Health Risk Assessment from Bush Fire Air Pollutants using Statistical Analysis and Geographic Information System: A Case Study in Northern Thailand

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Abstract
The association between fine particulate matter (PM_{10}), carbon monoxide (CO), ozone (O_3), volatile organic compounds (VOCs) and health risk were analysed from the air quality data and frequency of fire events in 2009-2013. The risk areas and Hazard Quotient (HQ) were compared and illustrated by Geographic Information System (GIS). Hazard Index (HI) of CO, O_3 and BTEX were significantly correlated with r = 0.57, 0.55 and 0.55 ($p < 0.05$) respectively. Carcinogenic risk of benzene and ethyl benzene were associated with fire events, r = 0.79 and 0.31 ($p < 0.05$) and the unit risk was higher than standard level, 1×10^{-6}.

1. Introduction

The 8 provinces in the north of Thailand covered the areas of 85,852.26 km^2. The land topography and general environment are the valleys, surrounded by paddy-fields and sandwiched in between mountain ranges (http://www.dopa.go.th/padmic/jungwad76/-jungwad76.htm). There are 6,141,268 people living in this region. The population density is about 71.5 person/km^2 (http://stat.bora.dopa.go.th/stat/y_-stat55.html). The environmental problem in this area mainly resulted from the burning of agricultural waste materials to prepare the planting areas and the fire was often spread to the forest nearby. This incident has occurred annually in the dry season from February to April. The frequency and extensive of bush fire has been increasing each year. For example, in 2011, 2012 and 2013 the fire events occurred 1,266, 2,686 and 3,252 times respectively (http://www.dnp.go.th/ forest fire /2546/firestatistic-%20Th.htm). Figure 1 is a comparison of two regional haze maps in March 2013 and November 2013. It is clear that the hotspot temperature was higher in March than in November, particularly in the northern part of Thailand. The hotspots depicted in the map are derived from the NOAA-18 satellite. Hotspots go undetected when the area is not covered in the satellite pass or under cloudy / overcast conditions. The surface winds (depicted by arrows in the map) are valid for 0600 UTC on the date indicated in the map. The length of the arrow represents the relative wind speed. The longer arrows correspond to the stronger winds. This map is updated by 1000 UTC (6 pm SGT) daily. Figure 1a shows that the widespread hotspots continued to be detected over Myanmar, Lao PDR, Cambodia, Vietnam and Thailand due to dry weather conditions in the northern ASEAN region. Moderate smoke haze was observed over northern Thailand. In The southern ASEAN region, isolated hotspots were detected in Peninsula Malaysia Borneo and Sumatra. Figure 1b shows that wet weather conditions prevail over the southern ASEAN region. Isolated hotspots were detected mainly in Borneo, Cambodia and southern Vietnam. The burning of forest creates large amount of particulate matter, PM_{10}, carbon monoxide (CO) and other pollutants which have adverse health effects (Viswanathan et al., 2006 and Johnston et al., 2002). From previous reports the health impact of PM_{10} in Bangkok were found associated with respiratory symptoms and cardiovascular diseases (Lungkulsen et al., 2006 and Buadong et al., 2009). Nevertheless, the air pollutants in Bangkok are mainly from vehicle combustions while in the north of Thailand, the major source of pollutants could come from the bush burning. In this study, we aim to illustrate the impact of bush fire on both the air quality and the health risk in the north of Thailand.

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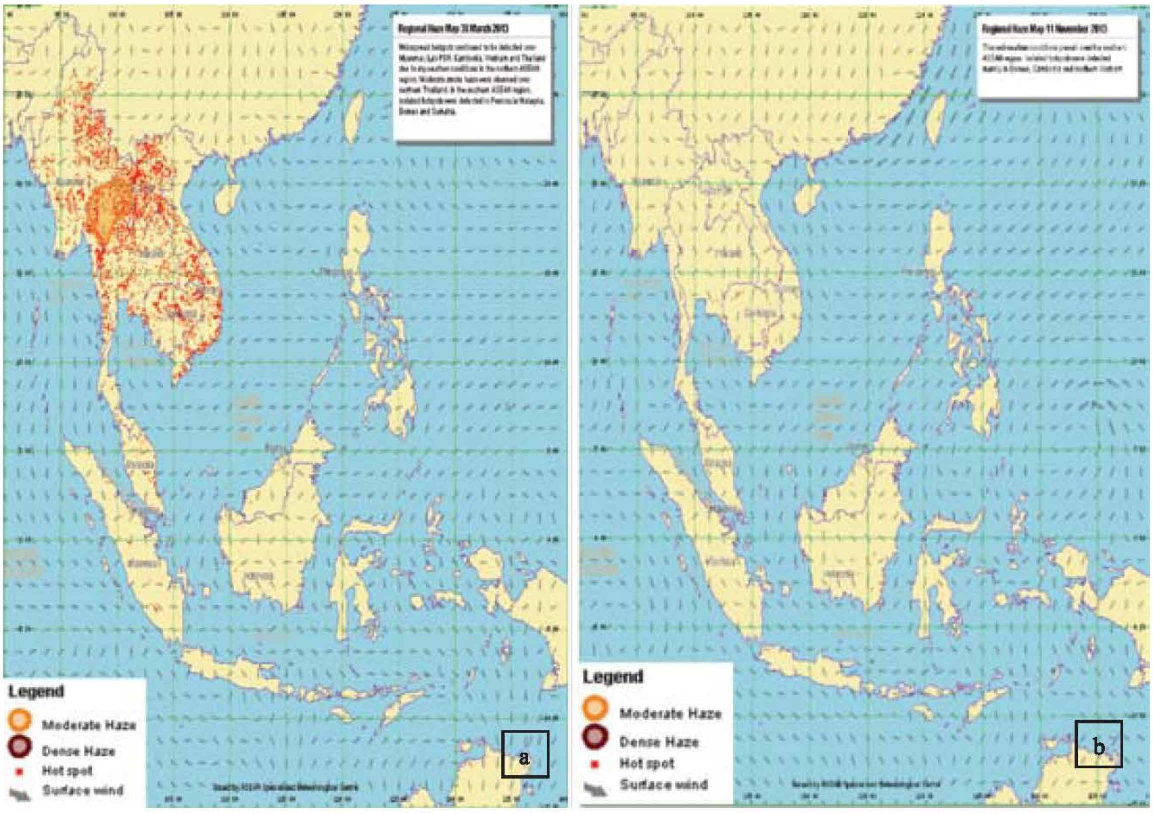

Figure1: Fire Maps of Thailand and vicinity areas, (a) date 30 March 2013 (b) date 11 November 2013 (http://www.weather.gov.sg/wip/c/portal/layout?p_l_id=PUB.1003.538)

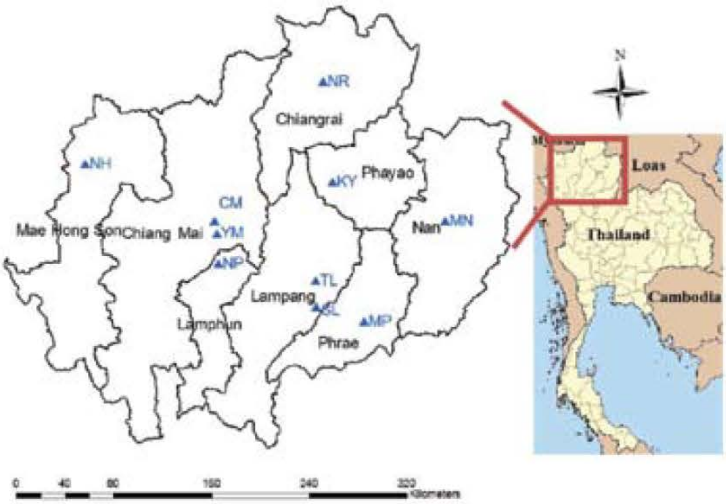

Figure 2: The studied site and location of 10 air pollutants monitoring stations: Sob Pad Lampang (SL), Ta See, Lampang (TL), City Hall, Chiang mai (CM), Yupparaj wittayalai school, Chiang mai (YM), Natural Resources and Environment office, Chiangrai (NR), Natural Resources and Environment office, Mae Hong Son (NH), Natural Resources and Environment office, Lamphun (NP), Knowledge park, Phayao (KY), Meteorological, Phrae (MP), Muang Nan Municipality office, Nan (MN)

2. Methodology

2.1 Studied Sites and Data Information

The location of 8 provinces in the upper north of Thailand, namely, Chiang Mai, Chiangrai, Lamphun, Lampang, Phrae, Nan, Phayao and Mae Hong Son with 10 monitoring stations were shown in Figure 2. Daily air quality data from 2009 to 2013 were obtained from Pollution Control Department. Air Pollutions were measured followed the standard methods, average 24 hours PM_{10} ($\mu g/m^3$) by Beta attenuator air sampling, average 8 hours CO (ppm) by Non-Dispersive Infrared Detection, average 8 hours O_3 (ppb) by Ultraviolet Absorption Photometry and average 24 hours VOCs sampling by canister air samplers and analysed by Gas Chromatography / Mass Spectrometry, GC/MS following US EPA Method TO-15. http://www.epa.gov/-ttnamti1/files/ambient/airtox/-15r.pdf

2.2 Exposure Assessment

The association between the health risk of pollutants exposed from the monthly incidence of bush fires were studied. Inhalation exposure concentrations, EC_{inh} ($\mu g/m^3$) were calculated from ambient air quality data by equation 1.

$$EC_{inh} = C \times ET \times EF \times ED / AT$$

Equation 1

Where: C: concentration of each pollutants: 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 × 365 days × 24 hours/day; for carcinogens, AT= 70 year × 365 days × 24 hours/day). All parameters used in the calculation EC_{inh} were found in reports published by US EPA (2009).

2.3 Risk Characterization

Risk Characterization ware separately quantified for non-carcinogenic and carcinogenic effects. CO, O_3 and BTEX health risks were evaluated by the hazard quotient (HQ), equation 2. Carcinogenic risks (CR) were evaluated from inhalation concentration of benzene and ethylbenzene by equation 3.

$$HQ = EC / RfC$$

Equation 2

$$CR = IUR \times EC$$

Equation 3

Where: RfC is inhalation reference concentration ($\mu g/m^3$) IUR is inhalation unit risk $(\mu g/m^3)^{-1}$.The RfC and IUR were downloaded from the US EPA website (http://www.epa.gov/region9/superfund/prg-/index.html). According to the classification group orders defined by the International Agency for Research on Cancer (IARC, 2011), benzene is a class 1 carcinogenic agent, and ethylbenzene is in class 2B. Toluene and xylenes have been categorized as non-carcinogenicity to human, reflecting the lack of evidence for the carcinogenicity of these two chemicals. The risk assessment and hazard quotient in this paper will analyse only the carcinogenic risk of benzene and ethylbenzene.

2.4 Statistical Analysis

For the data treatment, the t-test was applied to determine the statistical significance ($p < 0.05$) of the differences between the mean concentrations of both events, bush fire and without bush fire. The linear regression analysis is used in the relationship test between the air pollution exposure concentration and health risks with $p < 0.05$ were applied to indicate the statistical significance and describe the relationships among these two variables (Hinkle et al., 1998).

2.5 Geographic Information Systems

The Geographic Information System (GIS) has been used as a tool to map wild land fire risk in several regions (Henderson et al., 2008 and Chuvieco et al., 2010). In this study, air pollution distribution and risk areas were mapped to compare two events with and without bush fire in the north of Thailand.

To measure distances, a geodesic calculator was used to convert Bath-Geo WGS84 projection coordinates (longitude/latitude) into the Universal Transverse Mercator (UTM) Zone 47(47N). Spatial data of air pollution and HQ were prepared in spread sheet before upload in the GIS map using ARCGIS 9.3. The spatial distributions of different variables were illustrated. The small variations in pollutant concentration in the study area were estimated. The kriging running mode was selected for self-maps illustration. Kriging is regarded as the best linear unbiased estimator. Weights for sample values are calculated based on the parameters of the semivariogram model. The sum of all weights is normalized equal to 1. By this calculation, kriging variances or estimation errors were minimized (Moral et al., 2006). This is to ensure the unbiased estimation.

3. Results and Discussion

3.1 PM_{10}, CO and O_3 Concentration in with Bush Fire and without Bush Fire

The example of the ambient PM_{10}, CO and O_3 in the north areas in two scenarios with and without fire were compared in Table 1. 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 the studied areas. The increasing of PM_{10} in the dry season was consistency with other previous reports in Chiang Mai (Vinitketkumnuen et al., 2002 and Wiriya, et al., 2013). Furthermore, the correlation between exposure concentration data and number of fire, monthly were significantly correlated with $p < 0.05$ (Figure 3). This result is directly related to the increase frequency of fire, total 3,252 times in 2013 and 2,686 times in 2012. The comparison of bushfire frequency and and air pollution levels in March 2011 and 2013, indicated the increasing of the pollutants concentrations and distributions in 2013. The contour map in Figure 4, illustrated the spatial distribution of PM_{10}, CO and O_3 in 8 provinces. Gaseous pollutants, CO and O_3 were increased in the urban areas of all 8 provinces. The high impact area from PM_{10} was in Mae Hong Son, Figure 4a and 4b.

3.2 Health risk Assessment

PM_{10} risk assessment cannot be directly calculated from the concentrations because of differences in composition. The health risk of PM_{10} can be achieved from the analysis of PM-bound compounds. For instance, by the mutation assay, Vinitketkumnuen et al., 2002 found PM_{10} and $PM_{2.5}$ collecting in Chiang Mai from 1998-1999 were mutagenic to Salmonella typhimurium strain TA 100 without metabolic activation. Wiriya et al., 2013 reported that PM_{10}-bound polycyclic aromatic hydrocarbons (PAHs) in Chiang Mai in 2010-2011 had highest toxicity equivalent concentration of carcinogenic PAHs in the dry season. PM_{10} health risk assessment was not included in this study because of limitations of the analytical data. However, the high concentration of PM_{10} related to the increasing of health impact, as no threshold for PM has been identified below which no damage to health is observed. (WHO, 2011)

Table1: The comparison of PM_{10}, CO and O_3 monthly average concentrations in March 2013 and October 2012

	March			October		
	PM_{10} (µg/m^3)	CO (pm)	O_3 (ppb)	PM_{10} (µg/m^3)	CO (ppm)	O_3 (ppb)
Mean	135.32	1.13	36	33.76	0.5	14.4
Max	221.7	1.7	46	53.1	0.8	19
Min	105.1	0.6	29	17.3	0.3	10
SD	36.21	0.38	5.63	9.64	0.14	3.06
Median	123.55	1.15	33	31.5	0.5	14.5

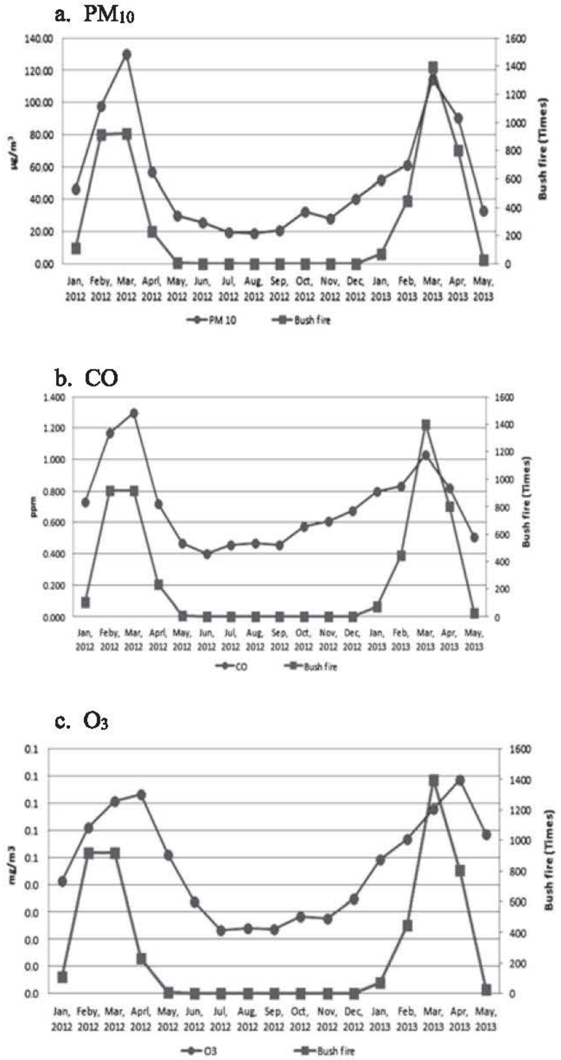

Figure 3: The correlation between exposure concentration data and frequency of fires in 2012 to 2013: (a) PM_{10}, (b) CO and (c) O_3

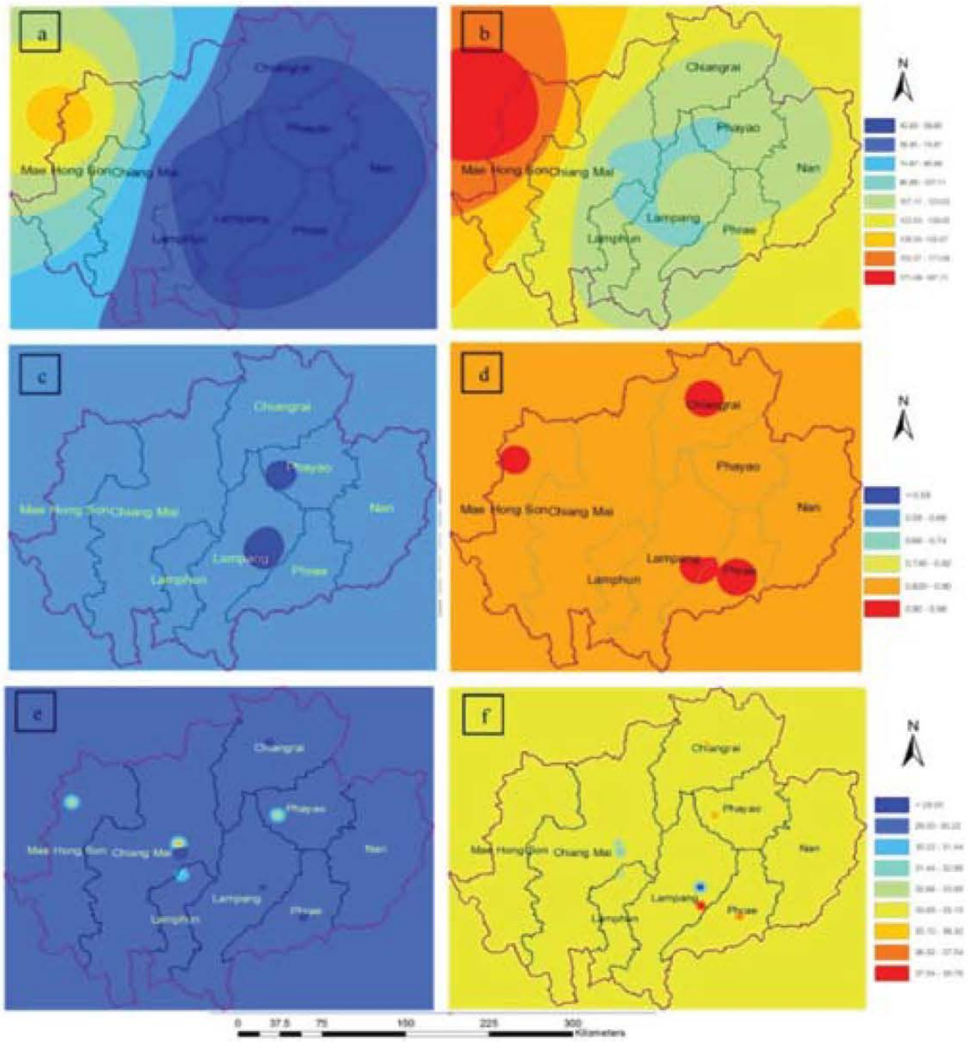

Figure 4: The comparison air pollution concentration in the upper north of Thailand during bush fire occurring in March 2011 and March 2013, (a) PM_{10} Concentration in 2011 (b) PM_{10} Concentration in 2013 (c) CO Concentration in 2011 (d) CO Concentration in 2013 (e) O_3 Concentration in 2011 (f) O_3 Concentration in 2013.

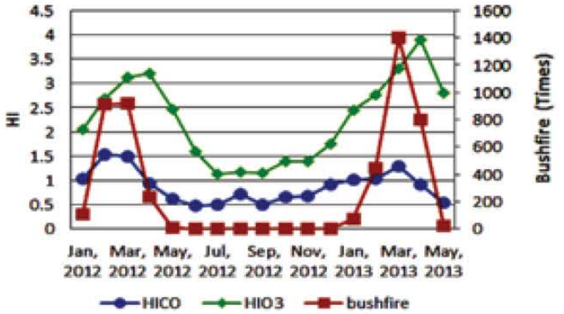

Figure 5: comparison HI value for CO and O_3 in upper north of Thailand in with bushfire and without fire

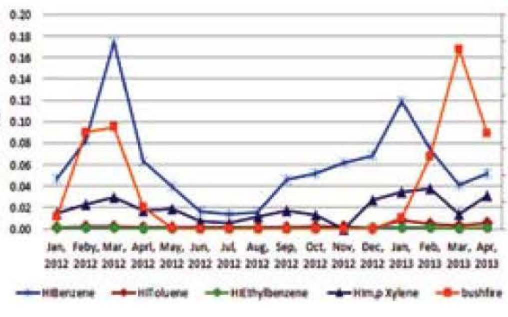

Figure 6: comparison HI value for BTEX in upper north of Thailand in with bush fire and without bushfire

Noncarcinogenic Risk: The Health Quotient (HQ) values for CO, O_3 and BTEX were less than 1. The risk still lay within the safe level. In the case of bush fire events and HQ value between March 2011 and March 2013, the HQ value of CO and O_3 in 2013 were found higher than those in 2011, (Figure 7). The hazard index (HI) is equal to the sum of HQ and is used to assess the overall potential for non-carcinogenic defects posed by more than one chemical. HI < 1 indicates that there is no significant risk of non-carcinogenic effects. Conversely, HI > 1 indicates the chance of non-carcinogenic effects occurring, with a probability of increasing health risk (USEPA, 2009). From the updated data 2012-2013, HI was increased during the dry season, in January to April. The HI of CO, O_3 and BTEX were associated with the bush fire frequency as shown in Figure 5 and 6. For the statistical analysis, HI of all pollutants was calculated from monitoring data in 2009-2013. HI_{CO}, HI_{O3} and HI_{BTEX} were significantly correlated with frequency of fire, r = 0.57, 0.55 and 0.55 respectively ($p < 0.05$). HI_{CO} and HI_{O3} were higher than the safe level (>1). In this study, there was only one station in Chiang Mai monitoring BTEX. HI_{BTEX} was assessed only in this area. However, the overall results indicated the potential non carcinogenic risk during the bush fire event.

Carcinogenic Risk: Carcinogenic risk (CR) is the probability of an individual developing any type of cancer from lifetime exposure to carcinogenic hazards. Inhalation exposure is typically the primary route of direct exposure to airborne carcinogenic agents. The carcinogenic risk of benzene and ethylbenzene were highest in March 2010 which was correlated to the frequency of fires, Table 2. According to the supplemental guidance for inhalation risk assessment Part F, USEPA, 2009, the acceptable CR for regulatory purposes is 1×10^{-6} - 1×10^{-4}. In our studies, CR for benzene and ethyl benzene were higher than 1×10^{-6} but the risk unit is still within the acceptable range. The results were calculated from the risk posed by toxic elements via inhalation. CR values for benzene and ethylbenzene were significantly correlated with frequency of fire, r = 0.79 and 0.31, ($p < 0.05$). The average of CR values for benzene and ethylbenzene in January to April (with fire) were found 12.10×10^{-6} and 1.18×10^{-6} higher than in May to December (without fire) 6.65×10^{-6} and 1.12×10^{-6} respectively.

Table 2: The monthly carcinogenic risk (CR) of benzene and ethylbenzene and the frequency of bushfire in Chiang Mai from 2009 to 2013

Month	Benzene		Ethylbenzene		Bush fire Numbers
	µg/m^3	CR (10^{-6})	µg/m^3	CR (10^{-6})	
Jan 2009	5.35	17.15	N/A	N/A	13
Feb 2009	5.15	16.51	N/A	N/A	556
Mar 2009	2.75	8.82	0.41	0.42	635
Apr 2009	2.55	8.17	0.77	0.79	184
Jan 2010	3.75	12.02	1.44	1.47	53
Feb 2010	6.60	21.15	1.62	1.66	732
Mar 2010	11.90	38.14	3.05	3.13	512
Apr 2010	3.30	10.57	0.87	0.89	324
Jan 2011	2.90	9.35	1.15	1.18	2
Feb 2011	2.45	7.85	0.65	0.66	180
Mar 2011	2.25	7.21	0.28	0.28	169
Apr 2011	2.75	8.82	0.69	0.70	97
Jan 2012	1.70	5.45	1.15	1.18	46
Feb 2012	3.00	9.62	1.49	1.53	358
Mar 2012	6.35	20.35	1.40	1.44	379
Apr 2012	2.30	7.37	0.86	0.88	81
Jan 2013	4.35	13.94	1.53	1.57	43
Feb 2013	2.70	8.65	0.63	0.65	269
Mar 2013	1.50	4.81	1.55	1.59	671
Apr 2013	1.90	6.09	1.15	1.18	356

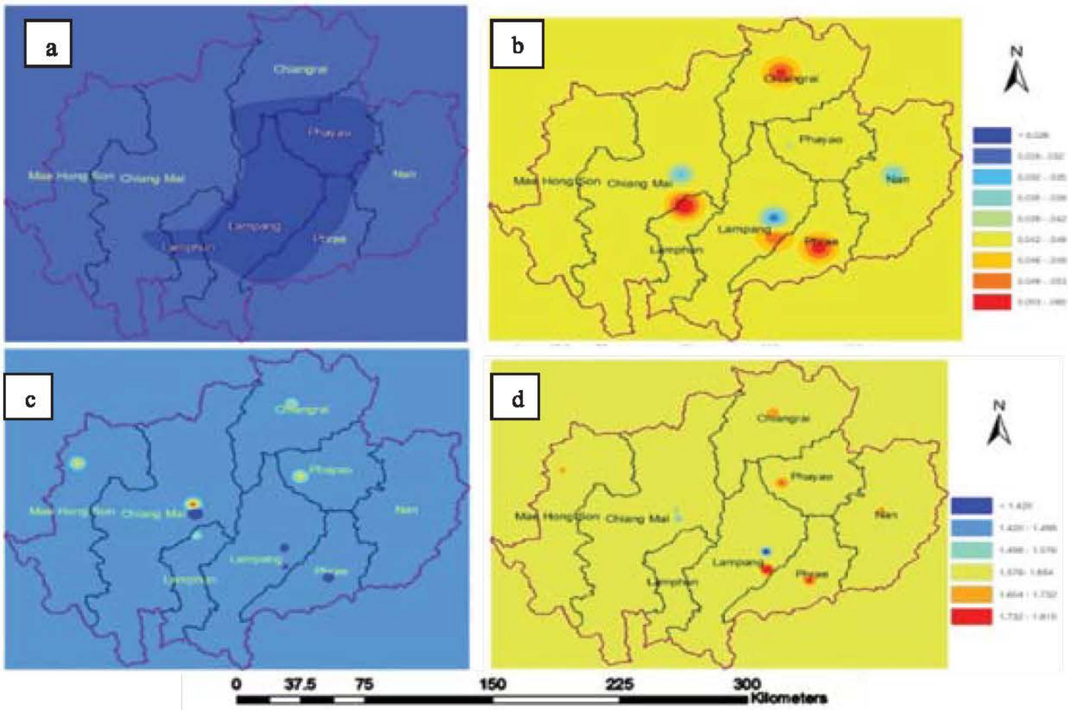

Figure 7: The comparison HQ_{co} and HQ_{O3} in the upper north of Thailand during bush fire occurring in March 2011 and March 2013, (a) HQ value of CO in 2011 (b) HQ value of CO in 2013 (c) HQ value of O_3 in 2011 (d) HQ value of O_3 in 2013

4. Conclusions

PM_{10}, CO and O_3 concentrations with bushfire were higher than without fire. During the dry season in 2013, the average daily concentrations of PM_{10} and O_3 were higher than standard level (< 120 $\mu g/m^3$ and < 0.07 ppm, respectively). This finding showed the significant of health impact related to bushfire episodes. HI of air pollutants were found significantly correlated with frequency of fires. The average Carcinogenic Risk (CR) of benzene and ethylbenzene from 2009 -2013 were 8.67×10^{-6} and 1.14×10^{-6}. Carcinogenic Risks for benzene and ethylbenzene were higher than standard level unit risk of 1×10^{-6}.

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