Investigation of Indoor Nitrogen Dioxide (NO_2) Exposure and Health Risk Assessment at a Cross-Border Checkpoint, Chiang Rai Province in Tourism Seasonality

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***Abstract*—The inhalation of indoor nitrogen dioxide (NO_2) is generated by traffic density and is associated with a risk to human health. The objective of this study was to assess indoor NO_2 levels at the Chiang Khong District border crossing at the 4th Thai-Laos Friendship Bridge (Chiang Khong-Huay Xai) in Chiang Rai Province in order to evaluate indoor air quality in tourist season within the limits of a health risk assessment. Indoor NO_2 samplings were collected by using a passive sampling method. The results for indoor NO_2 concentrations in all sampling sites in the Chiang Khong District border ranged between 18.7±5.8 to 37.8±28.9 μg/m^3. The highest indoor NO_2 concentration was measured in April 2023 (25.1±10.8 to 88.3±30.6 μg/m^3) because the total number of tourists and vehicles passing at a cross-border crossing was the highest, which is peak season and Songkran festival in Thailand. Moreover, a significant correlation between indoor NO_2 concentrations was found between the total number of vehicles and tourists (p<0.01). Indoor NO_2 concentrations have been influenced by trucks and cars. The levels of indoor NO_2 emitted by diesel-powered vehicles were obvious. Long-term Hazard Quotient (HQ) values in relation to non-carcinogenic hazards to human health caused by indoor NO_2 exposure revealed that children had higher HQ levels than adults.**

***Keywords*—nitrogen dioxide (NO_2), Hazard Quotient (HQ), non-carcinogenic risk assessment, air pollution**

I. Introduction

People worldwide spend 80% to 90% of their time indoors. As a result, most of their exposure to air pollution will occur inside and originate outside. Researchers studying air pollution are concerned about gaseous pollutants, specifically nitrogen dioxide (NO_2), because it is a harmful gaseous nitrogen oxide (NO_X) that is released into the environment by traffic and industrial emissions. Moreover, there are several important indoor sources, such as heating, cooking, and smoking [1]. NO_X usually appeared in the form of nitrogen monoxide (NO) and NO_2. When NO emissions are released into the environment, they react with O_2 to create NO_2. Moreover, NO_2 and Volatile Organic Compounds (VOCs) in reaction to sunlight generated ozone (O_3) [2]. Recent epidemiological research has shown that individual NO_2 exposure is more probable to be influenced by outside traffic, considering there are few primary sources of NO_2 indoors [3–5]. Trinh *et al.* [6] observed that diesel vehicles generated higher NO_X emissions (0.33–0.71 g/km) than gasoline vehicles (0.003–0.07 g/km). In the road vehicles in the UK investigated by Boulter *et al.* [7], the proportion of NO_2 in NO_X emissions from diesel cars (5%–70%) was 1–35 times higher than for gasoline cars (2%–4%). Alamer *et al.* [8] studied a prediction model for daily real-time NO and NO_2 emissions from heavily trafficked road in London, UK, carrying approximately 90,000 vehicles per day. NO and NO_2 values ranged from 0.02 to 725.94 and 0.06 to 291.15 μg/m^3, respectively. According to Ahmad *et al.* [9], NO_2 emissions from main highways, sub-roads, small roads, hospitals, and educational institutions ranged from 22.8±1.3 to 37.5±1.7, 22.4±1.3 to 38.1±1.4, 22.4±1.0 to 37.1±1.0, and 23.5±1.6 to 38.7±1.6 μg/m^3, respectively. Furthermore, mean NO_2 concentrations released from traffic area in Chiang Mai during the wet and dry seasons were determined to be 20.7±4.1 and 47.4±15.8 μg/m^3, respectively [10]. Several studies have investigated the association between indoor NO_2 concentrations and traffic density. Bozkurt *et al.* [11] measured indoor NO_2 exposure to industrial emissions, combustion processes, and vehicle traffic at a school, residence, and office in an industrial city in Turkey using passive sampling. Indoor NO_2 concentrations were 22.2±17.0 to 33.6±19.5 and 65.1±37.4 to 92.3±12.0 μg/m^3 (schools), 30.5±4.6 to 52.0±14.6 and 51.5±20.9 to 78.8±30.3 μg/m^3 (homes) and 38.5±10.4 to 43.4±24.6 and 56.5±13.9 to 63.1±17.4 μg/m^3 (office), respectively. They determined that NO_2 concentrations measured in the summer were lower than those measured in the winter and that NO_2 generated by motor vehicles was a source of NO_2. Moreover, inside an open-air classroom in Nakhon Si Thammarat province in Thailand, there was a considerable influence from outdoor NO_2 emitted from traffic in an urban environment [12]. Therefore, NO_2 is considered the primary source of traffic-related air pollution and has been applied as an indicator of motor vehicle emissions.

NO_2 inhalation has been correlated with significant respiratory irritation. NO_2 exposure was linked to asthma-related emergency room visits and hospitalizations [13]. Furthermore, NO_2 exposure of 10 ug/m^3 was previously linked to mortality and the risk of Chronic Obstructive Pulmonary Disease (COPD). An increase in NO_2 concentration has contributed to a 2.0% rise in linked COPD in adults, a 1.3% increase in hospital admissions, and a 2.6%

increase in mortality [14]. When NO_2 reacts with water, it produces nitrous acid (HONO), a prevalent contaminant in both outdoor and indoor environments. Therefore, short-term associations between NO_2 and the risk of eye and adnexa diseases [3, 15] and pink eye/allergic conjunctivitis [5]. As a result, ocular pain sensations and tear breakup time could be a type of biomarker for the adverse health effects of traffic density and NO_2 exposure [3, 16].

The Chiang Khong District Border Checkpoint at the 4th Thai-Laos Friendship Bridge (Chiang Khong-Huay Xai) in Chiang Rai Province is part of the Greater Mekong Subregion Economic Cooperation Program (GMS)'s North-South Economic Corridor (Route R3A). The route is crucial for China's trade, investment, and security benefits, and it is the primary tourism route for three beneficiary countries: China, Laos, and Thailand. The route begins in Kunming, Yunnan province, continues to the China-Laos border at Boten, Luang Namtha province, and connects to Huay Xai, Bokeo province in Laos, the 4th Thai-Laos Friendship Bridge, Chiang Khong district, Chiang Rai province, and ends in Bangkok [17, 18]. It was developed in response to increased trade and tourism in Chiang Rai province. In 2022, the accounts of cross-border trade in imported and exported trade were 18,143 and 47,784 million baths, respectively. In addition, the total number of tourists in the arrival and departure immigration paths was 183,900 and 197,616 persons, respectively, while the total number of vehicles was 201,101 and 199,360 cars [19]. Therefore, the Chiang Khong District Border Checkpoint at the 4th Thai-Laos Friendship Bridge (Chiang Khong-Huay Xai) is strategically situated to encourage investment and tourism development in Chiang Rai province and Thailand.

Indoor air quality has been assessed as an important problem because it is the source of adverse human health impacts. The purpose of this study was to investigate indoor NO_2 concentrations and assess non-carcinogenic risk at the Chiang Khong District Border Checkpoint on the 4th Thai-Laos Friendship Bridge (Chiang Khong-Huay Xai) in Chiang Rai Province. It is situated in high-traffic locations and among tourists to assess the level of indoor air quality and associated health risks.

II. Materials and Methods

A. Sampling Site

Chiang Khong District Border Checkpoint (20°12′58.1″N and 100°26′7.5″E) at the 4th Thai-Laos Friendship Bridge (Chiang Khong-Huay Xai) in Chiang Rai Province is situated in northern Thailand. Chiang Khong is a town on the Mekong River that borders Laos by 184 kilometers. The selection criteria for the sampling locations were based on the number of visitors and traffic. The Chiang Khong District Border Checkpoint has 8 sampling sites (Fig. 1 and Table 1), with 2 sites for departures from Thailand to Laos and 7 sites for arrivals. Table 1 and Fig. 1 display the sampling location classifications. The samples were continually exposed for a week from November 2022 to April 2023, during tourist season.

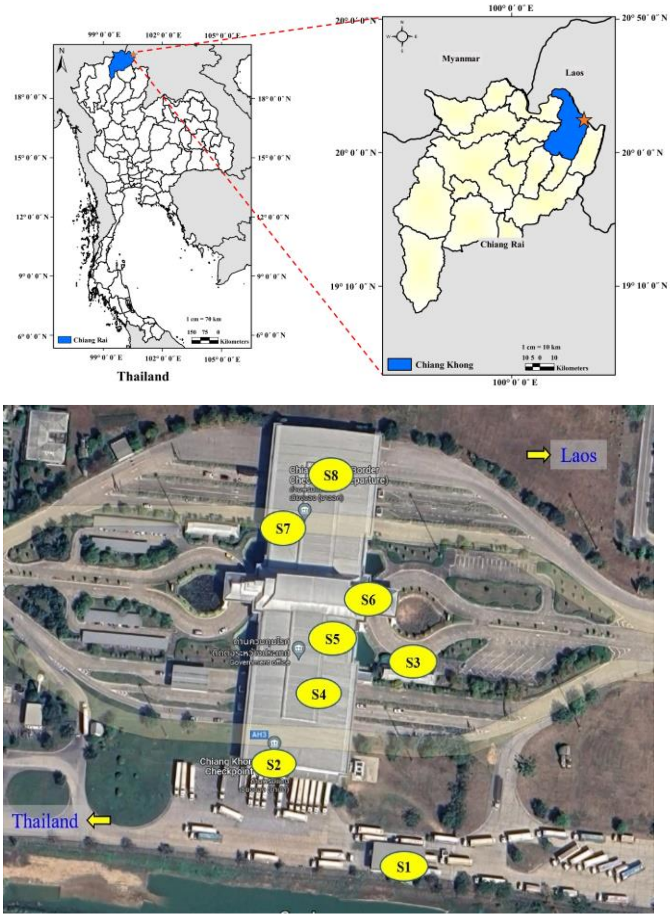


Fig. 1. Map of NO_2 sampling sites in Chiang Khong District Border Checkpoint at the 4th Thai-Laos Friendship Bridge (Chiang Khong-Huay Xai), Chiang Rai province. Note: Applied from Google maps.

Table 1. Characteristics of sampling sites in the Chiang Khong District Border Checkpoint

Path	Code	Sampling places	Details
Arrival	S1	International Health and Quarantine Office (1)	This location is referred to as the International Health and Quarantine Office. It is a verified document for the International Communicable Disease Control and Quarantine Division, which covers truck drivers in the logistics section. A container truck transporting imported agricultural products from China and Laos had been found in the area. There are two employees on the job.
	S2	Common Control Area (CCA)	The Plant Quarantine Station is the principal checkpoint for pest control and chemical contamination in imported agricultural products. Most imported agricultural products are transported by truck.
	S3	International Health and Quarantine Office (2)	It is a checked document for the international communicable disease control and quarantine division, which investigated the vaccination certificate for tourist immigration arrival. There are two employees on the job.
	S4	Immigration and Customs Checkpoint Arrival	Checkpoints for immigration and customs inspect immigration and customs documents. Tourists and their vehicles, such as cars, vans, and buses, were observed upon arrival.
	S5	Immigration Office for Arrival	The sample was obtained inside an immigration office. Tourists' documents, such as their passports, border pass, and temporary border pass, are verified. There are about 5–6 immigration officers working.
	S6	VISA On Arrival	The sample was collected outside of an immigration office. This tourist checkpoint was checked, and approval for a visa was allowed.

Departure	S7	Immigration Office for Departure	The sample was acquired inside an immigration office in preparation for departure. Tourists' documentation is checked, including passports, border passes, and temporary border passes. There are about 5–6 immigration officials working.
	S8	Immigration and Customs Checkpoint Departure	Immigration and customs checkpoints check immigration and customs forms. Tourists and their vehicles, such as cars, vans, trucks and buses, were observed upon departure.

A. NO_2 Sampling and Analysis

Passive diffusion tubes from the Environmental Chemistry Research Laboratory (ECRL), Chemistry Department, Faculty of Science, Chiang Mai University were used to determine the indoor NO_2 concentrations [20, 21]. The Polypropylene (PP) tube is 7.70 cm long and 1.50 cm in diameter, and it contained GF/A filter paper (Whatman, USA) impregnated with 50 µL of 20% TEA. A sampling set consisted of 5 sampling tubes and 3 blank tubes to fix in a shelter, which hung at 1.5–2.0 m above ground level for 1 week. After the sampling, the NO_2 concentration was determined colorimetrically as nitrite (NO_2^-). For extraction, the samples were added to 2 mL of de-ionized water in the tube and stirred well for 15 minutes to dissolve the nitrite in the water. One mL of the nitrite solution was mixed with 2 mL of the Saltzmann reagent. After extraction, the absorbance was measured by a spectrophotometer (ThermoScientific GENESYS 150, USA) at 540 nm.

B. Health Risk Assessment of NO_2

The Hazard Quotient (HQ) is a non-carcinogenic risk guideline used to assess human exposure to air contaminants. It was predicted that NO_2 concentrations would be inhaled from the inhalation exposure pathway for children and adults [22–24]. HQ is the toxicological effects analysis ratio, in which the Average Daily Dose (ADD) and the Reference Dosage (RfD) were used to compute the daily NO_2 inhalation using Eq. (1).

$$HQ = \frac{ADD}{RfD} \tag{1}$$

When the HQ>1.0, a non-carcinogenic effect may occur, while HQ<1.0 means no hazard or only negligible risks. The daily NO_2 exposure was calculated by the ADD as shown in Eq. (2) [22].

$$ADD = \frac{C \times Inh\,R \times ET \times EF \times ED}{BW \times AT} \tag{2}$$

where ADD is the ADD of pollutants; C is the concentration of NO_2 (µg/m^3); ED is the exposure duration (days); EF is the exposure frequency (days/year); ET is the exposure time (hour/day); BW is the body weight of the exposed group (kg); AT is the average time (days) and InhR is the inhalation rate (m^3/h). The values of these parameters were shown in Table 2, which is referred to by Sillapapiromsuk *et al.* [24] and Morakinyo *et al.* [25].

$$RfD = \frac{RfC \times 20\ m^3/day}{70\ Kg} \tag{3}$$

The Reference Dose (RfD) for indoor NO_2 exposure is based on the World Health Organization (WHO) guideline [26, 27], as shown in Eq. (3). RfC refers to the reference concentrations of indoor NO_2 for both short-term (Acute exposure) and long-term (Chronic exposure) exposure were 200 and 40 µg/m^3, respectively (Table 3). As a result, the RfD values of indoor NO_2 for acute and chronic exposures were 57.1 and 11.4 µg/kg-day, respectively.

Table 2. Parameters of health risk assessment through inhalation pathway for NO_2

Parameters	Age category			
	Child		Adult	
	Acute exposure	Chronic exposure	Acute exposure	Chronic exposure
Exposure frequency (EF) (days/year)	350	350	350	350
Exposure time (ET) (hour/day)	1	24	1	24
Exposure duration (ED) (year)	12	12	30	30
Averaging time (AT); AT = ED ×365 days (day)	4,380	4,380	10,950	10,950
Bodyweight (BW) (Kg)	45.3	45.3	71.8	71.8
Inhalation rate (InhR) (m^3/hour)	1.2	13.5	1.2	13.3
RfC (µg/m^3) (WHO guideline)	200		40	

C. Data Analysis

The indoor NO_2 concentrations at the Chiang Khong border checkpoint, Chiang Rai province were log–transformed (Shapiro-Wilk test, $p>0.05$) to achieve normal distribution. The determination of the difference between indoor nitrogen dioxide levels was statistically analyzed using the One-way Analysis of Variance (ANOVA) with Tukey analysis. One-way ANOVA compares the means of three or more independent groups to determine if there is a statistically significant difference between the corresponding population means. The Tukey test runs pairwise comparisons among each of the groups and uses a conservative error estimate to find the groups which are statistically different from one another. Pearson's correlation analysis was used to assess the relations between the number of tourists, the sum of vehicles, and the indoor NO_2 concentrations.

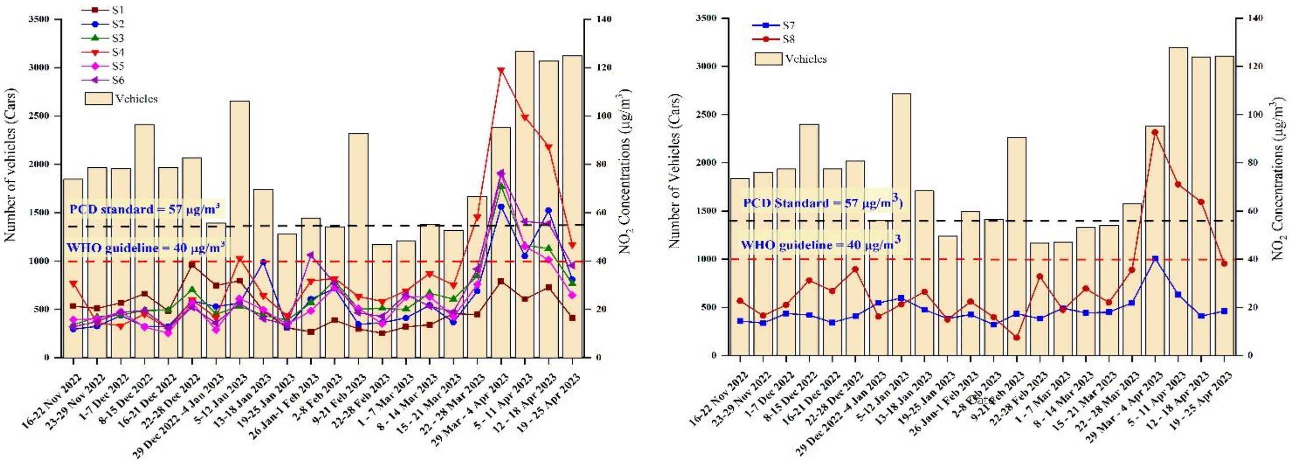
III. Result and Discussion

A. Nitrogen Dioxide (NO_2) Concentrations

Indoor nitrogen dioxide (NO_2) concentrations obtained from passive sampling at each sampling point in Chiang Khong border checkpoint, Chiang Rai are shown in Table 3 and Fig. 2. During six months of sampling, it was found that the indoor NO_2 concentrations of the S4 sampling site were the highest and significantly different ($p<0.05$) from the other sites. Their concentrations ranged from 12.0–119.2 µg/m^3. In contrast, the lowest indoor NO_2 levels were measured at the S1 and S7 sites, which were significantly different ($p<0.05$)

from the other sites. The mean concentrations were 20.7 ± 7.9 and 18.7 ± 5.8 μg/m^3, respectively. Both sampling sites are inside the international health and quarantine office and the immigration office for departure. The sites of the vehicles are clear.

Noticeably, concentrations of indoor NO_2 in all sampling sites started to increase in March 2023. Fig. 2 and Table 4 illustrate the inside NO_2 levels as well as the total number of vehicles in the arrival and departure paths at the Chiang Khong border checkpoint in Chiang Rai province during the studied periods. The sum of vehicles and the total number of tourists were found in April 2023, which affected the indoor NO_2 values in this month. This is due to the high season in Thailand and the high number of visitors and vehicles. Therefore, the pollutants accumulated indoors. The highest indoor NO_2 concentration in the Chiang Khong border checkpoint was found in April 2023 (25.1 ±10.8 to 88.3 ±30.6 μg/m^3), while the lowest value was found in November 2022 (12.4 ±0.8 to 22.6 ±11.6 μg/m^3). The mean indoor NO_2 concentrations were differentiated between the different sampling sites using a one-way ANOVA for each month. Table 3 reveals that the indoor NO_2 concentrations observed in April 2023 were significantly higher than those observed in other months (p<0.05), whereas the values measured in November 2022 were significantly lower. The results from December 2022 to February 2023 were not significantly different (p>0.05).



(a) (b)

Fig. 2. Concentrations of indoor NO_2 and the sum of vehicles in Chiang Khong District Border Checkpoint: (a) Arrival path and (b) Departure path

Table 3. Concentrations of indoor NO_2 in Chiang Khong border checkpoint, Chiang Rai

Path	Code	Indoor NO_2 concentrations (μg/m^3)						
		Nov. 2022^A	Dec. 2022^{AB}	Jan. 2023^{AB}	Feb. 2023^{AB}	Mar. 2023^B	Apr. 2023^C	Nov. 2022–Apr. 2023
Arrival	**S1^a**	20.9 ±0.7	26.7 ±8.3	20.9 ±9.7	12.5 ±2.8	15.6 ±2.9	25.4 ±6.7	20.7 ±7.9
	S2^{ab}	12.4 ±0.8	16.7 ±5.0	24.0 ±9.8	19.0 ±8.4	20.1 ±5.8	49.5 ±14.7	24.9 ±14.7
	S3^{ab}	15.2 ±2.3	21.3 ±4.6	19.1 ±2.9	24.1 ±6.6	26.2 ±5.8	48.3 ±16.7	26.4 ±13.3
	S4^b	22.6 ±11.6	16.8 ±5.4	26.5 ±10.3	27.2 ±5.0	37.7 ±14.0	88.3 ±30.6	37.8 ±28.9
	S5^{ab}	15.9 ±0.3	16.1 ±5.7	17.8 ±5.1	21.2 ±7.5	24.4 ±5.5	47.1 ±21.1	24.3 ±14.6
	S6^{ab}	13.9 ±1.5	17.9 ±3.8	21.9 ±12.0	22.2 ±7.5	25.8 ±7.9	56.6 ±15.7	27.5 ±17.0
Departure	**S7^a**	13.9 ±0.6	16.1 ±1.7	19.4 ±3.5	15.1 ±2.3	19.3 ±1.9	25.1 ±10.8	18.7 ±5.8
	S8^{ab}	19.6 ±4.3	28.7 ±6.3	20.2 ±4.7	18.7 ±13.0	26.1 ±7.3	66.4 ±22.5	31.0 ±20.3

a, b = Range of significant discrepancy (p<0.05) among clusters of sampling sites (vertical direction)
A, B, C = Range of significant discrepancy (p<0.05) among clusters of sampling months (horizontal direction)

Concentrations of indoor NO_2 were obtained from passive sampling at each sampling point in the Chiang Khong border checkpoint, Chiang Rai. As a result, it was found that the highest indoor NO_2 concentrations were at the S4 sampling site and significantly different from the other sites (p<0.05). Table 4 reported the number of tourists and vehicles in arrival and departure immigration at a cross-border checkpoint. This is probably due to the higher vehicle density at the S4 sampling site. It also contains immigration and customs checkpoints that inspect immigration and customs documents, leading to poor airflow and pollutant deposition. In addition, the highest indoor NO_2 values were observed in April 2023 (25.1 ±10.8 to 88.3 ±30.6 μg/m^3) because the highest number of tourists and vehicles were arriving at a cross-border crossing, which is peak season and Songkran festivity in Thailand (Fig. 2). Pearson's correlation studied the association between the number of vehicles and indoor NO_2. Trucks in the arrival and departure paths were shown to be significantly correlated (p<0.01) with the average indoor NO_2 concentrations. Furthermore, whereas the total number of tourists was significantly related to the total number of vehicles (p<0.01 and p<0.05), the positive associations between indoor NO_2 levels and the total number of vehicles on the arrival and departure routes were stronger. As a result, the tourists were exposed to high amounts of NO_2 indoors. According to Lozhkina and Lozhkin [28], diesel cars created

28.9 times more NO_X emissions than gasoline cars, while wormed and stabilized engines at speeds ranging from 30 to 60 km/h emitted 17.6 times more NO_X than gasoline cars. Ban-Weiss *et al.* [29] revealed that the NO_2 emissions of gasoline vehicles and diesel trucks in the Caldecott tunnel on California Highway 24 in the San Francisco Bay area were 37 ±7 and 1,470 ±7 mg/kg, respectively. The exposure to indoor NO_2 levels for garage workers with diesel engines (91.9 ±1.6 μg/m^3) was higher in Sweden using diffusive samplers than for garage workers with gasoline engines (41.6 ±1.2 μg/m^3). Furthermore, an assessment of workers exposed to diesel exhaust using or around diesel-fueled trucks, tractors in agriculture, and shunting engines revealed NO_2 emissions of 32.2 ±1.6 μg/m^3 [30]. As a result, our investigation found the highest number of trucks emitting NO_2 at the Chiang Khong border in Chiang Rai (Tables 4 and 5).

Table 4. Number of tourists and vehicles including arrival and departure at Chiang Khong border checkpoint, Chiang Rai

Path	Month	Tourist (person)			Vehicles (car)						
		Thai	Foreign	Sum	Trucks	Cars	Pickup Trucks	Vans	Buses	Motorcycles	Sum
Arrival	Nov 2022	10,144	10,639	20,783	6,337	702	775	48	30	21	7,913
	Dec 2022	10,884	11,527	22,411	6,664	722	871	46	28	82	8,413
	Jan 2023	11,261	13,131	25,435	6,503	879	948	75	36	72	8,513
	Feb 2023	8,807	21,494	20,301	3,171	706	813	49	27	80	4,846
	Mar 2023	8,053	12,163	20,216	3,753	805	910	52	28	35	5,583
	Apr 2023	10,014	19,712	29,726	9,589	956	1,047	49	28	82	11,751
	Sum	**58,163**	**79,666**	**138,872**	**36,017**	**4,770**	**5,364**	**319**	**177**	**372**	**47,720**
Departure	Nov 2022	10,708	14,157	24,865	6,262	669	756	44	30	39	7,800
	Dec 2022	9,224	12,578	21,802	6,586	735	869	51	28	66	8,300
	Jan 2023	11,284	20,340	30,487	6,506	891	903	73	34	145	8,552
	Feb 2023	8,444	17,665	26,109	3,135	734	791	53	28	104	4,845
	Mar 2023	8,239	16,604	24,843	3,569	835	896	39	28	66	5,433
	Apr 2023	10,216	22,567	32,873	9,633	971	1,061	43	28	54	11,790
	Sum	**58,115**	**103,911**	**160,979**	**35,691**	**4,835**	**5,276**	**303**	**176**	**474**	**46,720**

Table 5. Pearson's correlation between NO_2, number of tourists and vehicles including arrival and departure paths at Chiang Khong border checkpoint, Chiang Rai

Path	Parameter	Vehicles (cars) n=22						
		Truck	Car	Pickup Truck	Van	Bus	Motorcycle	Sum vehicles
Arrival	NO_2	0.528**	0.228*	0.164	−0.096	−0.0.85	0.077	0.466**
	Thai tourist	0.508**	0.526**	0.682**	−0.022	0.664**	0.422**	0.579**
	Foreign tourist	0.460**	0.864**	0.803**	−0.012	0.456**	0.490**	0.568**
	Sum tourist	0.534**	0.875**	0.875**	−0.013	0.599**	0.524**	0.645**
Departure	NO_2	0.429**	0.094	0.085	−0.304	−0.163	−0.243	0.411**
	Thai tourist	0.442**	0.430**	0.600**	0.304*	0.705**	0.244	0.512**
	Foreign tourist	0.262	0.824**	0.815**	0.321*	0.685**	0.351*	0.391**
	Sum tourist	0.356*	0.753**	0.810**	0.305*	0.751**	0.357*	0.475**

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

In Italy, Marcon *et al.* [4] used two weeks of passive samplers to measure the indoor NO_2 concentrations among residents in Viadana's industrial estate. They observed that the average of indoor NO_2 concentrations in cold, warm, and annual seasons was 19.9 μg/m^3 (17.5–22.0 μg/m^3), 9.9 μg/m^3 (6.7–13.0 μg/m^3) and 16.0 μg/m^3 (12.4–16.6 μg/m^3), respectively. The Effect of traffic and population density were similarly higher near the industry. According to Phantu and Bootdee [5], the indoor and outdoor NO_2 values at elementary schools surrounding an industrial estate, in Rayong province, Thailand were 9.0 ±4.4 to 16.7 ±2.7 and 8.2 ±2.1 to 17.7 ±6.7 μg/m^3, respectively. However, the mean of indoor NO_2 concentrations at the Chiang Khong border checkpoint in Chiang Rai province observed in this study (18.7 ±5.8 to 37.8 ±28.9 μg/m^3) was higher than those reported inside elementary schools in Rayong and the residents in Italy. When compared to a study from Malaysia, Norbäck *et al.* [3] reported indoor and outdoor NO_2 concentrations in junior high schools in Johor Bahru, Malaysia. It found that the indoor NO_2 values were 17.0–32.3 μg/m^3, which were similar to those obtained in this study (18.7 ±5.8 to 37.8 ±28.9 μg/m^3). Moreover, Blaszczyk *et al.* [31] investigated that the indoor NO_2 concentrations in urban and rural kindergartens in Silesia, Poland ranged between 6.8–9.8 μg/m^3 (mean 8.2 ±0.3 μg/m^3) and 4.2–13.5 μg/m^3 (mean 8.2 ±1.2 μg/m^3), respectively. The study's researchers went on to indicate that these high values were affected by emissions from vehicles. However, most of the indoor NO_2 levels in this study complied with the recommended standard of annual guidelines created by the WHO and PCD, except in March and April 2023. The percentages of days exceeding the annual guideline of WHO limit of 40 μg/m^3 and the ambient NO_2 at PCD of 57 μg/m^3 were 13.6%–27.3% (3–6 weeks) and 4.5%–18.2% (1–4 weeks), respectively [26, 32]. Although passive sampling devices are usually treated as qualitative tools, they still provide over longer time scales.

B. Effects of Vehicle Type on Indoor NO_2 Concentrations

Indoor NO_2 concentrations from sampling sites and vehicles type in the arrival and departure paths at the Chiang Khong border checkpoint in Chiang Rai province including truck, car, pickup truck, van, bus and motorcycle are presented in Table 4. Pearson's correlation of each pair of parameters is mentioned in Table 5. It was found that trucks in the arrival and departure paths were strongly correlated (p<0.01) with the average indoor NO_2 concentrations (r=0.528 and 0.429, respectively). Furthermore, the positive correlations between indoor NO_2 levels and the total number of vehicles in the arrival and departure paths were stronger (r=0.466 and 0.411, respectively). The arrival and departure pathways of the truck (r=0.356–0.534), car (r=0.753–0.875), pickup truck (r=0.810–0.875), bus (r=0.599–0.751), and motorcycle (r=0.357–0.524) were all favorably connected with the total number of visitors (p<0.01 and p<0.05). As a result, the tourists were affected by indoor NO_2 levels.

C. Non-Carcinogenic Risk Assessment

Non-carcinogenic risks are any undesirable health outcomes in an organism caused by environmental exposures other than cancer. The hazard quotient (HQ) was used in an epidemiological assessment of the non-carcinogenic risk of indoor NO_2 inhalation. Fig. 3 presents the HQ of short-term (acute exposure) and long-term (chronic exposure) non-carcinogenic health risks for indoor NO_2 exposure at the Chiang Khong border checkpoint in Chiang Rai province. As a result, All HQ values for acute exposure from inhalation to indoor NO_2 during a tourist period for children and adults were less than 1.0, indicating the presence of a low hazard, and HQ values for chronic exposure for children and adults indicated the possibility of a non-carcinogenic impact (HQ>1.0). Previous research by Bootdee *et al.* [33] revealed that the non-cancer risk of indoor NO_2 exposure in primary schools in Rayong province, Thailand, was less than 1.0 for both children and adults (0.02–0.21 and 0.02–0.17, respectively). Moreover, Phantu and Bootdee [5] reported that HQ values of indoor NO_2 in 8 Rayong city primary schools were less than 1.0 in children and teenagers (0.14–0.73 and 0.07–0.48). However, the logistic regression for the correlation between indoor NO_2 and classroom symptoms indicated eye irritation (p = 0.007), pink eye/allergic conjunctivitis (p = 0.012), runny nose (p = 0.020), sore throat (p = 0.038), wheeze (p = 0.022), and cough (p = 0.035). Kaewrat *et al.* [12] reported that HQ values for young children, children and teachers of indoor NO_2 exposure in a classroom in a primary school in Nakhon Si Thammarat province, Thailand were 0.62, 0.49, and 0.26, respectively. Hwang and Park [34] studied the HQ levels of children and adult females exposed to indoor NO_2 in South Korean postnatal care centers. They observed that the HQ values for acute indoor NO_2 exposure for children and adult females were 0.16–1.01 and 0.06–0.36, respectively, with values less than 1.0 suggesting there is no risk. As a result, this study observed that HQ values for chronic exposure to indoor NO_2 were greater than 1.0, implying the possibility of a non-carcinogenic influence. Children were more affected by indoor NO_2 inhalation than adults. Therefore, long-term indoor NO_2 exposure might be a health concern.

The hazard quotient (HQ) was used in an epidemiological assessment of the non-carcinogenic risk of indoor NO_2 inhalation. As a result, All HQ values for acute exposure from inhalation to indoor NO_2 during a tourist period for children and adults were less than 1.0, indicating the presence of a low hazard, and HQ values for chronic exposure for children and adults indicated the possibility of a non-carcinogenic impact (HQ>1.0). In the long term, children have higher HQ levels of indoor NO_2 exposure than adults. According to Miller *et al.* [35] and US-EPA [36], Children's inhalation rates differ from adults' due to differences in size, physiology, behavior, and activity level. Because of their rapid development and significantly greater lung Surface Area (SA) per unit of body weight, children have higher oxygen demand and breathing rates. Children need more energy because of their rapid growth and high levels of physical activity. Children also consume more energy for the production of heat than adults might because they have more surface area in comparison to their weight. Previous studies have shown that short- and long-term indoor NO_2 exposure from traffic emissions may raise the risk of Chronic Obstructive Pulmonary Disease (COPD) mortality and hospitalizations. They revealed that long-term COPD prevalence was higher than long-term and short-term COPD hospitalizations and mortality. The long-term risk of hospitalization increased by 1.8%, and the mortality rate increased by 2.6% [14]. In the short term, indoor NO_2 inhalation correlated to symptoms including eye and adnexa diseases, runny nose, sore throat, cough, and fatigue in students [3, 5, 15], while Zhong *et al.* [37] observed that a 10-ppb increase in NO_2 was linked with an additional 6.8–7.5% of dry eye occurrence. As a result, ocular pain sensations and tear breakup time could possibly be used as indicators for assessing the adverse health impacts of traffic density and NO_2 exposure [3, 16].

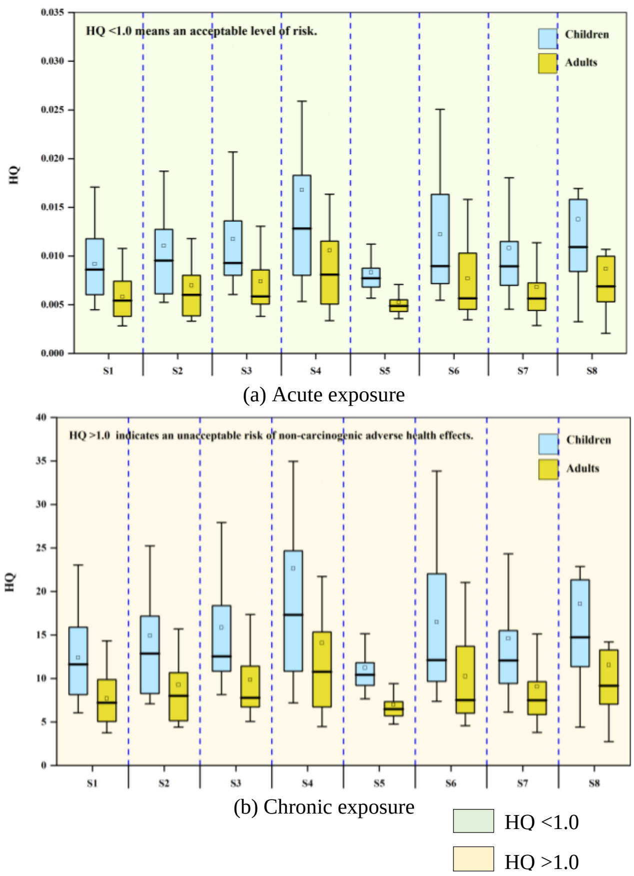


Fig. 3. Non-carcinogenic risks of indoor NO_2 exposure calculated by HQ for children and adults.

IV. CONCLUSION

Indoor NO_2 concentrations measured at the Chiang Khong border checkpoint in Chiang Rai were found to be significantly correlated with road traffic intensity during the tourist season. The levels of indoor NO_2 released by vehicles with diesel exhausts were obvious. Moreover, within the relevant range of significance, a major correlation for indoor NO_2 concentrations was found between the total number of vehicles and tourists. Trucks and cars have influenced indoor NO_2 concentrations. Officers working at immigration and customs checkpoints, as well as those working in offices in heavy traffic areas, may be exposed to NO_2. Long-term HQ values in connection with a non-carcinogenic risk to human health caused by indoor NO_2 exposure have shown that children had greater HQ levels of indoor NO_2 exposure than adults. The findings of health risk assessment and NO_2 concentrations in the ambient environment at a cross-border checkpoint in Chiang Rai Province are important for implementing transportation management, especially during the tourist season. Furthermore, a cross-border checkpoint in Nan Province, Thailand, is one of the potential areas for future research due to high road traffic intensity during the tourist season.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The experiments have been carried out with the assistance of Piyapan Chuamuangpan, Thitipong Ployleaung, Sopida Supotina, and Kunyarat Poungbut. The statistical analysis and data visualization were performed by Piyapan Chuamuangpan, and Susira Bootdee, who also wrote the study. Susira Bootdee created the idea and carried out all of the experiments, as well as writing the manuscript. The final manuscript was read and approved by Piyapan Chuamuangpan, Sopittaporn Sillapapiromsuk and Susira Bootdee. All authors had approved the final version.

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References

[1] H. Salonen, T. Salthammer, and L. Morawska, "Human exposure to NO_2 in school and office indoor environments," *Environ Int*, vol. 130, 104887, September 2019.

[2] A. F. Raffee, H. A. Hamid, S. N. Rahmat, and M. I. Jaffar, "Vector autoregressive model: A multivariate time series to forecast the ground level ozone (O_3) concentration in Malasia," *Chiang Mai J. Sci*., vol. 47, no. 6, pp. 1297–1309, 2020.

[3] D. Norbäck, J. H. Hashim, Z. Hashim, and F. Ali, "Volatile organic compounds (VOC), formaldehyde and nitrogen dioxide (NO_2) in schools in Johor Bahru, Malaysia: Associations with rhinitis, ocular, throat and dermal symptoms, headache and fatigue," *Sci. Total Environ.*, vol. 592, pp. 153–160, August 2017.

[4] A. Marcon, S. Panunzi, M. Stafoggia, C. Badaloni, K. De Hoogh, L. Guarda, F. Locatelli, C. Silocchi, P. Ricci, and P. Marchetti, "Spatial variability of nitrogen dioxide and formaldehyde and residential exposure of children in the industrial area of Viadana, Northern Italy," *Environ. Sci. Pollut. Res*., vol. 28, pp. 28096–28106, February 2021.

[5] S. Phantu and S. Bootdee, "Nitrogen dioxide exposure and health risk assessments of students in elementary schools in the vicinities of an industrial estate, located in Rayong province, Thailand," *Environ. Eng. Res.*, vol. 27, no. 5, 2022.

[6] H. T. Trinh, K. Imanishi, T. Morikawa, H. Hagino, and N. Takenka, "Gaseous nitrous acid (HONO) and nitrogen oxides (NO_X) emission from gasoline and diesel vehicles under real-world driving test cycles," *J. Air Waste Manage. Assoc*., vol. 64, no. 4, pp. 412–420, February 2017.

[7] P. G. Boulter, T. J. Barlow, and I. S. McCrae, "Emission factors 2009: Report 3—Exhaust emission factors for road vehicles in the United Kingdom," Transport Research Laboratory (TRL) and Information Handling Services (IHS) publication Berkshire; United Kingdom, 2009.

[8] M. Z. M. Alamar, O. Fetitah, I. M. Almanjahie *et al.*, "Modern functional statistical analysis: Application to air pollutant in London Marylebone road," *Chiang Mai J. Sci.*, vol. 49, no. 2, pp. 511–523, March 2022.

[9] S. S. Ahmad, P. Biiker, L. Emberson, and R. Shabbir, "Monitoring nitrogen dioxide levels in urban areas in Rawalpindi, Pakistan," *Water, Air, Soil Pollut*, vol. 220, pp. 141–150, January 2011.

[10] C. Khamkaew and S. Chantara, "Efficiency of a tailor made NO_2 passive sampler and correlations of NO_2, PM_{10} and PM_{10}-bound NO_3^- in urban air of Chiang Mai (Thailand)," *Chiang Mai J. Sci*., vol. 40, no. 3, pp. 386–400, July 2013.

[11] Z. Bozkurt, G. Doğan, D. Arslanbaş, B. Pekey, H. Pekey, Y. Dumanoğlu, A. Bayram, and G. Tuncel, "Determination of the personal, indoor and outdoor exposure levels of inorganic gaseous pollutants in different microenvironments in an industrial city," *Environ Monit Assess*, vol. 187, pp. 1–17, September 2015.

[12] J. Kaewrat, R. Janta, S. Sichum, and T. Kanabkaew, "Indoor air quality and human health risk assessment in the open-air classroom," *Sustainability*, vol. 13, 8302, July 2021.

[13] X. Y. Zheng, H. Ding, L. N. Jiang, S. W. Chen, J. P. Zheng, M. Qiu, Y. X. Zhou, Q. Chen, and W. J. Guan, "Association between air pollutants and asthma emergency room visits and hospital admissions in time-series studies: A systematic review and Meta-analysis," *PLoS One*, vol. 10, no. 9, September 2015.

[14] Z. Zhang, J. Wang, and W. Lu, "Exposure to nitrogen dioxide and Chronic Obstructive Pulmonary Disease (COPD) in adults: Systematic review and meta-analysis," *Environ Sci Pollut Res Int*, vol. 25, no. 15, pp. 15133–15145, May 2018.

[15] J. Song, Y. Liu, M. Lu, Z. An, J. Lu, L. Chao, L. Zheng, J. Li, S. Yao, W. Wu, and D. Xu, "Short-term exposure to nitrogen dioxide pollution and the risk of eye and adnexa diseases in Xinxiang, China," *Atmos. Environ*., vol. 218, 117001, December 2019.

[16] P. Novaes, P. H. N. Saldiva, M. Matsuda, M. Macchione, M. P. Rangel, K. Kara-Jose, and A. Berra, "The effects of chronic exposure to traffic derived air pollution on the ocular surface," *Environ. Res*., vol. 110, pp. 372–374, May 2010.

[17] S. Lin and C. Grundy-Warr, "One Bridge, two towns and three countries: Anticipatory geopolitics in the Greater Mekong subregion," *Geopolitics*, vol. 17, pp. 952–979, July 2012.

[18] N. P. Uttama, "Investment promotion policy in potential border zone," *Procedia Economics and Finance*, vol. 14, pp. 615–623, December 2014.

[19] Chiang Khong Customs House (CCH). (2023). Statistics of importation and exportation. [Online]. Available: https://chiangkhong.customs.go.th/list_strc_download.php?ini_content=statistic_and_report_180205_01&lang=th&root_left_menu=menu_report_and_news&left_menu=menu_statistics_report

[20] S. Bootdee, P. Chalemrom, and S. Chantara, "Validation and field application of tailor-made nitrogen dioxide passive sampler," *Int. J. Environ. Sci. Technol*., vol 9, no. 3, pp. 519–526, April 2012.

[21] S. Bootdee and S. Chantara, "Emission of fine particulate matter and nitrogen dioxide from incense burning in shrines, Chiang Mai, Thailand," *Int. J. Environ. Sci. Dev*., vol. 5, no. 2, pp. 228–232, April 2014.

[22] United State Environmental Protection Agency (US-EPA), "Risk assessment guidance for superfund volume I: Human health evaluation manual (Part F, supplemental guidance for inhalation risk assessment)," Washington D.C.: USA, 2009.

[23] A. C. Olufemi, A. Mji, and M. S. Mukhola, "Health risks of exposure to air pollutants among students in schools in the vicinities of coal mines," *Energ Explor Exploit.*, vol. 37, no. 6, pp. 1,638–1,656, November 2019.

[24] S. Sillapapiromsuk, G. Koontoop, and S. Bootdee, "Health risk assessment of ambient nitrogen dioxide concentrations in urban and industrial area in Rayong province, Thailand," *Trends Sci.*, vol. 19, no. 11, 4476, May 2022.

[25] O. M. Morakinyo, A. S. Adebowale, M. I. Mokgobu, and M. S. Mukhola, "Health risk of inhalation exposure to sub-10 µm particulate matter and gaseous pollutants in an urban-industrial area in South Africa: an ecological study," *BMJ Open*, vol. 7, March 2017.

[26] World Health Organization (WHO). (2010). WHO guidelines for indoor air quality: selected pollutants. [Online]. Available: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/policy/who-guidelines-for-indoor-air-quality
[27] United State Environmental Protection Agency (US-EPA). (1995). Health effects assessment summary tables. Washington D.C., USA. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://nepis.epa.gov/Exe/ZyPDF.cgi/2000GHZ2.PDF?Dockey=2000GHZ2.PDF
[28] O. V. Lozhkina and V. N. Lozhkin, "Estimation of nitrogen oxides emissions from petrol and diesel passenger cars by means of on-board monitoring: Effect of vehicle speed, vehicle technology, engine type on emission rates," *Transp. Res. D: Transp. Environ*., vol. 47, pp. 251–264, August 2016.
[29] G. A. Ban-Weiss, J. P. McLaunghlin, R. A. Harley, M. M. Lunden, T. W. Kirchstetter, A. J. Kean, A. W. Strawa, E. D. Stevenson, and G. R. Kendall, "Long-term changes in emissions of nitrogen oxides and particulate matter from on-road gasoline and diesel vehicles," *Atmos. Environ.*, vol. 42, pp. 220–232, January 2008.
[30] M. Lewné, N. Plato, and P. Gustavsson, "Exposure to particles, elemental carbon and nitrogen dioxide in workers exposed to motor exhaust," *Ann Occup Hyg*., vol 51, no. 8, pp. 693–701, November 2007.
[31] E. Blaszczyk, W. Rogula-Kozlowska, K. Klejnowski, P. Kubiesa, I. Fulara, and D. Mielżyńska-Švach, "Indoor air quality in urban and rural kindergartens: Short-term studies in Silesia, Poland," *Air Qual Atmos Health*, vol. 10, pp. 1,207–1,220. August 2017.
[32] Pollution Control Department (PCD). (2023). Standards and laws of air quality. [Online]. Available: https://www.pcd.go.th/laws
[33] S. Bootdee, S. Phantu, P. Lamlongrat, and T. Khumphai, "Indoor nitrogen dioxide investigation and Health risk assessment in primary schools at Rayong City, Thailand," *Curr. Appl. Sci. Technol*., vol. 19, no. 3, pp. 248–262, September 2019.
[34] S. H. Hwang, and W. M. Park, "Indoor air concentrations of carbon dioxide (CO_2), nitrogen dioxide (NO_2), and ozone (O_3) in multiple healthcare facilities," *Environ Geochem Health*, vol. 42, pp. 1487–1496, May 2020.
[35] M. D. Miller, M. A. Marty, A. Arcus, J. Brown, D. Morry, and M. Sandy, "Differences between Children and Adults: Implications for Risk Assessment at California EPA," *Int J Toxicol.*, vol. 21, pp. 403–418, September–October 2002.
[36] United State Environmental Protection Agency (US-EPA). (2011). Exposure factors handbook: 2011 Edition (Final Report). *National Center for Environmental Assessment*, Washington D.C., USA. EPA/600/R-09/052F. [Online]. Available: https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252
[37] J.-Y Zhong, Y.-C. Lee, C.-J. Hsieh, C.-C. Tseng, and L.-M. Yiin, "Association between dry eye disease, air pollution and weather changes in Taiwan," *Int. J. Environ. Res. Public Health*, vol.15, 2269, October 2018.