Estimating Health Risks in Sugarcane Burning Areas in Thailand Via a Geographical Information System Method

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The exposure level and health risk to air pollutants in the sugarcane plantation areas in Thailand were assessed in this study. Nine provinces were found to be at risk of exposure to pollutants from sugarcane burning, which usually occurs during the sugarcane harvesting season from December to May. Haze pollutants arise when the sugarcane is burned during the pre- and postharvest periods to prepare for the following crops plantation. Monthly concentrations of six haze pollutants monitored from January 2019-December 2019 were provided by the monitoring station of Thai government. ArcGIS software was used for each haze pollutant mapping in this research. The spatiotemporal specific air pollutant exposure level of each pollutant and spatial distributions of target pollutants were estimated by the overlay method. The health risk in this work were calculated using the ratios of the exposure pollutant concentrations and reference pollutant concentrations or well known in the hazard quotient values. The summation of hazard quotient or HQ values was calculated for the hazard index (HI). The HI of each area was compared and visualized using a GIS-mapping. In the pre- and postharvest seasons, sugarcane was burned, and this work showed high risk in target areas. HI values found above >1, indicating potential health risks. From January 2019-December 2019, the results of the hazard map containing the average HI values indicated that the potential at risk areas caused by sugarcane burning in the pre- and postharvest seasons were Khonkaen, Nakornsawan, Ratchaburi, Saraburi, Kanchanaburi, Nakhornratchasima, Leoi, Chonburi and Sakaeo Province, respectively.

1. INTRODUCTION

Sugarcane is grown in multiple regions throughout Thailand, and most sugarcane plantation areas in Thailand are located in the central and northeastern regions [1]. The sugarcane industry generally operates in two seasons; the sugarcane harvest (HV) season and the nonharvest (NHV) season. The HV season typically spans for six months each year, the period from December to April is the operating period of the sugarcane HV (dry season), while October to December is the non-operating periods or the NHV season (wet season) [2]. Many studies were reported some areas are often burned the sugarcane crops during the harvesting, the burning of sugarcane crops consequently generates various haze pollutants such as particulate matters (PMs), toxic gases, soot, ash, chemical aerosols and atmospheric particles with soluble ion compositions during the principal sugarcane growing region [3-4]. Those reports have revealed cause of disease of sugarcane burning and there are related to respiratory system and lung disease [5-6]. Geographic information systems or GIS are popular methods that apply to present, analyze, arrange data that are connected to geographical locations. Studies have mentioned GIS can be applied in multipurpose assessments related to environmental study and the most aspect is atmospheric data to predict outcomes and identify risk areas [7-9]. Health risk assessments (HRA) are methods for estimating the exposure risk connected to pollutant inhalation based on risk hazard. The United States Environmental Protection Agency (US EPA) were described about the health risk methods and also suggested the hazard index and hazard quotient [10-11]. The HI and HQ are used to characterize the risks posed by single chemicals and chemical mixtures, respectively [12]. Generally, the sum of the hazard quotients of pollutants refer to HI, the HQ is the calculation of the exposure divided by an appropriate acute or chronic value [12-14]. Therefore, the main purpose of this work was to assess the air pollution distributions in the studied at-risk areas by overlaying the distributions of the HV season and NHV season. These results provide scientific data with the goal of supporting Thailand's policies and management approaches to encourage refraining from sugarcane burning in the preharvest and postharvest seasons

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to address concerning health effects, improve the environment with an annually increasing positive trend, and permanently enhance the efficiency of sugarcane management systems.

2. MATERIALS AND METHOD

The location of the nine representative sugarcane plantation provinces in Thailand, namely, Kanchanaburi, Ratchaburi, Saraburi, Nakornratchasima, Khon Kaen, Loei, Nakhonsawan, Sakaeo and Chonburi Provinces, are shown in Figure 1 along with the location of 11 air monitoring stations. These air monitoring stations have data recorded from the Pollution Control Department (PCD) covering the study period of this work (January 2019 to December 2019) [15]. This work was used monthly average air pollutant data. Air Pollution was measured by following the standard methods.

2.1 Sugarcane plantation

The Office of the Cane and Sugar Board of the Ministry of Industry of Thailand was provided data on sugarcane plantation areas, and regional sugarcane industries [1].

2.2 Land use

No 2019 data collection report has been published by the Land Development Department (LDD). Agricultural land use data covering the period from 2014-2018 were provided by LDD [16].

2.3 Assessment of exposure level

The inhalation exposure concentrations or ECinh ($\mu g/m^3$) were calculated from ambient air data using equation 1. The association between the health risk posed by haze pollutants exposure and the average monthly incidence of haze pollutants was reported. [7,11].

$$\mathrm{ECinh} = \mathrm{C}\times\mathrm{ET}\times\mathrm{EF}\times\mathrm{ED}/\mathrm{AT} \tag{1}$$

Each haze concentration (PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO and O_3 (in $\mu g/m^3$)) is C; the exposure time is ET (24 hours/day); where EF is the exposure frequency (350 days/year); the exposure duration is ED (30 years), if the resident or worker is assumed to live in the same home or area for 30 years); and the average time is AT (for noncarcinogens, AT = ED in years × 365 days × 24 hours/day).The EC_{inh}, calculations were in accordance with reports published WHO [17] and Mitmark [7].

2.4 Risk Characterization

The risk characterization noncarcinogenic effects was separately quantified and were evaluated using equation 2 [7,18].

$$\mathrm{HQ} = \mathrm{EC}/\mathrm{RfC} \tag{2}$$

where, RfC is the inhalation reference concentration; according to previous studies, CO = 2.3×10^1 mg/m^3, O_3 =1.8×10^{-1} mg/m^3 [7,11,19], PM_{10} = 50 $\mu g/m^3$ [20-21] and $PM_{2.5}$ = 25 $\mu g/m^3$ [21].

The HI is the summation of the HQ, and was calculated in this study using equation 3 [7,10,18].

$$\mathrm{HI} = \sum \mathrm{HQ} \tag{3}$$

The noncarcinogenic defects are often used HI to assess potential and caused exposure of chemical. HI value <1 indicates that there is no significant risk of noncarcinogenic effects. Conversely, if the HI value is > one, a risk of the occurrence of noncarcinogenic effects exists; the probability of this occurrence increases as the HI value increases [7] [20-22].

2.5 Statistical study

The SPSS statistical program (26th version) was used in this work. ANOVA method was used for the statistical siginificances of the differences between the seasonal variation means ($p<0.05$) for the monitoring data treatment. Moreover, the frequency of risk areas from January 2019 to December 2019 was determinde by LSD method with ANOVA.

2.6 Geographical Information System

A GIS (version 10.6) method was applied to visualized the pollutant concentration distributions and to map the HI. The sugarcane plantation and land use areas were analyzed by the map overlay technique, a procedure used to combine the attributes of intersecting features that are represented in two or more georegistered data layers. Longitude and latitude also collected in this work. Spatial HI data were prepared in a spread sheet before they were uploaded to the ArcGIS software. This work also use GIS to determine the spatial distributions and variable factors. Target areas were estimated along with small variations, and graduated color symbology was used to display hazard maps at each location [7].

3. RESULT AND DISCUSSION

3.1 Characteristics of pollutant distribution

Sugarcane burnings frequently occurred during in the HV season, causing severe haze in areas when sugarcane is grown no haze occurs in the wet season. Each year, sugarcane plantations and production are increasingly expanding, as shown in Figure 2. The plantation area of each province measured in 2019 is shown in supplementary data (Figure S1) from panel (a) to panel (i). The largest sugarcane plantation area was that in Nakornsawan Province, as shown in Figure S1 (a), which covered an area of 811,354 rai, the second-largest area was that in Kanchanaburi Province (Figure S1 (b)), followed by Nakhornratchasima Province (Figure S1 (c)), Khonkaen Province (Figure S1 (d)), Sakaeo Province (Figure S1 (e)), Loei Province (Figure S1 (f)), Ratchaburi Province (Figure S1 (g)), Saraburi Province

(Figure S1 (h)) and Chonburi Province (Figure S1 (i)) which covered areas of 789,440 rai, 679,737 rai, 654,540 rai, 451,897 rai, 314, 937 rai, 189,032 rai, 148,740 rai, and 142,910 rai, respectively [1]. In addition, Figure S1 (a)-(i) shows in-deepth information on the sugarcane plantations and production of each district boundary within each province. Ta-khli, Phayuha-khiri and Tak-fa districts were found to be the largest sugarcane plantation areas in Nakornsawan Province (Figure S1 (a)). The six studied sugarcane burning-related pollutants, PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO and O_3, were found to be the major pollutants at all sites. The average monthly concentrations of PM_{10} and $PM_{2.5}$ in Khonkaen Province (46T) (PM_{10} = 711 μg/m^3 and $PM_{2.5}$ = 417 μg/m^3) were higher than those in other provinces (Figures 3 and 4). Particularly in the dry season, from December-May, the PM_{10} and $PM_{2.5}$ levels exceeded the limits of the National Ambient Air Quality Standards (NAAQSs) in Thailand (PM_{10} = 120 μg/m^3 and $PM_{2.5}$ = 50 μg/m^3). The average monthly concentrations of PM_{10} and $PM_{2.5}$ in Nakornsawan Province (41T) were 709 and 338 μg/m^3, respectively, followed by those in Ratchaburi Province (26T), where the average monthly concentrations of PM_{10} and $PM_{2.5}$ were 642 and 351 μg/m^3, respectively. In Kanchanaburi Province (79T), the average monthly concentrations of PM_{10} and $PM_{2.5}$ were found to be 458 and 329 μg/m^3, respectively. The measurement in Saraburi Province (25T) resulted in PM_{10} and $PM_{2.5}$ concentrations of 659 and 282 μg/m^3, respectively. The average monthly concentrations of PM_{10} and $PM_{2.5}$ in Loei Province (72T) were 527 and 295 μg/m^3, respectively, and those in Nakornratchasima Province (47T) were 551 and 163 μg/m^3, respectively. However, it was determined that the $PM_{2.5}$ concentration data recorded at the pollution control department (PCD) station in Nakornratchasima Province did not include data February to May in 2019. Chonburi Province has three monitoring stations, and station 33T reported average monthly PM_{10} and $PM_{2.5}$ concentrations of 696 and 260 μg/m^3, respectively, while stations 32T and 34T indicated average monthly PM_{10} concentration of 457 and 441 μg/m^3, respectively, and $PM_{2.5}$ concentration of 262 (32T) and 220 (34T) μg/m^3, respectively. The lowest concentrations of PM_{10} and $PM_{2.5}$ were found at Sakaeo Province (71T), where the results showed pollutants concentration of 282 and 236 μg/m^3, respectively. All above results are shown in Figures 3 and 4. The average monthly concentrations of SO_2, NO_2, CO and O_3 measured in all provinces are displayed in Figures 5 to 8. The average monthly concentrations of SO_2, NO_2, CO and O_3 in Khonkaen Province (46T) were 16 ppb, 126 ppb, 7.93 ppm, 458 ppb, respectively. The average monthly concentrations of SO_2, NO_2, CO and O_3 in Nakornsawan Province (41T) were 17 ppb, 156 ppb, 9.12 ppm, 326 ppb respectively.

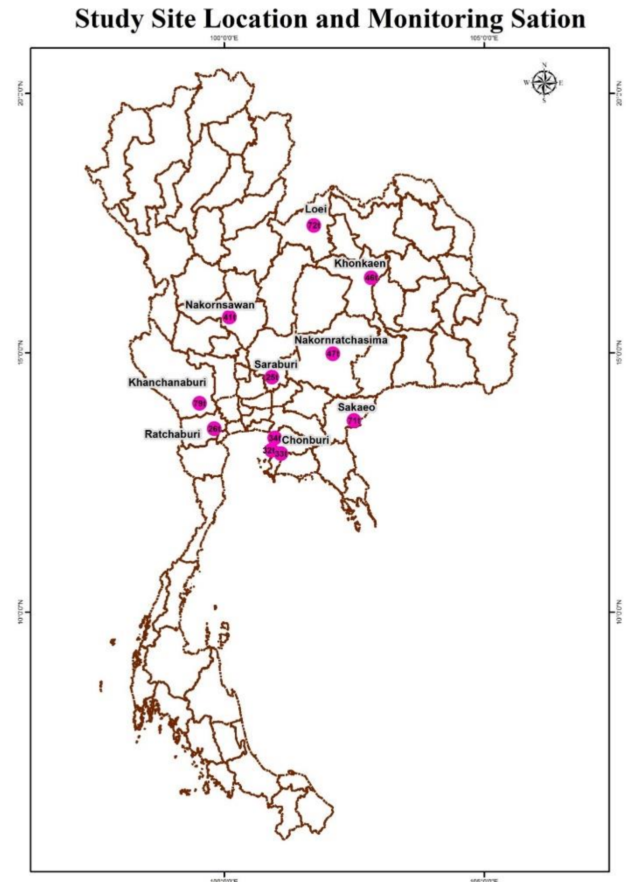


Fig. 1. Study site location and monitoring station: Kanchanaburi (79T), Ratchaburi (26T), Saraburi (25T), Nakornratchasima (47T), Khonkaen (46T), Loei (72T), Nakhonsawan (41T), Sakaeo (71T), Chonburi (32T,33T,34T).

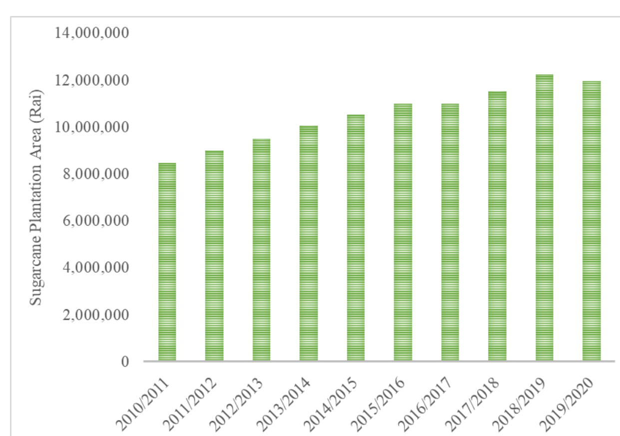


Fig. 2. Sugarcane Plantation in all region of Thailand from 2010-2020.

In Ratchaburi Province (26T), the average monthly concentrations of SO_2, NO_2, CO and O_3, were 13 ppb, 80 ppb, 7.31 ppm, 295 ppb, respectively. In Kanchanaburi Province (79T), the SO_2 , NO_2, CO and O_3 concentrations were 13 ppb, 93 ppb, 5.93 ppm, 228 ppb, respectively. The average monthly NO_2 and O_3 concentrations in Saraburi

Province (25T) were 201 ppb and 330 ppb, respectively, but no data were reported for SO_2 or NO_2. The results showed that the average monthly concentrations of SO_2, NO_2, CO and O_3 in Nakornratchasima Province (47T) were equal 12 ppb, 106 ppb,6.18 ppm, 317 ppb, respectively. No SO_2, NO_2, CO and O_3 data in Loei Province (72T) and Sakaeo Province (71T). Regarding the distrubution of monitoring stations, only 1 station was located in each province except Chonburi province, in which 3 stations measured air pollution. Some PCD Stations did not disclosed the data of some pollutants [15]; in Chonburi Province (32T), the average monthly data included the concentrations of three pollutants (SO_2 = 16 ppb, NO_2 =182 ppb and O_3 = 296 ppb). In addition, stations 33T and 34T in Chonburi province reported smaller concentrations than 32T (33T: NO_2 = 138 ppb and O_3 = 25 8ppb; 34T: NO_2 = 143 ppb, 7.26 ppm and O_3 = 295 ppb). As seen in Figures 5 to 8, although the distributions of of SO_2, NO_2, CO and O_3 reveal varied values, SO_2 and CO emissions are high in Nakornsawan Province and O_3 is very high in Konkaen Province. It is difficult to compare NO_2 values across entire provinces because values of zero were reported in some months and in some provinces. According to the data shown in Figures 3 to 8, almost all pollutants showed high distributions in provinces with large sugarcane plantation areas. A previous study of air pollutant emissions resulting from sugarcane burning in Thailand concluded that the air pollution emissions inventory was quite high, and the highest emission were found in the central and northeastern regions of Thailand [23-25], these areas were similar to the high-emissions areas in this study. The distribution of pollutants around sugarcane burning areas dominates in the central and northeastern parts of Thailand, particularly in Khonkaen and Nakornsawan Provinces. In provinces of concern, the emissions resulting from sugarcane burning published in a report by Phairuang [24] showed lower eimmsions of gaseous pollutants than PM concentrations (both PM_{10} and $PM_{2.5}$); this may have resulted from the presence of other major pollutant sources (e.g., motor vehicle or oil boiling). Their emission inventory methods estimated tht the highest PM amounts were emitted during the dry season from December to early April. The results of that study closely paralleled our research result, with the exception of the NO_2 distribution; their distribution was focused on NOx. Interestingly, the trend of pollutants measured in Khonkaen Province (46T) revealed the highest distribution of pollutants, even though the sugarcane plantation area in Khonkaen Province was smaller than that in Nakornsawan Province (41T), as presented in Figure S1 (a) and (d). This explained why the agricultural area data of Khonkaen Province were higher than those of Nakornsawan Province (Table 1); other agricultural waste burning was further impacting the measured air pollutants as an additional source. Moreover, it is important to consider the number of fire incidents considered in the recorded data; 428 agriculture land fires were recored in Khonkaen, while 301 were recorded in Nakornsawan. The highest frequency of agricultural land fires (FFCD) occurred in 2019 [26]. This explains why the pollution distribution of Khonkaen Province is higher than that of Nakornsawan Province; the decreased field burning in Nakornsawan Province led to lower pollution concentrations. In addition, Khonkaen Province, which is located on the western side of the northeastern region, exhibited a dense distribution of emitted pollutants because it located along the boundary connecting Loei and the Nakornrachasima Province on the northern and eastern sides of its northeastern region, respectively. Thus, the high measured pollutant values could be caused by the transportation of air pollutants into Khonkaen Province from other provinces. The wind speed is a key parameter that influence the tranport of air pollutants [27]. The distribution of air pollutants from sugarcane burning obtained in this study was compared to the distributions obtained in other regions; in Sao Paulo, southeastern Brazil, sugarcane growing is one of the main land uses,and burning is common in sugarcane areas. In a study of Brazilian sugarcane burning, the average annual concentrations of $PM_{2.5}$ and PM_{10} were found to be 16.1 and 41.1 µg/m^3, respectively [28]. In another region of Bazil, in the city of Araquara, Silva paesented the average concentration of total polycyclic Aromatic hydrocarbons (PAHs) in two particulate matter fractions ($PM_{2.5}$ and PM_{10}) during the sucacane HV and NHV seasons [29]. The average 24-hour total PAHs concentrations ($PM_{2.5}$ fraction) were 3.3 ng/m^3 in the HV season and 0.99 ng/m^3 in the NHV season. while The average 24-hour total PAHs concentrations (PM_{10} fraction) were 8.9 ng/m^3 (HV) and 3.6 ng/m^3 (NHV). The total PAHs obtained in this study included 13 compounds of 16 PAH standards except for naphthalene, acenaphthene and fluorine, and the values obtained in the HV seasons were 5 times higher those obtained in NHV season. Emission inventories of air pollutants resulting from the burning of sugarcane are widely studies. An emission inventory research study published by Daniela [30] estimated the annual emissions of CO, NO_x, $PM_{2.5}$ and PM_{10} (1130, 26, 45, 120 (Gr/year, respectively) in the pre-harvest sucane burning period. Kanokanjana et al. in 2012 [31] reported the amount of polluants released as CO (929±341 Gg), CO_2 (8,864±1,863 Gg), and $PM_{2.5}$ (152±113 Gg). The above studies indicated that both particulate matter and gaseouse pollutants are generated during sugarcane burning. Data on air pollutants resulting from sugarcane burning in sugarcane plantation areas in Thailand are lacking. Our study reports the required data associated with the air pollution caused by sugarcane burning. Sugarcane is one of the most crucial sources of biomass for burning activities in Thailand, especially in the dry season, is burned and high levels of pollution are emitted to the atmosphere.

Table 1 Agriculture area and compared to total province's area were summarized from 2014 to 2018, (1 rai = 0.4 acres, 1 rai = 0.16 hectares and 1 rai = 1,600 square metres).

Province	2014		2015		2016		2017		2018	
	Rai	%	Rai	%	Rai	%	Rai	%	Rai	%
Khonkaen	4,843,210	71.18	4,722,322	69.39	4,835,982	71.06	4,870,358	71.57	4,854,887	71.33
Nakornratchasima	8,931,032	69.71	8,880,225	69.34	8,773,950	68.50	8,776,748	68.52	8,762,435	68.39
Loei	8,931,032	69.71	8,880,225	69.34	4,091,502	57.30	4,155,873	58.17	4,213,164	58.99
Kanchanaburi	3,414,585	28.04	3,400,317	27.88	3,367,074	27.67	3,502,838	28.76	3,523,055	28.93
Ratchaburi	1,681,173	52.00	1,649,896	50.80	1,648,319	50.73	1,667,361	51.33	1,663,353	51.21
Saraburi	1,681,173	52.00	1,275,135	57.00	1,159,486	51.87	1,157,221	51.76	1,152,315	51.57
Nakornsawan	4,347,326	72.47	4,636,803	77.3	4,664,545	77.76	4,698,715	78.34	4,705,120	78.42
Chonburi	1746504	64.06	1709836	62.68	1,697,908	62.24	1,628,574	59.73	1,561,590	57.24
Sakaeoi	3,167,518	70.43	3,108,417	69.13	3,145,701	69.97	3,047,886	67.77	3,046,917	67.74

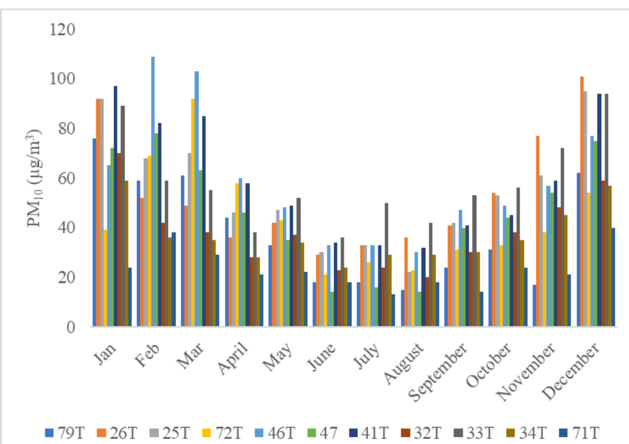


Fig. 3. Sum of PM_{10} distribution in wet and dry season in 2019.

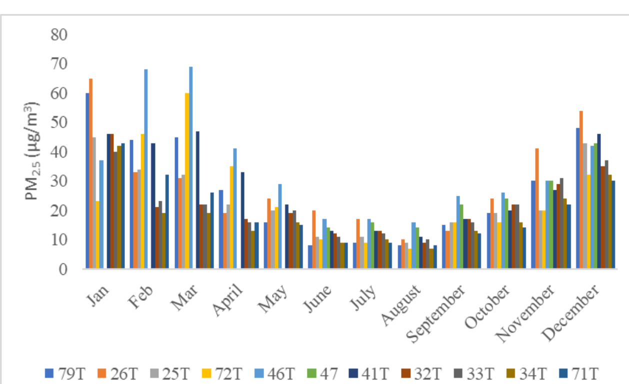


Fig. 4. Sum of $PM_{2.5}$ distribution in wet and dry season in 2019.

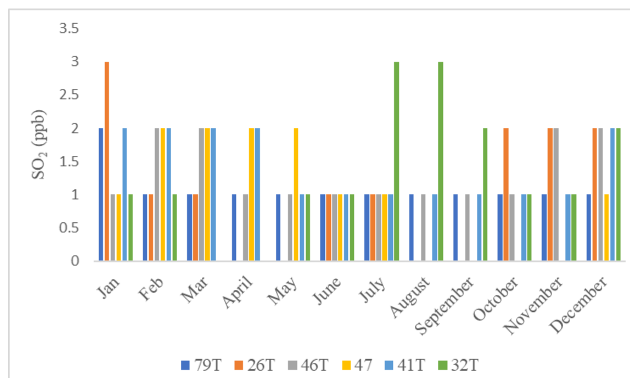


Fig. 5. Sum of SO2 distribution in wet and dry season in 2019.

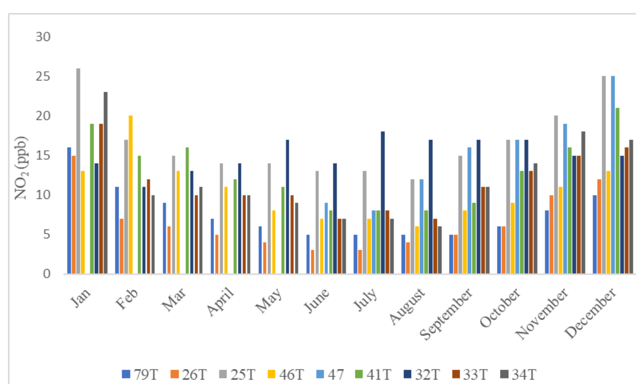


Fig. 6. Sum of NO2 distribution in wet and dry season in 2019.

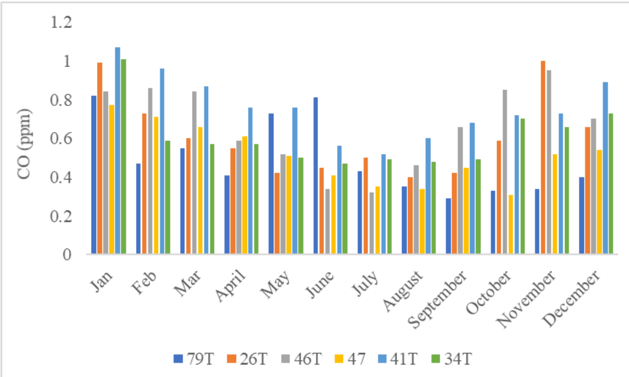


Fig. 7. Sum of CO distribution in wet and dry season in 2019.

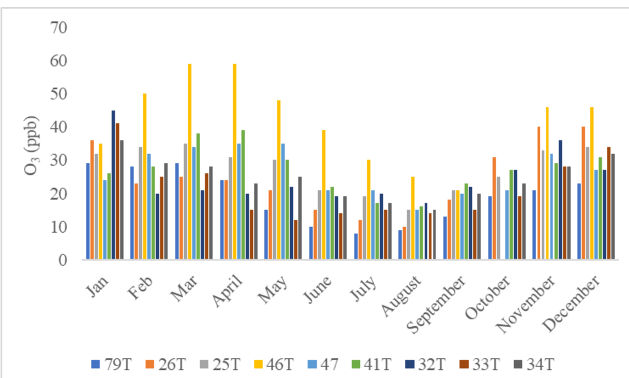


Fig. 8. Sum of O3 distribution in wet and dry season in 2019.

3.2 Influence of agricultural land use on air pollutant levels

Land use data are shown in Figure S2. In particularly, agricultural land can influence the PM_{10} and $PM_{2.5}$ levels measured in a given region. The impact of the land use type and intensity on the PM_{10} and $PM_{2.5}$ levels were estimated. The land use and land cover information used in this study were obtained from the Land Development of Thailand [16]. ArcGIS 10.6 was used for the spatial-analysis, and mapping was adopted to examine the land use classification and land cover information. In the results, it was found that the presence of large agricultural areas could influence the PM_{10} and $PM_{2.5}$ levels in a given region. Study of PM_{10} and $PM_{2.5}$ distributions based on GIS mapping can be easily understand, and the major factors that affect PM_{10} and $PM_{2.5}$ levels can be explored using GIS. Figure S2 (a)-(i) shows the land use type map and spatial distribution in each province in 2018; this figure demonstrated that the percentages of agricultural land, forestland, residential and construction land, wetland, and other land cover 60.05%, 23.41%, 8.85%, 3.2% and 3.99% respectively. Agricultural land was found to be the dominant land use type, followed by forestland while wetland showed the lowest coverage. Sugarcane is considered to be among the most important crops in agricultural lands in the studied provinces (Table 1). The comparison among the nine provinces considered in this research showed that the province with the highest agricultural land density was Nakornratchasima Province with an agricultural area of 8,762,435 rai, which could be estimated at 68.39% of the province's total area, while the agricultural area itself was largest, the percentage of agricultural land within the entire provincial area was less than those of Nakornsawan Province and Khonkaen Province. Nakornsawan Province has an agricultural land area 4,705,120 rai, or 78.42% of the province's total area. Khonkaen Province has an agricultural land area 4,854,887 rai, or the total area of province. The other provinces had lower agricultural areas and percentages than the three provinces listed above. As shown in Figures 3 and 4, the air pollutant levels seemed to be dominant in the central and northeastern regions of Thailand. Moreover, the land use type and location influenced the distribution of pollutants. When studying the location factor, one should consider that sugarcane areas are located in the central and northeastern regions of Thailand. According to the results of this study, a strong relationship may exist between the agricultural lands and sugarcane plantations that are affected by pollutant levels at any given time. As reported by evidence from other reports, assessments of land use and pollutants from cultivated lands have been conducted in many studies in regions with extremely high sugarcane cultivation areas, such as Brazil [28-30]. Agricultural waste burning affected air pollution in Thailand [31-35], and sugarcane burning is among the most influential factor affecting pollutant levels. As reported by Junpen [23], from January to March of 2019, the amount of $PM_{2.5}$ emitted noticeably increased and spread throughout cultivated areas in all regions of Thailand (central, northeastern, and northern). When the final month of sugarcane production was reached, the amount of $PM_{2.5}$ emitted began to decrease. Phairuang found that agricultural land is associated with air pollution and mentioned that sugarcane is usually burned in its corresponding agricultural fields. Sugarcane burning was found to contribute the most to pollutant emissions in Nakornsawan and Khonkaen Provinces [24]. From these results, it could be assumed that large agricultural areas can induce great air pollutant emissions due to burning during agricultural activities.

3.3 Risk assessments with the HQ and HI

Common air pollutants include PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO and O_3 [36]. The HQ and HI are commonly used to estimate and assess health risks resulting from exposure to pollutants [37-39]. Therefore, the HQ and HI were used in this study to estimate health risk levels. In this study, the exposure concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO and O_3 were calculated using the ambient air concentrations and equation 1, and the HQs were calculated using equation 2. As an example, the HQs of the 11 monitoring sites in 2019 are compared in Table S1. All sites have HQs ranging from 0.02-0.52 in the wet season and from 0.03-1.10 in the dry season; these values indicate that, during the wet season, there are no potential adverse health effects, as the wet season HQs were less than 1 (HQ<1). The $PM_{2.5}$ HQs determined for the Khonkaen site (station 46T) in the dry season and the long-term annual HQs showed values >1. These results indicated that potential health impacts resulting from $PM_{2.5}$ exposurecould harm the residents in the surrounding areas. According to the results of the HQ analysis, the SO_2, NO_2, CO and O_3 HQs were lower than those of PM_{10} and $PM_{2.5}$ but potential hazards to human health still existed in association with these pollutants [7,21]. The HI values of short-term and long-term exposure durations were calculated using equation 3. The HI values and related areas are summarized in Figure 9. For short-term duration in NHV season (wet season), the HI values ranged from 0.63-1.63. The lowest HI value was observed at Loei site (station 72T), while Khonkaen exhibited the highest risk area, with an HI value over 1. At all sites in the dry season, the HI value was high than 1. The risk areas were identified by different HIs, and the impacted site were visualized by using GIS-based maps, as shown in Figure 10. The risk areas in sugarcane plantations in Thailand were identified by the province and site locations. In the dry season, potential risk resulted from exposure to high pollution levels, especially $PM_{2.5}$. The HI values were than 1 at all sites, indicating potential health risk. Most hazardous areas were varied in location; for example, hazardous areas were identified in the dry season in Khonkaen (46T), Nakornsawan (41T), Saraburi (25T), Ratchaburi (26T) and Kanchanaburi (79T) Provinces. Similar to those of Mitmark were obtained the HQs of PM_{10}, CO and O_3 were high in the dry season [7]. The HQ of CO and O_3 were less than 1, which could indicate no potential adverse health effect from these two pollutants. The HQs of PM_{10} obtained in this study were over 1. These results showed potential health effects resulting from PM_{10} exposure in the dry season. The hazard map created in their study indicated potential health risks because the average HI values were over 1 in Chiang Rai, Mae Hong Sorn, Phayao and Phare Provinces, Thailand. The populations in these at-risk areas could suffer harm due to exposure to PM_{10} [7]. Moreover, similar values have been reported in Tehran, Iran, with annual mean $PM_{2.5}$ and PM_{10} concentrations measured from ambient air at selected study sites varying form 22.6-39.5 µg/m^3 and from 62.5-104.3 µg/m^3, respectively. The average HQ of $PM_{2.5}$ was 6.3, and that PM_{10} was 1.6, indicating potential health effects resulting from exposure $PM_{2.5}$ and PM_{10} [21]. However, when considering the change in land use and hazardous areas that occurred from 2014-2018 (Table 1), the agricultural areas in all nine provinces were found to have increased [16]. This could have induced increased biomass burning, resulting in sugarcane emissions and the spread of pollutants to ambient air. Among the nine provinces compared in this study, the largest agricultural area was found in Nakornsawan Province, where agricultural covered an area of 4,705,120 rai, the highest increase was also found in this region, with the agricultural area increased from 72.74% in 2014 to 78.42% in 2018. Although the agricultural areas in Khonkaen Province did not increase extensively, only by 11,677 rai, continuous increases in PM_{10} and $PM_{2.5}$ were recorded, as shown in Figures 4 and 5. Therefore, emissions resulting from the burning of sugarcane from new agricultural burning or urbanization areas that may contribute to high-risk areas. Further monitoring and pollution prevention policies are recommended in Khonkaen, Nakornsawan and Ratchaburi Provinces.

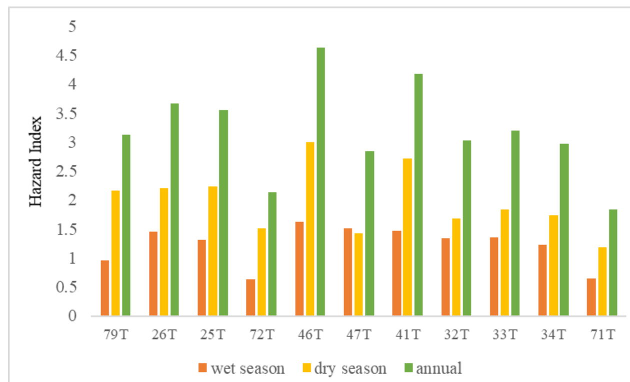
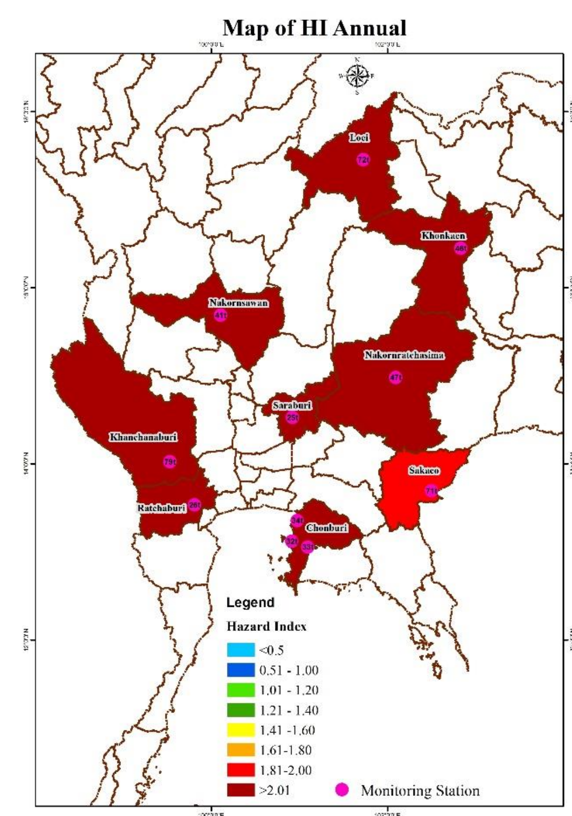
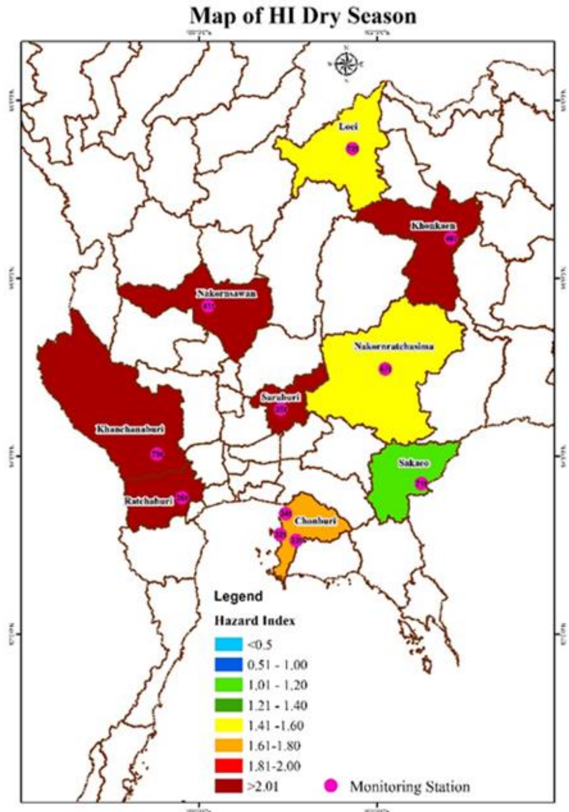


Fig. 9. Comparison of hazard of nine provinces in wet and dry season in 2019.





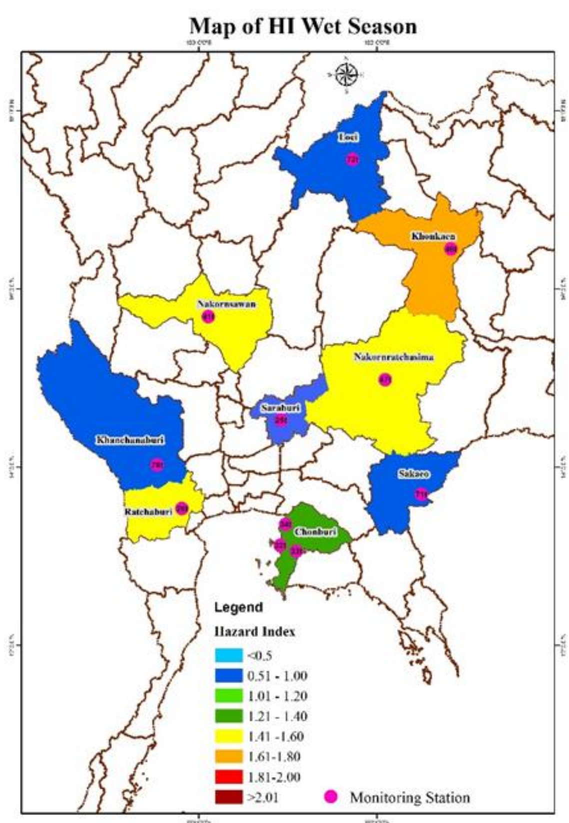


Fig. 10. Hazard map of nine provinces in wet season, dry season and annual in 2019.

4. CONCLUSION

This study presented data and conducts a health risk assessment of sugarcane burning activities in Thailand. We observed air pollutant levels in ambient air during the sugarcane harvesting season. The HIs of each of the sugarcane burning areas was compared and visualized using a GIS-based map. Larger areas of the agricultural land use type and higher sugarcane burning in sugarcane plantation areas likely led to the higher concentrations of air pollutants observed in the northeastern, middle and northern regions. The association between the exposure concentration and risk areas was compared in the nine studied provinces. During the sugarcane harvesting season, the HIs of the nine provinces were greater than 1, and the HIs of some provinces reached 3, indicating potential health risks. Three high-risk provinces were determined among the hazard maps and average HI values, Khonkhaen Province, Nakornsawan Province and Ratchaburi Provinces.

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