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Using GIS Tools to Estimate Health Risk from Biomass Burning in Northern Thailand

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Abstract

The assessment of adverse health effect from air pollutants exposure in the north of Thailand was studied. Eight provinces were in the risk areas from biomass burning pollutants which occurred in the dry season from January to April annually. The haze pollutants are from the burning of agricultural wastes to prepare for the next crops plantation in addition to natural forest fires. The pollutants such as, fine particulate matter (PM_{10}), carbon monoxide (CO) and ozone (O_3) have adverse health effects to the resident and tourists in this area. Daily concentrations of three monitored air pollutants (PM_{10}, O_3, CO) during January 2011-December 2015 were provided by the Pollution control department in Thailand. Each individual was geo-coded in ArcGIS10.1 software. The spatial distribution of three pollutants and the temporal-spatial specific air pollutants exposure level for each individual was estimated by the Inverse Distance Weighted (IDW) interpolation. The Hazard Quotient (HQ) of PM_{10}, CO and O_3 were calculated from the ratio of exposure concentration and reference concentration Hazard Indices (HI_{PM10,CO,O_3}) are calculated from summation of HQ. The HI of each co-ordinate areas were compared and illustrated by a GIS-based map. In the dry season, most areas were exposed to air pollution and HI >1 which indicated potential health risks. The hazard map identified from average HI in 2011-2015, indicated potential health risk areas in the dry season were Chiang Rai, Mae Hong Sorn, Phayao and Phrae.

Keywords: GIS, Health risk, Northern haze, Thailand.

Introduction

The Geographic Information System (GIS) is a tool that can analyze, manage and present data that are linked to geographical locations. GIS based models can be applied in a multi objective assessment related to air quality data to predict the outcome and identify the risk areas (Pilla and Broderick, 2015; Pope and Wu, 2014). The wild fire emissions in several regions were mapping and defined the potential risk locations as hot spots using air modeling and GIS (Youssouf et al., 2014; Chuvieco, et al., 2010). In this present work, the air pollution distribution and risk areas were interpolated and compared between two events with and without biomass burning. The investigated area, north Thailand, covered 85,852.40 km^2 with valley topography surrounded by paddy-fields and sandwiched in between mountain ranges. There were eight provinces, namely, Chiang Rai, Chiang Mai, Nan,Phayao, Phrae, Mae Hong Son, Lampang and Lamphun with population 5,672,168. People living in this area could expose to air pollutants from the burning of agricultural wastes and natural bush fires. In the north of Thailand forest fires usually occur in the dry season from December to May. The frequent and extensive bushfires have increased annually from 2011 to 2015, particularly in upper north of Thailand. The information of a number of times the fire occurred was compared and summarized in Table 1. The highest frequency of bushfires occurred in 2015 (FFCD, 2015).

Table 1. *The Annual Comparison between Frequency of Fire (Time) and the Impact Area (1 rai = 0.4 acre) in 8 Provinces, North Thailand*

Provinces	2011		2012		2013		2014		2015	
	(time)	(rai)	(time)	(rai)	(time)	(rai)	(time)	(rai)	(time)	(rai)
Chiang Rai	31	85	181	922	98	690	91	905	147	1,130
Chiang Mai	448	2,796	865	6,264	1,361	14,541	937	9,044	1,179	12,611
Nan	2	8	29	311	123	1,260	88	972	78	934
Phayao	39	165	76	317	38	194	36	327	62	429
Phrae	42	227	158	1,470	147	1,011	111	927	140	1,004
MaeHongSon	176	820	413	2,499	508	2,955	429	2,919	471	3,840
Lampang	131	669	242	1,463	310	1,994	375	1,746	399	2,958
Lamphun	162	943	219	1,557	166	1,449	238	1,959	297	3,552
Total	**1,031**	**5,713**	**2,183**	**1,4803**	**2,751**	**2,4094**	**2,305**	**18,799**	**2,773**	**26,458**

Wildfires, biomass burning or vegetation fires have become more concerned in public health and ecosystems impacts. Emissions from biomass burning include large amount of gaseous compounds and particulate matters contributing to the air environment. The relative contribution of wildfire emissions to the global annual emissions is approximately 64% primary organic carbon (POC), 32% of black carbon (BC), 41% of carbon monoxide (CO) and 15% of nitrogen oxides (NOx). These pollutants can have short or long term health effects on the exposed populations (Youssouf et al., 2014; Viswanathan et al., 2006; Johnston et al., 2002). From previous reports, potential risk from air pollutions were found associated with visibility, non-carcinogenic effect, carcinogenic and mutagenic risk (Jinsart et al., 2014; Pungkhom and Jinsart, 2014; Vinitketkumnuen et al., 2002). In this study, we aim to identify the hazard areas effect from major emissions, PM$_{10}$, CO and

NO_2. These pollutants were chosen as the main pollutants due to their health significance and their complete data set from ambient air monitoring stations. Pollution distribution and health risk area maps were interpolated and illustrated as hazard index map using GIS model.

Methodology

Site Location & Monitoring Station

The eight provinces in the north of Thailand, namely, Chiang Rai, Chiang Mai, Nan, Phayao, Phrae, Mae Hong Son, Lampang and Lamphun with 10 monitoring stations were shown in Figure 1. Air quality data from 2011 to 2015 were obtained from Pollution Control Department. Air Pollutions were measured followed the standard methods, PM_{10} by Beta attenuator air sampling average 24 hours in $\mu g/m^3$, CO by Non-Dispersive Infrared Detection average 8 hours in ppm, O_3 by Ultraviolet Absorption Photometry average 8 hours in ppb. Measurement methods were consistent among monitoring stations.

Figure 1. *Study Sites Location and Monitoring Stations: Natural Resources and Environment Office, Chiang Rai (NR), City Hall, Chiang Mai (CM), Yupparajwittayalai school, Chiang Mai (YM), Sob Pad Lampang (SL), Ta See,Lampang (TL),Natural Resources and Environment office, Mae Hong Son (NH), Natural Resources and Environment office, Lamphun (NP), Knowledge park, Phayao (KY), Meteorological, Phrae (MP), Muang Nan Municipality office, Nan (MN)*
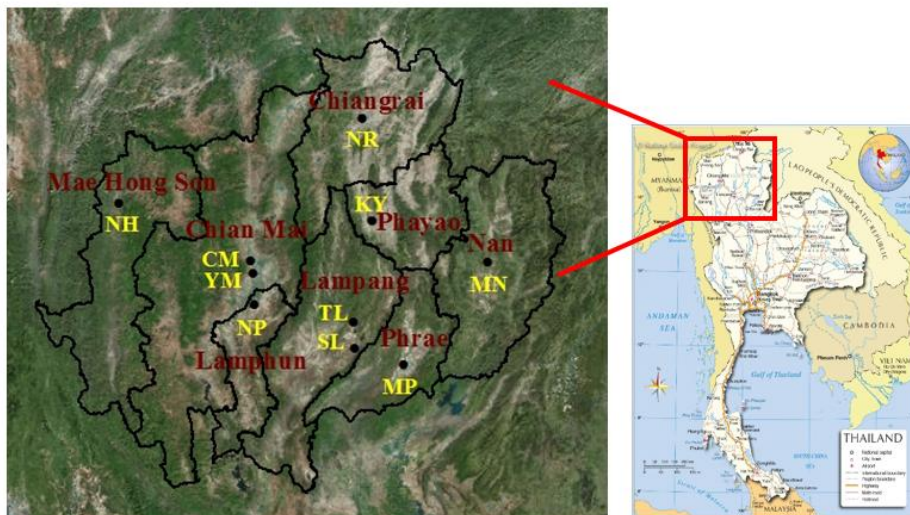
Exposure Assessment

The association between the health risk of pollutants exposed from the monthly incidence of haze pollutants were studied. Inhalation exposure concentrations, EC_{inh} ($\mu g/m^3$) were calculated from ambient air quality data by equation1.

$$EC_{inh} = C \times ET \times EF \times ED /AT \qquad \text{Equation 1}$$

Where: C: concentration of each pollutants:PM_{10}, CO and O_3 ($\mu g/m^3$); ET: exposure time (24 hours/day); EF: exposure frequency (350 day/year); ED: exposure duration (30 years); AT: average time (for non-carcinogens, AT = ED in years $\times$ 365 days $\times$ 24 hours/day). All parameters used in the calculation EC_{inh} were found in reports published by U.S. EPA (2009).

Risk Characterization

Risk Characterization ware separately quantified for non-carcinogenic effects. PM_{10}, CO and O_3 were evaluated by the hazard quotient (HQ), equation2.

$$HQ = EC/ RfC \qquad \text{Equation 2}$$

Where: RfC is inhalation reference concentration; $CO = 2.3 \times 10^1 mg/m^3$ O_3 $= 1.8 \times 10^{-1} mg/m^3$ OEHHA (2014) (http://oehha.ca.gov/air/allrels.html); $PM_{10} = 50 \mu g/m^3$ WHO (2005).

The hazard index (HI) is the summation of HQ, equation 3.

$$HI = \Sigma HQ \qquad \text{Equation 3}$$

Where: HI is used to assess the overall potential for non-carcinogenic defects exposed by more than one chemical. HI below one indicates that there is no significant risk of non-carcinogenic effects. Conversely, if HI is more than one, there should be a risk of non-carcinogenic effects occurring, with a probability increase as the value of HI increases (U.S. EPA, 2013).

Statistical Analysis

For the monitoring data treatment, the Anova ($p < 0.05$) was applied to determine the statistical significance for the differences between the means of season variation. Fisher's Least Significant Difference (LSD) method is used in Anova to create confidence intervals for all pair wise differences between factor level means while controlling the individual error rate to a specific

significance level. Therefore, LSD was used to test frequency of risk areas from year 2011 to 2015.

Geographic Information Systems

PM$_{10}$, CO and O$_3$ concentration distribution and Hazard indices (HI) were mapping. To measure the distances, a geodesic calculator was used to convert Bath-Geo WGS84 projection coordinates (longitude/latitude) into the Universal Transverse Mercator (UTM) Zone 47(47N) (http://twcc.fr/). Spatial data of HI were prepared in the spread sheet before upload in the GIS map using the ArcGIS version 10.1. The spatial distributions of different variables were illustrated. The small variations of the pollutants concentrations in the study area were estimated. We used the Inverse Distance Weighted (IDW) interpolation method to estimate the hazard and self-maps illustration. Weights for sample values of each input points were normalized inverse of the distance from the control point to the interpolation point. It weights the points closer to the processing points more than those further away. A required number of points within a specified radius are used to determine the output value for each location (Thepanondh and Toruksa, 2011).

Results and Discussion

Data Treatment

From Anova test, the ambient air pollution concentration among 10 stations was statistical significance different ($p < 0.05$) between the dry season and the wet season in 2011-2015. The results of the Least Significant Difference (LSD) analysis indicated that Mae Hong Sorn, Phayao and Phrae were high frequency risk areas.

Air Pollution Distribution

Biomass burnings frequently occurred in the dry season, thing which caused severe haze in the areas while in the wet season, haze was not found.The frequency and expansion of bush fire has been increasing each year. From Table 1, in 2013, 2014 and 2015 the fire events occurred 2,751, 2,350 and 2,773 times respectively (FFCD, 2015). Among three related biomass burning pollutants, PM$_{10}$, CO and O$_3$, PM$_{10}$ were found as the major pollutants in all the sites. Particularly in the dry season, Jan-Apr, PM$_{10}$ levels were higher than National Ambient Air Quality Standard (120μg/m^3). The comparison of the monthly average PM$_{10}$ from 2011-2015 was shown in Figure 2 which was found in the same trend.

Hazard Quotient (HQ)

The exposure concentrations of PM_{10}, CO and O_3 were calculated from ambient air concentrations following the equation 1. Then HQs were calculated from the equation 2. For example, HQs of 10 monitoring sites in 2012 were compared in Table 2. All sites have HQ_{CO} and $HQ_{O3} < 1$ which could mean no potential adverse health effects from CO and O_3. The HQs of PM_{10} all sites in the dry season and long term annual HQ at MP and NR stations found HQ >1. These indicated potential health impacts from PM_{10} exposure that could harm the population in the areas.

Figure 2. *PM_{10} Distributed in 2011-2015, Comparison Dry Season   (January - April) and Wet Season (July- October)*
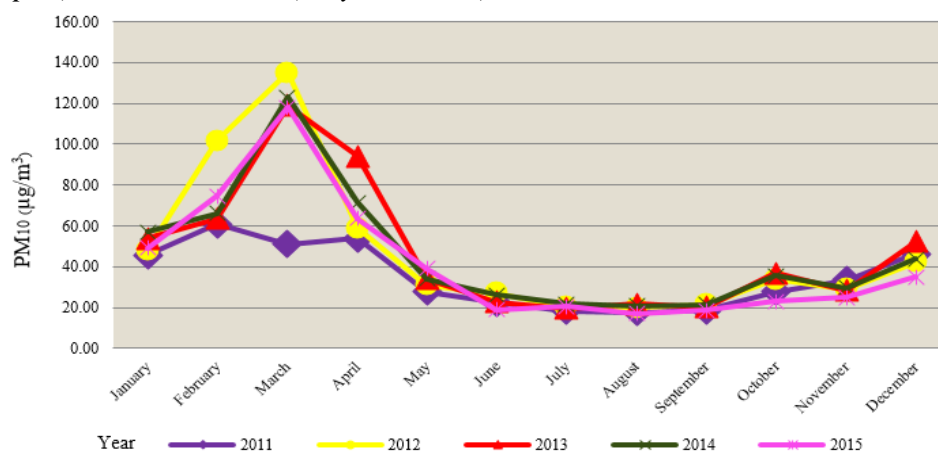
Table 2. *HQs of PM_{10}, CO and O_3 Exposure in 2012*

Pollutant	Station	Dry Season		Wet Season		Annual	
		EC ($\mu g/m^3$)	HQ	EC ($\mu g/m^3$)	HQ	EC ($\mu g/m^3$)	HQ
PM_{10}	SL	78.89	1.58	26.27	0.53	46.78	0.94
	TL	82.68	1.65	29.17	0.58	46.22	0.92
	CM	71.51	1.43	23.42	0.47	41.34	0.83
	YM	62.11	1.24	27.78	0.56	40.27	0.81
	NR	94.91	1.90	23.37	0.47	50.66	1.01
	NH	95.03	1.90	13.38	0.27	42.63	0.85
	NP	84.10	1.68	20.14	0.40	44.28	0.89
	KY	91.43	1.83	18.58	0.37	48.64	0.97
	MP	90.11	1.80	25.32	0.51	51.72	1.03
	MN	76.09	1.52	20.26	0.41	41.98	0.84
CO	SL	1.18	0.05	0.63	0.03	0.84	0.04
	TL	0.52	0.02	0.27	0.01	0.37	0.02
	CM	0.74	0.03	0.41	0.02	0.56	0.02
	YM	1.21	0.05	0.58	0.03	0.80	0.03
	NR	1.24	0.05	0.55	0.02	0.80	0.03
	NH	1.10	0.05	0.41	0.02	0.68	0.03
	NP	0.88	0.04	0.41	0.02	0.59	0.03
	KY	0.63	0.03	0.36	0.02	0.47	0.02
	MP	1.02	0.04	0.71	0.03	0.80	0.03
	MN	0.88	0.04	0.36	0.02	0.53	0.02

|						
	SL	0.07	0.39	0.02	0.12	0.04	0.24
	TL	0.06	0.31	0.02	0.09	0.03	0.18
	CM	0.07	0.37	0.02	0.12	0.04	0.23
	YM	0.05	0.30	0.02	0.13	0.04	0.21
O_3	NR	0.05	0.29	0.02	0.13	0.04	0.20
	NH	0.05	0.25	0.02	0.09	0.03	0.16
	NP	0.04	0.22	0.03	0.17	0.04	0.21
	KY	0.07	0.40	0.03	0.16	0.05	0.27
	MP	0.06	0.31	0.03	0.18	0.04	0.24
	MN	0.06	0.33	0.03	0.14	0.04	0.21

Hazard Index (HI)

The hazard index (HI) of short term and long term exposures were calculated from equation 3. HI and related areas were summarized in Figure 3. For the short term in Non-Haze wet season, HI was lower than 1 at all sites but in the dry season HI was higher than 1. The risk areas were identified by different HI and the impact sites were illustrated by GIS-based maps in Figure 4. Health risk areas in north Thailand were identified by province and site locations. In the dry season, there was potential risk from exposure of high level of pollutions, particularly PM_{10}. HI of all sites was more than 1 which indicated potential health risk. Most hazard areas were varied such as in 2011 at Phayao (KY); in 2012 at Chiang Rai (NR), Mae Hong Sorn (NH), Phayao (KY) and Phrae (MP); in 2013 at Mae Hong Sorn (NH), and Phrae (MP); in 2014 at Phrae (MP) and in 2015 at Chiang Rai (NR), Mae Hong Sorn (NH), Phayao (KY) and Phrae (MP). From both hazard map and average HI in 2011-2015, four high risk provinces were located in Chiang Rai (NR), Mae Hong Sorn (NH), Phayao (KY) and Phrae (MP), Figures 3 and 4.

Figure 3. *Hazard Indices ($HI_{PM10,CO,O3}$) of the Eight Provinces, Sites Comparison during Dry Season and Wet Season in 2011-2015*
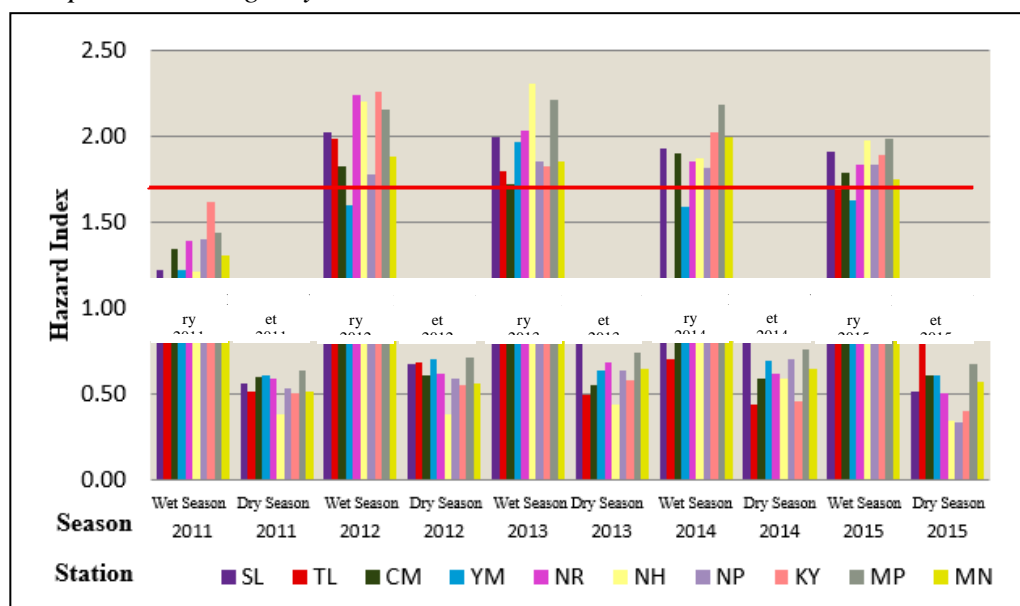
Figure 4. *GIS Base Map of HI$_{PM10,CO,O3}$ in North Thailand, Risk Area* ☆
(A) 2011 Dry Season, (B) 2012 Dry Season, (C) 2013 Dry Season,
(D) 2014 Dry Season, (E) 2015 Dry Season, (F) 2015 Wet Season
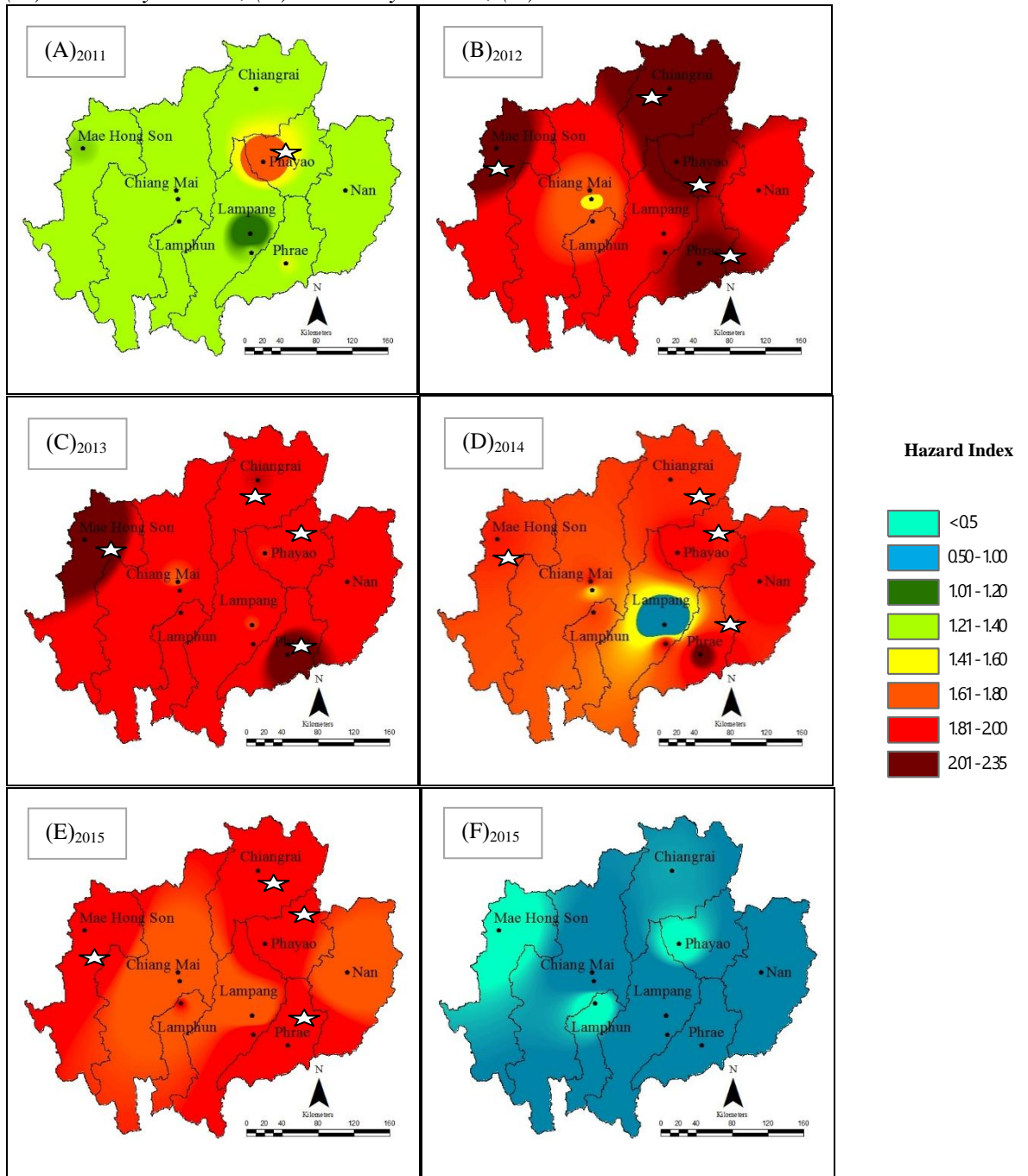
However, when compared between land use data and the hazard areas, from 2008-2015, Table 3, agriculture areas in all eight provinces were increasing (LDD, 2015). This could induce more biomass burning from agriculture wastes and spread to the wild land. Among 8 provinces in comparison, largest agriculture areas were covered in Chiang Rai, 3,551,846

rai. While in Phrae, agriculture areas was found highest increasing from 22% to 28% increased 725180 rai (1 rai = 0.4 acre). Although in Mae Hong Sorn, the vegetation areas were not much increased, only 216,604 rai but there was continuous increasing of wildfire areas as shown in Table 1. Therefore the wildfire emissions were dominant in this province including the pollutants transported from the border line. In the case of, Phayao had increasing land use for agriculture 158,440 rai, Table 3 but showed high level of air pollutions and HI which implied that some other source emissions from new urbanization areas were contributed to this high risk zone. The further monitoring and pollution prevention policy was recommended for Chiang Rai, Phrae, MaeHongSorn and Phayao.

Table 3. *Land Use Data of Agriculture Area (rai) and Percentage % Compared to Total Province Area in North Thailand, Data were Summarized from Two Groups of Survey Year Duration in 2008-2010 and 2012-2015 (2011 No Data)*

Land Use: agriculture areas (1 rai = 0.4 acre)					
Province	Years 2008 - 2010		Years 2013 - 2015		Increasing
	Rai	%	Rai	%	Rai
Chiang Rai	3,217,613	44.07	3,551,846	48.66	334,233
Chiang Mai	2,777,253	22.02	3,004,782	23.91	227,529
Nan	1,912,265	26.67	2,420,786	33.76	508,521
Phayao	1,430,728	36.14	1,589,168	40.1	158,440
Phrae	890,881	21.79	1,616,061	28.41	725,180
MaeHongSon	1,168,741	14.76	1,385,345	17.48	216,604
Lampang	1,311,388	16.74	1,690,953	21.56	379,565
Lamphun	797,199	28.31	864,976	30.7	67,777

Source: http://www.ldd.go.th/web_OLP/report_research_N.html #north.

Conclusions

The HI's of each of the co-ordinate areas were compared and illustrated by a GIS-based map. The association between exposure concentration and risk areas were compared. In the dry season, HI of eight provinces was more than 1 which indicated potential health risk. From hazard map and average HI, three high risk provinces in the north Thailand were Mae Hong Sorn, Phayao and Phrae.

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