have been implicated in the cases of respiratory problems in the region during the burning season. Neighboring countries of Laos and Myanmar also contribute to the problem, as burning activities performed in those areas lead to transboundary haze. A lot still needs to be done in terms of working with neighboring countries on managing transboundary smoke

haze. The earlier this is done, the better for the parties involved as witnessed in the case of Maesai, a district on the boundary between Thailand and Myanmar, which recorded its highest level of smoke haze in March, 2016. In order to reduce the public health challenges, several efforts have been made via public and private partnerships, policy formulation and implementation and awareness campaigns. However, even in 2016, open burning is still the most common method of managing agricultural wastes regardless of the accompanying public and environmental health impacts. Despite suggestions of alternative methods of waste disposal and the presence of monitoring stations, air quality is still affected during burning season. Reviewed literature showed that burning is the cheapest alternative preferred by farmers. Policy makers and researchers alike can do more regarding workable alternatives to open burning. Reviewed literature reported the involvement of organizations that require crops as raw materials, as a result this lead to the generation of more agricultural wastes.

Nowadays, farmers have to farm two or three times compared to the past because of the high commercial demand of sugarcane, corn and rice. Thus, policies involving partnership with such organizations on how to effectively manage agricultural wastes after harvesting can be put in place, instead of making it the sole responsibility of farmers to manage wastes after harvest. Lastly, there is limited literature on the health impacts of open burning in Northern Thailand; moreover, some data and information are provided in Thai only. This hinders access to the information on issues regarding air pollution. Therefore, there is a need to avail information in other languages for non–Thai researchers who are interested in the issue. Further research in the said area and identification of the major factors related to open burning are needed in order to create awareness and provide a direction towards achieving better results compared to those in the past. As for transboundary haze pollution in the Northern Thailand, it requires collaborative actions by various agencies and stakeholders of Thailand, Lao and Myanmar, together with a consideration on problem solving in terms of cooperative policy and agricultural waste management technology.

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