SEASONAL AND METEOROLOGICAL INFLUENCES ON THE CONCENTRATION OF PM2.5 AT CAMS-3 IN DHAKA CITY USING DECADAL DATA

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ABSTRACT

Fine particles (PM2.5) if stay in the air at a high concentration for an extended period could be very harmful for human health. On the basis of average annual PM2.5 concentration, IQ-Air in their 2021 World Air Quality Report ranked Dhaka as the second most polluted city in the world with an average PM2.5 concentration of 78.11µg/m3. In 2023, the University of Chicago's Air Quality Life Index indicated that if Dhaka could able to maintain the WHO guidelines for PM2.5 concentration level in the air, average life expectancy could have gained by 8.1 years. Researchers have studied meteorological influences on PM2.5 concentration with limited data and there is a need for further study. This study analyzes time series data (i.e., decadal data: 2013-2022) encompassing the most recent years to better understand long term state of PM2.5 concentration in the air of Dhaka. Specifically, the purpose is to (1) perform statistical analysis on the PM2.5 data while taking into consideration of monthly and seasonal variation of PM2.5 concentration and compare the mean values with the local and international ambient air quality standards (i.e., DoE, US-EPA standards) to understand the health effects of PM2.5 concentration in the air, and (2) assess the influences of seasonally varied meteorological parameters (i.e. temperature, relative humidity, precipitation and wind speed) on the concentration of PM2.5. This study utilizes PM2.5 concentration data of the Continuous Air Quality Monitoring Station #3 (CAMS #3-Darus-salam) and meteorological data of Bangladesh Meteorological Department (BMD).

It is found that PM2.5 (annual averaging values) has been remained in the air at a very high concentration throughout the ten-year (2013-2022) analysis period causing serious public health hazard and premature deaths. Monthly analysis (i.e., January and July) of data reveals that the averaging 24-hr PM2.5 concentration reaches at its maximum value of 145 µg/m3 in January (Dry season) and at its minimum value of 20.6 µg/m3 in July (Wet season). Regarding the influence of meteorological parameters on PM2.5, it is found that all three parameter values (i.e. temperature, relative humidity, and precipitation) are inversely (negatively) correlated with the PM2.5 values, and the meteorological factors including the wind effect (i.e., potential for transporting of PM2.5 from nearby Brick Kilns) may play significant roles in the increment of PM2.5 concentration during the Dry season. The findings of this study indicate that the existing policies and strategies are substantially inadequate to control/maintain the national ambient air quality standards for PM2.5 in Dhaka city and may induce policy makers to reflect on the past policies and learn the lessons from earlier mistakes. It is recommended that the government re-examines the existing policies and develop/redevelop more effective policies and strategies to control and maintain PM2.5 concentration in the air of Dhaka to ensure sustainable development and healthy living for the city dwellers. Furthermore, public awareness on the danger of prevailing PM2.5 concentration as well as civic responsibility in reducing the PM2.5 concentration is also needed.

Keywords: *PM2.5,, air quality, seasonal influence, meteorological influence*

1. INTRODUCTION

Dhaka is a densely populated unsustainable and unhealthy mega city with a poor track record of maintaining ambient air quality standards (Chowdhury 2014; Chowdhury et al. 2023). Unplanned urbanization including poorly regulated industrialization, transportation and land developments (i.e., infrastructure and building construction activities) is primarily responsible for air pollution in Dhaka city. Bangladesh as a country and Dhaka as the capital of Bangladesh have been ranked consistently among the heavily air polluted countries and cities lists. For instance, in 2021, IQ-Air in their World Air Quality Report ranked Dhaka as the second most polluted city in the world with an average PM2.5 concentration of 78.11µg/m3 (IQ-Air, 2023). And most recently, in the list of countries based on 2022 global environmental performance index (EPI), Bangladesh has been ranked 177 among 180 countries with a score 23.1 (Wolf, et., al., 2022). EPI is a composite index that includes 11 broad issues including air quality. Furthermore, Randall et. al. (2011) found that Particulate Matter is the primary pollutant in the air of Dhaka during dry season (November-March) when PM2.5 concentration reaches at its peak (at a very dangerous level).

PM2.5 are fine particles (particulate matters) with an aerodynamic diameter of ≤2.5 milli-micron (µm) per cubic meter (m3) of air. They are inhalable droplets of solid and liquid mixtures of various substances such as dust and other particulate matter in the form of smoke, mist etc. They stay in the atmosphere as suspended substances for a long period of time and move a longer distance than other course particulate matters. The composition of PM2.5 (particulate matter) including physical and chemical properties depends on the source that generates such particles. Fine particles (PM2.5) if exists in the air at a high concentration for an extended period could be very harmful for human health. This is due to the fact that, if inhaled excessively, PM2.5 may penetrate deeply into the lung causing respiratory illness including lung cancer, cardiovascular disease and in some cases cardiac arrest and premature death (Pope et. al., 2002). High concentration of PM2.5 can also cause visibility problems, affect plants and other living beings as well as degrade water quality (Garcia et. al., 2023).

The purpose is to (1) perform statistical analysis on the PM2.5 data while taking into consideration of monthly and seasonal variation of PM2.5 concentration and compare the mean values with the local and international ambient air quality standards (i.e., DoE, US-EPA standards) to understand the health effects of PM2.5 concentration in the air, and (2) assess the influences of seasonally varied meteorological parameters (i.e. temperature, relative humidity, precipitation and wind speed) on the concentration of PM2.5.

1.1 Study Area and Data

The Continuous Air Quality Monitoring Station #3 (CAMS-3) is located in Darus-salam, Mirpur, an area within Dhaka city (see Fig. 1), the capital of Bangladesh and the data include PM2.5, Meteorological (i.e. temperature, precipitation, relative humidity, wind speed and wind direction), and Brick Kiln locations data. The source of PM2.5 and Brick Kiln data is the Department of Environment (DoE) while the source of Meteorological data is Bangladesh Meteorological Department. The DoE as part of their air quality monitoring network program operates a total of 11 continuous air monitoring stations throughout Bangladesh and the PM2.5 data used in this study were collected at the Continuous Air Quality Monitoring Station #3 (CAMS-3) which is located at a close proximity of Mirpur road in Darus-salam, Mirpur. This station monitors and records PM2.5 concentration data continuously in real time with a satisfactory capturing rate.

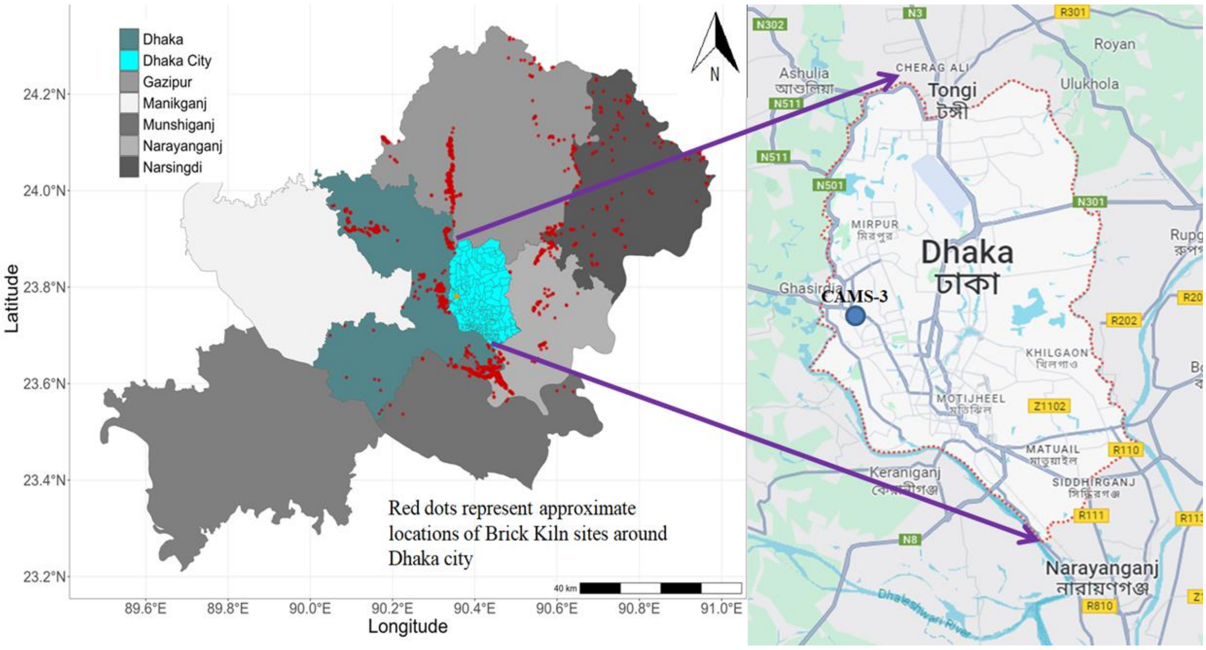


Figure 1: Dhaka City showing the approximate location of CAMS-3 (Darus-salam; Lat/Lon: 23.78N/90.36E) and its surrounding areas (Source: DoE and Google Map).

1.2 Major Sources of PM2.5 in the air of Dhaka

A number of sources that are responsible for releasing PM2.5 in the air of Dhaka have been identified by others (Begum et. al., 2008; Randall et. al., 2011; Rouf et. al., 2011; and Rana 2019). The anthropogenic sources of PM2.5 concentration in Dhaka city include both mobile (road traffic- fossil fuel, tire-road friction etc) and point (Brick Kilns, infrastructure and building construction sites, development sites, diesel powered generators, irrigation and agricultural equipments, miscellaneous industries/factories, open refuse/solid waste/wood fire etc) sources. Open burning of solid waste, particularly plastic waste in landfills, slums, and residential areas further contributes to elevated PM2.5 concentration (ESDO, 2020). Studies (Randall et. al., 2011; Rana 2019) also identified motor vehicles (combustion of fossil fuel and road dust mainly generated by road-tire frictions) and Brick Kilns (with energy source coal and wood) as two major sources of air pollution in Dhaka city. The Norwegian Institute for Air Research (NILU) under the project titled "the Clean Air and Sustainability Project-CASE" found that vehicular emission and road dust contribute to 10.4% and 7.7% of fine particles (PM2.5) in Dhaka city (Randall et. al., 2011). Others (Randall et al. 2014; and Begum and Hopke 2019) indicated that Brick Kiln industry alone contributes as high as 58% of PM2.5 concentration in the air of Dhaka during the dry season.

2. METHODOLOGY

The methodology includes both quantitative (mean values, box-whisker plots etc) and qualitative (characteristic and trend analysis) analysis of the decadal data (2013-2022) as well as secondary data and findings from other sources (i.e., from the review of literatures). As part of the data analysis, yearly (Fig. 2), monthly (Figs. 3 & 4) and daily (Figs. 5 & 6) mean values of PM2.5 and meteorological (i.e., relative humidity, rainfall and temperature) data are estimated. The CAMS-3 data are analyzed and mean values of monthly and seasonally varying average concentrations of PM2.5 are compared with the national and international ambient air quality (AAQ) standards (See Table 1) to determine the long term state of PM2.5 concentration in Dhaka city and its likely impact on public health. Trend analysis (Fig. 3) includes comparison of the monthly varied mean value of PM2.5 data with the corresponding meteorological data to ascertain whether the direction of change in data correlates positively or negatively. Wind rose plots are generated to qualitatively (graphically) characterize the wind speed and wind direction, and then utilize them to examine the potential wind factor that may contribute to PM2.5 concentration by transporting fine particles from the surrounding Brick Kiln fields.

3. DATA ANALYSIS AND MAJOR FINDINGS

Fig. 2 shows the Box and Whisker plots (time series analysis) of PM2.5 concentrations. The figure shows that average (mean) yearly concentration of PM2.5 ranges between 70.63 µg/m3 in 2016 and 97.8 µg/m3 in 2019. The figure also reveals that the average annual concentrations of PM2.5 were consistently higher in all ten years (i.e., 2013-2022) than that of Bangladesh and international ambient air quality standard values (Table 1). This is a grave concern from the public health and environmental perspectives as the World Bank (WB, 2020, 2022) found that the estimated global health (mortality and morbidity) cost of PM2.5 in 2019 was $8.1 trillion, which is equivalent to 6.1 percent of global GDP (PPP). The same study also reported that the death rate associated with PM2.5 is significantly higher in low-and lower-middle income countries such as in Bangladesh than in high-income countries. Furthermore, the study indicated that the death tolls from the failure of maintaining ambient PM2.5 in Bangladesh in 2016 and 2019 were 109 thousands (12.8% of all death) and 169 thousands (20% of all death), respectively; and the death toll in 2019 was 55 percent higher than that of 2016 (WB, 2020, 2022).

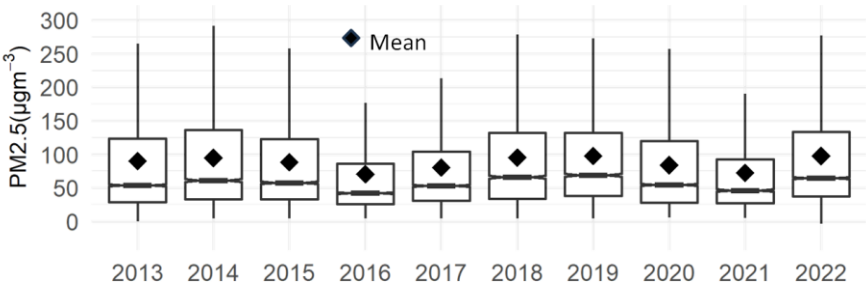


Figure 2: Box-whisker (time series) plots showing mean (yearly) values of PM2.5 concentration

Table 1: Ambient Air Quality Standards and World Health Organization guideline values for PM2.5 (Source: Baldwin and Calkins, 2007; Randall et. al., 2011; APCR 2022).

Averaging Period	Bangladesh Standards (Until June 2022)	Bangladesh Standards (Since July 2022)	WHO Guideline Values	US EPA Standards
	µg/m3			
Annual	15	35	10	15
24-hour	65	65	25	35

Figure 3 shows average monthly values of PM2.5 and meteorological data, while the same data are presented in Figure 4 as box-whisker plots. These two figures demonstrate that the data plots for PM2.5 follow fairly a concave shaped characteristic trend, while the data points for each and all of the meteorological parameters follow fairly convex shaped characteristic trends. Therefore, it can be qualitatively concluded that all three data associated with the meteorological parameters (temperature, precipitation and relative humidity) are inversely (negatively) correlated with the PM2.5 data.

To understand the seasonal influence on the concentration of PM2.5, seasonal analysis is performed. In Bangladesh, a period of consecutive 12 months (a year) may be divided into two or four seasons. The two seasons include Wet (May-October) and Dry (November-March) seasons (Chowdhury et al. 2023), while the four sessions include Winter (December-February), Pre-monsoon (March-May), Monsoon (June-September), and Post-monsoon (October-November) seasons (Begum et al, 2014). This study takes into consideration of two seasons considering that Dhaka experiences tropical /subtropical climate with wet season being hot and humid (characterized by frequent rainfalls, moderate to high wind speed, wetness of air and soil) and dry season being mild (characterized by low to moderate humidity, little to no rain, dryness of air and soil). As shown in Fig. 3, the mean values of PM2.5 concentration range approximately between 28.6 - 55 µg/m3 during the Wet season (May-October), while they range approximately between 94.5 -145 µg/m3 during the Dry season (Nov-March).

Taking into consideration of 24 hour averaging period, the Bangladesh national ambient air quality standard of 65 µg/m3 is compared with the monthly averaging values separately for two seasons and the findings are that PM2.5 concentration in each and all months under the Dry season exceed the national ambient air quality standards (Table 1) while PM2.5 concentration in none of the months under the Wet season exceed the national ambient air quality standards. Furthermore, the maximum concentration of PM2.5 is observed in January (Dry season) with a value of 145 µg/m3 and the minimum concentration is observed in July (Wet season) with a value of 20.6 µg/m3. The primary reason for reduced level of PM2.5 concentration during the Wet season over the Dry season is that the rainfall during the Wet season not only increases the humidity but also washes away fine particles or forces them to settle down on ground from time to time. Moreover, the Brick Kiln fields remain closed during the wet season.

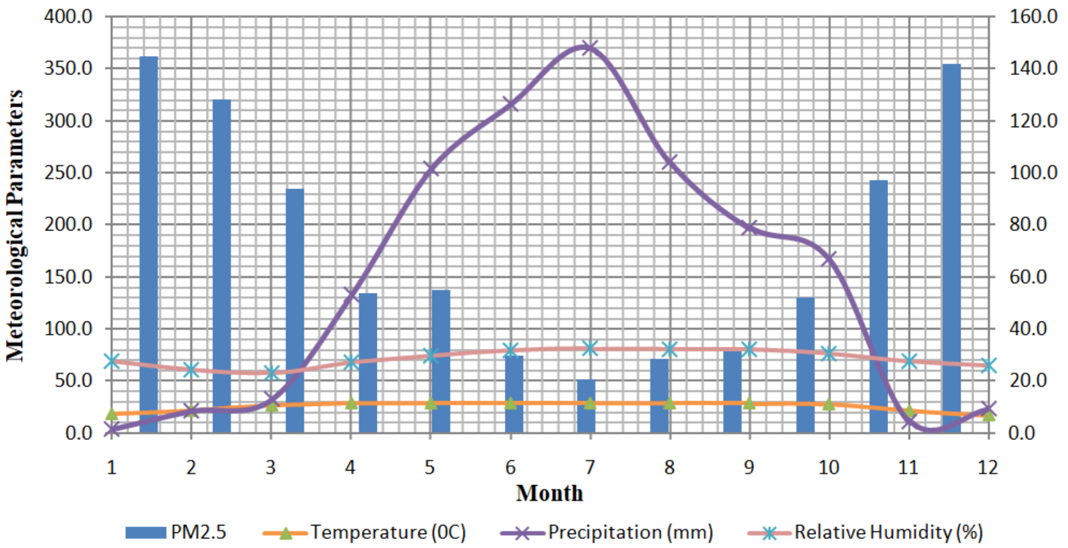
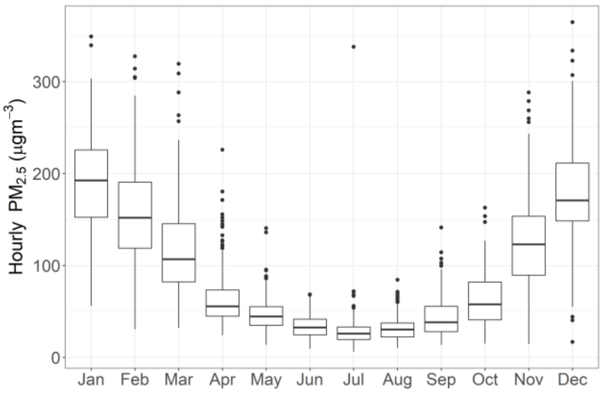
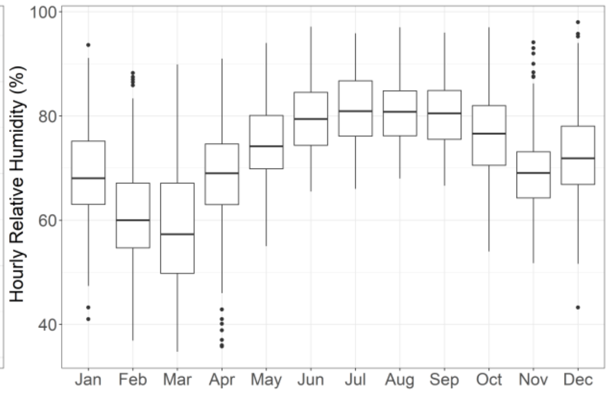


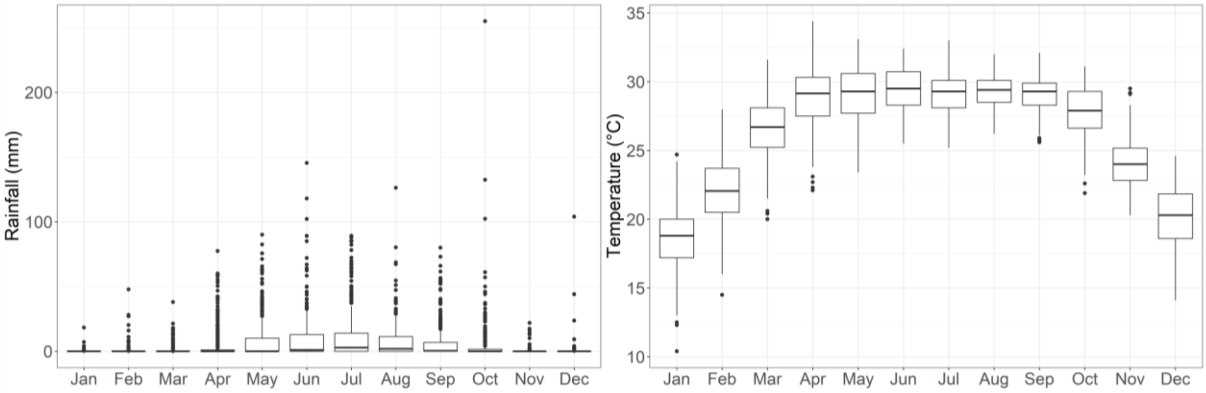
Figure 3: Average monthly values of PM2.5 (µg/m3) and meteorological data



(a)



(b)



(c) (d)

Figure 4: Box-whisker plots of monthly values of PM2.5 (μg/m3) and meteorological data

Further analysis of the concentration of PM2.5 in January and July reveals that not only the monthly average values but also the daily average values (most of the days in a 31 day month) exceed the national ambient air quality standard value of 65 μg/m3 in January (Fig. 5) and the opposite becomes true in July (Fig. 6).

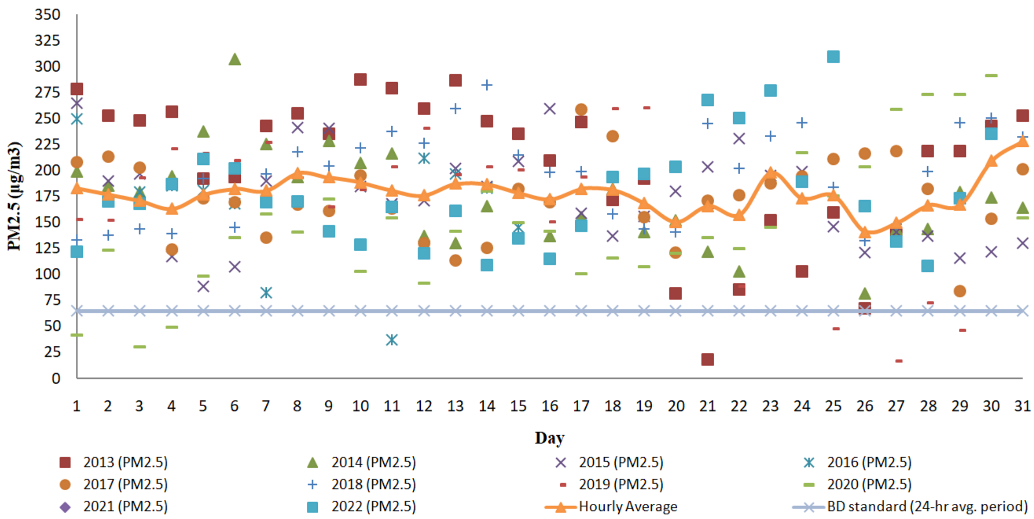


Figure 5: Daily values of average concentration of PM2.5 (μg/m3) in January (2013-2022)

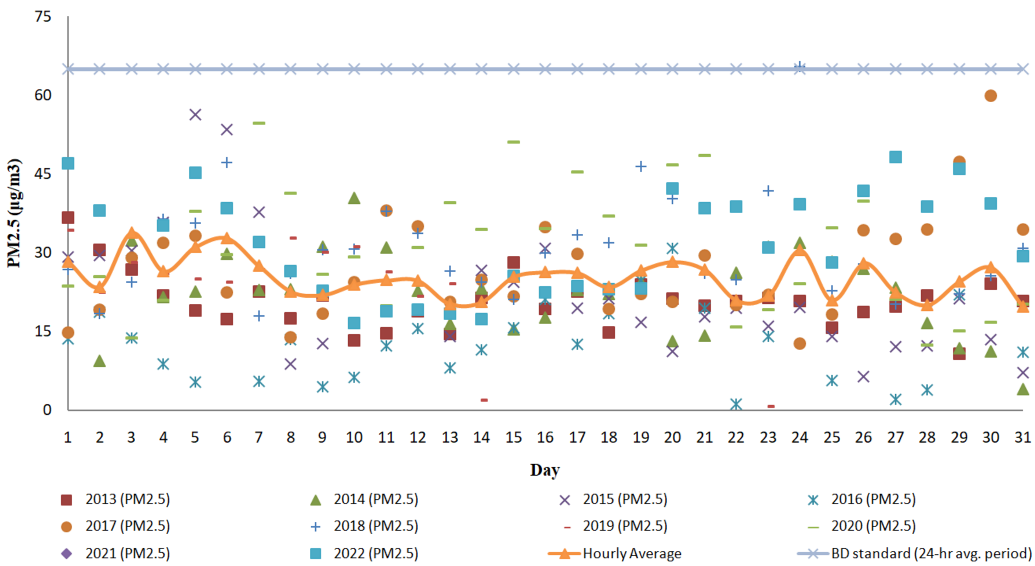


Figure 6: Daily values of average concentration of PM2.5 (µg/m3) in July (2013-2022)

As mentioned previously, the maximum concentration of PM2.5 is observed in January (Dry season) with a value of 145 µg/m3 and the minimum concentration is observed in July (Wet season) with a value of 20.6 µg/m3. We further examine whether the wind speed and wind direction have any likely influence on the concentration of PM2.5 in the air of Dhaka. Observing/Analyzing the wind rose plots (i.e., wind speed and wind direction) of January and July (Figure 7) and the locations map of Brick Kiln fields (Figure 1) the followings are observed: (a) a large number of Brick Kiln fields are located around Dhaka city and a good number of them (in the west and north-west directions) are located at a close distance from the CAMS-3 site; (b) the wind blows primarily from the north-west direction in January with a maximum speed of 2 to 4 m/s and from the southern direction in July with a maximum speed of 4 to 6 m/s. Given that the Brick Kilns are active mostly in dry season, Brick Kiln could be an additional factor that contributes in increasing the concentration of PM2.5 in the air of Dhaka in January (i.e., in dry season). It is to mention here that other sources contribute to PM2.5 in the air of Dhaka as reviewed in Sec. 1.2 are not explicitly investigated in this study.

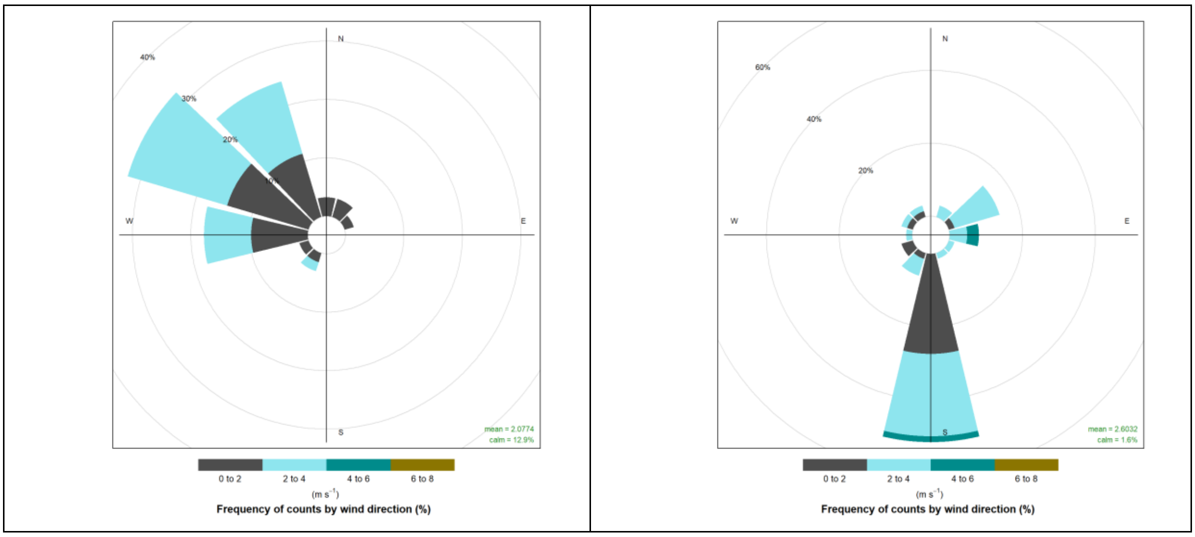


Figure 7: The wind rose plots (January (left) and July (right))

4. CONCLUSIONS

This study examines the state of PM2.5 concentration in the air of Dhaka and its likely effects on human health based on monthly, seasonally and yearly varied decadal data (2013-2022) from the continuous air monitoring station (i.e., CAMS #3-Darus-salam). It is found that PM2.5 (annual averaging values) has been remained in the air at a very high concentration throughout the ten-year (2013-2022) analysis period causing serious public health hazard and premature deaths. Monthly analysis (i.e., January and July) of data reveals that the averaging 24-hr PM2.5 concentration reaches at its maximum value of 145 µg/m3 in January (Dry season) and at its minimum value of 20.6 µg/m3 in July (Wet season). Regarding the influence of meteorological parameters on PM2.5, it is found that all three parameter values (i.e. temperature, relative humidity, and precipitation) are inversely (negatively) correlated with the PM2.5 values, and the meteorological factors including the wind effect (i.e., potential for transporting of PM2.5 from nearby Brick Kilns) may play significant roles in the increment of PM2.5 concentration during the Dry season.

The findings of this study indicate that the existing policies and strategies are substantially inadequate to control/maintain the national ambient air quality standards for PM2.5 in Dhaka city and may induce policy makers to reflect on the past policies and learn the lessons from earlier mistakes. It is recommended that the government re-examines the existing policies and develop/redevelop more effective policies and strategies to control and maintain PM2.5 concentration in the air of Dhaka to ensure sustainable development and healthy living for the city dwellers. Furthermore, public awareness on the danger of prevailing PM2.5 concentration as well as civic responsibility in reducing the PM2.5 concentration is also needed.

AUTHOR CONTRIBUTIONS

The first author (Md. Shoaib Chowdhury) has planned, conceived (scope, objective, & methodology), & prepared/written the manuscript. The co-author has prepared numerous figures under the guidance/ direction of first author.

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