WALAILAK JOURNAL
Applied Sciences
http://wjst.wu.ac.th https://doi.org/10.48048/wjst.2021.11510

Health Risk Assessment of Residents in a Tourist City: A Case Study of Nakhon Si Thammarat Province

Jenjira KAEWRAT[1,2] and Rungruang JANTA[1,2,*]

[1]School of Languages and General Education, Walailak University, Nakhon Si Thammarat 80160, Thailand
[2]Center of Excellence in Sustainable Disaster Management, Walailak University, Nakhon Si Thammarat 80160, Thailand

([*]Corresponding author's e-mail: rungruang.ja@mail.wu.ac.th)

Received: 31 July 2020, Revised: 6 December 2020, Accepted: 31 December 2020

Abstract

Nakhon Si Thammarat is one of the most popular tourist destinations among the secondary tourism cities according to economic promotions. The rapid growth of the tourism industry is evidenced by increasing road traffic, especially at weekends, contributing to high nitrogen dioxide (NO_2) concentration. The concentration of NO_2 was measured in the main tourist destinations of Nakhon Si Thammarat Province. Likewise, health risks from NO_2 exposure were also evaluated for the local residents. Air mass movement was applied to indicate risk areas of non-cancer health effects from exposure to NO_2. Air samples were collected over 24 hours using a passive sampling technique at 3 areas in the tourist destination on weekdays and weekends during the wet season in 2018 and 2019. Results showed that NO_2 concentrations at weekends were 2 - 3 times higher than on weekdays due to increased vehicular traffic. Anthropogenic activities had a greater influence than meteorological conditions on pollutant concentration. The NO_2 concentration was within the ambient air quality standard, but toxicological risk quotients for the residents were above the recommended limits for human health. Findings indicated that local residents risked non-cancer health effects from long-term exposure to NO_2. Therefore, sensitive residents should avoid outdoor activities on weekends. Moreover, the tourism authority should consider controlling visitor numbers, providing a parking area, and providing public transportation systems to reduce traffic-related pollutants for sustainable tourism in Thailand.

Keywords: Tourism, Traffic-related pollutant, Health risk assessment, Nakhon Si Thammarat

Introduction

Nitrogen dioxide (NO_2) is recognized as a major traffic-related air pollutant produced by the reaction of nitrogen and oxygen gases during vehicle engines' internal combustion process. Nitrogen is released during fuel combustion at high temperatures and combines with oxygen atoms to form nitric oxide (NO), which then reacts rapidly with oxygen atoms to create NO_2. The concentration of NO_2 is directly related to traffic volume and flow [1-4]. Beckerman *et al*. [5] highlighted the correlation between NO_2 and many traffic-related pollutants, including volatile organic compounds (VOCs), black carbon, particulate matter (PM), and ozone along major expressways. Exposure to NO_2 is associated with adverse health effects, including eye and adnexa diseases, age-related macular degeneration (ARMD), DNA methylation irregularity, respiratory inflammation, asthma, and lung function impairment [6-9]. Duan *et al*. [10] reported an increase of 0.06 - 3.51 % in China's cardiovascular deaths for every 10 μg m^{-3} NO_2 level increase. Moreover, NO_2 is a precursor of traffic-related pollutants such as ozone (O_3) and $PM_{2.5}$, presenting indirect health effects from NO_2. Additionally, NO_2 emitted into the atmosphere reacts with water (humidity) to form nitric acid (NO_2) and falls as precipitation, known as acid rain, which degrades ecosystems of plants, soil, trees, and buildings.

Tourism is a significant contributor to the economy of Thailand. The Thailand Ministry of Tourism and Sports reported revenue of 300 billion baht from the tourism industry in 2019, with amounts of 100 and 200 billion baht from domestic and international tourism, respectively [11]. Tourism is one of the fastest-growing industries in Thailand because it has both an ancient cultural heritage and natural attractions that draw huge numbers of tourists every year. The Tourism Authority of Thailand (TAT) has also promoted secondary tourism cities since 2018 to alleviate congestion at prime tourist areas and geographically balance economic growth. Nakhon Si Thammarat Province is one of the most popular areas among the smaller cities with various tourist destinations such as mountains, beaches, and cultural heritage. The economy has grown rapidly, and the province received around 350,000 visitors with an income of 1.2 billion baht in 2018 [11]. However, tourism is also a significant contributor to environmental deterioration through waste generation and especially traffic pollution in the form of NO_2. Saenz-de-Miera and Rosselló [12] observed the relationship between tourist numbers and lower traffic speed as a result of higher traffic volume and increased congestion. An increase in tourist numbers was positively associated with traffic-related pollutants. Saenz-de-Miera and Rosselló [13] observed a 1 % tourist increase in Mallorca related to a 0.45 % increase in PM_{10} concentration. Nitrogen dioxide concentration in Chiang Mai and Nakhon Si Thammarat's tourist cities were comparable in the range 13 to 96 $\mu g\ m^{-3}$, while the concentration in Seoul, Korea ranged 41 - 181 $\mu g\ m^{-3}$ [14-16]. Results indicated that NO_2 levels in tourist cities were influenced by factors such as tourism and other anthropogenic activities. Many studies have investigated air pollutants in tourist cities, but these mainly focused on megacities, and studies of air pollution in natural tourist destinations are limited. Hence, this study explored the effect of tourism on air quality at a natural tourist destination, and it also assessed local residents' health risks. An air mass movement model was used to indicate the risk area from NO_2 exposure. Results provide useful basic information for tourism authorities to improve strategy formulation for sustainable tourism in Thailand.

Materials and methods

Study area

The study area was located in Kiriwong Village, Lansaka District, Nakhon Si Thammarat Province. This province is located on the Malay Peninsula, which experiences both the Southwest Monsoon and Northeast Monsoon. The rainy season runs from June to February (9 months), with only 3 months as the dry season (March to May). Annual temperature and rainfall average 27 ºC and 2,500 mm, respectively. Kiriwong Village is 20 km from the city of Nakhon Si Thammarat, and this area is known to have the best air quality in Thailand. The village is located in a valley surrounded by mountain ranges, with a river flowing through the middle. Kiriwong Village is a famous natural attraction in the area as a model community for eco-tourism management.

Nitrogen dioxide samples were collected from 3 areas in Kiriwong Village. The 1st sampling site was located at Kiriwong Bridge, known as the gate of the village. This area is a famous place where visitors take photographs. The 2nd sampling site was on the road in the village. The 3rd sampling site was the activity area of Kiriwong Village. This area is a highlight for visitors to Kiriwong Village where they can enjoy activities by the river (**Figure 1**).

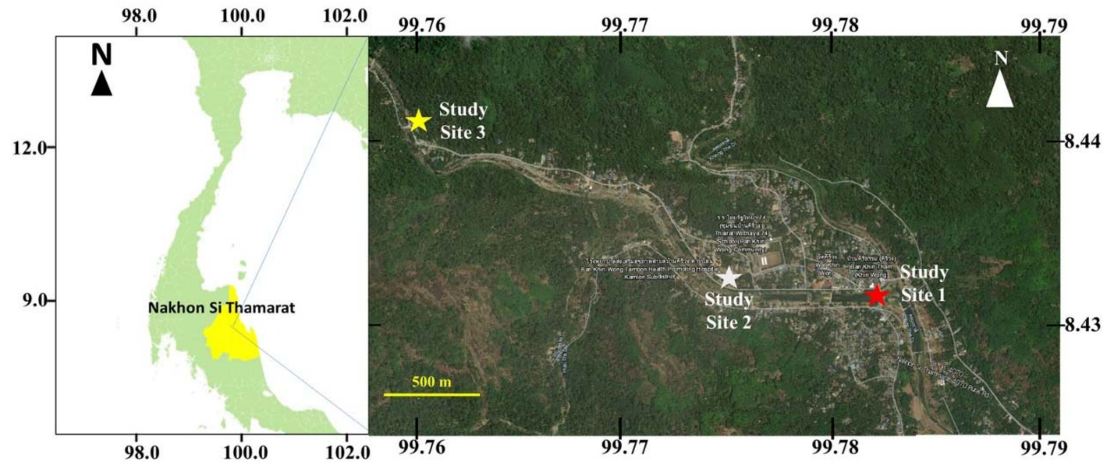

Figure 1 Study area of the three tourist destinations in Kiriwong Village.
(Study site 1: Kiriwong Bridge; Study site 2: Road in the village; study site 3: Activity area).

Nitrogen dioxide sampling

At Nakhon Si Thammarat, the weather is a major consideration during the rainy season (9 months). Kiriwong Village is located in a valley surrounded by forests and experiences rainfall during the summer rainy season. This study also focused on the health risks of NO_2 exposure to increase air pollution awareness by the local authorities and residents in the tourist destination area. Thus, sample collection was conducted in the rainy season. 48 NO_2 samples were collected over a 24-hour period using a passive sampler on weekdays and at weekends during the rainy season in 2 different years (October - November 2018 and July - August 2019).

This study's passive sampler was developed by the Environmental Chemistry Research Laboratory (ECRL), Chiang Mai University, Thailand. Details on device preparation are provided in Bootdee *et al.* [16]. In brief, the passive sampler consists of 8 passive tubes per set: 5 sample tubes and 3 blank tubes. The absorbent, consisting of filter paper coated with triethanolamine (TEA), was placed at the passive tubes' bottom. Before using, all passive tubes were covered and sealed with parafilm. Covers were removed from the sample tubes during the collection of the NO_2 samples, while covers of the blank tubes remained in place. All passive tubes were hung at 1.5 - 2.0 m above ground level in a shelter to prevent interference from meteorological conditions. After 24 h, the samples were covered and sealed with parafilm and then transferred to the laboratory for analysis.

The samples were extracted using 2 mL of deionized water (DI water). The extracted solution 1 mL was pipetted to mix with 2 mL of Saltzman reagent to form purple azodye. Finally, the purple solution was measured for absorbance using a spectrophotometer (Dynamica VIS-20, Switzerland) at 540 nm. The NO_2 concentration in the sample was calculated from the standard curve of NO_2^- solution. Details of chemical preparation and extraction are explained in detail in Bootdee *et al.* [16].

Meteorological conditions

Meteorological conditions including atmospheric pressure and temperature were measured using a digital barometer, while information of the amount of rain was obtained from the Lan Saka Hydrology Irrigation Center.

Vehicle counting

Vehicle numbers were manually counted during the 2-week sampling period. Observation time from 8:00 am to 4:30 pm was subdivided into 27 periods of 18 min. In each period, the number of vehicles was recorded for 3 min, alternating with a break of 15 min. The number of vehicles recorded was then converted to the number for the total observation period.

Statistical analysis

The t-test was used to compare the concentration of NO_2 between weekdays and weekends, while analysis of variance (ANOVA) was applied to compare NO_2 concentration among sampling sites. Spearman's correlation was applied for correlation testing between NO_2 concentration and meteorological data. Correlation strength was separated by the absolute value of the correlation coefficient and classified as very strong (r_s = ±0.80 to ±1.0), strong (r_s = ±0.60 to ±0.79), moderate (r_s = ±0.40 to ±0.59), weak (r_s = ±0.20 to ±0.39) and very weak (r_s = ±0.00 to ±0.19) [17]. Positive and negative correlations were shown by plus and minus symbols, respectively.

Health risk assessment

Humans are normally exposed to nitrogen dioxide via the inhalation route. Therefore, the non-cancer risk from inhalation was considered in this study. The assessment focused on residents of Kiriwong Village who were classified into three age groups as infants (0 - 1 year), children (1 - 12 years) and adults (> 12 years).

The focus of this study was to determine the minimum health risk of NO_2 intake. Mean concentration of NO_2 measured during the rainy season was applied for health risk evaluation. Concentration of NO_2 at weekends was found to be significantly higher than on weekdays. The annual concentration used in the risk assessment was calculated from Eq. (1).

$$C_{avg} = \frac{(C_{weekday} \times N_{weekday}) + (C_{weekend} \times N_{weekend})}{365} \quad (1)$$

where C_{avg} is annual concentration of NO_2 (mg m^{-3}), $C_{weekday}$ and $C_{weekend}$ are NO_2 concentration on weekdays and weekends, respectively, and $N_{weekday}$ and $N_{weekend}$ are numbers of weekdays (261 days) and weekend days (104 days) in a year.

The hazard quotient (HQ) was applied to evaluate the health risk from NO_2 intake. HQ is the ratio of potential exposure to pollutants and its adverse effect level. Lina *et al.* [18], referred to Limy (1996), indicated guidelines for interpreting HQ value as follows: HQ values less than 0.1 shows no hazard exists; HQ values in the range 0.1 - 1.0 shows low hazard risk; HQ values in the range 1.1 - 10 shows moderate hazard risk; and finally, HQ values over 10 shows high hazard risk. The HQ value was calculated from Eq. (2) [19].

$$HQ = \frac{ADD}{RfD} \quad (2)$$

where the average daily dose ADD (mg kg^{-1} day^{-1}) is the exposure of NO_2 by respiratory inhalation (mg kg^{-1} day^{-1}), and the reference dose (RfD) of NO_2 is 1.1×10^{-2} mg kg^{-1} day^{-1} [20].

The ADD of residents was evaluated from Eq. (3) [20,21]. Details of each parameter are presented in **Table 1**.

$$ADD = \frac{C_{avg} \times IR \times ED \times AF \times EF}{BW \times AT} \quad (3)$$

where for ADD of pollutants, C_{avg} is the concentration of NO_2 (mg m^{-3}) with an assumption that NO_2 concentration outdoors = NO_2 concentration indoors, IR is the inhalation rate of residents (m^3 day^{-1}), ED is the exposure duration (days), AF is the bioavailability factor (unitless), EF is the exposure frequency (day $year^{-1}$), BW is the body weight of the exposure (kg), and AT is the average time (days).

Table 1 Exposure factor of the residents.

Exposed parameters		Symbol	Unit	Infant (0 - 1 year)	Children (1 - 12 year)	Adult (> 12 year)	References
Atmospheric NO_2	Site 1	C_{avg}	mg m^{-3}	0.057	0.057	0.057	This study
	Site 2	C_{avg}	mg m^{-3}	0.030	0.030	0.030	This study
	Site 3	C_{avg}	mg m^{-3}	0.032	0.032	0.032	This study
Body weight		BW	kg	10	26	55	[22,23]
The average time		AT	day		ED×365 (day/year)		[22]
The exposure duration		ED	year	1	6	30	
Bioavailability factor		AF	-	1	1	1	[22]
The exposure frequency		EF	day $year^{-1}$	365	365	365	
Inhalation rate		IR	m^3 day^{-1}	4.5	10	20	[22]

Risk area assessment using air mass movements

This study used air mass movements to conduct a preliminary evaluation of the risk area from NO_2 exposure. A forward trajectory is the path of an air mass moving forward from its origin. The forward trajectory analysis helps determine the dispersion of pollutants and is usually calculated by the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. The HYSPLIT model is widely used to compute long-range transport of various air pollutants, including PM_{10}, NO_2, and O_3 [24,25], because this model is simple, utilizes quick responses, and is complete for computing [26]. Forward trajectory analysis of NO_2 during the study period was calculated using HYSPLIT's TrajStat Trajectory Statistics function, which was processed by the HYSPLIT model [27]. The trajectory model's meteorological input was the Global Data Assimilation System (GDAS) and meteorological data (1º×1º). Since the lifespan of atmospheric NO_2 is about 4 h [28], a 2-hour forward trajectory was calculated in this study with the assumption of non-degradation of the pollutant during air mass movement. Moreover, the trajectories were calculated twice per day at traffic congestion periods (10:00 and 15:00 Local Sidereal Time (LST)) at 10 m above ground level (AGL) because these were times of maximal tourist arrivals and departures. A total of 1,460 trajectories (January 2018 - December 2019) per sampling site were clustered using the TrajStat application.

The forward trajectory (path of air movement) represented the direction of receptor exposure to the pollutant, while the number of trajectories indicated the annual frequency that the receptor was exposed to the pollutant. The exposure frequency (EF) of each cluster was calculated by Eq. (4). After that, the EF value was then calculated for the HQ value for each of the clustered trajectories in order to indicate the risk area of NO_2 exposure.

$$EF_i = \%\ Cluster_i \times EF \quad (4)$$

where EF_i is the exposure frequency of cluster i, and % $cluster_i$ is the percentage of trajectories in cluster i.

Results and discussion

Nitrogen dioxide concentration

The concentration of nitrogen dioxide collected from Kiriwong Village during the rainy season ranged from 21.6 to 111.9 µg m^{-3}. Air samples in this study were collected over 24 h, while Thailand's air quality standard was regulated for 1 h and the annual mean of NO_2 concentration. Therefore, NO_2 concentrations in this study were compared with Japan's ambient air quality standard of NO_2 for 24 h. Results showed that NO_2 concentrations were acceptable under the Japanese standard of 113 µg m^{-3}. Mean concentration of NO_2 was highest at study site 1 (98.6 and 40.1 µg m^{-3}) for weekends and weekdays, respectively, and significantly different from the other 2 sites ($p < 0.05$). No significant difference in concentration was observed between study site 2 and study site 3 (**Figure 2**). However, NO_2 concentrations strongly correlated among the 3 study sites with coefficients ranging from 0.6 to 0.88 at 99 % confidence level (Spearman's correlation test) because all the site locations were on the same road. Study site 1 was located at the T-intersection and tourists usually pass this site before going to study sites 2 and 3. Observations of traffic volumes at all sites showed that the volume at site 1 was about twice that at sites 2 and 3. Moreover, site 1, known as the gate of Kiriwong Village, is renowned as one of the landmarks of Kiriwong Village. Tourists always stop for a while at this site for photos without turning off their engines; thus, enormous quantities of pollutants accumulate in this area. Areas with traffic delay (slow vehicle flow), had higher NO_2 concentration than areas with free-flow traffic [3,4]. Thus, traffic delay increased the impact of pollutant emission and accumulation in the area.

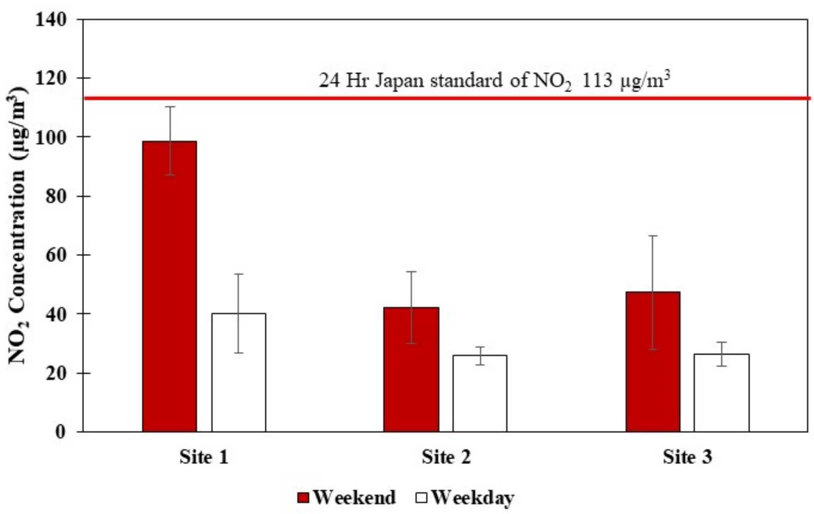

Figure 2 Comparison of nitrogen dioxide concentration between weekdays and weekends at Kiriwong Village during the rainy season

Nitrogen dioxide concentrations on weekdays ranged between 26.7 - 53.5, 22.7 - 28.9 and 22.1 - 30.5 µg m^{-3} for study sites 1, 2 and 3, respectively. Concentrations on weekdays and at weekends were significantly different ($p < 0.05$) at 95 % confidence level. Concentrations at weekends ranged between 87.0 - 110.2, 30.0 - 54.5 and 27.9 - 66.6 µg m^{-3} for study sites 1, 2 and 3, respectively. These were 1.6 to 2.5 times greater than weekday values. This result was related to the number of vehicles at weekends (~4,000 - 9,000 vehicles) as 1.5 to 2 times the number on weekdays (~3,000 - 4,500 vehicles) because tourists often make longer trips at weekends than on weekdays. The most common form of vehicular transport found in Kiriwong Village (55 %) was a motorcycle, but large numbers of cars (45 %) were also recorded. Moreover, tourists used cars at weekends twice as much as during weekday trips. Therefore, high traffic density occurred on local streets resulting in delays or traffic congestion [29-31]. The level of air pollutants in tourist destinations differs from megacities such as Moscow, Tokyo and Osaka, where NO_2 is largely emitted on weekdays rather than at weekends because of the operation of industrial enterprises and traffic intensity [32,33]. The NO_2 concentration in each area related to the travel behavior of tourists and the system of transportation.

There was no significance between NO_2 concentration and meteorological conditions of temperature, air pressure, and rainfall. However, pollution levels showed a weak positive relationship with air pressure (r_s *value* = 0.16 to 0.26), while a very weak negative relationship was evident between temperature (r_s *value* = -0.19 to -0.010) and rainfall amount (r_s *value* = -0.18 to -0.02). This result indicated that high pressure was more likely caused by nitrogen dioxide accumulation in the area [34]. The study area was located in a valley, and temperature inversion in which a layer of cool air at the surface was overlain by a layer of warmer air occurred, especially in the early morning and evening. This inversion led to accumulation of air pollutants in the area. Longer sunshine duration and higher air temperature reduced temperature inversion formation, which was more conducive to NO_2 diffusion [35]. Rainfall is affected by the concentration of air pollutants in terms of the atmospheric washing effect, and lower NO_2 levels are always observed after a rainy day. Results here concurred with many other studies, where variations in NO_2 concentration in areas located near emission sources were influenced by local anthropogenic sources such as traffic volume and traffic flow, rather than local meteorological conditions [16, 36, 37].

Health risk assessment of nitrogen dioxide exposure

The hazard quotient (HQ) was applied to estimate non-carcinogenic risks to humans from NO_2 intake by inhalation. The annual concentration of each study site was calculated following Eq. (1), with concentrations of 56.8, 30.5 and 32.3 μg m^{-3} for study sites 1, 2 and 3, respectively. Annual concentrations were then calculated for the HQ value using Eqs. (2) and (3), with the assumption that the outdoor and indoor concentrations of NO_2 were equal because of the open house style. The HQ value of this village ranged from 1.0 to 2.3 (**Figure 3**), indicating unacceptable exposure conditions with non-cancer risks for human health. The highest HQ value was found at study site 1 (1.9 - 2.3), followed by study site 3 (1.1 - 1.3). Both these sites presented moderate hazard levels for all resident groups [18], while the hazard level was low for adult residents at study site 2 [18]. The HQ value contrasted with NO_2 concentration, which was within the accepted ambient air quality standard. These results indicated that local residents were safe from acute effects, but they were at risk of long-term health effects from exposure to NO_2.

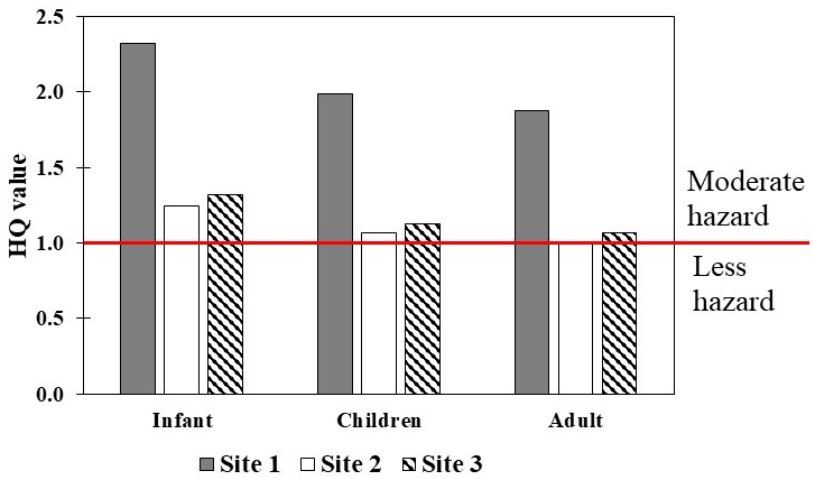

Figure 3 HQ value comparison among the resident groups

The highest risk group of residents was determined as the infant group (1.3 - 2.3), followed by children (1.1 - 2.0), and then adults (1.0 - 1.9). This was most likely due to the highest NO_2 intake per unit body weight for infants. This result concurred with a study by Bootdee *et al.* [38] that determined the HQ value of children exposed to NO_2 at primary schools in Rayong City as higher than that of adults. Other atmospheric pollutants indicated that the HQ of children (< 8 years old) from formaldehyde exposure in facilities in South Korea was higher than the acceptable level of 1, while adults were below the acceptable level [39]. Similarly, the risk to child residents (< 8 years old) was 12 % greater than the risk to adolescents (12 - 14 years) exposed to PM_{10} in the Brazilian Amazon region [40]. The total risk (HI) of non-carcinogenic pollutants for adult residents was half that of children and infants from exposure to PM_{10} and NO_2 in Kraków, Poland. Moreover, this study showed that the HI of women (3.19) was higher than that of men (2.67) because of the lower body weight of women [19]. However, HQ value was also based on the activity patterns of the receptor. Women spend more time in dwellings, and the HQ values of indoor VOCs for women were higher than those for men [41]. Du *et al.* [42] indicated that working males had higher risk levels from hazardous air pollutant (HAP) exposure than females due to their greater inhalation rate and longer working hours than females. Therefore, changing personal behavior to reduce air pollution exposure, such as spending more time in airtight buildings and avoiding outdoor activities during air pollution episodes (weekends), was suggested to reduce the residents' human health risks [43]. Traffic management and limitations on vehicle numbers at tourist destinations should also be considered to reduce pollutant concentrations at the source.

Risk area evaluation from nitrogen dioxide exposure

Risk area evaluation in this study was based on air mass movement because NO_2 is normally distributed to the downwind area via movement of air. Higher clustered trajectories indicated higher exposure frequency and health risk from exposure to pollutants. The trajectories of all study areas were similar because of the short distance between the sites. Therefore, the risk area was focused at study site 1 because this had the highest HQ value.

A total of 1,460 forward trajectories were clustered into two groups (**Figure 4)**, which consisted of cluster 1 (yellow line): 861 trajectories (59 %) and cluster 2 (blue dotted line): 599 trajectories (41 %). Air mass trajectories in cluster 1 were influenced by the northeast monsoon from October to February (5 months), while the southwest monsoon during May to September (5 months) was mainly impacted by Cluster 2 [44]. Trajectories in cluster 1 were also affected by the sea breeze to the east during the monsoon transition month. The number of trajectories in cluster 1 was greater than those in Cluster 2.

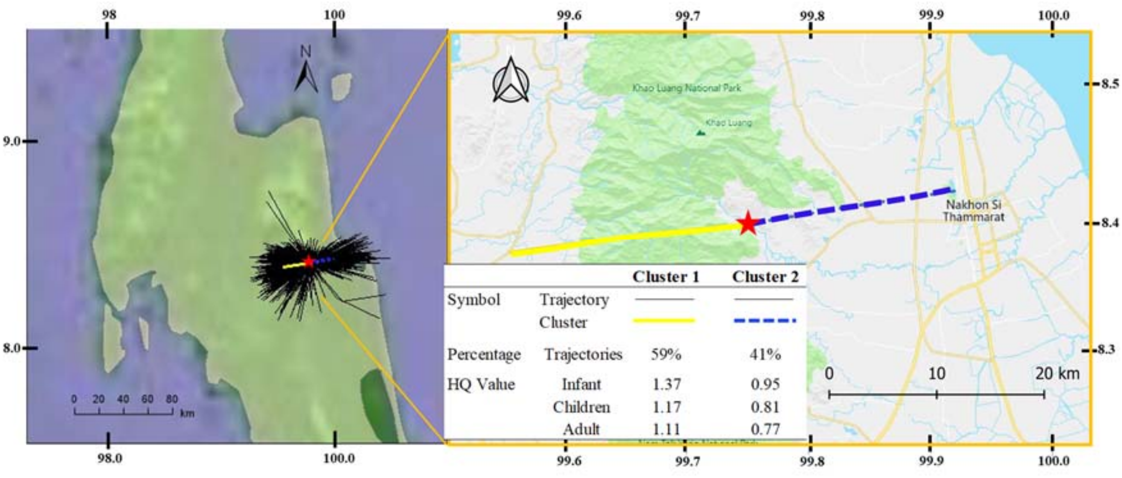

Figure 4 HQ values of cluster trajectories.

The number of trajectories in each cluster was converted to the exposure frequency (EF), and the EF of each cluster was then used to calculate the HQ value following Eqs. (3) and (4), respectively. The HQ value in each cluster implied that air mass movement analysis was clearly indicated risk area for long-term health effects from exposure to air pollutants, as presented in **Table 2**.

Table 2 Exposure frequency (EF) and HQ value of each cluster.

Study area	Cluster	The exposure frequency; EF (Day year^{-1})	HQ value		
			Infant (0 - 1 year)	Children (1 - 12 year)	Adult (> 12 year)
Site 1	Cluster 1	215	1.37	1.17	1.11
	Cluster 2	150	0.95	0.81	0.77
Site 2	Cluster 1	215	0.74	0.63	0.59
	Cluster 2	150	0.51	0.44	0.41
Site 3	Cluster 1	215	0.78	0.67	0.63
	Cluster 2	150	0.54	0.46	0.44

The exposure frequency of cluster 1 was 215 days, while cluster 2 was 150 days. The HQ values of cluster 1 study site 1 for all resident groups were higher than 1. The area to the west of study site 1 showed the highest risk, where the hazard from NO_2 exposure was unacceptable for residents. Therefore, residents should avoid outdoor activities at weekends and spend more time in houses with windows shut tightly [43], whereas cluster 2 hazard was acceptable. HQ values for study sites 2 and 3 indicated minimal hazard from inhalation intake of NO_2. Results implied that the tourism authority should immediately take steps to improve traffic management in tourism areas by extending public transport and limiting tourist or vehicle numbers to reduce annual NO_2 concentration to less than 0.25 µg m^{-3} and to maintain the HQ value at an acceptable level.

Conclusions

Nitrogen dioxide levels emitted by traffic in the tourism destination of Kiriwong Village were assessed using passive sampling. The NO_2 concentration was highest at landmark areas with high traffic density. Pollutant concentration at weekends was 2 - 3 times greater than on weekdays and positively correlated with the number of tourists visiting the area. However, NO_2 concentrations were within the 24-hour Japan air quality standard (113 µg m^{-3}). Anthropogenic sources such as traffic volume and traffic flow mainly influenced pollutant levels. A toxicity assessment determined that NO_2 exposure might cause long-term adverse health effects among residents, especially those living to the west of study site 1. Sensitive residents should avoid outdoor activities during periods of peak traffic volume. Moreover, the tourism authority should be aware of the environmental degradation resulting from tourist activities and transportation systems in tourist destinations. Tourism management should be improved as the 1st priority by controlling visitor numbers and providing adequate public transportation systems and parking areas.

Acknowledgements

The authors offer sincere thanks to Ms. Nuttida Nuttee and Ms. Narisa Ratthong for their kind assistance in sample collection. The support from the School of Languages and General Education is also greatly appreciated.

References

[1] NL Gilbert, MS Goldberg, JR Brook and M Jerrett. The influence of highway traffic on ambient nitrogen dioxide concentrations beyond the immediate vicinity of highways. *Atmos. Environ.* 2007; **41**, 2670-3.

[2] PG Obara, CL Roberts, CH Young and CD Williams. Validating the correlation of traffic-associated hydrocarbon and nitrogen dioxide with distance from a trunk road within a rural environment in UK. *Microchem. J.* 2011; **99**, 138-44.

[3] S Mukerjee, L Smith, H Brantley, C Stallings, L Neas, S Kimbrough and R Williams. Comparison of modeled traffic exposure zones using on-road air pollution measurements. *Atmos. Pollut. Res.* 2015; **6**, 82-7.

[4] L Smith, S Mukerjee, K Kovalcik, E Sams, C Stallings, E Hudgens, J Scott, T Krantz and L Neas. Near-road measurements for nitrogen dioxide and its association with traffic exposure zones. *Atmos. Pollut. Res.* 2015; **6**, 1082-6.

[5] B Beckerman, M Jerrett, JR Brook, DK Verma, MA Arain and MM Finkelstein. Correlation of nitrogen dioxide with other traffic pollutants near a major expressway. *Atmos. Environ.* 2008; **42**, 275-90.

[6] CJ Chang and HH Yang. Impact on eye health regarding gaseous and particulate pollutants. *Aerosol. Air Qual. Res.* 2020; **20**, 1695-9.

[7] G Favarato, HR Anderson, R Atkinson, G Fuller, I Mills and H Walton. Traffic-related pollution and asthma prevalence in children. Quantification of associations with nitrogen dioxide. *Air Qual. Atmos. Health.* 2014; **7**, 459-66.

[8] Y Jiang, Y Niu, Y Xia, C Liu, Z Lin, W Wang, Y Ge, X Leia, C Wang, J Caia, R Chena and H Kan. Effects of personal nitrogen dioxide exposure on airway inflammation and lung function. *Environ. Res*. 2019; **177**, 108620.

[9] 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.* 2019; **218**, 117001.

[10] Y Duan, Y Liao, H Li, S Yan, Z Zhao, S Yu, Y Fu, Z Wang, P Yin, J Cheng and H Jiang. Effect of changes in season and temperature on cardiovascular mortality associated with nitrogen dioxide air pollution in Shenzhen, China. *Sci. Total Environ*. 2019; **697**, 134051.

[11] Tourism Statistic 2019, Available at: https://www.mots.go.th/old/more_news.php?cid=411, accessed May 2020.

[12] O Saenz-de-Miera and J Rosselló. The responsibility of tourism in traffic congestion and hyper-congestion: A case study from Mallorca, Spain. *Tour. Manag.* 2012; **33**, 466-79.

[13] O Saenz-de-Miera and J Rosselló. Modeling tourism impacts on air pollution: The case study of PM_{10} in Mallorca. *Tour. Manag.* 2014; **40**, 273-81.

[14] H Bae, W Yang and M Chung. Indoor and outdoor concentrations of RSP, NO_2 and selected volatile organic compounds at 32 shoe stalls located near busy roadways in Seoul, Korea. *Sci. Total Environ*. 2004; **323**, 99-105.

[15] R Janta, J Kaewrat, C Rattikansukha and S Sichum. Measurement of nitrogen dioxide concentration in traffic areas of Nakhon Si Thammarat Province and health risk assessment (*in Thai*). *J. King Mongkut's University of Technology North Bangkok* 2020; **30**, 481-94.

[16] S Bootdee, P Chalemrom and S Chantara. Validation and field application of tailor-made nitrogen dioxide passive samplers. *Int. J. Environ. Sci. Technol.* 2012; **9**, 515-26.

[17] A Rauf, H Li, S Ullah, L Meng, B Wang and M Wang. Statistical study about the influence of particle precipitation on mesosphere summer echoes in polar latitudes during July 2013. *Earth Planets Space* 2018; **70**, 1-13.

[18] ND Lina, JC Engelbrecht, CY Wright and MA Osthuizen. Human health risks posed by exposure to PM_{10} for four life stages in a low socio: Economic community in South Africa. *Pan Afr. Med. J.* 2014; **18**, 1-12.

[19] US EPA. Concepts methods and data sources for cumulative health risk assessment of multiple chemicals, exposures and effects: A resource document, EPA/600/R-06/013F. *In:* Proceedings of the National Center for Environmental Assessment, Office of Research and Development, Cincinnati, United States, 2007.
[20] V Garbero, A Montaldo, N Lazovic, P Salizzoni, S Berrone and L Soulhac. The impact of the urban air pollution on the human health: A case-study in Turin. *Air Pollut. Model. App*. 2011; **11**, 729-32.
[21] ATSDR. *Public health assessment guidance manual.* Agency for Toxic Substances and Disease Registry, 2005.
[22] A Gruszecka-Kosowska. Assessment of the Krakow inhabitants' health risk caused by the exposure to inhalation of outdoor air contaminants. *Stoch. Environ. Res. Risk Assess*. 2018; **32**, 485-99.
[23] R Onchang and P Hemwat. Students' perception of industrial environmental stimuli: Focus on particulate matter (*in Thai*). *Sci. Tech.* 2016; **3**, 349-62.
[24] K Vellingiri, KH Kim, JM Lim, JH Lee, CJ Ma, BH Jeon, JR Sohn, P Kumar and CH Kang. Identification of nitrogen dioxide and ozone source regions for an urban area in Korea using back trajectory analysis. *Atmos. Res.* 2016; **176-177**, 212-21.
[25] P Punsompong and S Chantara. Identification of potential sources of PM_{10} pollution from biomass burning in northern Thailand using statistical analysis of trajectories. *Atmos. Pollut. Res.* 2018; **9**, 1038-51.
[26] T Rungratanaubon, S Bualert, P Choomanee and B Shutes. Vertical variation of nitrogen oxide (NOx) concentration using a backward air mass trajectories model in an urban area of Bangkok, Thailand. *KMUTNB Int. J. Appl. Sci. Technol.* 2018; **11**, 73-81.
[27] YQ Wang, XY Zhang and RR Draxler. "TrajStat: GIS-based software that uses various trajectory statistical analysis methods to identify potential sources from long-term air pollution measurement data. *Environ. Model. Softw.* 2009; **24**, 938-9.
[28] S Beirle, KF Boersma, U Platt, MG Lawrence and T Wagner. Megacity emissions and lifetimes of nitrogen oxides probed from space. *Science* 2011; **333**, 1737-9.
[29] S Anowar, S Yasmin and R Tay. Comparison of crashes during public holidays and regular weekends. *Accid. Anal. Prev.* 2013; **51**, 93-7.
[30] M Cools, E Moons and G Wets. Assessing the impact of public holidays on travel time expenditure. *Transp. Res. Rec.* 2010; **2157**, 29-37.
[31] L Yang, Q Shen and Z Li. Comparing travel mode and trip chain choices between holidays and weekdays. *Transp. Res. Part A Policy Pract*. 2016; **91**, 273-85.
[32] NF Elansky, AV Shilkin, NA Ponomarev, EG Semutnikova and PV Zakharova. Weekly patterns and weekend effects of air pollution in the Moscow megacity. *Atmos. Environ.* 2015; **224**, 117303.
[33] Y Sadanaga, S Shibata, M Hamana, N Takenaka and H Bandow. Weekday/weekend difference of ozone and its precursors in urban areas of Japan, focusing on nitrogen oxides and hydrocarbons. *Atmos. Environ.* 2008; **42**, 4708-23.
[34] L Wang, J Wang, X Tan and C Fang. Analysis of NOx pollution characteristics in the atmospheric environment in Changchun City. *Atmosphere* 2020; **11**, 2-12.
[35] Y Zhang. Dynamic effect analysis of meteorological conditions on air pollution: A case study from Beijing. *Sci. Total Environ*. 2019; **684**, 178-85.
[36] S Pintarić, T Bodrozić-Dzakić, H Pintarić, Z Rusan and S Ljubicić. Effects of nitrogen dioxide and meteorological conditions on the number of patients presenting to emergency department. *Acta. Clin. Croat.* 2012; **51**, 9-15.
[37] D Roberts-Semple, F Song and Y Gao. Seasonal characteristics of ambient nitrogen oxides and ground-level ozone in metropolitan northeastern New Jersey. *Atmos. Pollut. Res.* 2012; **3**, 247-57.
[38] 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. J. Appl. Sci. Technol.* 2020; **19**, 248-62.
[39] SH Hwang, J Roh and WM Park. Evaluation of PM_{10}, CO_2, airborne bacteria, TVOCs and formaldehyde in facilities for susceptible populations in South Korea. *Environ. Pollut.* 2018; **242**, 700-8.

[40] BFAD Oliveira, E Igotti, P Artzxo, PHN Saldiva, WL Juger and S Hacon. Risk assessment of $PM_{2.5}$ to child residents in Brazilian Amazon region with biofuel production. *Environ. Health* 2012; **11**, 64.
[41] Z Cheng, B Li, W Yu, H Wang, T Zhang, J Xiong and Z Bu. Risk assessment of inhalation exposure to VOCs in dwellings in Chongqing, China. *Toxicol. Res*. 2018; **7**, 59-72.
[42] Z Du, J Mo and Y Zhang. Risk assessment of population inhalation exposure to volatile organic compounds and carbonyls in urban China. *Environ. Int.* 2014; **73**, 33-45.
[43] R Laumbach, Q Meng and H Kipen. What can individuals do to reduce personal health risks from air pollution? *J. Thorac. Dis.* 2015; **7**, 96-107.
[44] The Climate of Nakhon Si Thammarat, Thailand, Available at: http://www.marine.tmd.go.th/thai/tus_type, accessed May 2020.