The Inhalation Exposure of $PM_{2.5}$ and PM_{10} from Traffic Exhaust at the Uthai Tani Bus Station and Two Roadside Areas in Uthai Tani, Thailand

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***Abstract*—This study aimed to determine the concentration of $PM_{2.5}$ (particulate matter less than 2.5 µm in size) and PM_{10} (particulate matter less than 10 µm in size) from traffic exhaust around bus stations in Uthai Tani Province, Thailand, and to assess the inhalation exposure of people to $PM_{2.5}$ and PM_{10} around these bus stations. The $PM_{2.5}$ and PM_{10} concentrations at three stations in the city of Uthai Tani were evaluated using air quality detectors (model PMS5003) between January and May 2022. The $PM_{2.5}$ and PM_{10} exposure of the people near those stations was evaluated, and the health risk was determined based on the hazard quotient (HQ). The results indicated that the highest daily $PM_{2.5}$ and PM_{10} concentrations were detected at main road in front of the Central Stadium, with $PM_{2.5}$ and PM_{10} concentrations of 58.40 and 64.13 µg/m^3, respectively. The lowest daily $PM_{2.5}$ and PM_{10} concentrations were found at the main bus station in Uthai Tani Province, with $PM_{2.5}$ and PM_{10} concentrations of 51.41 and 58.01 µg/m^3, respectively. In addition, during rush hour (7:00 to 8:00 a.m.), the $PM_{2.5}$ and PM_{10} concentrations reached the peak values of 75.25 and 81.07 µg/m^3, respectively. From the exposure assessment, the highest intake of $PM_{2.5}$ and PM_{10} for people nearby were 29.32×10^{-3} mg/kg-day and 30.96×10^{-3} mg/kg-day, respectively at 8:00 a.m. The HQ values from $PM_{2.5}$ and PM_{10} exposure were both greater than 1.**

***Keywords*—$PM_{2.5}$, PM_{10}, inhalation exposure assessment, hazard quotient**

I. Introduction

Uthai Tani Province, Thailand, is dealing with the issue of air pollution. The levels of air pollution in the inner city of Uthai Tani are higher than those established by Thailand's National Ambient Air Quality Standards (TNAAQS) [1]. Dust particles are the main pollutants, which have various sizes depending on the source. More than 90% of dust from roads and blowing soil, including dust from construction, is larger than 2.5 µm in size. Less than 10% of the dust is $PM_{2.5}$. Approximately 80% of the incomplete combustion from agricultural waste is $PM_{2.5}$, whereas more than 90% of the combustion products from vehicles and burning wood in household furnaces is $PM_{2.5}$. Dust control on the road or in the air by water spraying may effectively reduce the large particles but is ineffective at reducing $PM_{2.5}$ in the air [2].

In Thailand, particulate pollution causes and significantly aggravates many health problems. The main sources of the particles are construction sites, road repairs, and demolition sites, including open burning of solid waste. Although the particle concentrations from these sources continuously decline in the main cities, this issue becomes prevalent in the areas far away from the major cities. Uthai Tani is one of those areas [3]. Exposure to high levels of air pollution can induce several serious health conditions with short-term and long-term effects. The short-term ones are dry throat and coughing, as well as chest pains and mild infections of the respiratory tract, whereas the long-term ones involve continuous chest infections and coughing, leading to the scarring of lung tissue, respiratory diseases, and permanently decreased lung capacity. In 2022, the Uthai Tani Provincial Health Office reported that acute upper respiratory tract infections have the highest prevalence rate of 279 per 100,000 population [4]. For dust pollution, the high-risk groups are not only older adults, children, and people with heart and lung diseases but also healthy adults who have lived near highly polluted areas, such as industrial areas, busy roads, or areas of traffic congestion for extended periods [5].

PM_{10} is particulate matter of 10 µm or less in diameter, and $PM_{2.5}$ is particulate matter of 2.5 µm or less in diameter. $PM_{2.5}$ is generally described as fine particles. In comparison, a human hair is approximately 100 micrometers, and thus ~40 fine particles can be placed on its width [6]. Particles in this size range make up a large proportion of dust and can be inhaled deep into the lungs. Larger particles tend to be trapped in the nose, mouth, or throat. The chemical properties vary depending on the source of the particles. Note that particulates do not consist of one chemical but belong to a classification based on size rather than chemical properties [7]. $PM_{2.5}$ and PM_{10} are released from various emission sources. $PM_{2.5}$ is generally emitted from the combustion of fuels; gasoline, oil, diesel fuel, or wood, whereas PM_{10} originates from different activities that generate dust, including construction, landfills, agriculture, wildfires, waste burning, and wind-blown dust from a road [8, 9]. The main sources of particulate pollution in the city of Uthai Tani are the main bus station and two main roads (road number 333 and number 3220) of the city. These areas are densely populated, especially surrounding the bus station. The people who reside in these areas are at risk of exposure to the particles released from these sources. Therefore, we aimed to study the $PM_{2.5}$ and PM_{10} concentrations from traffic exhaust and assess the inhalation exposure of people around bus stations in Uthai Tani Province. The $PM_{2.5}$ and PM_{10} exposure of the people near those stations was evaluated, and the health risk was determined based on the hazard quotient (HQ).

II. Research Method

A. Sampling Sites

This study was conducted in the urban area of Uthai Tani Province. Three dust sampling stations were selected to measure the concentrations of $PM_{2.5}$ and PM_{10}. The first station (SA01) was the main bus station of Uthai Tani Province. The second station (SA02) was located on the main road in front of the Central Stadium. The third station (SA03) was located on the main road in front of Ramkhamhaeng University. Fig. 1 shows the locations of the measurement stations.

Fig. 1. Diagram of the dust measurement points.
Source: https://www.google.co.th/maps

A. Sampling Instrument and Sampling Period

The $PM_{2.5}$ and PM_{10} concentrations were measured at each sampling site using a dust detector (model PMS5003), with a total of 1,080 samples. The sample collection was divided into 9 periods with intervals of 2 h (6:00 a.m., 8:00 a.m., 10:00 a.m., 12:00 p.m., 2:00 p.m., 4:00 p.m., 6:00 p.m., 8:00 p.m., and 11:00 p.m.) and performed Monday to Sunday between January and May 2022.

B. Assessment the Exposure of $PM_{2.5}$ and PM_{10}

The sample population consisted of individuals who lived near the bus stations in front of the Central Stadium and Ramkhamhaeng University. Approximately 20% of the total population was randomly sampled. Then, 180 questionnaires were collected to assess the exposure, using 60 questionnaires in each location. The data, such as exposure time (ET), exposure frequency (EF), exposure duration (ED), and body weight (BW), were collected and analyzed using descriptive statistics (mean and maximum) [10–12].

C. Exposure Assessment of $PM_{2.5}$ and PM_{10}

An exposure assessment is a method for involves estimating or quantifying the concentration of a substance. It which consists of the following steps as follows:

Step 1. gathering the data of the concentration of $PM_{2.5}$ and PM_{10} concentration data of each location and the data from the questionnaires as explained in Study Population [13].

Step 2. assessing the exposure to $PM_{2.5}$ and PM_{10} through inhalation using the quantity of average daily intake (ADI), as expressed in the equation below [14].

$$ADI = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT} \quad (1)$$

where *ADI* is the average daily exposure (mg/kg-body weight/day)

CA is the concentration of dost in the air (mg/m^3)

IR is the breathing rate (m^3/h)

ET is time of exposure (h/day)

EF is the frequency of exposure (day/year)

ED is the duration of exposure (years)

(Average life expectancy of the population – age of passengers)

BW is body weight (kg)

AT is the exposure time (days) (EDX365 days/year), which was constant.

for the parameters

D. Risk Assessment of $PM_{2.5}$ and PM_{10}

Risk level was calculated to explain the health effects from $PM_{2.5}$ and PM_{10} exposure in term of Hazard Quotient (HQ) according to the equation below [14].
expressed as:

$$Hazard\ Quotient\ (HQ) = \frac{Exposure\ (mg/kg/day)}{RfC\ (mg/kg/day)} \quad (2)$$

where *HQ* is risk ratio

Exposure is daily exposure value (mg/kg/day)

RfC (Reference Concentration) is the reference. concentration of the pollutant or the amount that enters the body through inhalation without causing Health Hazard (mg/kg/day)

III. Results

A. Determination of the $PM_{2.5}$ and PM_{10} Concentrations

The $PM_{2.5}$ and PM_{10} concentrations are shown based on the time of day, day of the week, month, and sampling station in Figs. 2, 3, 4, and 5, respectively.

From Fig. 2, the lowest $PM_{2.5}$ concentration was 42.44 μg/m^3 at 4:00 p.m., and the highest level was 75.25 μg/m^3 in the pre-working period at 8:00 a.m. This is consistent with the study reported by Pakorn Pimsan [15], who indicated that most people use a similar path during rush hour (7:00–8:00 a.m. and 3:00–4:00 p.m.). This causes traffic congestion and additional dust may be released from the car exhaust. The lowest PM_{10} level was 48.89 μg/m^3 at 4:00 p.m., and the highest level was 81.07 μg/m^3 in the pre-working period at 8:00 a.m.

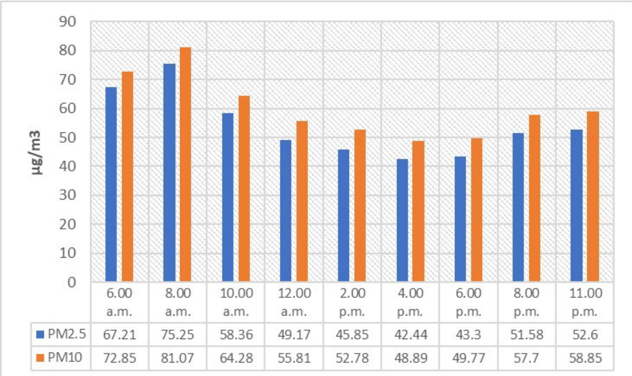

Fig. 2. $PM_{2.5}$ and PM_{10} concentrations based on the time of day.

From Fig. 3, the daily $PM_{2.5}$ concentration was the lowest on Saturday (48.49 μg/m^3) and peaked on Sunday (57.69 μg/m^3). The $PM_{2.5}$ level was 51.44 to 57.33 μg/m^3 on weekdays. The PM_{10} concentration exhibited the same trend as the $PM_{2.5}$ concentration. The lowest PM_{10} value was 55.25 μg/m^3 on Saturday and the highest was 64 μg/m^3 on Sunday. On weekdays, the PM_{10} concentrations were between 57.08 to 63.33 μg/m^3 on weekdays.

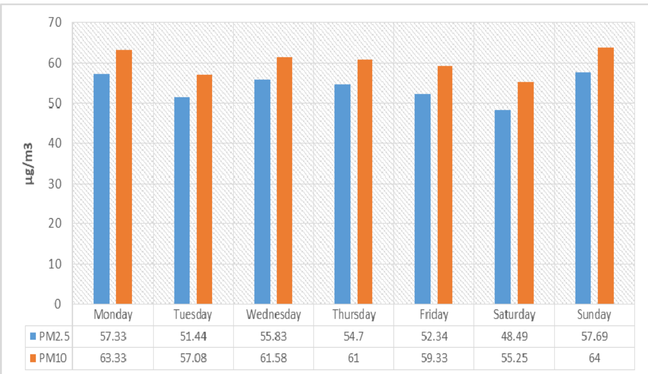

Fig. 3. $PM_{2.5}$ and PM_{10} dust concentration each day.

From Fig. 4, the monthly $PM_{2.5}$ concentration was the lowest in May (20.21 μg/m^3) and the highest in April (64.72 μg/m^3). In January, February, and March, the concentrations were 63.94, 61.91, and 59.10 μg/m^3, respectively. The concentration level varies according to the season. For example, the concentration is higher in the summer than in the rainy season. For the monthly concentration of PM_{10}, it exhibited a minimum of 21.68 μg/m^3 in May and a maximum of 72.51 μg/m^3 in April. In January, February, and March, the concentrations were 71.05, 69.64, and 66.25 μg/m^3, respectively. The $PM_{2.5}$ level, the PM_{10} level varies depending on the season.

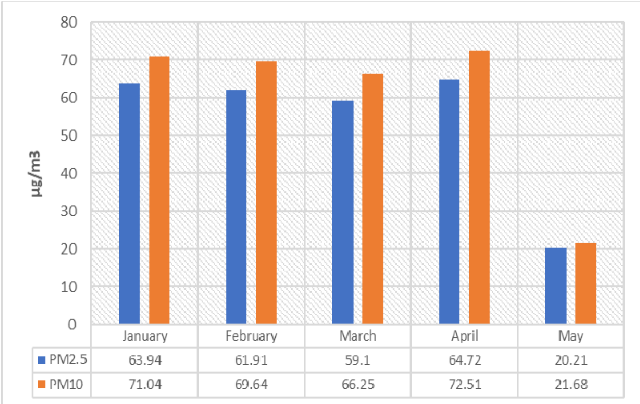

Fig. 4. $PM_{2.5}$ and PM_{10} concentrations based on month.

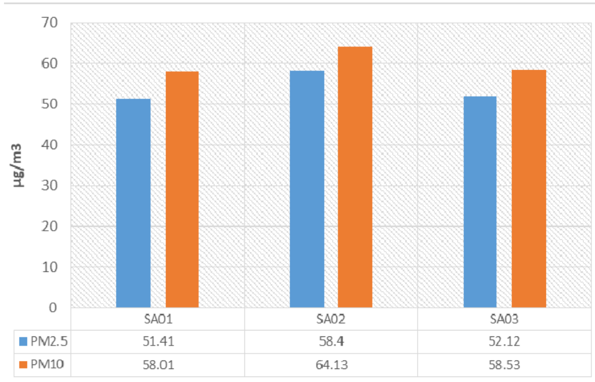

Fig. 5. $PM_{2.5}$ and PM_{10} dust level at each sampling sites.

From Fig. 5, the lowest $PM_{2.5}$ concentration was 51.41 μg/m^3 at the Uthai Tani bus station, and the highest level was 58.40 μg/m^3 at main road in front of the Central Stadium. The main road in front of Ramkhamhaeng University, the $PM_{2.5}$ concentration was 52.12 μg/m^3. Notably, these concentrations exceeded the standard level (50 μg/m^3) set by the TNAAQS. The lowest PM_{10} level was 58.01 μg/m^3 at the Uthai Tani bus station, whereas the highest level was 64.13 μg/m^3 at main road in front of the Central Stadium. The main road in front of Ramkhamhaeng University, the PM_{10} level was 58.53 μg/m^3.

From the results, the main road in front of the Central Stadium appears to be an important route that people use to travel, particularly because it connects the city with other districts and the Nakhon Sawan Province, which leads to heavy traffic every day. Near Ramkhamhaeng University, more teaching and learning was conducted using online methods, to minimize and monitor the spread of the coronavirus. There is also less traffic around the Uthai Tani bus station and less public transportation being used because there is a small population, and most of them are engaged in agriculture, farming, and gardening. The open burning of agricultural waste is performed every day at twilling time.

B. Inhalation Exposure of $PM_{2.5}$ and PM_{10}

Inhalation exposure of $PM_{2.5}$ is shown in Table 1, which was in the range of 15.39×10^{-3} to 29.32×10^{-3} mg/kg-day during the pre-workout period (8:00 a.m.). The highest level of $PM_{2.5}$ dust exposure was 29.32×10^{-3} mg/kg-day, and the lowest level was 15.39×10^{-3} mg/kg-day during the afternoon (4:00 p.m.), which occurred in April 2022. In January, the highest level of $PM_{2.5}$ exposure was 24.60×10^{-3} mg/kg-day, and the lowest level was 7.32×10^{-3} mg/kg-day in May. On

Monday, the highest exposure to $PM_{2.5}$ was 22.23×10^{-3} mg/kg-day, and the lowest exposure was 17.72×10^{-3} mg/kg-day, on Saturday.

Table 1. Inhalation exposure level of $PM_{2.5}$

Measurement station	SA01	SA02	SA03
6:00 a.m.	25.70	25.14	24.21
8:00 a.m.	28.00	29.32	26.57
10:00 a.m.	21.43	22.43	21.20
12:00 a.m.	18.10	19.41	17.27
2:00 p.m.	17.34	17.01	16.85
4:00 p.m.	16.15	15.85	15.39
6:00 p.m.	16.08	16.42	15.80
8:00 p.m.	21.04	18.00	18.73
11:00 p.m.	20.38	18.79	19.66
Monday	22.23	20.85	21.00
Tuesday	19.50	19.30	18.63
Wednesday	21.14	21.17	20.00
Thursday	20.87	20.92	19.25
Friday	19.67	20.30	18.40
Saturday	18.25	17.72	18.20
Sunday	21.62	21.60	21.18
January	24.56	23.21	23.68
February	23.60	23.70	21.77
March	21.89	22.45	21.57
April	24.36	24.60	23.25
May	7.9	7.34	7.32

Note: exposure level unit ((mg/kg/day)$\times10^{-3}$)

Inhalation exposure of PM_{10} is shown in Table 2. The level of PM_{10} dust exposure was in the range of 17.85×10^{-3} to 30.96×10^{-3} mg/kg-day during the pre-workout period (08.00 a.m.). The highest PM_{10} expose (30.96×10^{-3} mg/kg-day) occurred in the morning (8:00 a.m.) and the lowest exposure (17.85×10^{-3} mg/kg-day occurred in the afternoon (4:00 p.m.) in April, the highest exposure to PM_{10} was 27.93×10^{-3} mg/kg-day and the lowest was 7.35×10^{-3} mg/kg-day in May. On Monday, the highest exposure to PM_{10} was 24.63×10^{-3} mg/kg-day and the lowest was 19.93×10^{-3} mg/kg-day on Saturday.

Table 2. Inhalation exposure level of PM_{10}

Measurement station	SA01	SA02	SA03
6:00 a.m.	28.18	26.89	26.33
8:00 a.m.	30.62	30.96	28.87
10:00 a.m.	23.73	24.36	23.61
12:00 a.m.	20.83	21.49	19.92
2:00 p.m.	20.21	19.27	19.48
4:00 p.m.	18.76	18.01	17.85
6:00 p.m.	18.69	18.66	18.20
8:00 p.m.	23.66	20.03	20.96
11:00 p.m.	23.19	20.62	22.05
Monday	24.63	22.75	23.24
Tuesday	21.80	21.14	20.63
Wednesday	23.56	22.87	22.19
Thursday	23.61	22.65	21.85
Friday	22.66	22.31	21.13
Saturday	21.15	19.93	20.62
Sunday	24.26	23.36	23.77
January	27.37	25.87	26.14
February	26.78	26.12	24.86
March	24.92	24.55	24.50
April	27.93	26.81	26.26
May	8.49	7.35	7.85

Note: exposure level unit ((mg/kg/day)$\times10^{-3}$)

C. Risk Assessment of $PM_{2.5}$ and PM_{10}

Risk characterization can be divided into 4 levels based on the risk ratio (HQ) as follows:

$HQ < 0.1$ means no danger.

$0.1 \geq HQ \leq 1.0$ means low level of danger.

$1.1 \geq HQ \leq 10$ means moderate danger.

$HQ > 10$ means there is a high level of danger [16]

Table 3. Risk assessment level of $PM_{2.5}$

Measurement station	SA01	SA02	SA03
6:00 a.m.	5.14	5.03	4.84
8:00 a.m.	5.60	5.86	5.31
10:00 a.m.	4.29	4.49	4.24
12:00 a.m.	3.62	3.88	3.45
2:00 p.m.	3.47	3.40	3.37
4:00 p.m.	3.23	3.17	3.08
6:00 p.m.	3.22	3.28	3.16
8:00 p.m.	4.21	3.60	3.75
11:00 p.m.	4.08	3.76	3.93
Monday	4.45	4.17	4.20
Tuesday	3.90	3.86	3.73
Wednesday	4.23	4.23	4.00
Thursday	4.17	4.18	3.85
Friday	3.93	4.06	3.68
Saturday	3.65	3.54	3.64
Sunday	4.32	4.32	4.24
January	4.91	4.64	4.74
February	4.72	4.74	4.35
March	4.38	4.49	4.31
April	4.87	4.92	4.65
May	1.59	1.47	1.46

The risk assessment of $PM_{2.5}$ for people in the Uthai Tani area is shown in Table 3. The HQ values at the measurement points were in the range of 1.46 to 5.86, which were all greater than 1, indicating moderate danger. The risk assessment of PM_{10} for people in the Uthai Tani area is shown in Table 4. The HQ values were in the range of 0.67 to 2.81, which were mostly greater than 1, indicating moderate danger.

Table 4. Risk assessment level of PM_{10}

Measurement station	SA01	SA02	SA03
6:00 a.m.	2.56	2.44	2.40
8:00 a.m.	2.78	2.81	2.62
10:00 a.m.	2.16	2.21	2.15
12:00 a.m.	1.89	1.95	1.81
2:00 p.m.	1.84	1.75	1.77
4:00 p.m.	1.71	1.64	1.62
6:00 p.m.	1.70	1.70	1.65
8:00 p.m.	2.15	1.82	1.90
11:00 p.m.	2.11	1.87	2.00
Monday	2.24	2.07	2.11
Tuesday	1.98	1.92	1.88
Wednesday	2.14	2.08	2.02
Thursday	2.15	2.06	1.97
Friday	2.06	2.03	1.92
Saturday	1.92	1.81	1.87
Sunday	2.21	2.12	2.16
January	2.49	2.35	2.38
February	2.43	2.37	2.26
March	2.27	2.23	2.23
April	2.54	2.44	2.39
May	0.77	0.67	0.71

IV. CONCLUSION

The $PM_{2.5}$ and PM_{10} concentrations were examined at three sites in Uthai Tani Province. The daily $PM_{2.5}$ concentration exceeded the national standard of 50 µg/m^3 at 8:00 a.m., 10:00 a.m., 12:00 a.m., 8:00 p.m., and 11:00 p.m. The main source of $PM_{2.5}$ was combustion emissions from the high volume of traffic in urban areas. Notably, agricultural waste burning was conducted in the twilling periods of Uthai Tani city. The PM_{10} concentrations did not exceed the national standard of 120 µg/m^3. The main sources of PM_{10} were road dust, industrial dust, construction, and combustion emissions. The dust levels were higher in the dry season, specifically January, February, March, and April. The dust levels decreased in the wet season, which starts in May of every year.

The inhalation exposure was evaluated, and the health risk was calculated. The exposure levels of $PM_{2.5}$ and PM_{10} dust were high in the morning and nighttime because the air temperatures were low then the fine dust stayed at the ground level until the temperatures increased in the afternoon time and the dust flowed to the upper air levels. The $PM_{2.5}$ HQ values were in the range of 1.46 to 5.86, indicating moderate danger and adverse health effects. The PM_{10} HQ values were in the range of 0.67 to 2.81, also indicating moderate danger. In comparison with the study reported by group research of Amporn Boonrangsri, the HQ range of $PM_{2.5}$ in Bangkok was 1.17 to 3.38 in 2019. The Uthai Tani government must develop a policy to reduce the concentration of fine particles emitted from various sources and communicate the issue to the public, especially for high-risk groups such as children, old people, and sick people.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Opas Pukklin collected research data, calculated the particle levels, and performed the statistical analysis. Opas Pukklin and Pajaree Thongsanit wrote the article together and submitted it to the conference.

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