The Effect of Meteorological Parameters on Particulate Matter ($PM_{2.5}$) in Yangon City, Myanmar

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Abstract

Daily average monitoring data for $PM_{2.5}$ and meteorological parameters at Kaba-aye, Yangon from 2018 to 2021 are analyzed using statistical methods to investigate the effect of meteorological parameters on the $PM_{2.5}$ concentration and possible source of $PM_{2.5}$. The study found that, $PM_{2.5}$ concentration is the highest in the month of February with 41.71 μg/m^3 with the annual increasing rate of 1.96 μg/m^3 per year. The concentration of $PM_{2.5}$ was observed to be higher during non-monsoon season (November to April) than in monsoon (May to October). The concentration of $PM_{2.5}$ remained always above the WHO Standard except monsoon season. The significant negative correlation of $PM_{2.5}$ with rainfall amount and relative humidity in monsoon season, while significant negative correlation with rainfall and mean temperature in non-monsoon season. Diurnal variation of $PM_{2.5}$ showed bimodal distribution with one maximum in the morning and the other at evening. The observed seasonality and diurnal variability of $PM_{2.5}$ distributions are attributed mainly to the rush hours of traffic conjunction and climate factors.

Keywords: $PM_{2.5}$, meteorological parameters, monsoon, non-monsoon, diurnal variation

1. INTRODUCTION

The Republic of the Union of Myanmar is located in Southeast Asia country. Myanmar climate is mainly influenced by a tropical to sub-tropical monsoon from the India Ocean (South West monsoon) and cold air mass from the East Asia continent. As of monsoon country, Myanmar climate can be expressed as three seasons, such as, hot and dry inter-monsoonal (mid- February to mid-May), rainy, southwest monsoon (mid-May to late October), and cool, relatively dry northeast monsoon season (late October to mid-February). Different parts of the country have different weather conditions due to the diversity of geography and its topographical reliefs. The normal annual rainfall (1981-2010) of the mountain ranges over the west coast along Rakhine and southern regions receive the highest rainfall about 5080 mm, the lower elevation of deltaic area about 2540 mm, and rain shadow area, that located in central Myanmar about 762 mm, respectively (Aung et al., 2017; Sein et al., 2018).

As Myanmar is one of the developing countries with the rapid economic growth and urbanization, has been experiencing air pollution ($PM_{2.5}$) problem, especially in Yangon city. Yangon city is a second capital of Myanmar, with a highly congested and populated city (Yi et al., 2018). Thus, high $PM_{2.5}$ concentration caused from the anthropogenic pollutant emissions, including vehicle exhausts, heating, and waste burning.

Several studies have been done regarding air pollution research in region and globally. However, Myanmar has limited study to assess particulate matter ($PM_{2.5}$) in Yangon. Yi et al., 2018 made assessment the distribution of $PM_{2.5}$ in different townships (7 townships) of Yangon using the pocket $PM_{2.5}$ sensor by monitoring 15 minutes per day for 5 days. Tun et. al, 2018, assess the ambient dust pollution in Mingaladon area, using 24 hourly data for 61 days. In 2020, Sricharoenvech et. al, determined the possible source contribution to PM_{10} using ambient air PM_{10} sampler for one year. All of the previous studies carried out for very short term monitoring. Moreover, there is limited research on the influence of weather parameters on particulate matter. Therefore, this study is conducted to fill the gap by investigating the effect of meteorological parameters on the particulate matter ($PM_{2.5}$) using 24 hours, hourly continuous data measured by the official method in Yangon.

2. METHODOLOGY

2.1 Study Site

The study site is located in the Yangon city, former capital city of Myanmar. Yangon is considered as the most populated density and largest economic zone in Myanmar. Yangon, one of the deltaic area has monsoon climate with the average temperature range about 21 – 33 ºC, and the normal annual rainfall is about 2783 mm (Aung et al., 2017). There are three major weather stations inside Yangon, namely, Mingalandon, Kaba-aye, and Hmawbi as shown in Figure 1. Thirty years' monthly average value from 1980 to 2010 of rainfall, maximum and minimum temperature of those three stations was used to compare the weather phenomena of three locations in Yangon. Similar variations in rainfall and temperature were observed in Figure 2. Among three weather stations, the monitoring data of Kaba-aye station is used for further analysis which has both weather and $PM_{2.5}$ monitoring station. In addition, seasonal pattern of monsoon and non-monsoon was defined based on the thirty years' monthly average during the period 1981-2010 rainfall pattern, such as, from May to October as monsoon (wet) and from November to next year April as non-monsoon (dry) period.

The $PM_{2.5}$ monitoring site is situated Kaba-aye weather station belongs to the Department of Meteorology and Hydrology (DMH) that was installed in March 2018. The site is monitoring $PM_{2.5}$ for the 24 hours automatic continuous, and data are available from 2018 Mach to present.

The site is categorized as urban site according to the Acid Deposition Monitoring Network in East Asia (EANET) criteria (EANET 2013). The site is 0.09 to 0.12 km away from the main road and traffic congestion (Figure 3a). Traffic congestion is quite common around the area due to the great numbers of vehicles. It is also surrounded by the different types of industrial areas in 3.71 to 8.7 km away from the South East, 10.24 to 16.83 km away from the West-South-West, and 7.81 to 10.92 km away from the North, respectively (Figure 3b) (Google Earth, 2022).

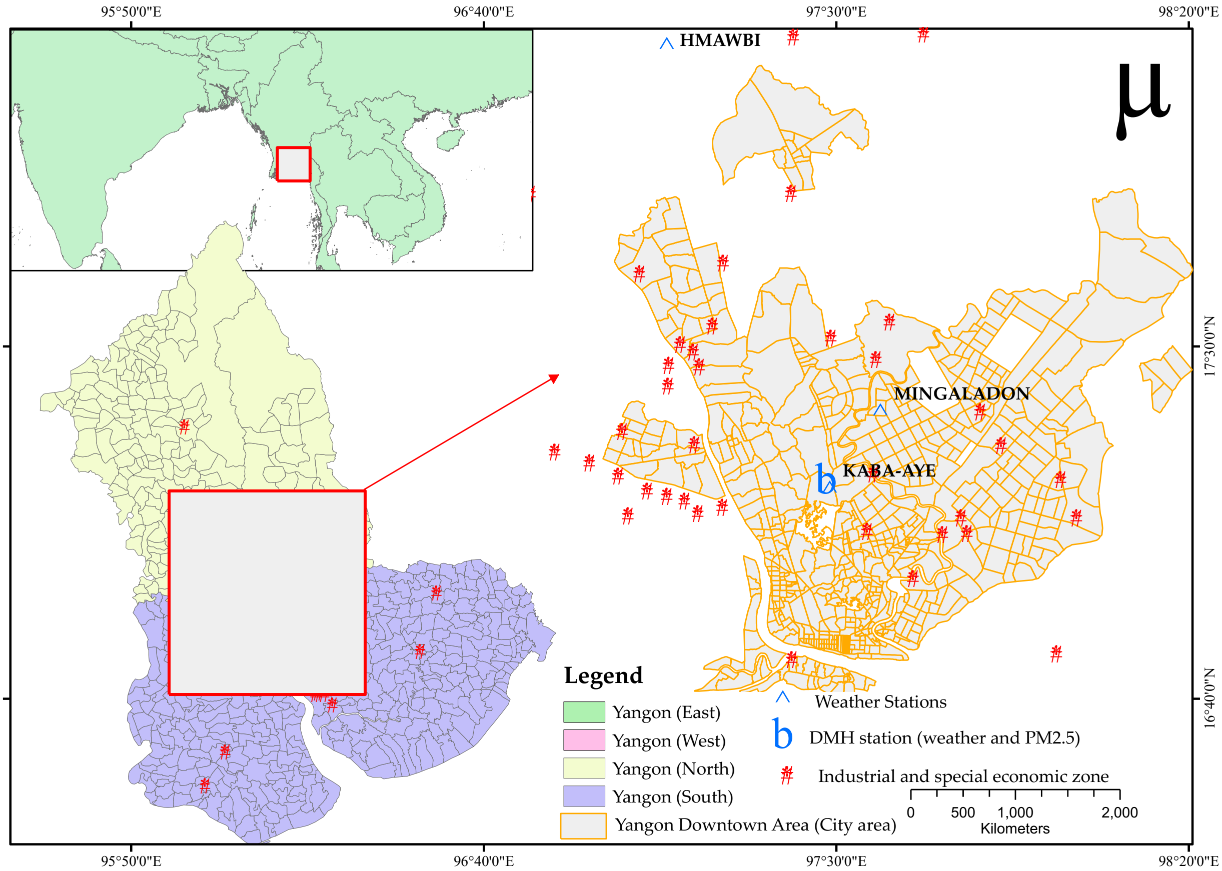
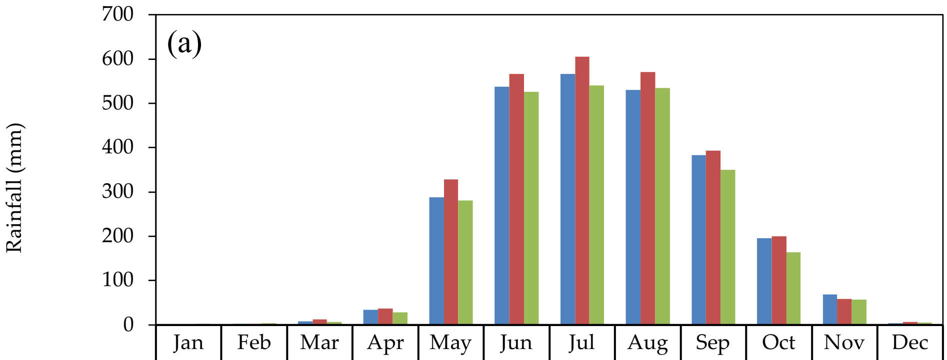
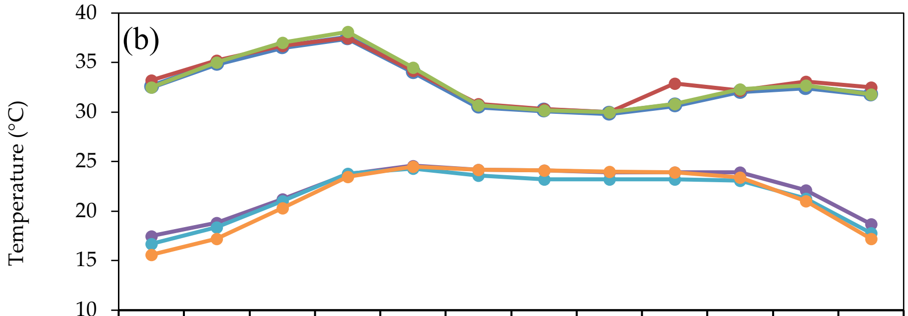


Figure1. Location of the study site with three meteorological stations.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mingaladon	0.5	3.1	8.9	34.3	288.6	537.3	565.8	530.8	383.2	195.8	68.4	4.3
Kaba-aye	0.4	3.1	12.4	37.8	328.1	565.6	605.8	570.7	393.7	200.3	58.6	6.8
Hmawbi	2.2	3.5	7.2	28.2	281.3	526.4	540.7	534.8	349.4	164.3	57.8	5.4



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mingaladon	32.6	34.9	36.6	37.5	34.1	30.6	30.2	29.9	30.7	32.1	32.5	31.8
Kaba-aye	33.2	35.2	36.7	37.5	34.2	30.8	30.3	30	32.9	32.2	33.1	32.5
Hmawbi	32.5	35	37	38.1	34.5	30.7	30.2	30	30.8	32.3	32.7	31.8
Mingaladon	17.5	18.8	21.2	23.7	24.6	24.2	24.1	23.9	23.9	23.9	22.1	18.7
Kaba-aye	16.7	18.4	21	23.8	24.3	23.6	23.2	23.2	23.2	23.1	21.3	17.8
Hmawbi	15.6	17.2	20.3	23.5	24.5	24.2	24.1	24	23.9	23.4	21	17.2

Figure 2. Comparison of monthly average during 1981-2010 (a) rainfall, (b) maximum and minimum temperature at Mingaladon, Kaba-aye, and Hmawbi stations.

Figure 3. Location of the (a) different industrial zones (red triangle), (b) distance between DMH (station under study) and the main road and traffic conjunction.

2.2 Data and Method

The automatic particulate matter ($PM_{2.5}$) monitoring equipment (FPM-377C, DKK-TOA Corporation, Japan) are utilized for hourly measurement of $PM_{2.5}$ concentrations. The hourly $PM_{2.5}$ data from April, 2018 to December, 2021 are collected at DMH. The collected data has missing values especially from 28th March 2020 to 8th May 2020 due to the failure of the CF memory card errors (DMH, 2020). Similarly, daily data of rainfall, mean temperature, relative humidity, and wind speed and wind direction (for 09:30, 12:30, 18:30) also collected from the surface synoptic station, DMH. The collected data of both PM2.5 concentration and climate parameters are the same length from 2018 to 2021. All the weather data except wind directions are aggregated from daily to monthly, monsoon and non-monsoon, and annual to investigate the trend of climate variations. Similarly, hourly $PM_{2.5}$ concentration data is aggregated the same way to find out the diurnal variations and annual trend. The linear trend was performed using Thiel-Sen nonparametric method based on Kendall's tau (τ) (Sen, 1968). Statistical significant level was set up at $p < 0.05$. Moreover, correlation analysis is used to check the relation between $PM_{2.5}$ and meteorological factors. In addition, wind-rose diagram for $PM_{2.5}$ were plotted to determine the possible source of $PM_{2.5}$ in the site area. Figure 4 illustrates the overall methodology of the study.

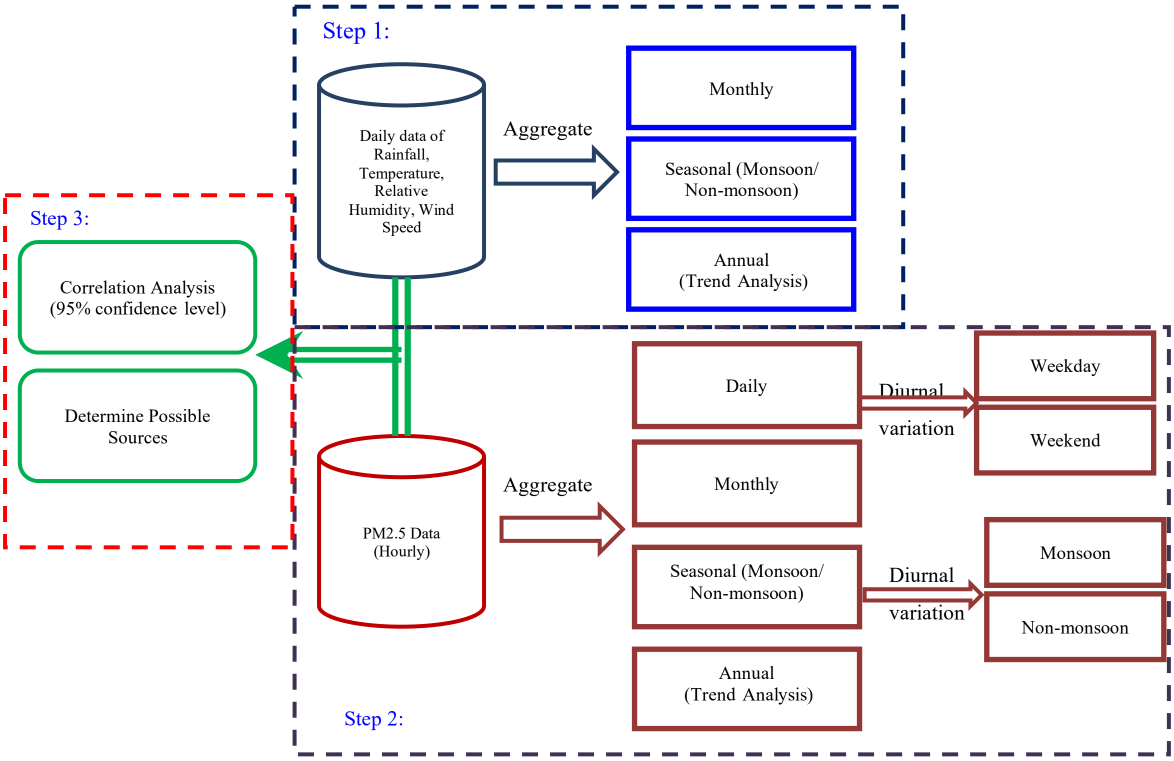


Figure 4. Overall methodology of the study.

3. RESULTS AND DISCUSSION

3.1 Temporal Variations of $PM_{2.5}$ Concentration

To understand the general trend of $PM_{2.5}$ mass concentrations, the daily, monthly, and annual variations of $PM_{2.5}$ were graphically investigated in Figure 5. Daily mean of $PM_{2.5}$ concentration exceeded the WHO standard of 24 hours mean 25µg/m^3 in most of the time that presented in Figure 5a (Nielsen, 2009). Figure 5b shows the monthly mean of $PM_{2.5}$ concentration. The highest month was February with 41.71 µg/m^3 followed by January, December, March, April and November with 41.47 µg/m^3, 37.99 µg/m^3, 36.95 µg/m^3, 32.74 µg/m^3, and 29.76 µg/m^3, respectively. During the transition period from April to May and October to November, the change from non-monsoonal to monsoonal winds causes large fluctuations in mass concentrations decreasing from 32.74 μg/m³ to 12.53 μg/m³. The lowest concentration can be seen during May to October (monsoon season). The highest concentration can be observed during November to April (non-monsoon season). Thus, $PM_{2.5}$ concentration shows great seasonal variations, with the most severe $PM_{2.5}$ pollution in non-monsoon season and the air quality will be poor. The annual trend of $PM_{2.5}$ concentration significant increased with the increasing rate of 1.96 μg/m³ per year as shown in Figure 5c. The annual average of $PM_{2.5}$ concentration exceeded the WHO average annual limit of $PM_{2.5}$ standard, 10 μg/m³ in all years of study period 2018 to 2021 (Nielsen, 2009). This result is similar with the result finding from Shi et al., 2018, and they have reported the annual average of $PM_{2.5}$ concentration in South and South East Asia countries including Myanmar exceeds WHO standard. Similarly the significant increased $PM_{2.5}$ was found during their study period 1999 to 2014 however a different increasing rate was found due to different study period of this research (Shi et al., 2018).

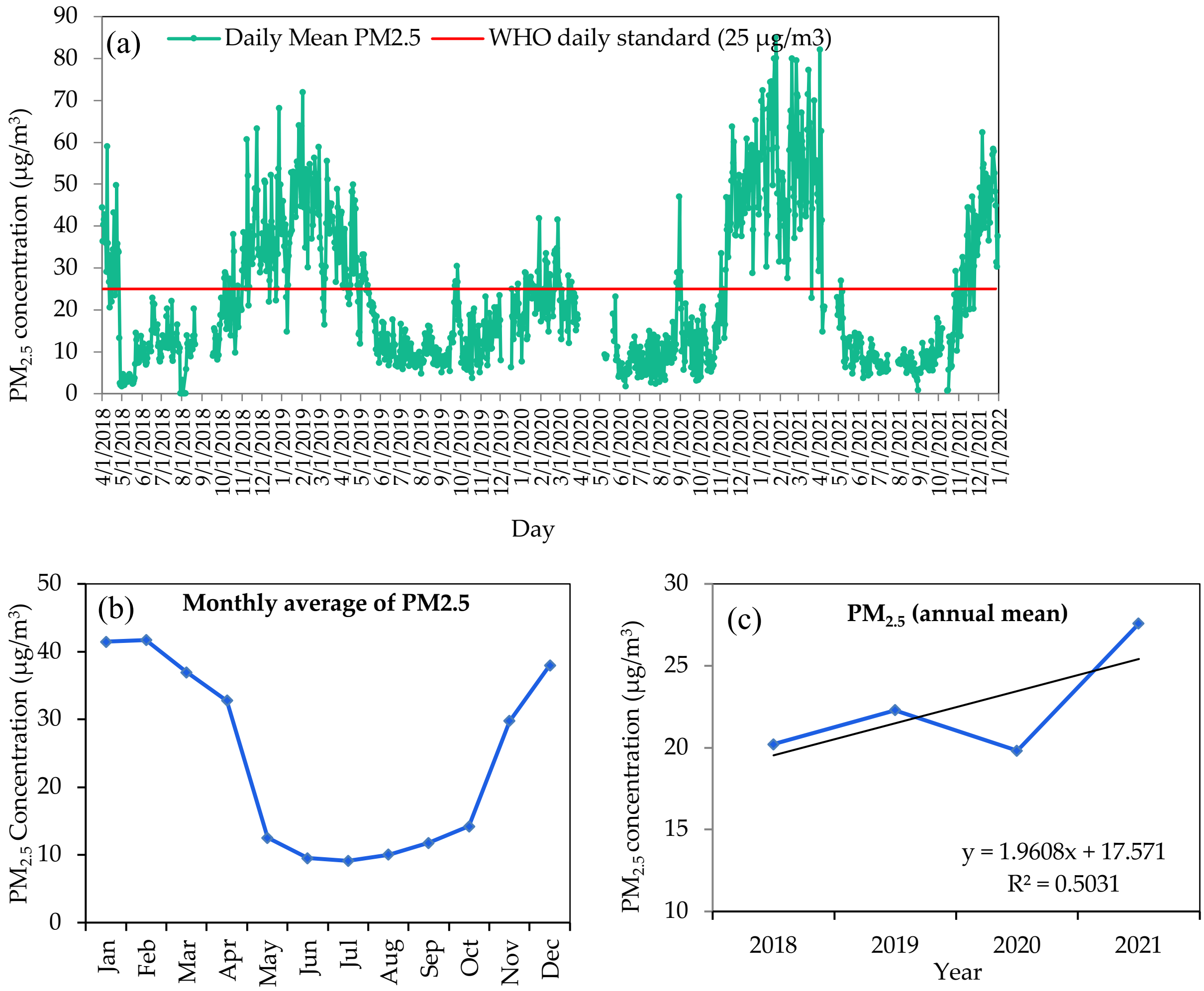


Figure 5. Variations of $PM_{2.5}$ mass concentrations in (a) daily average, (b) monthly average, and (c) annual average.

3.2 Influence of Meteorological Parameters on $PM_{2.5}$ Concentration

The monthly average of $PM_{2.5}$ concentrations and meteorological parameters of rainfall amount, mean temperature, relative humidity at Kaba-aye station are plotted in Figure 6. The distributions show concentration range during non-monsoon season (November to April) at 29.76 – 41.71 µg/m^3 was higher than that of monsoon season at 9.12 – 14.22 µg/m^3 in monsoon season (May to October). As shown in Figure 6a, $PM_{2.5}$ concentrations tended to be lower during the monsoon season with high precipitation and higher $PM_{2.5}$ concentrations during the non-monsoon season with low precipitation. This suggests that the washout effect of pollutants by precipitation is significant. Similarly, Figure 6c shows an inverse correlation between relative humidity and $PM_{2.5}$ concentration. Figure 6b shows the average temperature had a positive effect on particulate matter $PM_{2.5}$ concentration.

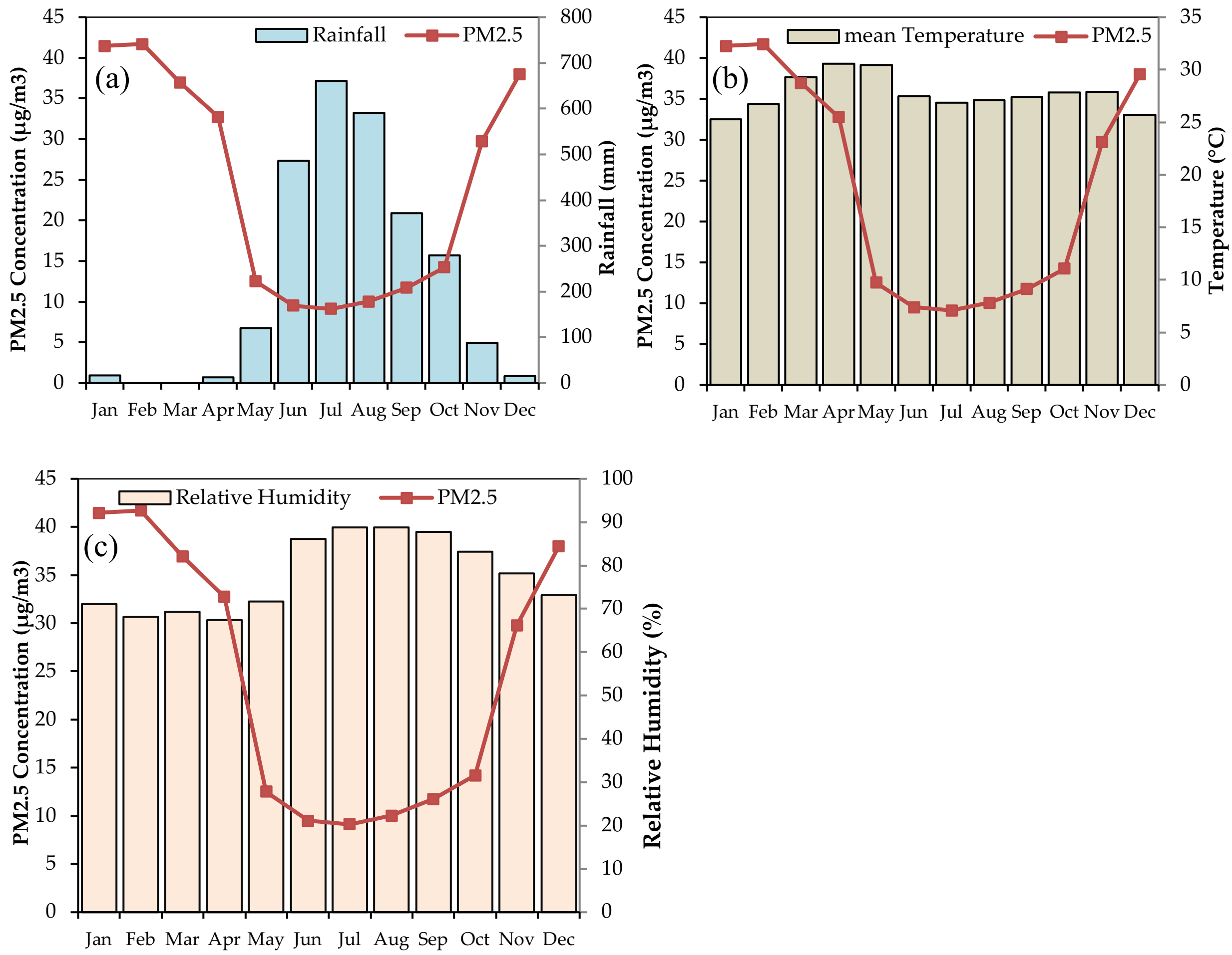


Figure 6. Monthly average of $PM_{2.5}$ concentrations and meteorological parameters of (a) rainfall, (b) mean temperature, and (c) relative humidity.

3.3 Correlation between $PM_{2.5}$ and Meteorological Parameters

Table 1 shows the Pearson correlation between $PM_{2.5}$ and meteorological parameters in monsoon and non-monsoon season. The result indicated that significant negative correlation (r =

-0.16, $p < 0.01$) was observed between $PM_{2.5}$ and rainfall amount in non-monsoon season whereas insignificant in monsoon season (r = -0.07). Thus, air pollutants including $PM_{2.5}$ was reduced by washout process induced by rain that promotes wet deposition effect of particulate matter. Moreover, precipitation can effectively remove the atmospheric particulate matter, especially the small size of particle (Wang & Ogawa, 2015).

$PM_{2.5}$ during monsoon season is significant positively correlated with temperature (r = 0.09, $p < 0.05$) in monsoon while strongly significant negative correlation with temperature (r = -0.16, $p < 0.01$) in non-monsoon season. Generally, the day time temperature reaches the highest with the presence of solar radiation that can affect the formation of fine particles and favorable of the transformations process within the atmosphere (Pateraki et al., 2012; Trivedi et al., 2014; Wang & Ogawa, 2015). However, this result finding of PM was negative correlation with temperature could be the effects of vehicle emissions from nearest road side (Nam et al., 2010). In addition, the positive correlation with temperature during the monsoon season is due to the generation of photochemical reactions on sunny days with high solar radiation intensity compared to days with low solar radiation intensity due to rainfall. On the other hand, the negative correlation with temperature during the non-monsoon season is due to convection caused by solar radiation and dilution of the $PM_{2.5}$ concentration in the boundary layer due to the rise of the atmospheric boundary layer.

Insignificant negative correlation between $PM_{2.5}$ and wind speed can be seen in non-monsoon while there is no relation in monsoon season. Thus, the wind speed may not be a major factor according to the correlation of $PM_{2.5}$ and wind speed in this study. In general, low wind speed can blow away the pollutants within certain range, however, high wind speed can transport large amount of pollutants from far away (Wang & Ogawa, 2015). Similarly, the effect of wind speeds will favor the spatial distribution of $PM_{2.5}$ concentrations, e.g. low wind speeds lead the atmosphere is relatively stable and the local emission is largely limited for dispersion (Liu et al., 2015).

$PM_{2.5}$ has a strong negative correlation with relative humidity (r = -0.15, $p < 0.01$) in monsoon, however, positive correlation in non-monsoon but the correlation is very low. Thus, $PM_{2.5}$ concentration will decrease while relative humidity increase in monsoon season. The higher relative humidity favor to remove the particulate matters, particularly of coarse size range, through development of atmospheric instability and consequent rain bearing clouds and rain (Trivedi et al., 2014; Arieff et al., 2017).

The result of correlation between $PM_{2.5}$ and meteorological parameter in this study indicate clear and strong negative influence of $PM_{2.5}$ with rainfall and temperature during non-monsoon season. Thus, rainfall and temperature could be the main factors to reduce or increase pollution level in non-monsoon whereas relative humidity and temperature will be the main parameters of monsoon season in this study area.

Table 1: Correlation between $PM_{2.5}$ and meteorological parameters.

Variable	Rainfall (mm)	Mean Temperature (°C)	Wind Speed (mph)	Relative Humidity (%)	Period
$PM_{2.5}$ (μg/m^3)	-0.07	0.09*	0.00	-0.15**	Monsoon
$PM_{2.5}$ (μg/m^3)	-0.16**	-0.16**	-0.07	0.06	Non-monsoon

Note: * indicates correlation is significant at $p < 0.05$ and ** indicates at $p < 0.01$.

3.4 Diurnal Variations of $PM_{2.5}$

Figure 7 shows diurnal variations of $PM_{2.5}$ during the study period, from 2018 to 2021. On average, the $PM_{2.5}$ concentrations generally decreased from midnight to 06:00, followed by a morning peak at approximately 07:00 to 09:00. After that, concentrations decreased until 17:00, and then they increased until 22:00. The lowest $PM_{2.5}$ occurred at 14:00 in the afternoon, and the highest $PM_{2.5}$ appeared at 08:00 in the morning. Thus, $PM_{2.5}$ behaves a strong bimodal pattern with peaks between morning 07:00 to 09:00 and evening 18:00 to 22:00. As the study site is urban site, the morning and evening peaks are mainly affected by enhanced anthropogenic activity during rush hour, and the afternoon valley might to be a higher atmospheric mixing layer, which is beneficial for diffusion of air pollution. This result finding is consistence with the result finding from India, China and Myanmar (Krishna & Beig, 2018; Liu et al., 2015; Wang et al., 2015; Yi et al., 2018).

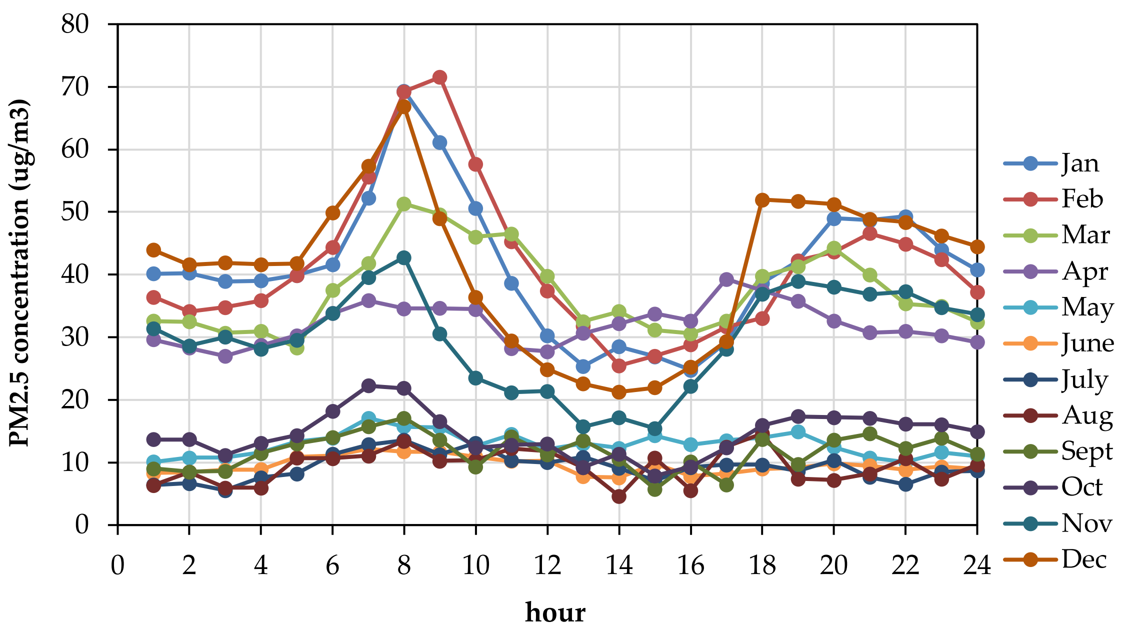


Figure 7. Diurnal Variations of $PM_{2.5}$ concentration.

Figure 8 shows the diurnal variations of weekday/weekend and monsoon/non-monsoon seasons. The morning peak at 8:00 a.m. (34.04 μg/m^3 at weekend and 36.24 μg/m^3 at weekday) and the evening peak at 5:00 p.m. (24.14 μg/m^3 at weekend and 26.80 μg/m^3 at weekday) can be found both weekday and weekend. There is no difference in $PM_{2.5}$ concentrations between weekday and weekend in study area. This result is similar with Huang et al., 2015 who studied for Beijing. Some studies found that air pollutant concentrations with higher levels during weekdays and lower during weekends (Blanchard & Tanenbaum, 2006; Motallebi et al., 2003). However, this pattern will not be prevailing in all cities, especially for $PM_{2.5}$ (Hu et al., 2014; Shen et al., 2014).

Diurnal variations of $PM_{2.5}$ concentrations were significantly different among monsoon and non-monsoon. In non-monsoon season, the morning peak with the value of about 55.67 μg/m^3 was more obvious than evening peak with the value of 43.13 μg/m^3 and the minimum is afternoon at 3:00 p.m. with a value of 26.03 μg/m^3. Similar trend was observed in monsoon season; however, daily variation of $PM_{2.5}$ was not clearly indicated. The mass concentration in non-monsoon has significant range about 40.10 μg/m^3 and 26.81 μg/m^3 different in the morning peak and evening that of monsoon season. Thus, it can be assumed that mass concentration in non-monsoon was two times higher than that of monsoon season. The lower magnitude during monsoon season is contributed to the rain and washout mechanism which makes the mass concentration values lesser in magnitude. Regarding the result finding, people living in the study area may suffer twice of air pollution problem that makes more health-related problems in non-monsoon season than monsoon season. As the monitoring site is located near main road, the high concentration of $PM_{2.5}$ in the morning and evening peaks could be the emissions from anthropogenic pollutant emissions, including heating, vehicles exhausts that are one of the major sources of air pollution in urban areas.

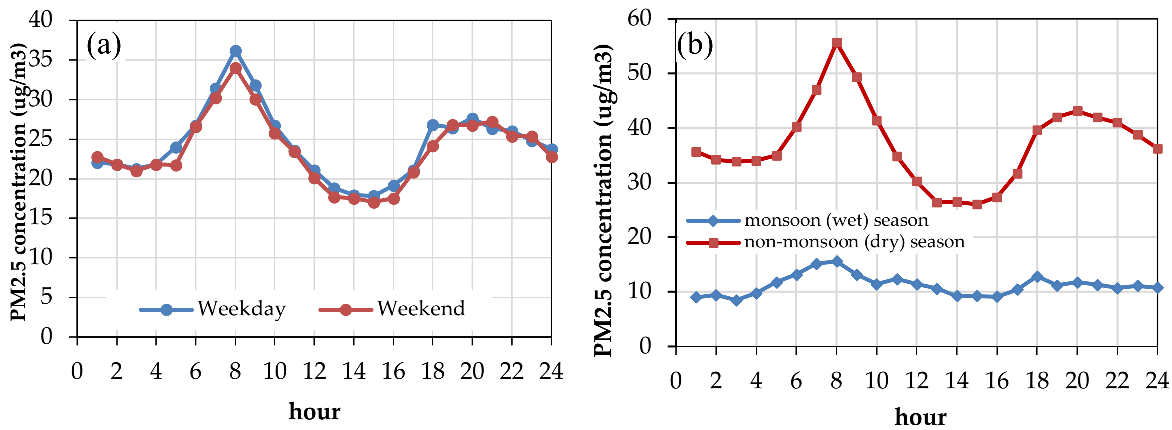


Figure 8. Diurnal variations of $PM_{2.5}$ concentration at (a) weekday and weekend, and (b) monsoon and non-monsoon.

3.5 Possible Sources of $PM_{2.5}$

To determine the possible source of $PM_{2.5}$, wind speed and $PM_{2.5}$ concentration rose diagram are plotted for three different times, 09:30, 12:30, and 18:30 for monsoon and non-monsoon.

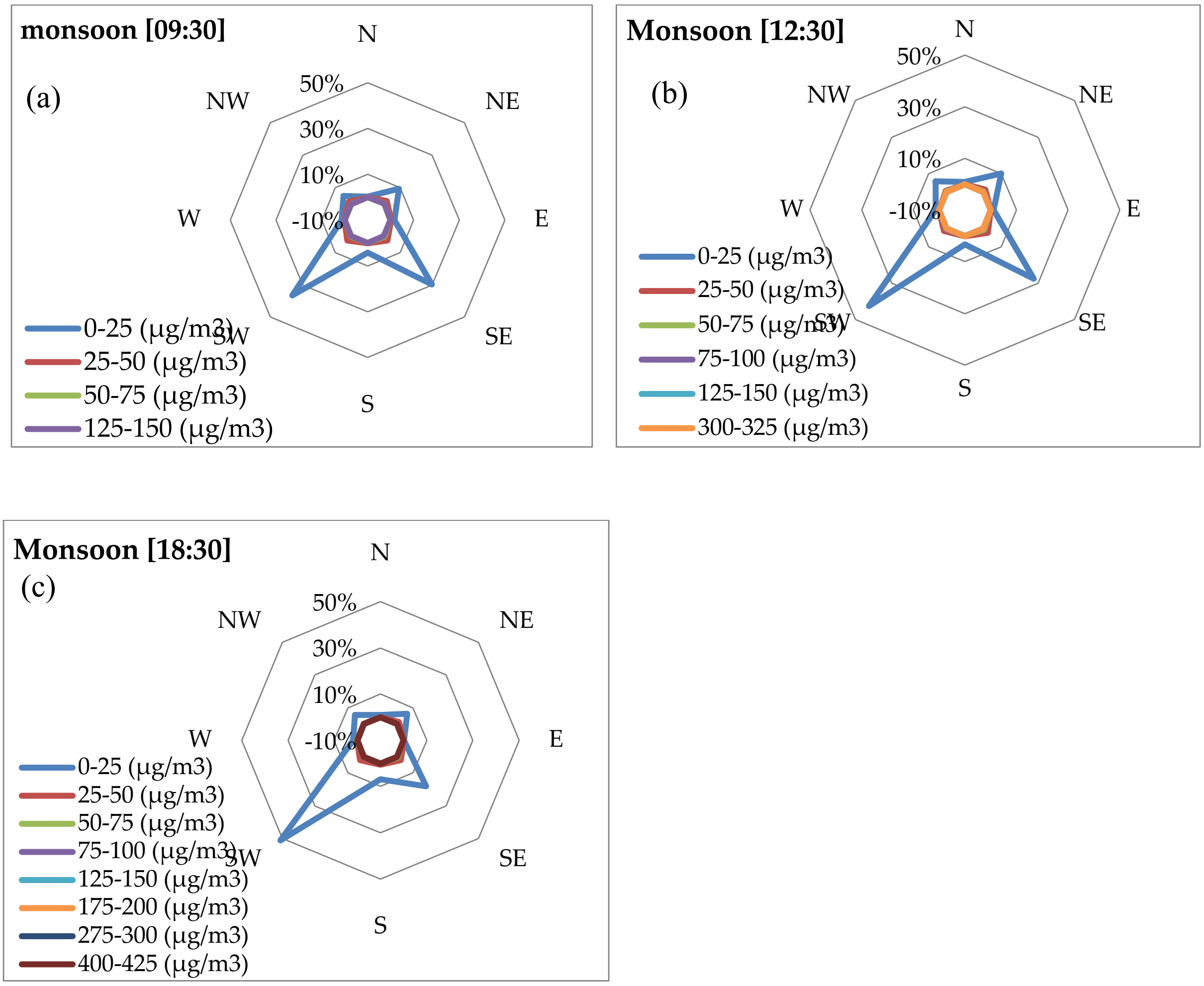


Figure 9. $PM_{2.5}$ concentration rose, and frequency of wind direction at (a) 09:30, (b) 12:30, and (c) 18:30 during monsoon season.

Figure 9(a), (b), and (c) show the $PM_{2.5}$ concentration rose and frequency of wind direction at 09:30, 12:30, and 18:30 during monsoon season. During monsoon season, the wind direction is mainly influenced South-West (SW), followed by South-East (SE), and North-East (NE) direction at three times. The different wind directions transported different amount of $PM_{2.5}$ concentrations. The highest wind speed and $PM_{2.5}$ concentration amount can be found in the evening, 18:30 with maximum concentration amount of 425 µg/m^3. $PM_{2.5}$ concentration range varied from 0 to 425 µg/m^3 while 90% of concentration amount was observed ≤ 25 µg/m^3 in monsoon season.

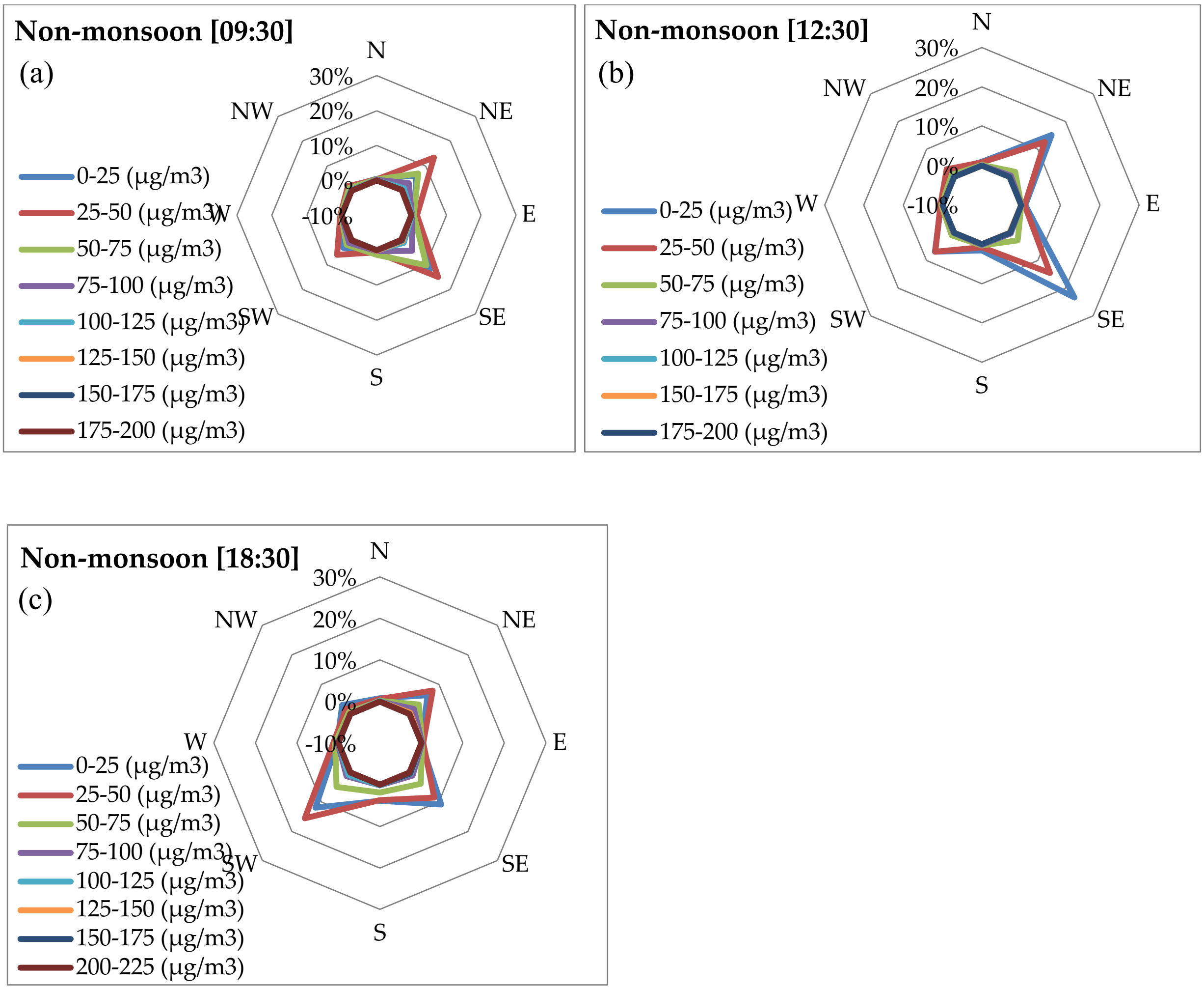


Figure 10. $PM_{2.5}$ concentration rose, and frequency of wind direction at (a) 09:30, (b) 12:30, and (c) 18:30 during non-monsoon season.

During non-monsoon season, the wind direction is mainly influenced from South-East (SE), followed by North-East (NE) from morning to afternoon, while South-West (SW) and South-East (SE) direction in the evening. Generally, most of the wind comes from the SE and NE. Similar in non-monsoon, the different wind directions transported different amount of $PM_{2.5}$ concentrations. The highest $PM_{2.5}$ concentration amount can be found in the evening, 18:30 with maximum concentration amount of 225 µg/m^3. $PM_{2.5}$ concentration range varied from 0 to 225 µg/m^3 while 90% of concentration amount was observed ≤ 75 µg/m^3 in non-monsoon season.

$PM_{2.5}$ concentration deposited range between 0 - 425 µg/m^3 in monsoon and 0 – 225 µg/m^3 in non-monsoon. In monsoon, the SW and SE wind transported the most pollutants. In non-monsoon, SE and NE wind transported the most pollutants than wind in other directions. NE wind is common in both monsoon and non-monsoon season. Thus, it can be concluded that the pollutants in study area, Kaba-aye, are mainly from SW and SE direction in monsoon whereas from SE and NE in non-monsoon season. According to the $PM_{2.5}$ concentration amount, the highest amount received with monsoon wind (SW) although, the other meteorological parameters, such as, rain, and relative humidity were not favor to dispread the pollutants and deposited with rain. On the other hands, the highest $PM_{2.5}$ concentration amount in non-monsoon is lower than (half of monsoon) monsoon, however, there is no rain and low temperature also favorable for distribution of $PM_{2.5}$ and caused pollution in the study area than monsoon. Therefore, air pollution during non-monsoon (November to April) is more serious while air quality is better in monsoon (May to October) season.

The monitoring site is very close to the main road and traffic conjunction (0.09 – 0.12 km) from SE and NE direction. Moreover, the site is located in the commercial area which has high traffic flow compared to the other area. Diurnal variation showed that the peaked twice in morning 8 a.m., and evening 5 p.m. also indicated that the peak of traffic congestion in rush hours. Therefore, it can be assumed that the main source of pollution in this area mainly caused by the transportation sectors.

4. CONCLUSIONS

This study is a preliminary analysis of $PM_{2.5}$ concentration monitored as 1-hour data from 2018 to 2021 by automatic measuring instruments and its relation to meteorological parameters in Kaba-aye, Yangon. The key findings can be summarized as follows:

- $PM_{2.5}$ concentration is highest in non-monsoon season and the maximum monthly concentration can be observed during February with 41.71 $\mu g/m^3$.
- Transition period of monsoon to non-monsoon, $PM_{2.5}$ concentration is significant sharply increased, and vice visa.
- $PM_{2.5}$ concentration is significant increased with the rate of 1.96 $\mu g/m^3$ per year.
- $PM_{2.5}$ has significant negative correlation with rainfall amount and mean temperature, and insignificant with wind speed during non-monsoon season.
- $PM_{2.5}$ has significant negative correlation with relative humidity and insignificant with rainfall while significant positive with mean temperature during monsoon season.
- There is no relation with $PM_{2.5}$ and wind speed during monsoon season.
- Diurnal variations in $PM_{2.5}$ concentrations during the non-monsoon season showed two peaks in the morning and evening, but were not clear during the monsoon season. Comparing the morning and evening peaks for both seasons, significant differences of 40.10 $\mu g/m^3$ and 26.81 $\mu g/m^3$ were found, respectively.
- In monsoon season, $PM_{2.5}$ concentration spread from South West and South East direction, and deposited with monsoon rain.
- In non-monsoon season, $PM_{2.5}$ concentration spread from South East and North East direction, and dispersed in and around the area.

- Possible source of $PM_{2.5}$ contributed from transportation due to the nearest road sides and climate factors.

This study makes a preliminary analysis of PM pollution and its relation to meteorological factors in Kaba-aye, Yangon. The results may contribute future policies directed at emissions control in Myanmar. However, there are still some limitations of the study. There is only one single site PM monitoring in this study because of the limitation of monitoring site. More detailed observations, not only of $PM_{2.5}$ mass concentrations but also of the chemical components and optical properties, from industrial areas, residential areas, are still needed to further study the PM pollution of this area in future.

5. ACKNOWLEDGEMENTS

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