Health Risk Assessment of Ambient Nitrogen Dioxide Concentrations in Urban and Industrial Area in Rayong Province, Thailand

Sopittaporn Sillapapiromsuk[1], Gun Koontoop[2] and Susira Bootdee[2,*]

[1]*Faculty of Science, Lampang Rajabhat University, Lampang 52100, Thailand*
[2]*Faculty of Science, Energy and Environment, King Mongkut's University of Technology North Bangkok (Rayong campus), Rayong 21120, Thailand*

(*Corresponding author's e-mail: susira.b@sciee.kmutnb.ac.th)

Abstract

Nitrogen dioxide (NO_2) is a hazardous gas and an air pollutant that is released from a variety of sources, including fossil fuel mining and burning, automobile emissions and other sources. The inhalation of NO_2 has been linked to the exact causes of a variety of health issues, including respiratory disorders and a variety of other maladies. The largest source of NO_2 exposure is through traffic density emissions. The concentrations of ambient NO_2 in Rayong province's urban, industrial and background areas were measured during rainy, winter and summer seasons. Samples of NO_2 were collected with the use of passive samplers during September 2017 to April 2018. The result of the analysis revealed that NO_2 concentration of urban area, industrial area and background area were 13.9 - 43.0, 10.4 - 34.0 and 5.8 - 35.2 μg/m³, respectively. It is to be noted that NO_2 concentrations in urban and industrial areas were significantly higher than those in background areas ($p < 0.05$). The dominant source is located nearby high traffic density and industrial establishments. However, the NO_2 values obtained from seasonal variations were not significantly different ($p > 0.05$). A weak correlation was observed between NO_2 concentrations and total precipitation (r = −0.237). The low wind speed has no effect on NO_2 dispersion. As a result of the geographical and seasonal variation of NO_2 concentrations, it was determined that local activities such as traffic density had a much greater impact on NO_2 levels than meteorological factors. The hazard quotient (HQ) values from NO_2 exposure in Rayong province were less than 1, indicating that the risk was negligible. The inhalation of NO_2 by residents who live near the roadside and highway, on the other hand, may endanger their health.

Keywords: Nitrogen dioxide (NO_2), Passive sampler, Air pollution, Health risk assessment, Hazard quotient (HQ)

Introduction

One of the most important pollutant indicators for measuring urban air quality is nitrogen dioxide (NO_2). Carbon monoxide (CO), nitrous acid (HONO), ozone (O_3), sulfur dioxide (SO_2), particulate matter (PM_{10} and $PM_{2.5}$) and polycyclic aromatic hydrocarbons (PAHs) are all well correlated with NO_2 concentrations [1-3]. Moreover, it is the most toxic form of nitrogen oxide (NO_X) and adversely affects the human health [4,5]. The combustion of fossil fuels in motor vehicles is 1 of the major sources of anthropogenic NO_x in metropolises. Varghese and Ghosh [6] revealed oxides of nitrogen are major components of automobile exhaust. Experimental analysis of the air quality at an underpass inside a leading Indian University revealed the ambient nitrate concentration to be approximately 10 ppb. Moreover, Coghlan [7] reported that NO_x is produced from diesel burning in an engine, which 70 % of the NO_x produced is NO_2, compared with only 10 to 15 % when petrol is burned. Nitric oxide (NO) concentrations were 1,100 ppm or less depending on engine load, which was found NO_2 concentrations greater than 60 ppm [8]. Therefore, NO_2 has been considered to be the main traffic-related air pollution and has been used as a toxicity indicator in motor vehicle exhaust [4,9].

Several studies investigated sources of ambient NO_2 concentration. Hien *et al.* [10] used passive diffusion tube sampler to monitor ambient NO_2 concentrations at the inner-city background, traffic hot spots, industry hot spots and rural sites in Hanoi, Vietnam. They discovered that traffic hotspots had the

highest NO_2 value (84.6 g/m³). They concluded that motorcycles were the primary source of NO_2 (more than 90 % of all motorized vehicles in Hanoi). The study looked at the NO_2 exposure of driver passengers and pedestrians in Poland. The obtained results showed that the exposure to NO_2 concentrations of inside cars moving on urban roads, inside city buses, and pedestrian routes ranged from 82.1 ± 6.7 to 112.2 ± 34.9, 38.4 ± 14.6 to 66.8 ± 24.3 and 21.6 ± 7.5 to 46.3 ± 11.1 g/m³, respectively. Ahmad *et al.* [11] used a passive sampler to measure the ambient NO_2 levels emitted from traffic in an urban area in Rawalpindi, Pakistan. It was found that NO_2 concentrations from main road, sub-road and small road ranged 20.87 ± 0.95 to 35.85 ± 1.51, 21.01 ± 0.69 to 36.09 ± 1.98 and 20.48 ± 0.68 to 35.62 ± 1.65 µg/m³, respectively. Bozkurt *et al.* [12] used passive sampling to monitor NO_2 levels that were released from industrial emission, combustion processes and vehicle traffic in school, home and office at industrial city, Turkey. Outdoor NO_2 concentrations in summer and winter season were 25.6 ± 29.1 and 93.8 ± 40.0 µg/m³ (schools), 28.1 ± 11.1 and 64.0 ± 21.3 µg/m³ (homes) and 38.5 ± 19.6 and 53.8 ± 23.6 µg/m³ (office), respectively. They concluded that NO_2 concentrations measured in the summer were lower than those measured in the winter, and that NO_2 emitted by motor vehicles was a source of NO_2. Furthermore, outdoor NO_2 sources such as motor vehicles contributed to indoor NO_2 levels in houses and residential areas near a main street [13]. Thailand standard for NO_2 levels in ambient air are 30 ppb or 320 µg/m³ (1 h) and 170 ppb or 57 µg/m³ (annual average). The values are higher than WHO (200 µg/m³ for 1 h and 40 µg/m³ for annual).

Inhaling nitrogen dioxide has been linked to respiratory irritation. There is evidence that NO_2 is linked to an increase in respiratory symptoms and decreased lung function in the general population, particularly in children, as in asthma [4,5]. Previous research looked into the link between street-level NO_2 and ultrafine particles (UFPs) and the occurrence of postmenopausal breast cancer. NO_2 and UFPs have been linked to an increased risk of postmenopausal breast cancer [14]. Furthermore, NO_2 has been linked to ocular symptoms and fatigue [15].

Rayong province was chosen in one of the 3 eastern provinces (Chachoengsao, Chonburi and Rayong provinces) for an area-based development initiative under the Thailand's Eastern Economic Corridor (EEC). The EEC project has been planning under scheme of the strategy Thailand 4.0 economic policy. The concept of industry 4.0 aimed at transforming the country into an innovative, value-based industry, with an emphasis on 12 fields such as automation and robotics, aviation and logistics, biofuel and biochemicals, and digital. Rayong province is already an important industrial base, which can be upgraded and expanded to attract a new wave of investments in a hub of high-tech industries, innovation, and logistics as well as a regional gateway for trade and investment [16,17]. Therefore, many construction activities, industrial development, urban population, and the increase of the transportation activities are prevalent at Rayong, which is expected to become the main source of air pollution in the study site.

Nitrogen dioxide is a serious concern in terms of its impact on human health. As a result, the primary goals of this study are to measure the spatial and seasonal variation of ambient NO_2 concentrations in Rayong province, Thailand, in order to assess health risk.

Materials and methods

Sampling sites

Rayong province is located in Thailand's eastern region. It is one of Thailand's industrial estates. Sampling locations were surveyed and chosen at random in Rayong province, Thailand. The population density, traffic density and human activities were also used to select sampling sites. There were 25 sites (**Figure 1** and **Table 1**) in total of the downtown (Maung district, Rayong province) were divided into 10 sites of urban areas (Rayong city municipality) and 10 sites of industrial areas (Maptaphut municipality) and 5 sites of background areas (Wang Chan district). The sampling site categories are shown in **Table 1** and **Figure 1**.

The sampling sites were chosen at random based on the main road and highway. During the rainy season (September to October 2017), winter season (November 2017 to January 2018), and summer season (April 2018), the samples were continuously exposed for 1 week (February to April 2018). Rayong meteorological station (RMS), Thai Meteorological Department, provided data on meteorological variables such as air temperature (Air temp.), total precipitation (Total precip.), wind speed (WS), wind direction (WD) and relative humidity (RH) in Rayong province (TMD).
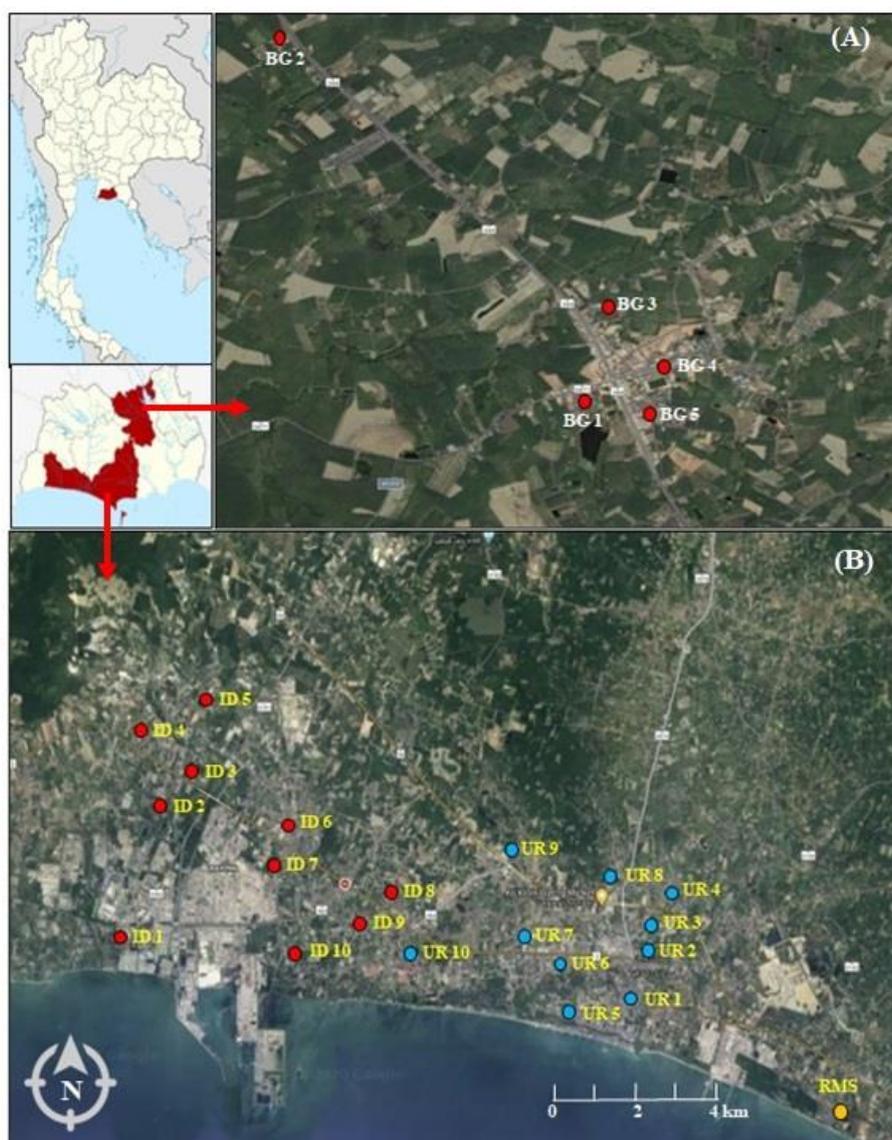
Figure 1 Map of NO_2 sampling sites; (A) Background area and (B) Industrial and urban area in Rayong province.
Source: Google map

Table 1 Characteristics of sampling sites in Rayong province.

Code	Sampling places	Details
UR1-UR10	Urban area	This urban area is identified as the Rayong municipality. It is a community area which includes residential and business buildings, transportation network and high traffic density.
ID1-ID10	Industrial area	It is the Maptaphut industrial estate at Maptaphut municipality, which is the main of the industrial estates in Rayong province. It was developed and began operation in 1989 and covered an area of 2,746.64 acres. Most of the area is occupied by industrial plants including petroleum industries, coal-fired power plant, petrochemical and plastic industries, community areas and transportation networks.
BG1-BG5	Background area	Most of the area is used for agricultural purpose such as rubber tree and pineapple filed. It was low vehicles traffic.

NO₂ sampling and analysis

The ambient NO₂ concentrations were collected by passive diffusion tube from Environmental Chemistry Research Laboratory (ECRL), Chemistry department, Faculty of Science, Chiang Mai University [18]. The polypropylene (PP) diffusion tube (7.70 cm length and 1.50 cm inter diameter) contained GF/A filter paper (Whatman, USA) and was impregnated with 50 µL of 20 % TEA. A set of sampling 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 NO₂ concentration was determined colorimetrically as nitrite (NO_2^-). For extraction, the samples were added with 2 mL of de-ionized water and stirred well for 15 min to dissolve the nitrite in water. One mL of the nitrite solution was mixed with 2 mL saltzmann reagent. After extraction, the absorbance was measured by spectrophotometer (Shimadzu UV 2600, Japan) at 540 nm.

Non-carcinogenic risk assessment of NO₂

The human health risk assessment was calculated by using the hazard quotient (HQ) to evaluate the inhalation of the long-term average NO₂ concentrations. It was assumed the intake of NO₂ concentrations via the inhalation exposure pathway for different receptors including child and adult. The daily intake of NO₂ was calculated by the Average Daily Dose (ADD) as shown in Eq. (1) [19,20].

$$ADD = \frac{C \times Inh\,R \times EF \times ED}{BW \times AT} \tag{1}$$

C is the concentration of NO₂ ($\mu g/m^3$); ED is the exposure duration (days); BW is the bodyweight of the exposed group (kg); AT is the average time (days); InhR is the inhalation rate (m^3/day) and EF is the exposure frequency (days/year). The values of these parameters are shown in **Table 2**.

The ratio of exposure to toxicity or the hazard quotient (HQ) was calculated from ADD and the reference dose (RfD) of each pollutant using the following Eq. (2) [19].

$$HQ = \frac{ADD}{RfD} \tag{2}$$

The reference concentrations (RfD) allowable for human exposure to NO₂ is 1.1×10^{-2} mg/kg·day [21]. When the HQ < 1.0, there is no hazard or only negligible risks, while the HQ > 1.0 indicate a potential non-carcinogenic effect [17].

Table 2 Parameters of health risk assessment through inhalation pathway for NO₂.

Parameters	Exposed group	
	Child [22]	**Adult** [19]
Exposure frequency (EF)	350 days/year	350 days/year
Exposure duration (ED)	18 years	30 years
Averaging time (AT) AT = ED×365 days	6,570 days	10,950 days
Bodyweight (BW)	45.3 kg	71.8 kg
Inhalation rate (InhR)	8.7 m³/day [20]	21.4 m³/day

Results and discussion

NO₂ concentrations

Nitrogen dioxide (NO₂) concentrations obtained from passive sampling at each sampling site are shown in **Table 3** and **Figure 2**. Spatial variation was observed the NO₂ concentrations in urban area, industrial area and background area ranged from 13.9 - 43.0, 10.4 - 34.0 and 5.8 - 35.2 µg/m³, respectively. Moreover, the average NO₂ concentrations during winter, summer and rainy season were 19.6 ± 10.1 to 26.8 ± 6.3, 21.9 ± 6.6 to 24.5 ± 7.4 and 15.5 ± 9.0 to 21.8 ± 6.6 µg/m³, respectively. Noticeably, concentrations of NO₂ in all sampling sites started to be increasing at the end of October (end of rainy season). This is due to lower rain precipitation and pollutants are accumulated in the atmosphere (**Figure 2**). The highest NO₂ concentrations in ambient air of urban area, industrial area and background area were

found at UR9, ID7 and BG2, respectively. The sampling site of UR9 (13.5 - 75.1 µg/m^3) has the highest NO$_2$ concentration in urban area, which is situated near Thapma market and intersection highway road (National Highway no. 36; NH36). The number of vehicles passing the NH36 was manually counted, which was approximately 50,444 cars/day (Rayong City Monicipality). The traffic jams often occur during rush hour and road construction. The highest NO$_2$ values obtained from industrial area were Maptaput Health Promoting Hospital (ID 7), which is situated near petroleum refining plant (14.6 - 74.5 µg/m^3). Khamying and Thepanondh [23] analyzed the industrial source contribution to ambient NO$_2$ concentration in Maptaphut area using AERMOD dispersion model. They reported that the 1 h average concentrations of NO$_2$ emission to ambient air from petrochemical plant and refinery were 186.25 µg/m^3 (4.24 %) and 0.92 µg/m^3 (0.02 %), respectively. The BG2 (near Wang Chan-Chon Buri road (highway 344), which is transportation networks) was the highest NO$_2$ concentrations in background area (10.7 - 68.0 µg/m^3). However, the spatial and seasonal variation of NO$_2$ concentrations were not exceed the annual (57 µg/m^3) of the Pollution Control Department (PCD) standard. Previously, an investigation of the spatial distribution of NO$_2$ concentrations from various source areas in Southern Italy revealed that the NO$_2$ emission source was primarily related to vehicle traffic and secondarily to the industrial area [24]. According to Hien *et al.* [10], the highest NO$_2$ concentrations (84.6 g/m^3) in Hanoi were measured at the intersection road, which is the second ring road that crosses the arterial road connecting with the trans-national highway. Furthermore, NO$_2$ concentrations in urban areas (27.4 - 63.3 g/m^3) in Nakhon Si Thammarat province were 2 - 4 times higher than in sub-urban areas (13.6 - 17.5 g/m^3), which was influenced by traffic density [25]. The ambient NO$_2$ concentrations at tourism cities in Kiriwong Village, Nakhon Si Thammarat province obtained from weekends (27.9 - 110.2 µg/m^3) were higher than weekdays (22.1 - 53.5 µg/m^3), which related to number of vehicles at weekends was higher 1.5 - 2.0 times than the number on weekdays [26]. Ahmad *et al.* [27] investigated seasonal variation of ambient NO$_2$ in Pakistan. They were found that the values of winter season were higher than summer season. Because of the decreased NO$_2$ levels in summer season, the NO$_2$ may cause the photochemical reaction of NO$_x$ into secondary air pollutant rise, which the increased solar radiation is leading to the increased levels of ozone (O$_3$) in the atmosphere as shown in Eqs. (3) - (4).

$$NO_{2\ (g)} + h\nu \longrightarrow NO_{(g)} + O^{\bullet} \tag{3}$$

$$O^{\bullet} + O_{2\ (g)} \longrightarrow O_{3\ (g)} \tag{4}$$

Moreover, the average values of ambient temperature in winter season were lower than those of rainy and summer season (**Table 3**). Ratto and Nico [28] revealed the decreasing air temperature supports low mixing height, which stopes the dispersion of pollutants. Therefore, NO$_2$ concentrations in the winter season were found to increase levels.

One-Way ANOVA was used to test the difference of the mean of NO$_2$ concentrations between spatial and seasonal variations. Based on Complete Randomized Design (CRD), the concentration of NO$_2$ were log-transformed to achieve normal distribution. The concentrations of NO$_2$ released from urban and industrial area were not found to be significantly different ($p < 0.05$), but both values were significantly higher than background area. The NO$_2$ values obtained from seasonal variations were not significantly different ($p > 0.05$).

**Table 3** Concentrations of NO$_2$ in rainy, winter and summer seasons in Rayong province.

Sampling site		NO$_2$ concentrations (µg/m^3 ± SD)		
		Rainy season n = 80	Winter season n = 80	Summer season n = 60
Urban area[A] N = 10	Max	37.8	41.9	43.0
	Min	13.9	18.6	17.7
	Median	20.4	26.3	23.1
	Mean (± SD)	21.8 ± 6.6 [a]	26.8 ± 6.3 [a]	24.5 ± 7.4 [a]
Industrial area[A] N = 10	Max	32.4	34.0	33.1
	Min	13.8	17.7	10.4
	Median	20.8	25.7	20.2
	Mean (± SD)	21.4 ± 5.3 [a]	25.3 ± 5.5 [a]	21.9 ± 6.6 [a]
	Max	30.0	35.2	33.1

Sampling site		NO$_2$ concentrations (μg/m^3 ± SD)		
		Rainy season $n = 80$	Winter season $n = 80$	Summer season $n = 60$
Background area[B] N = 5	Min	5.8	9.0	12.1
	Median	13.8	16.1	22.9
	Mean (± SD)	15.5 ± 9.0 [a]	19.6 ± 10.1 [a]	22.4 ± 9.0 [a]
Total precipitation (mm)		317.5	82.6	98.6
Relative humidity (%)		76.0 ± 7.4	64.0 ± 10.4	73.8 ± 4.8
Wind speed (m/s)		1.09 ± 0.27	1.33 ± 0.36	1.49 ± 0.16
Ambient temperature (°C)		25.6 ± 2.1	24.7 ± 1.6	27.6 ± 1.8

Note: [a] = Significant differences ($p < 0.05$) among groups of sampling seasonal variation
[A, B] = Significant differences ($p < 0.05$) among groups of sampling spatial variation
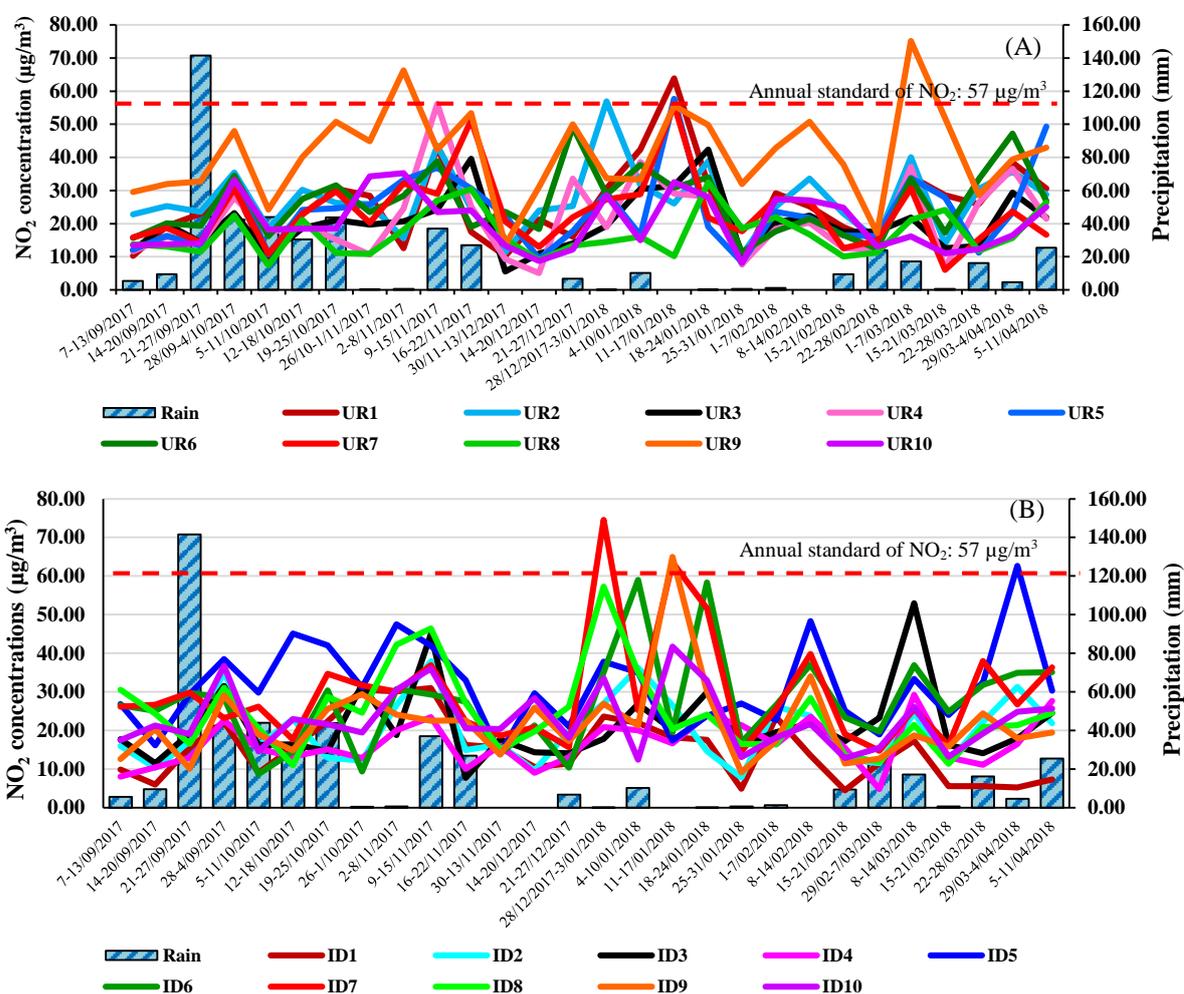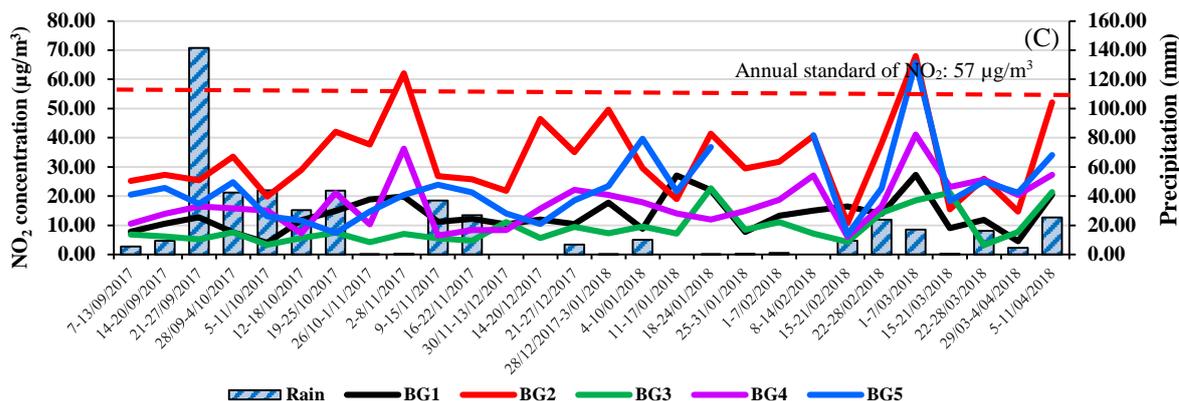
Figure 2 Weekly variation of NO_2 concentration and precipitation in urban area (A), industrial area (B) and background area (C).

### Correlation between NO_2 and meteorological condition

The Pearson's rank-correlation of NO_2, wind speed (WS), air temperature (Air Temp.), relative humidity (RH) and total precipitation (Total precip.) are shown in **Table 4**. NO_2 concentrations were significantly negative correlated ($p < 0.05$) with total precipitation (r = −0.237). Moreover, the passive correlations between relative humidity and total precipitation (r = 0.612) and relative humidity and wind speed (r = 0.784) were strong significantly correlated ($p < 0.01$). The negative correlation between wind speed and air temperature (r = −0.985) were higher than that between relative humidity and air temperature (r = −0.878). Similarly, the negative correlation between NO_2 concentration and total of precipitation were observed in Pakistan [11,27], Pattaya city Chon Buri province [29] and Lampang province, Thailand [30]. The increasing total of precipitation is related to relative humidity, which rainfall cleanse and eliminates NO_2 from ambient air [31] as shown in **Figure 2** and Eq. (5).

$$2NO_{2\,(g)} + H_2O_{(l)} \longrightarrow HNO_{3\,(aq)} + HNO_{2\,(aq)} \tag{5}$$
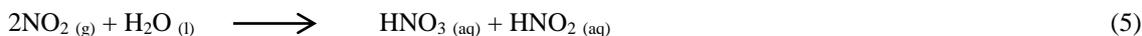
Table 4 Correlation of NO_2 and metrological condition in Rayong province.

n = 75	NO₂	WS	Air Temp	RH	Total precip.
NO₂	1.000				
WS	0.085	1.000			
Air Temp.	−0.044	−0.985**	1.000		
RH	−0.080	0.784**	−0.878**	1.000	
Total precip.	−0.237*	−0.011	−0.159	0.612**	1.000

Note: * Correlation is significant at the 0.05 level (2-tailed).
    ** Correlation is significant at the 0.01 level (2-tailed).
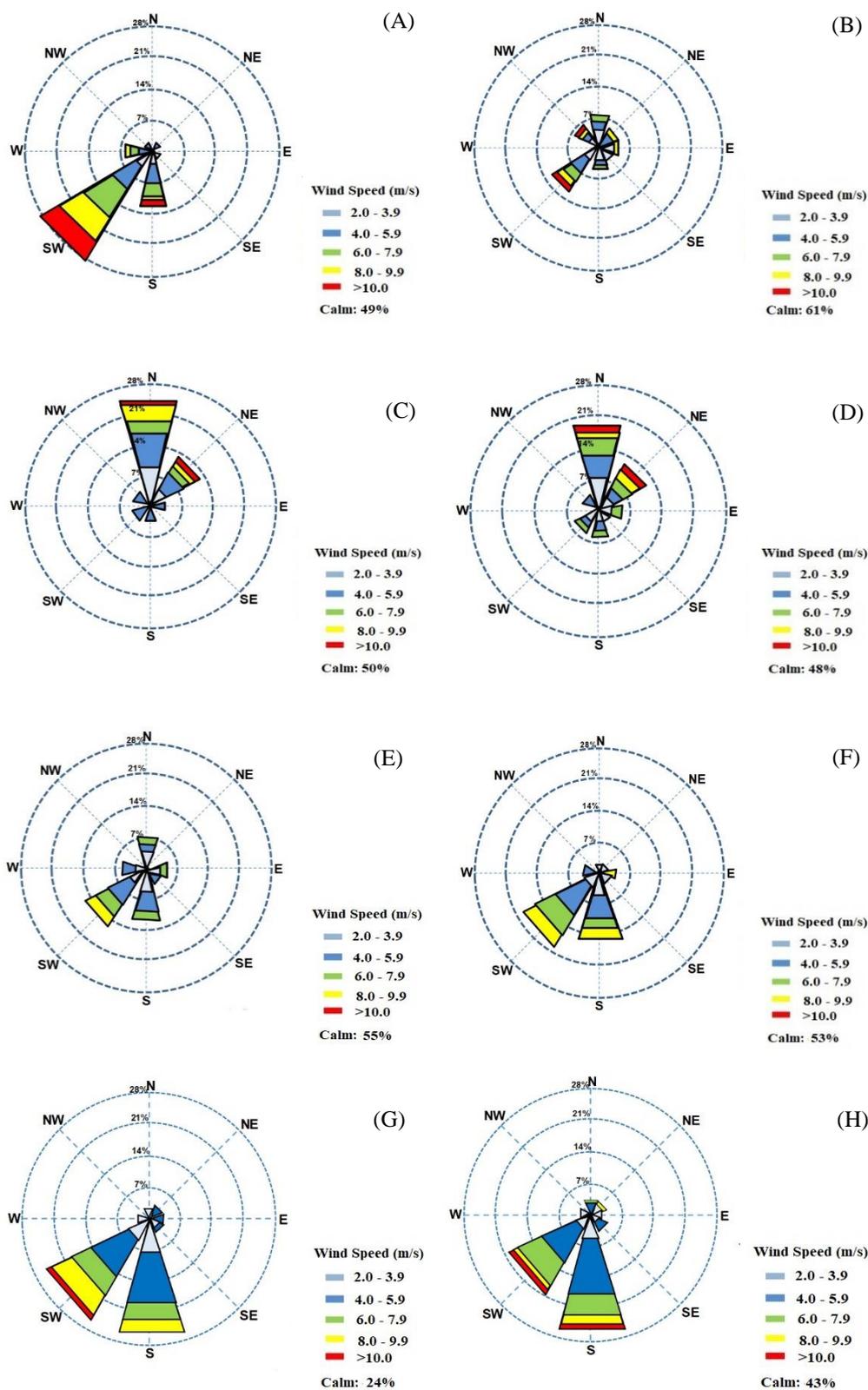
Figure 3 Wind rose diagram (wind speed and wind direction) in Rayong province; Sep. 2017 (A), Oct. 2017 (B), Nov. 2017 (C), Dec. 2017 (D), Jan. 2018 (E), Feb. 2018 (F), Mar. 2018 (G) and Apr. 2018 (H).

Figure 3 depicted the wind speed and direction levels (wind rose diagram) in Rayong province from September 2017 to April 2018. The southwestern wind direction was dominant during the rainy season (September - October 2017; A - B) and the summer season (February - April 2018; E - H). According to Khamyingkert and Thepanondh [23], the southwestern wind was the dominant wind direction in Maptaput. It was observed that air pollutants were transported to the north and northeast. **Figure 3** (C and D) showed wind direction coming from north and northern during November to December 2017, which was winter season influenced to the northeast monsoon in Thailand. The average levels of wind speed in rainy, winter and summer season in Rayong province were 1.09 ± 0.27, 1.33 ± 0.36 and 1.49 ± 0.16 m/s, respectively. Mostly, average wind speed was low and the calm condition (approximately 50 %). During 8 months of sampling, no correlation between wind speeds with NO_2 was observed (**Table 4**). Low wind speed and calm conditions, in general, indicate the accumulation of air pollutants [28]. The meteorological conditions may not have affected the ambient NO_2 concentrations, as no significant differences were found in the correlation of NO_2 concentrations between different meteorological variables. As a result, the NO_2 concentrations obtained indicated that the values could be emitted by local activity (traffic intensity, industrial plants and human activity) in Rayong province.

Non-carcinogenic risk assessment of NO_2

The non-carcinogenic risk assessment is calculated by the hazard quotient (HQ) for human health risk from inhalation of ambient NO_2 exposure were presented in **Figure 4**. The average daily dose (ADD) of NO_2 exposure in child were lower than adult (**Table 5**). The ADD values of NO_2 intake for child in urban, industrial area and background area were 2.6 - 7.9, 1.9 - 6.1 and 1.1 - 6.5 µg/kg·day, while the values for adult were 4.0 - 12.3, 3.0 - 9.7 and 1.7 - 10.1 µg/kg·day, respectively. Moreover, it was found that the HQ values of urban area, industrial area and background area in Rayong province were less than 1 (HQ < 1.0), which implies no hazard. The highest of HQ values for child and adult was found in winter season, while HQ levels for adults in rainy, winter and summer season were higher than child. Moreover, the HQ values of NO_2 for adults at UR9 in winter (HQ = 1.09) and summer (HQ = 1.12) season obtained higher than 1.0, which was indicated adverse human health effects. It is located near the Thapma market and intersection highway road (NH 36), which is high traffic density. Gusti [32] reported that source of SO_2 and NO_2 from vehicle passing on highway, energy production and waste disposal. Actually, SO_2 and NO_2 are dissolved in water vapor that we breathe through the exposure pathway causing irritation and airway obstruction. Bangroy *et al.* [33] studied health risk assessment of NO_2 concentrations at schools in Tha Sala district, Nakhon Si Thammarat. They found that the HQ values greater than 1, which could have adverse effects from NO_2 intake for child (HQ = 1.46 - 2.55) and adult (HQ = 1.25 - 2.18) to relate with traffic area. Kaewrat and Janta [26] revealed the HQ values of inhalation NO_2 for infant group, children, and adults from tourism city of Kiriwong Village were 1.3 - 2.3, 1.1 - 2.1 and 1.0 - 1.9, respectively. Moreover, the analysis of non-carcinogenic risks from inhalation to NO_2 in the vicinities of coal mines in South Africa. They reported that the HQ values of NO_2 exposure for adult was 0.0007 - 0.0019 that indicated a negligible risk [19]. However, previous epidemiological studies revealed that the inhalation of low NO_2 levels have been linked to an increased risk of incident asthma in children aged 14 - 16 years, as well as ocular symptoms and fatigue [15,34].

The population living near high concentrations of traffic emissions in urban and industrial areas makes this issue even more pressing because they are exposed to NO_2 on a daily basis. The majority of these people were exposed to this polluted environment and their health prospects are seriously jeopardized as a result. As a result, we recommend that the government also implement transportation management policies such as vehicle restrictions in downtown cities and the expansion of logistics such as rail transport.

Table 5 Average a daily dose (ADD) of NO_2 exposure in the sampling sites in Rayong province.

Sampling site		NO_2 concentrations ($\mu g/m^3 \pm$ SD)			ADD ($\mu g/kg \cdot day$)					
		Rainy n = 8	Winter n = 11	Summer n = 9	Child			Adult		
					Rainy	Winter	Summer	Rainy	Winter	Summer
Urban area	UR1	21.8 ± 8.4	27.0 ± 17.3	27.3 ± 7.2	4.0	5.0	5.0	6.2	7.7	7.8
	UR2	26.0 ± 5.1	28.0 ± 14.1	27.3 ± 8.9	4.8	5.2	5.0	7.4	8.0	7.8
	UR3	17.4 ± 4.6	22.6 ± 12.2	19.6 ± 5.1	3.2	4.2	3.6	5.0	6.5	5.6
	UR4	16.5 ± 5.5	25.1 ± 14.9	21.3 ± 10.6	3.0	4.6	3.9	4.7	7.2	6.1
	UR5	20.2 ± 8.3	25.6 ± 14.2	24.9 ± 11.4	3.7	4.7	4.6	5.8	7.3	7.1
	UR6	23.5 ± 7.0	29.1 ± 10.8	25.1 ± 11.1	4.3	5.4	4.6	6.7	8.3	7.2
	UR7	20.4 ± 7.0	29.4 ± 13.4	19.4 ± 8.2	3.8	5.4	3.6	5.8	8.3	5.5
	UR8	13.9 ± 5.2	18.6 ± 7.9	17.7 ± 6.0	2.6	3.4	3.2	4.0	5.3	5.0
	UR9	37.8 ± 9.5	41.9 ± 14.8	43.0 ± 16.1	7.0	7.7	7.9	10.8	12.0	12.3
	UR10	20.5 ± 8.5	20.8 ± 9.7	19.2 ± 6.7	3.8	3.8	3.5	5.9	6.0	5.5
Industrial area	ID1	16.4 ± 8.2	18.3 ± 8.0	10.4 ± 6.6	3.0	3.4	1.9	4.7	5.2	3.0
	ID2	17.8 ± 7.9	21.6 ± 10.1	20.6 ± 7.1	3.3	4.0	3.8	5.1	6.2	5.9
	ID3	19.9 ± 7.6	20.8 ± 10.0	23.1 ± 11.7	3.7	3.8	4.2	5.7	6.0	6.6
	ID4	13.8 ± 4.3	17.7 ± 5.2	17.5 ± 7.9	2.5	3.3	3.2	3.9	5.0	5.0
	ID5	32.4 ± 9.3	29.8 ± 10.5	33.1 ± 14.0	6.0	5.5	6.1	9.2	8.5	9.5
	ID6	21.6 ± 9.2	29.3 ± 16.4	30.0 ± 6.5	4.0	5.4	5.5	6.2	8.4	8.6
	ID7	27.0 ± 5.2	34.0 ± 20.5	26.9 ± 9.4	5.0	6.3	5.0	7.7	9.7	7.7
	ID8	23.4 ± 7.0	30.0 ± 13.6	18.8 ± 5.9	4.3	5.5	3.5	6.7	8.6	5.4
	ID9	20.1 ± 7.4	25.3 ± 14.5	19.1 ± 6.8	3.7	4.7	3.5	5.8	7.2	5.4
	ID10	21.6 ± 6.6	26.2 ± 9.8	19.7 ± 5.2	4.0	4.8	3.6	6.2	7.5	5.6
Background area	BG1	11.1 ± 4.7	14.5 ±6.2	14.7 ± 6.5	2.0	2.7	2.7	3.2	4.2	4.2
	BG2	30.0 ± 7.3	30.2 ± 13.3	33.1 ± 18.9	5.5	6.5	6.1	8.6	10.1	9.4
	BG3	5.8 ± 1.5	9.0 ± 4.9	12.1 ± 7.1	1.1	1.7	2.2	1.7	2.6	3.5
	BG4	13.8 ± 4.3	16.1 ± 8.4	22.9 ± 9.5	2.6	3.0	4.2	4.0	4.6	6.5
	BG5	16.6 ± 5.9	23.0 ± 9.1	29.4 ± 17.9	3.1	4.2	5.4	4.7	6.6	8.4
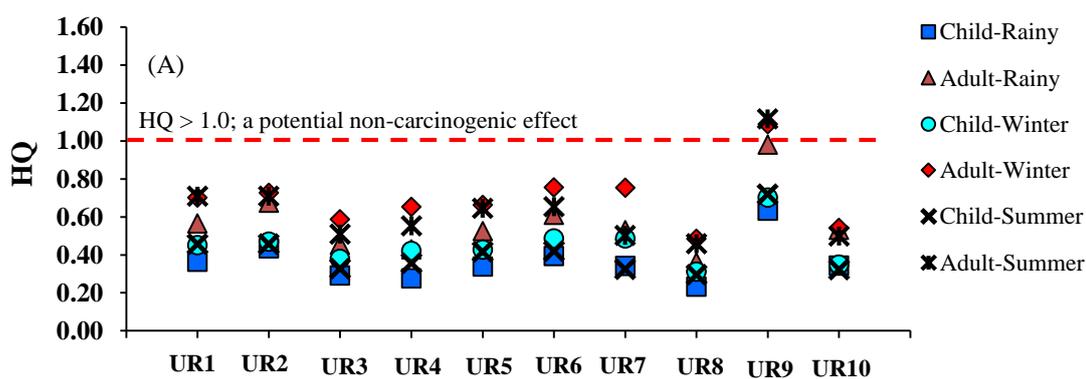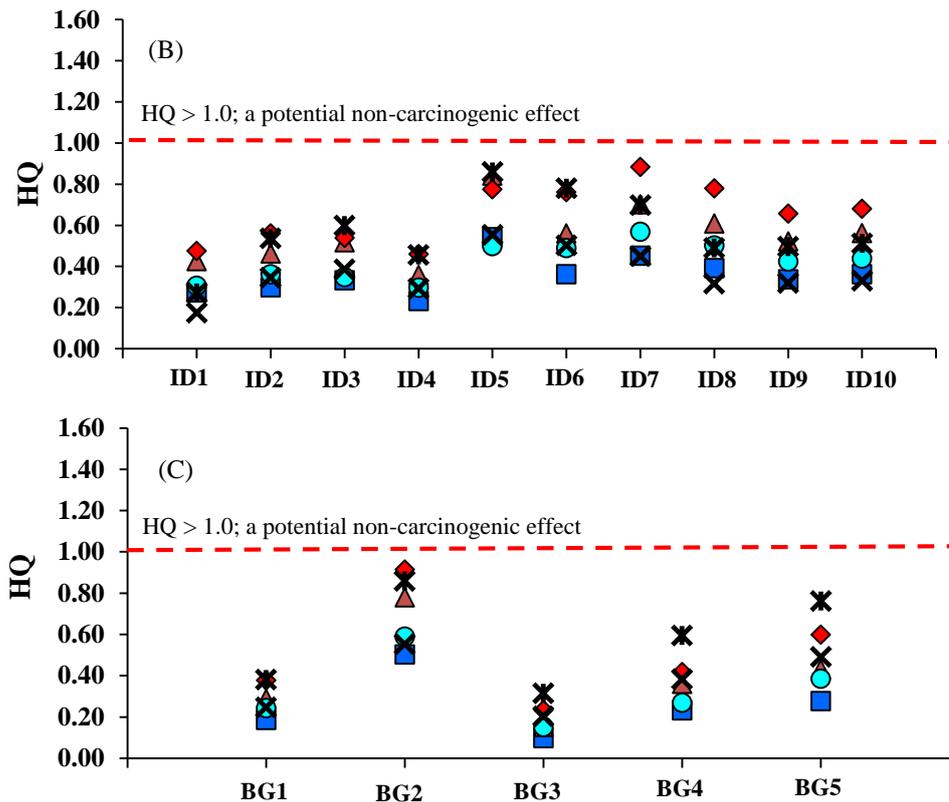
Figure 4 The toxicological risk of exposed NO_2 for child and adult in Rayong province: Urban area (A), Industrial area (B) and Background area (C).

Conclusions

The concentrations of ambient NO_2 in Rayong provinces urban, industrial and background areas were found to be related to local activities caused by both traffic density during rush hour and industrial establishments. It was clear that NO_2 concentrations in urban and industrial areas were significantly higher than those in the background area. Furthermore, the NO_2 values obtained from seasonal variations did not differ significantly ($p > 0.05$). An investigation of correlation between meteorological conditions and NO_2 levels, meteorological conditions were not significantly affected to the NO_2 concentrations, while total precipitation and NO_2 concentrations were related ($p < 0.05$). NO_2 levels were found to be lower during the rainy season as a result of the effect of rainfall. The results show that NO_2 levels are far more affected by local activities than by meteorological factors. However, NO_2 levels in Rayong province were lower than the annual PCD standard (57 g/m^3). NO_2 exposure did not pose a risk to human health because the HQ values in relation to a non-carcinogenic risk were less than 1, but NO_2 inhalation by local residents who live near the roadside and highway road did pose a risk to their health.

Acknowledgements

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