PM$_{2.5}$ Levels in the Muang District of Khon Kaen Province by Ambient PM$_{2.5}$ detectors with Real-time Sensors

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Abstract

The recent ambient PM$_{2.5}$ levels in Khon Kaen Province tend to be higher than in the previous decade. Notably, urban areas have higher PM$_{2.5}$ concentrations than rural areas. This study aimed to evaluate the ambient PM$_{2.5}$ concentrations and examine their temporal variation by season and time of day in the Muang District of Khon Kaen Province. Data were collected from May 2021 – April 2022 using ambient PM$_{2.5}$ detectors with Public Health Particulate Matter (PHPM) real-time sensors in all sub districts at a total of 36 sites, which displayed data through a smartphone application. Linear regression analysis was used to relate the variation of 24-hour average PM$_{2.5}$ levels. Mean difference, 95% CI and p-values were reported. The results showed that the 24-hour average ambient PM$_{2.5}$ concentrations were 30.58 + 2.35 µg/m³. The highest concentration was found in the summer season (in March), 70.44 + 10.38 µg/m³ (higher than the Thailand Ambient Air Quality Standard of 50 µg/m³ in a 24-hour period), especially from 10:00 p.m.–12:00 a.m., which was 35.87 + 2.98 µg/m³. Also, there was a significant difference in terms of average seasonal PM$_{2.5}$ levels (p-value < 0.001); 20.55 µg/m³ (95% CI: 18.14 – 22.97) for the summer season and 15.45 µg/m³ (95% CI: 13.03 – 17.87) for the winter season. In terms of daily values, 3.17 µg/m³ (95% CI: 1.36 – 4.97) was observed at 10:00 p.m. The summer season (in March), from 10:00 p.m.–12:00 a.m., showed the highest concentrations of PM$_{2.5}$. These results can be used to aid in monitoring particulate matter levels for local agencies and raise awareness among the public to limit their exposure particulate matter.

1. Introduction

Air pollution is a significant public health problem as nine-tenths of the world's population is highly affected by breathing polluted air. It is also the fourth largest cause of death, with a mortality rate of 9% or approximately 4.2 million people worldwide each year (WHO, 2019; Stanaway *et al.,* 2018; Ritchie & Roser, 2017). The morbidity rate resulting from air pollution in Thailand is 2,363.24 per 100,000 people (Bureau of Epidemiology, 2020; Bureau of Registration Administration, 2020). Concurrently, the Thai mortality rate is 25 per 100,000 people, ranked as the world's 21st most polluted country with a US Air Quality Index (AQI) of 127 or at the lightly tainted level

for public health (IQAir, 2019a; Ritchie & Roser, 2017). Fine particulate matter ($PM_{2.5}$) is one of six routinely measured air pollutants and is commonly accepted as the most insidiously harmful to human health due to its prevalence in the environment and a broad range of health effects (Zhang *et al.*, 2013). Currently, Thailand is ranked as having the world's 28th highest level of $PM_{2.5}$, at a moderate level (24.25 µg/m³) (IQAir, 2019b; Strategy and Planning Division, Office of the Permanent Secretary, Ministry of Public Health, 2018).

In Khon Kaen, Thailand, urban areas especially encounter relatively high traffic density along with road construction and industrial manufacturing processes for various types of products and technologies used by industries. For example, metal processing plants produce air pollutants during the smelting process, as do surface excavations, construction, demolition, compacting and milling of raw materials, and transportation. These activities cause urban areas to experience higher $PM_{2.5}$ levels than rural areas (Department of Health and Department of Disease Control, 2015). In such areas, the $PM_{2.5}$ concentration is 22.6 µg/m³, ranking 45th worldwide and 5th in the ASEAN. Therefore, it can be said that Khon Kaen's air quality is unhealthy for people (Air Quality and Noise Management Division, 2019).

In a previous study, an urban area, Nakorn Ratchasima City, Thailand, was found to have high concentrations of $PM_{2.5}$ and showed 24-hour average $PM_{2.5}$ values of 29.93 µg/m³ (Thongsaeng *et al.*, 2019). Another study conducted in Ubon Ratchathani Province revealed that $PM_{2.5}$ concentrations measured in at Ubon Ratchathani Rajabhat University, Muang District, were 37 – 61 µg/m³ (Salao *et al.*, 2021), which exceeded the Thailand Ambient Air Quality Standard for $PM_{2.5}$ (50 µg/m³) (Ministry of Natural Resources and Environment, 2010). Such measurements indicate that air quality in these areas is unhealthy, potentially aggravating respiratory diseases.

$PM_{2.5}$ can be breathed into the human body, reaching deeply into bronchioles and alveoli as well as causing itching of the nose, throat, and eyes (Burki, 2019; Kirrane *et al.*, 2019; Qi *et al.*, 2017) leading to coughing, sneezing, runny nose, shortness of breath, and respiratory diseases (Chairattanawan & Patthirasinsiri, 2020; Wongsakoonkan *et al.*, 2018). Among Thai people, 60 – 70% encounter respiratory diseases aggravated by $PM_{2.5}$. This affects 1,466.87 per 100,000 people in Thailand (Wadkien, 2020; Emergency Operations Center, 2020; Bureau of Occupational and Environmental Disease, 2015).

Khon Kaen is a large province in Thailand facing high concentrations of $PM_{2.5}$. It has a morbidity rate of respiratory diseases caused by $PM_{2.5}$ of 643 per 100,000 people. The highest morbidity is in the Muang (City) District, 1,710.80 per 100,000 people (Bureau of Epidemiology, 2020; Bureau of Registration Administration, 2020). For this reason, $PM_{2.5}$ concentrations in the Muang District of Khon Kaen Province must be monitored and compared in terms of season and time of day to mitigate respiratory diseases caused by $PM_{2.5}$, hence motivating the current study.

2. Materials and Methods

2.1 Instruments

This cross-sectional study analyzed the ambient $PM_{2.5}$ concentrations in 18 sub-districts in the Muang District of Khon Kaen Province, using ambient $PM_{2.5}$ detectors with real-time sensors (PHPM sensor; Public Health Particulate Matter sensor) as US EPA specific method [US EPA, 2016] (Fig. 1a). The PHPM sensors use light a scattering technique to measure the concentration of airborne particles. Applying Mie's theory, a red laser shines through a cavity through which air is moved by a fan. Particulate matter scatters light which is measured using a photodiode. The degree of scattering is used to determine particle mass. These readings are converted to $PM_{2.5}$ concentrations through a smartphone application. Data was recorded every 30 minutes for 24 hours.

2.2 Validation of Public Health Particulate Matter Sensor (PHPM sensor)

This device was validated using a standard commercial product, the DustTrak™ DRX Aerosol Monitor 8533 (TSI Incorporated, Shoreview, Minnesota, USA) (Fig. 1b). The DRX Aerosol Monitor simultaneously measures both mass and size fractions. Additionally, the monitor has a multi-channel, data-logging, light-scattering laser photometer that records real time aerosol mass readings and collects gravimetric samples.

2.3 Data Collection

The directors of health promotion hospitals and community leaders in all sub-districts were informed about the research objectives and data collection procedures. Then, ambient $PM_{2.5}$ detectors (PHPM sensor) were installed at 36 sites in sub-district health promotion hospitals and community halls of 18 sub-districts in the Muang District of Khon Kaen Province. The readings of the Pollution Control Department station (PCD station) "MET ONE air particle counters" (Station 46t) (16.4418° N, 102.8368° E) are compared to the sensor placed at the Regional Health Promotion Center 7 (Nai Muang sub district) (16.4293° N, 102.8511° E) to assess accuracy of the data. These two stations are 2.06 km distant from each other. Their height from the ground was at least 1.5 meters, according to the standards for measuring ambient $PM_{2.5}$ concentrations (Ministry of Natural Resources and Environment, 2010). The measurements were made from May 2021 to April 2022

during the three seasons of Thailand, the rainy season (from May to mid October), winter season (from mid-October to mid-February), and summer season (from mid February to April) (Climatological Center, 2020).

2.4 Data Analysis

Stata Version 17 was used for statistical analysis. Pearson's correlation coefficient, r, was computed to measure the association between the 24-hour average $PM_{2.5}$ estimates from the PHPM and measurements from the PCD station for each sampling season independently. Linear regression was used to analyze the differences in the 24-hour average $PM_{2.5}$ concentrations among seasons (rainy, winter, and summer) and time periods (6:00 a.m. to 12:00 a.m.) in the Muang District of Khon Kaen Province.

3. Results and Discussion

3.1 The Concentration from PCD Station and PHPM Sensor

Overall, a positive correlation was observed between the PHPM estimates and the 24-hour Average Ambient $PM_{2.5}$ Concentrations from the PCD station (Figure 2). The highest 24-hour Average Ambient $PM_{2.5}$ concentrations were observed in summer season (Figure 2c) and the lowest in rainy season (Figure 2a). Overall, the estimates from the PHPM were lower than the data from the PCD station with a high Pearson's correlation coefficient (r = 0.90) (Table 1).

(a)   **(b)**

Figure 1. (a) Ambient $PM_{2.5}$ detector with a real-time sensor (PHPM)
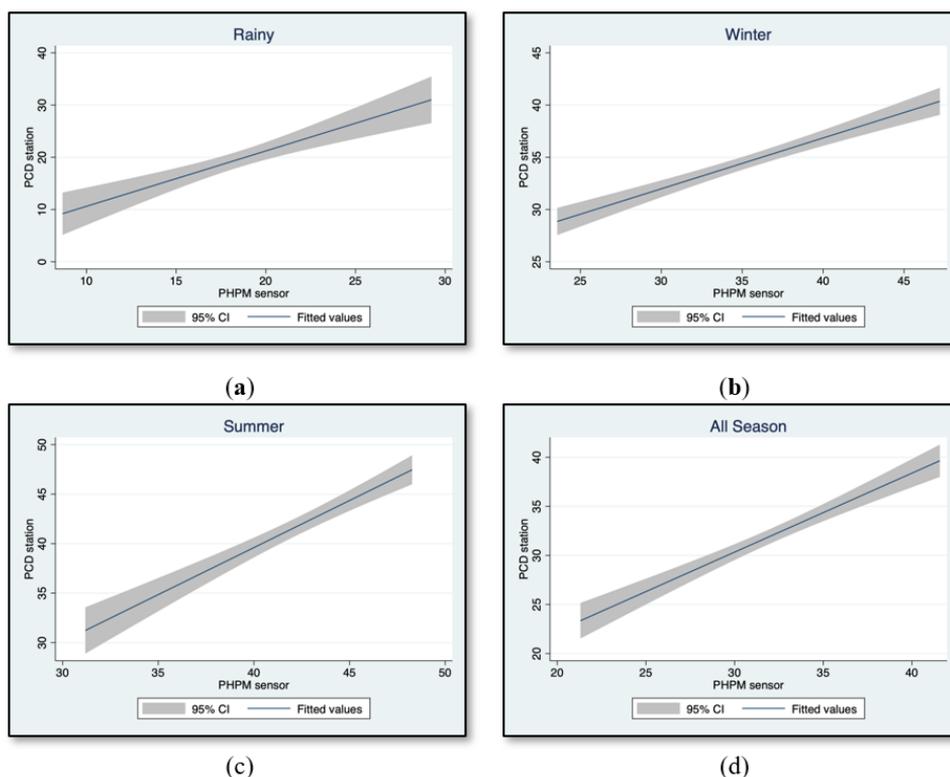(b) DustTrak™ DRX Aerosol Monitor 8533

Figure 2. Estimated 24-hour Average $PM_{2.5}$ Levels, as measured by the PHPM device (at Regional Health Promotion Center 7) on the x-axis compared to the observed of 24-hour Average $PM_{2.5}$ Levels from the PCD station equipment, as measured at: (a) rainy; (b) winter; (c) summer; (d) and all seasons.

Table 1. Pearson's correlation coefficient, r, of the 24-hour Average Ambient $PM_{2.5}$ Concentrations in the Muang District of Khon Kaen Province for each monitoring station, classified by season

Season	Estimated $PM_{2.5}$ in PHPM (Regional Health Promotion Center 7, µg/m³)**	Observed $PM_{2.5}$ in PCD station* (µg/m³)**	Correlation, r
Rainy (May to mid-October)	19.50 (17.31-21.69)	18.38 (16.87-19.89)	0.73
Winter (mid-October to mid-February)	34.62 (33.31-35.93)	35.41 (33.01-37.81)	0.89
Summer (mid-February to April)	41.79 (39.92-43.66)	42.31 (40.57-44.05)	0.88
All Season	31.97 (30.34-33.61)	32.03 (30.21-33.86)	0.90

* Pollution Control Department station in Mueang, Khon Kaen (Station 46t)
** Mean and Range (in parentheses) are reported.

Generally, the values reported by the PHPM system were lower than the PCD station estimates ($\pm 2.16\%$), indicating the PHPM device was underestimating $PM_{2.5}$. However, the PHPM system performed well, yielding a high correlation with $PM_{2.5}$ concentrations in the ambient air. Linear regression defined the relationship of $PM_{2.5}$ from the PHPM device as (Equation 1):

$$PM_{2.5} \ (\mu g/m^3) = 0.08 + (0.99 \times PHPM) \quad (1)$$

The sensor accurate of the PHPM was determined using Equation 2 (Kare, 2022):

$$\%Accuracy = 100 - \%Error \quad (2)$$

$$and \quad \%Error = \left| \frac{X_{measure} - X_{true}}{X_{true}} \right| \times 100 \quad (3)$$

From the Equations (2) and (3), %Accuracy is equal to 99.81%.

3.2 Overall Ambient $PM_{2.5}$

In analyzing the ambient $PM_{2.5}$ concentrations in the Muang District of Khon Kaen Province after adjusting following Equation 1 (Accuracy = 99.81%), the concentrations at all sites were lower than the daily standard ($< 50 \ \mu g/m^3$). The 24 hour average ambient $PM_{2.5}$ concentrations in PHPM device were $30.58 + 2.35 \ \mu g/m^3$. The maximum was in Don Han Sub district ($33.34 \ \mu g/m^3$), while the minimum was in Bueng Niam Sub-district ($25.87 \ \mu g/m^3$). In the summer, the 24-hour average ambient $PM_{2.5}$ concentration was $39.13 + 5.77 \ \mu g/m^3$. The maximum was in Don Han Sub-district ($44.71 \ \mu g/m3$), while the minimum was in Khok Si Sub district ($26.49 \ \mu g/m^3$). In the rainy season, the 24-hour average ambient $PM_{2.5}$ concentration was $18.58 + 1.74 \ \mu g/m^3$. The maximum was in Non-Thon Sub-district ($21.41 \ \mu g/m^3$), while the minimum was in Ban Wa Sub-district ($14.92 \ \mu g/m^3$). In the winter, the 24-hour average ambient $PM_{2.5}$ concentration was $34.03 + 1.67 \ \mu g/m^3$. The maximum was in Ban Pet Sub-district ($36.21 \ \mu g/m^3$), while the minimum was in Mueang Kao Sub-district ($29.63 \ \mu g/m^3$), as presented in Figure 3. These results are consistent with previous studies reporting that the 24-hour average concentrations of $PM_{2.5}$ in an urban area was $29.93 \ \mu g/m^3$ (Thongsaeng *et al.,* 2019). Moreover, Salao *et al.* (2021) found $PM_{2.5}$ concentrations between 37 and 61 $\mu g/m^3$ on the Ubon Ratchathani Rajabhat University campus in the Muang District of Ubon Ratchathani. The higher concentrations of $PM_{2.5}$ in urban areas are caused by greater traffic volume and industrial activities, e.g., metal smelting, surface excavations, construction, demolition, compacting and milling of raw materials. (Climatological Center, 2020).

3.3 Seasonal Ambient $PM_{2.5}$

In seasonal comparison, the highest 24-hour ambient $PM_{2.5}$ concentrations were found in the summer, $39.13 + 5.77 \ \mu g/m^3$. The levels were especially high in March, $70.44 + 10.38 \ \mu g/m^3$ (higher than the daily standard of $50 \ \mu g/m^3$). The lowest ambient $PM_{2.5}$ concentration was found in the rainy season, $18.58 \ \mu g/m^3$. The lowest values were in September, $8.10 + 0.76 \ \mu g/m^3$ (Figure 4). There was a significant difference between all seasons (*p*-value < 0.001), $20.55 \ \mu g/m^3$ (mean difference = 20.55; 95% CI: 18.14 – 22.97) for the summer season and 15.45 $\mu g/m^3$ (mean difference = 15.45; 95% CI: 13.03 – 17.87) for the winter season. Details of these results are presented in Table 2.

Following the previous studies of Bootdee (2021) and Suburairat & Bunjongsiri (2020), the 24-hour average $PM_{2.5}$ concentration in the rainy season was $38.8 + 25.2 \ \mu g/m^3$. Then, the 24 hour average $PM_{2.5}$ concentration in the summer season was $52.7 + 33.9 \ \mu g/m^3$. As reported by the Air Quality and Noise Management Division (2019), the $PM_{2.5}$ value could be as much as $153 \ \mu g/m^3$. In the summer, especially in March, farmers prepare their land for rice cultivation by burning debris such as rice straw, corn stover, and sugarcane stubble, which results in the release of particulate matter (Department of Health and Department of Disease Control, 2015). Farmers typically burn sugarcane leaves in the winter season or during November-December to make the cutting process easier. Also, the weather in winter can cause high atmospheric pressure with a steady and dry climate. As a result, the vertical motion of air and pollutants is complicated, so particulate matter and air pollution can occur more in the winter season than at other times (Climatological Center, 2020).
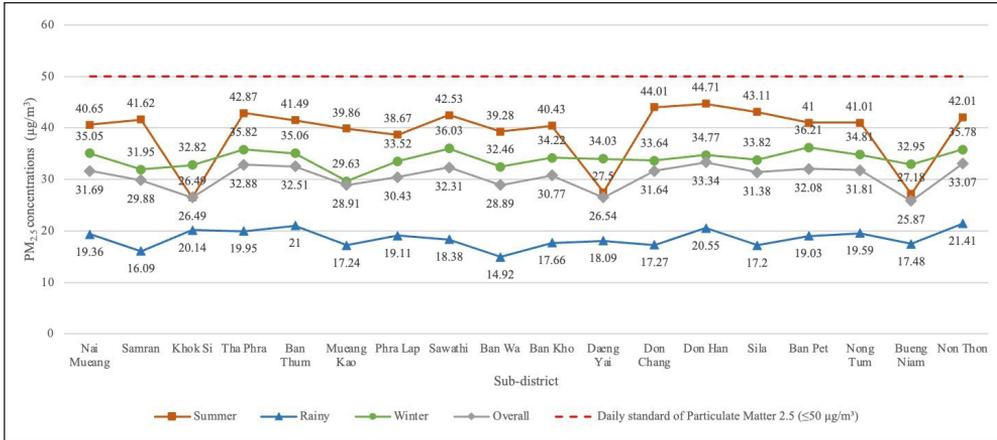
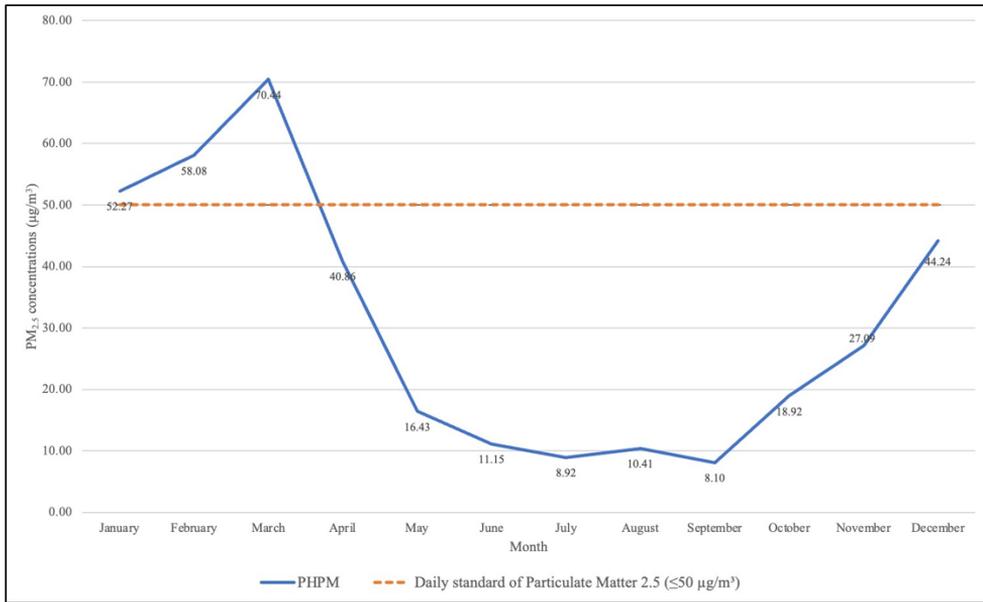**Figure 3.** Seasonal variation of 24-hour Average PM$_{2.5}$ Levels

Figure 4. Monthly variation of 24-hour Average PM$_{2.5}$ Levels

Table 2. Mean Difference of the 24-hour Average Ambient PM$_{2.5}$ Concentrations in the Muang District of Khon Kaen Province Classified by Season

Season	Mean	Standard Deviation	Mean Difference	95% CI	*P*-value
Rainy (May to mid-October)	18.58	1.74	Ref*	Ref*	< 0.001
Winter (mid-October to mid-February)	34.03	1.67	15.45	13.03 – 17.87	
Summer (mid-February to April)	39.13	5.77	20.55	18.14 – 22.97	

* Reference value of Mean Difference and 95% CI (equal 0) of the 24-hour Average Ambient PM$_{2.5}$ in terms of seasonal values.

3.4 Time Periods Ambient PM$_{2.5}$

During the day, an increasing trend of ambient PM$_{2.5}$ concentrations in the Muang District of Khon Kaen Province was observed from 2:00 p.m. – 12:00 a.m. (see Figure 5). The highest 1-hour ambient PM$_{2.5}$ concentration was found at 10:00 p.m. – 12:00 a.m. (35.87 + 2.98 µg/m³). The maximum was in Don Han Sub district (39.22 µg/m³), while the lowest PM$_{2.5}$ level was at 12:00 p.m.–2:00 p.m. (24.51 + 2.44 µg/m³). The minimum was in Khok Si Sub-district (19.56 µg/m³) (see Figure 5).

There was a significant difference between time periods (*p*-value < 0.001); 3.17 µg/m³ (mean difference = 3.17; 95% CI: 1.36 – 4.97) for 10:00 p.m. (see Table 3). Similarly, Zhao *et al.* (2009) found the highest 1-hour ambient PM$_{2.5}$ concentration occurred from 7:00 a.m. – 8:00 a.m. and again from 7:00 p.m. – 11:00 p.m. The high levels of PM$_{2.5}$ in the morning are caused by various daily anthropogenic activities, such as road traffic, agricultural operations and industrial manufacturing. In the afternoon, fewer human activities can lead to higher levels of PM$_{2.5}$ in the evening (Suburairat & Bunjongsiri, 2020).
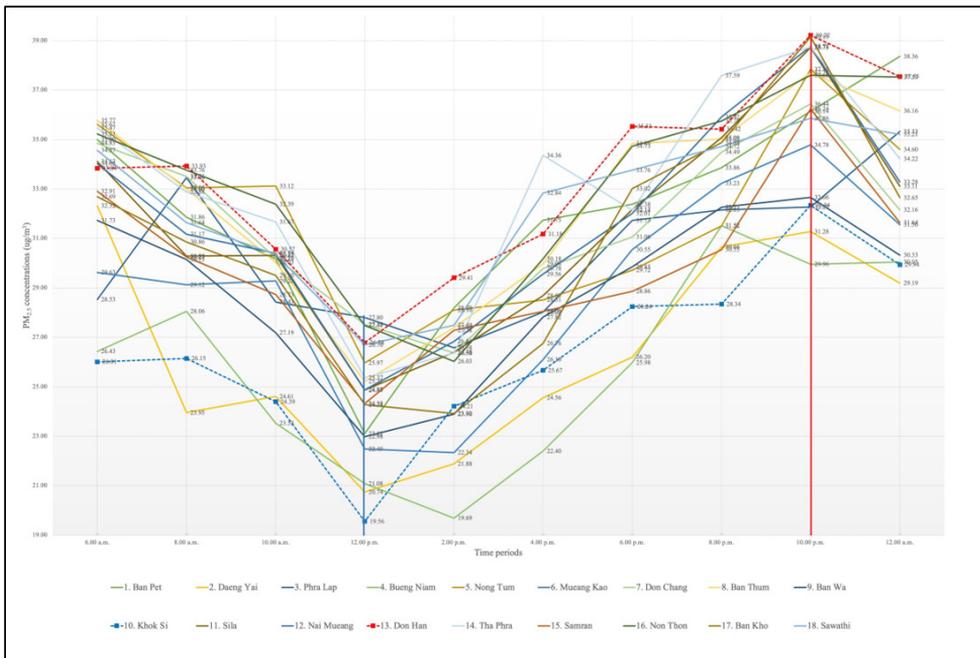

Figure 5. Hourly Average PM$_{2.5}$ Classified by Time-of-Day

Table 3. Mean Difference of the 1-hour Average Ambient PM$_{2.5}$ Concentrations in the Muang District of Khon Kaen Province Classified by Time-of-Day

Time	Mean (µg/m³)	Standard Deviation	Mean Difference	95% CI	P-value
6:00 a.m.	32.71	3.09	Ref*	Ref*	< 0.001
8:00 a.m.	30.95	2.75	-1.76	-3.56, 0.05	
10:00 a.m.	29.16	2.67	-3.55	-5.35, -1.74	
12:00 p.m.	24.51	2.44	-8.20	-10.00, -6.39	
2:00 p.m.	25.69	2.53	-7.02	-8.82, -5.21	
4:00 p.m.	28.68	2.96	-4.03	-5.83, -2.22	
6:00 p.m.	31.27	2.76	-1.44	-3.25, 0.36	
8:00 p.m.	33.50	2.37	0.79	-1.01, 2.60	
10:00 p.m.	35.87	2.98	3.17	1.36, 4.97	
12:00 a.m.	33.49	2.81	0.78	-1.02, 2.59	

* Reference value of Mean Difference and 95% CI (equal 0) of the 24-hour Average Ambient PM$_{2.5}$ in terms of daily values.

4. Conclusion

This research can be used as primary data providing surveillance of particulate matter levels to raise public awareness of the dangers of exposure to $PM_{2.5}$, especially in the summer (highest in March) from 10:00 p.m. –12:00 a.m., when the $PM_{2.5}$ concentration is greatest. Moreover, the results of the current study can be used as supportive data for policy implementation to address public health problems with the overarching goal to reduce respiratory disease rates caused by air pollution in the Muang District of Khon Kaen Province, especially in the Don Han Sub-district, where $PM_{2.5}$ is highest. However, the issue of seasonal particulate matter should be additionally studied to understand the differences between the seasons when particulate matter is found at higher and lower levels. Furthermore, it is crucial to know the number of days that the concentrations exceed the standard limit for further study to quantify risk exposure in each area.

Acknowledgment

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