Seasonal and regional variation of particulate matter dispersion in Yangon City and Taunggyi City, Myanmar

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Abstract. Particulate matter (PM) pollution is well-known to be associated with hazardous health outcomes. Data on the PM concentrations in Myanmar are, however, limited. Since, it is very important to determine the air pollution status for further prevention of PM-related health risks in exposed populations, we conducted this preliminary study to assess the PM2.5 and PM10 concentrations in Yangon and Taunggyi Cities during the dry and wet seasons. The PM measurements were made by mobile sensing using Pocket PM2.5 Sensors (Yaguchi Electric Co., Ltd., Miyagi, Japan) in six randomly selected townships of Yangon from January 25th-29th 2018 (dry season) and September 15th-19th 2018 (wet season) and seven quarters (townships are termed as quarters in Taunggyi) of Taunggyi from July 19th-22nd 2018 (wet season). The findings revealed that the PM concentrations in Yangon were significantly higher in the dry season than in the wet season. In the wet season, the PM levels in Yangon dropped to the WHO guideline. However, while the PM10 levels were higher in Taunggyi than in Yangon, the PM2.5 concentrations were significantly higher in Yangon than in Taunggyi. The highest PM levels were found in the Hlaing Tharyar township of Yangon and Myo-ma quarter of Taunggyi among the measured locations. In conclusion, our findings indicated significant seasonal variations in the PM concentrations in Yangon and significant regional variations between the two cities within the same season.

1. Introduction
Particulate matter (PM) pollution is associated with a number of health hazards, including an elevated risk of cardiopulmonary diseases, neurological diseases and birth-related outcomes [1-3]. Inevitably, the burden of the risks associated with air pollution is greater in developing countries than in developed countries [4].

Based on the aerodynamic diameter of the particles, suspended PM in the atmosphere can be divided into PM10 (diameter ≤10 μm), PM2.5 (diameter ≤2.5 μm), and ultrafine particles (diameter <0.1 μm). Among these, PM2.5 and ultrafine particles pose the highest health hazards, owing to their small particle
sizes and thereby, their ability to more readily cross the respiratory and blood brain barriers and activate the systemic inflammatory response [5]. Suspended PM comprises a complex mixture of extremely small aerosol particles and liquid droplets, such as acids, organic chemicals from vehicular emission, metals, and earth crust or dust particles emitted from either man-made or natural sources [4].

The measured PM concentrations in Myanmar tended to vary widely and weather was considered as one of the factors contributing to the large alterations in the measured PM levels. According to a previous study conducted in China, the PM$_{2.5}$ concentrations were the highest during winter and lowest during summer [6]. In the United States, the maximum organic carbon concentration was observed in the summer and the minimum in the winter [7]. In Kenitra City, Morocco, the PM$_{2.5}$-PM$_{10}$ concentrations were found to reach their peaks in the summer and fall in the winter [8]. Furthermore, it has been reported that the incidence of PM exposure-associated cerebral ischemia in the rat is season-dependent and higher in the winter [9].

Myanmar, one of the countries in Southeast Asia, has three fairly distinct seasons; summer, rainy season, and winter. The summer season runs from mid-February to mid-May, followed by the rainy season from mid-May to mid-October, and then the winter season from mid-October to mid-February [10]. The rainy season mainly receives rain from the southwest monsoon, which brings ample amounts of moisture-laden winds from the Bay of Bengal towards inland Myanmar [11]. Rainfall is typically light from November to April, especially in central Myanmar. The recorded published rainfall data in Myanmar are 0.4-59 mm in Yangon and 1-62 mm in Taunggyi in the dry season, 200-606 mm in Yangon and 113-185 mm in Taunggyi in the rainy season, and the recorded temperature data are 21˚C-38˚C in Yangon and 13˚C-29˚C in Taunggyi in the summer, and 17˚C-35˚C in Yangon and 8˚C-25˚C in Taunggyi in the winter [12].

Due to the limited data published on pollution and the importance of surveying the degree of pollution exposure of the resident population, we attempted to measure the PM concentrations during two seasons in two geographically diverse cities of Myanmar. Yangon, the former capital city of Myanmar located at sea level, is currently the largest, most populated and industrialized city in the country, with a metro population of 5,998,000. Taunggyi is the fifth largest city in Myanmar that is located 4712 feet above sea level, and has a population of 380,665 [13]. The Taunggyi economy is largely based on agriculture. Interestingly, this city received the ASEAN environmentally sustainable city award in 2008 [14] and was rated by the city dwellers in a population-based survey as being the city with the cleanest air [15]. However, there are no published data on the suspended PM concentrations in the air in Taunggyi. This study reported herein is a collaborative work between the Department of Physiology, University of Medicine 1, Yangon, Myanmar, and the National Institute for Environmental Studies (NIES), Tsukuba, Japan.

2. Methods

2.1. Air sample collection

In Yangon City, the suspended PM concentrations in the air were measured at each of six randomly selected townships (Hlaing, Hlaing Tharyar, Kamayut, Kyimyindine, Pazundaung, and South Okkalapa) during two time-periods of the year, namely, from 25th to 29th January, 2018 (dry season), and 15th to 19th September, 2018 (wet season), by mobile sensing at 07:00h, 13:00h, and 19:00h, for 15 minutes, each day.

Similarly, in Taunggyi City, the suspended PM concentrations were measured in seven randomly selected quarters (Townships are termed quarters in Taunggyi city: Thit-taw, Pha-yar-phyu, Yay-aye-kwin, Sao-san-tun, Kan-aut, Myo-ma, and Ho-pone) from 19th to 22nd July, 2018 (wet season) at 07:30h, 12:00h and 16:30h each day. PM$_{2.5}$ mobile tracking was also performed in three major roads of Taunggyi City: the East round road, West round road and Bogyoke Aung San road (Pyi Htaung Su road).
2.2. Materials
Pocket PM$_{2.5}$ Sensors (Yaguchi Electric Co., Ltd., Miyagi, Japan) were utilized for the measurement of the PM$_{2.5}$ and PM$_{10}$ concentrations. These sensors consist of a laser LED (light-emitting diode), PD (photodiode) sensor, fan, amplifier, and USB (Universal Serial Bus) encoder. The sensor runs on the platform of the Android operating system of a smartphone and can generate log data in CSV (comma-separated values) together with GPS (Global Positioning System). The screen displays the PM$_{2.5}$ and PM$_{10}$ concentrations in ug/m$^3$, with the screen color changing with changing PM concentrations. The validity of the measurement, principle of measurement and specifications of the Pocket Sensor are reported in our previously published paper [16]. All the Pocket PM$_{2.5}$ Sensors were calibrated with a constantly observing PM$_{2.5}$ counter (PM-712, Kimoto Electric Co., Ltd.) set up at the Air Quality Research Station, National Institute for Environmental Studies (NIES), Tsukuba, Japan (http://www.nies.go.jp/aqrs/index.html).

2.3. Statistical Analysis
Data are expressed as the means (±SEM). Statistical comparison of the concentrations between the dry and wet seasons was performed using a paired t-test and that between Taunggyi and Yangon Cities was performed using an unpaired t-test. All the statistical analysis were performed with SPSS version 21.

3. Results
In the current study, ambient PM$_{2.5}$ and PM$_{10}$ concentrations were measured by mobile sensing in six townships of Yangon City during the dry and wet seasons. The spatial variations in the PM concentrations between Yangon and Taunggyi Cities were assessed in the wet season of the same year.

3.1. Seasonal variation of PM$_{2.5}$ and PM$_{10}$ concentrations in Yangon between dry and wet seasons

| Townships        | Time of day | Dry season PM$_{2.5}$ | Wet season PM$_{2.5}$ | Dry season PM$_{10}$ | Wet season PM$_{10}$ |
|------------------|-------------|-----------------------|-----------------------|----------------------|----------------------|
|                  |             | 117.7 (0.6)           | 28.1 (0.3)***         | 136.8 (0.7)          | 29.9 (0.3)***        |
| Hlaing           | Morning     | 39 (0.2)              | 16.1 (0.3)***         | 44.6 (0.2)           | 18.5 (0.3)***        |
|                  | Afternoon   | 94.8 (0.5)            | 24.3 (0.2)***         | 103.2 (0.6)          | 25.9 (0.2)***        |
|                  | Evening     | 83.8 (0.4)            | 22.8 (0.1)***         | 94.8 (0.4)           | 24.8 (0.2)***        |
|                  | Average     | 164.9 (0.8)           | 30.8 (0.4)***         | 257.4 (1.2)          | 46.6 (0.5)***        |
| Hlaing Tharyar   | Morning     | 31.6 (0.2)            | 9.0 (0.1)***          | 51.1 (0.3)           | 17 (0.3)***          |
|                  | Afternoon   | 100.5 (0.5)           | 24.8 (0.3)***         | 191.3 (1.0)          | 38 (0.5)***          |
|                  | Evening     | 99 (0.6)              | 21.5 (0.2)***         | 166.6 (0.9)          | 34 (0.3)***          |
|                  | Average     | 104.3 (1.0)           | 25.5 (0.3)***         | 139.6 (1.5)          | 32.9 (0.3)***        |
| Kyimyindine      | Morning     | 31.8 (0.2)            | 13.1 (0.2)***         | 46.2 (0.3)           | 19.2 (0.3)***        |
|                  | Afternoon   | 71.1 (0.4)            | 25.8 (0.3)***         | 99 (0.4)             | 33.8 (0.3)***        |
|                  | Evening     | 69.1 (0.5)            | 21.4 (0.2)***         | 95 (0.6)             | 28.6 (0.2)***        |
|                  | Average     | 104.3 (1.0)           | 25.5 (0.3)***         | 139.6 (1.5)          | 32.9 (0.3)***        |
| Kamayut          | Morning     | 91.9 (0.6)            | 20.4 (0.2)***         | 156.5 (0.8)          | 36.3 (0.3)***        |
|                  | Afternoon   | 30.1 (0.2)            | 11.1 (0.2)***         | 63 (0.5)             | 25.7 (0.3)***        |
|                  | Evening     | 60.7 (0.3)            | 23 (0.3)***           | 121.2 (0.7)          | 44.3 (0.5)***        |
|                  | Average     | 60.9 (0.3)            | 18.2 (0.1)***         | 113.6 (0.5)          | 35.4 (0.2)***        |
| Pazuntaung       | Morning     | 78.4 (0.4)            | 26.2 (0.3)***         | 140.8 (0.7)          | 54.6 (0.6)***        |
|                  | Afternoon   | 35.7 (0.4)            | 11.0 (0.6)***         | 70.9 (0.6)           | 33.3 (0.9)***        |
|                  | Evening     | 67.4 (0.5)            | 24.3 (0.5)***         | 135.4 (1.1)          | 55.8 (1.0)***        |
|                  | Average     | 60.5 (0.3)            | 20.5 (0.3)***         | 115.7 (0.6)          | 47.9 (0.5)***        |
Seasonal comparison revealed that the PM$_{2.5}$ and PM$_{10}$ concentrations were statistically significantly higher in the dry season than in the wet season in the morning, afternoon, as well as evening hours, in all the townships of Yangon City. Among the six measured townships of Taunggyi, Hlaing Tharyar showed the highest PM$_{2.5}$ concentrations in both the dry and wet seasons. Hlaing Tharyar also showed the highest morning and evening PM$_{2.5}$ variability between the dry and wet seasons (5.4 times and 4.0 times, respectively); highest afternoon variability (4.8 times) was observed in South Okkalapa (Table 1 and Figure 1(a)). The lowest seasonal variations were observed in the Pazundaung, Hlaing, and Kamayut Townships (3.0, 2.4, and 2.6 times for morning, afternoon, and evening, respectively) (Table 1 and Figure 1(a)).

In regard to the PM$_{10}$ concentrations, the highest PM$_{10}$ concentration was seen during the wet season in Pazundaung Township, although the lowest variability in the morning, afternoon, and evening hours was also observed in this township (Table 1 and Figure 1(b)). The highest seasonal variabilities were seen in the morning (5.5 times) and evening (4.6 times) in Hlaing Tharyar, and in the afternoon (4.6 times) in South Okkalapa.
As compared to the United States Environmental Protection Agency (USEPA) guideline (i.e., 35 µg/m³ for PM$_{2.5}$ and 150 µg/m³ for PM$_{10}$) [17], the average PM$_{2.5}$ concentrations in the Yangon townships were above the guideline in the dry season (Table 1). On the other hand, the mean PM$_{10}$ concentrations in the dry season and wet season in the Yangon townships were within the guideline, except for the dry season concentration in Hlaing Tharyar (Table 1).

3.2. Wet season PM$_{2.5}$ and PM$_{10}$ concentrations of Taunggyi City

Table 2. PM$_{2.5}$ and PM$_{10}$ concentrations (mean (SEM)) of Taunggyi City.

| Quarter       | PM$_{2.5}$ Morning | PM$_{2.5}$ Afternoon | PM$_{2.5}$ Evening | PM$_{2.5}$ Average |
|---------------|-------------------|----------------------|-------------------|-------------------|
| Thit-taw      | 5.29 (0.1)        | 5.50 (0.1)           | 9.68 (0.3)        | 6.82 (0.1)        |
| PM$_{10}$     | 18.69 (0.9)       | 20.01 (0.6)          | 47.58 (1.9)       | 28.76 (0.8)       |
| Pha-yar-phyu  | 10.33 (0.3)       | 8.52 (0.1)           | 9.62 (0.3)        | 9.49 (0.1)        |
| PM$_{10}$     | 51.31 (1.3)       | 52.61 (1.4)          | 42.84 (1.1)       | 48.59 (0.7)       |
| Yay-aye-kwin  | 9.16 (0.3)        | 7.16 (0.2)           | 8.15 (0.1)        | 8.16 (0.1)        |
| PM$_{10}$     | 23.85 (0.8)       | 27.80 (0.8)          | 30.26 (0.4)       | 27.3 (0.4)        |
| Sao-san-tun   | 11.70 (0.5)       | 12.21 (0.7)          | 9.54 (0.2)        | 11.15 (0.3)       |
| PM$_{10}$     | 32.86 (0.6)       | 35.94 (1.4)          | 32.31 (0.8)       | 33.7 (0.6)        |
| Kan-aut       | 8.62 (0.1)        | 7.28 (0.2)           | 10.14 (0.2)       | 8.68 (0.1)        |
| PM$_{10}$     | 21.42 (0.5)       | 17.47 (0.5)          | 32.56 (1.3)       | 23.82 (0.5)       |
| Myo-ma        | 8.01 (0.2)        | 9.92 (0.3)           | 17.43 (0.6)       | 11.79 (0.3)       |
| PM$_{10}$     | 24.56 (0.9)       | 84.49 (3.8)          | 139.25 (6.9)      | 32.77 (2.9)       |
| Ho-pone       | 2.84 (0.1)        | 4.57 (0.1)           | 7.57 (0.2)        | 4.99 (0.1)        |
| PM$_{10}$     | 7.53 (0.2)        | 14.67 (0.6)          | 46.04 (1.9)       | 22.74 (0.8)       |
| Seven quarters’ | 8 (0.1)           | 7.9 (0.1)            | 10.4 (0.1)        | 8.7 (0.1)         |
| Average       | 20.3 (0.4)        | 36.2 (0.8)           | 53.7 (1.3)        | 38.4 (0.5)        |

Remarks: Thit-taw, Sao-san-tun, Kan-aut, Ho-pone are residential areas, and Pha-yar-phyu and Myo-ma are commercial areas.

Figure 2. Distribution of PM$_{2.5}$ and PM$_{10}$ concentrations in Taunggyi City.
In Taunggyi City, the average concentrations of both PM$_{2.5}$ and PM$_{10}$ concentrations of recorded quarters were within the respective guideline values, except for the in the afternoon and evening concentrations in the Myo-ma quarter (Table 2).

### 3.3. Wet season regional PM$_{2.5}$ and PM$_{10}$ concentrations variation between Yangon and Taunggyi Cities

#### Table 3. Comparison of PM$_{2.5}$ and PM$_{10}$ concentrations of two Cities in wet season.

|                  | Mean PM$_{2.5}$ (SEM) | Mean PM$_{10}$ (SEM) |
|------------------|-----------------------|----------------------|
|                  | Yangon | Taunggyi | Yangon | Taunggyi |
| Morning          | 26.6 (0.1) | 8.0 (0.1)*** | 39.3 (0.2) | 20.3 (0.4)*** |
| Afternoon        | 11.6 (0.1) | 7.9 (0.1)*** | 21.4 (0.2) | 36.2 (0.8)*** |
| Evening          | 24.3 (0.1) | 10.4 (0.1)*** | 38 (0.2) | 53.7 (1.3)*** |
| Average          | 20.8 (0.1) | 8.7 (0.1)*** | 32.9 (0.1) | 38.4 (0.5)*** |

*** represents p value <0.001 in comparison to those of Yangon value.

![Figure 3](image-url)

**Figure 3.** Regional variation of PM$_{2.5}$ and PM$_{10}$ concentrations between Yangon and Taunggyi Cities.

In regards to regional variations in the wet season, the mean PM$_{2.5}$ concentration was higher in Yangon than in Taunggyi in the morning, afternoon as well as evening hours, and the mean of the three time points (3.3, 1.5, 2.3, and 2.4 times, respectively (Table 3 and Figure. 3(a)). Interestingly, although the PM$_{2.5}$ concentrations were higher in Yangon than in Taunggyi, the PM$_{10}$ concentrations, apart from the morning hours, were higher in Taunggyi than in Yangon (by 1.7, 1.4, and 1.2 times in the afternoon, evening and mean of the three time points, respectively) (Table 3 and Figure. 3(b)).
Figure 4. (a) Location of Yangon and Taunggyi (i.e., the largest and fifth largest Cities of Myanmar) were shown in the map.
(b) PM$_{2.5}$ concentration was measured as mobile sensing over Taunggyi City on three main roads (East round road; on the right side of map, West round road; on the left side of map, and Bogyoke Aung San road; the middle road) covering most area of Taunggyi City. The mobile sensing PM$_{2.5}$ measurement showed higher PM$_{2.5}$ concentration along West round road and lower PM$_{2.5}$ concentration along East round road.

4. Discussion
Following the rise in urbanization and combustion-related energy usage, PM pollution has become nearly inevitable in many parts of the world, with consequent alarming PM-associated health effects in the exposed population. Developing countries tend to suffer from even higher pollution levels, possibly because of the lower social and educational backgrounds and relatively poor regulation of industries and vehicles. Furthermore, pollution data from developing countries are limited, even though it is of utmost importance to continually assess the pollution status to evaluate the situation and seek regulatory intervention.

In this study, we attempted to investigate the spatial and temporal variations of PM$_{2.5}$ and PM$_{10}$ pollutant dispersion in two major cities of Myanmar. Some previous studies conducted in other countries have reported a trend towards significantly higher PM concentrations in the winter as compared to the summer season [6, 9]. A Chinese study performed in 2015 reported marked seasonal variability in the PM$_{2.5}$ concentrations, with the highest concentrations recorded during the winter and lowest recorded during the summer [6]. The authors speculated the enhanced anthropogenic emissions from fossil fuel combustion and biomass burning and unfavorable meteorological conditions (i.e., more frequent occurrences of stagnant weather and temperature inversions during cold periods) as the possible reason for the greater levels of pollution in the winter [6]. In the United States, the maximum organic carbon concentration was noted in the summer and the minimum in the winter [7]. Similarly, a study performed in Kenitra City of Morocco showed the highest PM$_{2.5}$-PM$_{10}$ concentrations in the summer and the lowest concentrations in the winter [8]. There are a few published studies that have shown the impact of the seasonal variations of PM concentrations on PM-associated health issues. According to a study by Guo et al., the incidence of PM$_{10}$ exposure-induced ischemia-like injuries in the rat brain was season-dependent, i.e., higher in the winter [9].

In the present study, we found marked seasonal variability of the PM$_{2.5}$ and PM$_{10}$ concentrations in Yangon City, with the concentrations in the dry season exceeding USEPA guideline and those in the wet season being within the recommended value in the guideline. The underlying reason for the seasonal
variability may be the higher frequency of rainfall and higher humidity in the wet season causing the suspended particles to be trapped on the surface of earth and to be eventually into the fluid drainage outlets. During the dry season, in many townships, the most noticeable sources of pollution were from the burning of dried leaves, especially in the morning, and from street-food shops and vehicles. During the wet season, emission from vehicles and street-food shop stove-burning occurred at nearly the same rate; however, the lack of burning of dried leaves in this season could be one of the factors contributing to the reduction of the PM concentrations in this season.

Regardless of the seasonal variability and PM size, Yangon displayed a pattern of diurnal variation, namely, the highest PM concentrations in the morning, followed by an afternoon dip and then evening rise in every township. The highest concentrations in the morning hours were considered to be due to the smog and smoke from the burning of dried leaves and the burning of street food shop stoves. The reason for the afternoon dip in the PM concentrations was speculated by Harrison et al., as being due to the high temperatures at that time of the day causing the loss of semi-volatile PM (principally nitrate, with some organic compounds) [18]. Our previous study showed that the evening 19:00h vehicular density was higher than that of the morning 07:00h density [16]. Thus, vehicular exhaust might contribute more to the PM concentrations in the evening at 19:00h than in the morning at 07:00h.

Interestingly, the diurnal variations of the PM concentrations in Taunggyi were different from those in Yangon (Figure 1 and 2). The Myo-ma, Ho-pone and Thit-taw quarters of Taunggyi showed a trend towards lowest in the morning, higher in the afternoon and highest in the evening concentrations of both PM$_{2.5}$ and PM$_{10}$ (Figure 2). These trends could be attributed to the difference in the lifestyles of the people and different vehicular densities during these hours. Comparison of the data between Yangon and Taunggyi Cities revealed higher PM$_{2.5}$ concentrations in Yangon than in Taunggyi (Table 3 and Figure 3(a)). On the other hand, unexpectedly, the PM$_{10}$ concentrations were higher in Taunggyi city than in Yangon (Table 3 and Figure 3(b)). The source of the PM$_{10}$ in Taunggyi city was possibly the large number of construction sites due to the ongoing city development plan, especially in the Myo-ma quarter and West round road.

The economy of Taunggyi, the capital city of Shan state, is largely based on agriculture and the lower population density. The rush hours were not consistent with the usual office hours and the movements of people and vehicles were found to be busier towards the afternoon and evening hours. Furthermore, the city received the ASEAN environmentally sustainable city award in 2008 and the most clean air city award in 2017 [14, 15], in line with our findings that the PM concentrations were within the recommended concentrations in the USEPA guideline and significantly lower than those in Yangon.

This study is the first to report on the regional variations in PM concentrations between Taunggyi and Yangon cities and on the seasonal variations in PM concentrations in Yangon city, Myanmar. In the future, we propose to analyze the constituents of PM in different regions and conduct health-related studies of PM-exposed populations.

5. Conclusion

In this study, we found that the PM$_{2.5}$ and PM$_{10}$ concentrations were significantly higher during the dry season as compared to the wet season in Yangon; furthermore, while the PM$_{2.5}$ concentration was higher in Yangon, the PM$_{10}$ concentration was higher in Taunggyi during the wet season. The major source of PM in Yangon was vehicular exhaust and that in Taunggyi was from construction during this study period. Our study indicates reliable PM$_{2.5}$ and PM$_{10}$ real-time assessments, both temporally and spatially, with Pocket PM$_{2.5}$ Sensors, whereas fixed station PM$_{2.5}$ monitors have limitations in terms of mobile sensing and economic practicalities, especially in developing countries. Further studies to investigate the detailed composition of PM in these two regions and the seasonal and regional variations in PM-related health risks are needed in the future.

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Ethical Approval
This study was approved by the Research and Ethics Committee (REC) of the University of Medicine 1, Yangon. Approval number is 114/UM1, REC.2017.

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Disclaimer
There is no conflict of interest.

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