

Time Series Analysis PM_{2.5} Concentration for Capital City Dhaka from 2016 to 2023

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Abstract: Dhaka, as the epicenter of economic, political, and cultural activity, has been actively pursuing urbanization, modernization, and development in line with global trends. The rise in unplanned urbanization, industrialization, and other human activities have led to an escalation in air pollution levels. The quality of air in Dhaka is progressively declining over time. It has become a significant challenge due to its detrimental effects on both human health and the environment. The objectives of the study to analyze the air quality in Dhaka city over eight years, from 2016 to 2023 and to assess the relation between concentration of PM_{2.5} and meteorological characteristics in Dhaka city. AQI and PM_{2.5} data has been collected from the website of U.S. Embassy Dhaka and meteorological data from the Bangladesh Meteorological Department (BMD). Data processing and analysis have been conducted by using SPSS and Microsoft Excel. Annual variations indicated that 2023 experienced the highest air pollution levels with an average PM_{2.5} concentration of 103.67 µg/m³ which is 2.96 times higher than the national ambient air quality standards level. Furthermore, shifting variation analysis demonstrated that air quality deteriorated in the night to morning, reaching an unhealthy level, largely attributed to heavy traffic. Along with that seasonal variations illustrate that winter had the highest PM_{2.5} levels where monsoon had lower, linked to factors like biomass burning and reduced rainfall. This variance is due to the interaction of a number of different meteorological phenomena. Moreover, Weekly variations showed Thursday to have the highest air pollution. The percentage of "Good" days is very poor and with that "Unhealthy" and "Very Unhealthy" AQI categories significantly increased, posing a serious threat to public health. To address this, a range of short, mid, and long-term strategies are recommended, including improved public awareness, sustainable constructions and transportation options, and stricter environmental regulations.

Keywords: Air Quality Index (AQI), Public Health, Meteorological Influence, PM_{2.5} Concentration, Time Series Analysis

1. Introduction

The Poor air quality is an increasing issue worldwide, with pollutants emerging as a major contributor to its adverse effects on the well-being of people and the environment [1, 20]. It is a major concern amongst pollution factors of Bangladesh, especially its capital, Dhaka City. Dhaka is also as a matter of fact, the 9th largest city of the world and bears 14.4 million people [2] The Dhaka city is in the center of the

geological position of Bangladesh. Among several other reasons including the city being the economic hub of Bangladesh, actively leads the way to alarmingly increasing air pollution levels [3]. According to the World Air Quality Report 2022, Dhaka City ranked as the fifth most polluted city in the world, with an average PM_{2.5} concentration of 65.8 µg/m³. PM_{2.5} refers to fine particulate matter that can penetrate deep into the lungs and cause respiratory problems such as coughing, wheezing, shortness of breath, and asthma [4]. Long-term exposure to certain air pollutants, such as

particulate matter, has been linked to an increased risk of lung cancer [5, 14]. Even exposure to air pollution during pregnancy can increase the risk of premature birth, low birth weight, and developmental problems in infants [6]. Air pollution is also a major contributor to climate change, as it traps greenhouse gases such as carbon dioxide and methane into the atmosphere [7]. The main sources of air pollution in Dhaka City include vehicular emissions, industrial emissions, construction activities, mega development project work, brick kilns, and open burning of waste. Brick-kiln emission is a mentionable perturb to the environment and air quality of South-East Asian countries, its affects majorly targeting the larger cities. Dhaka being Bangladesh’s cradle for heightening levels of urbanization, it is responsible for air contamination caused by 1230 brick-kilns [8]. Gradually increasing air pollution well-knowingly threatens human health. Just like growing population contributes to it, the affects in return harm the population. Out of 92000 early deaths resulted from exposure to contaminated air in Bangladesh, 13100 of the deceased population are from Dhaka City alone [9]. Other sources of PM apart from the previously discussed issues are sorption from grimy, unpaved streets, and refuse burning and destruction by slum dwellers. Two of the majorly concerning pollutants here are lead and particulate matters. However, the government has had effective roles in addressing the mentionable contributions from two-stroke, three-wheel vehicles, commonly known as baby taxies when it comes to the emanation of particulate matters [10]. It is crucial to know the probable sources of air contamination and their robustness so that both effective and efficient measures can be taken for the betterment of air quality. Local community-based initiatives can technically manage the communal sources; nevertheless, transboundary and regional concerns would essentialize intergovernmental interventions. Gaseous pollutants are comparatively less severe contaminants than particulate matters in the case of Bangladesh [11]. On this emerge, the air quality of Dhaka city during last eight years studied. The data was collected from US embassy air monitoring site. For this study from 2016 to 2023 years data was collected weekly, annually and yearly based. The two major objectives of this study are to find out the temporal variation of AQI and PM_{2.5} concentration in Dhaka city from 2016 to 2023 and to assess the relation between concentration of PM_{2.5} and meteorological characteristics in Dhaka city.

2. Methods

For this study literature review has been done, PM_{2.5} data were collected from January 1, 2016 to December 31, 2023, of

Dhaka city to investigate the relationship between temporal variation of AQI of PM_{2.5} and meteorological characteristics. World’s Air Pollution: Real-time Air Quality Index Project (www.aqicn.org), which is a publicly available air quality data, provided daily AQI based on 24 hours average on the hourly reading for PM_{2.5}. Ground based PM_{2.5} monitoring station, situated near/at the US embassies and consulates of each of the country, records these data. AQI and PM_{2.5} data collected from website of U.S. Embassy in Bangladesh (Dhaka) and meteorological data from the Bangladesh Meteorological Department (BMD). After that SPSSv20 and Microsoft Excelv10 were used for data processing, analysis and preparing tables and graphs.

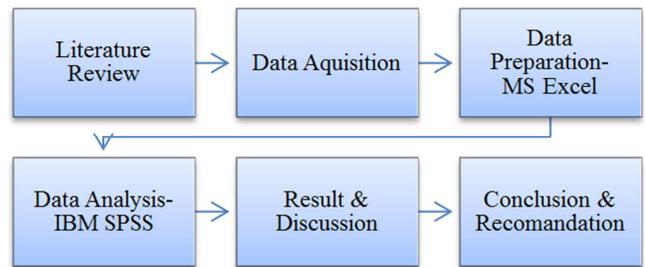


Figure 1. Methodology Flow Diagram.

AQI is used as a daily reporting of air quality. It measures how clean or polluted the air is and the health impacts related to it [16, 17]. A certain segment of population, who might be sensitive to excess level of pollution, could be guided earlier by the help of AQI. AQI standards have been established by USEPA to express how polluted the present air is or how much polluted it can get the U.S. Environmental Protection Agency’s (EPA) AQI system was used to determine the AQI in this study (Table 1). Based on population density and exposure, each country consists of its own national AQI [26]. Moreover, the following equation was used to establish the daily (24 hours) PM_{2.5} based AQI [13].

$$I_P = \frac{(I_{HI} - I_{LO})}{(BP_{HI} - BP_{LO})} (C_P - BP_{LO}) + I_{LO}$$

- Where, IP = Index value for PM_{2.5}
- C_P = Rounded concentration of PM_{2.5}
- BP_{HI} = Higher breakpoint value of CP
- BP_{LO} = Lower breakpoint value of CP
- I_{HI} = Index breakpoint value of BP_{HI}
- I_{LO} = Index breakpoint value of BP_{LO}

The breakpoints for PM_{2.5} concentrations along with the ranges of PM_{2.5}-AQI category are stated.

Table 1. Air Quality Index (AQI) Basics.

Levels of Concern	Values of Index Value	Description of Air Quality
Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected
Unhealthy	151 to 200	Some members of the general public may experience health effects; members of

Levels of Concern	Values of Index Value	Description of Air Quality
Very Unhealthy	201 to 300	sensitive groups may experience more serious health effects. Health alert: The risk of health effects is increased for everyone.
Hazardous	301 to 500	Health warning of emergency conditions: everyone is more likely to be affected.

*Source: www.airnow.gov

3. Result & Discussion

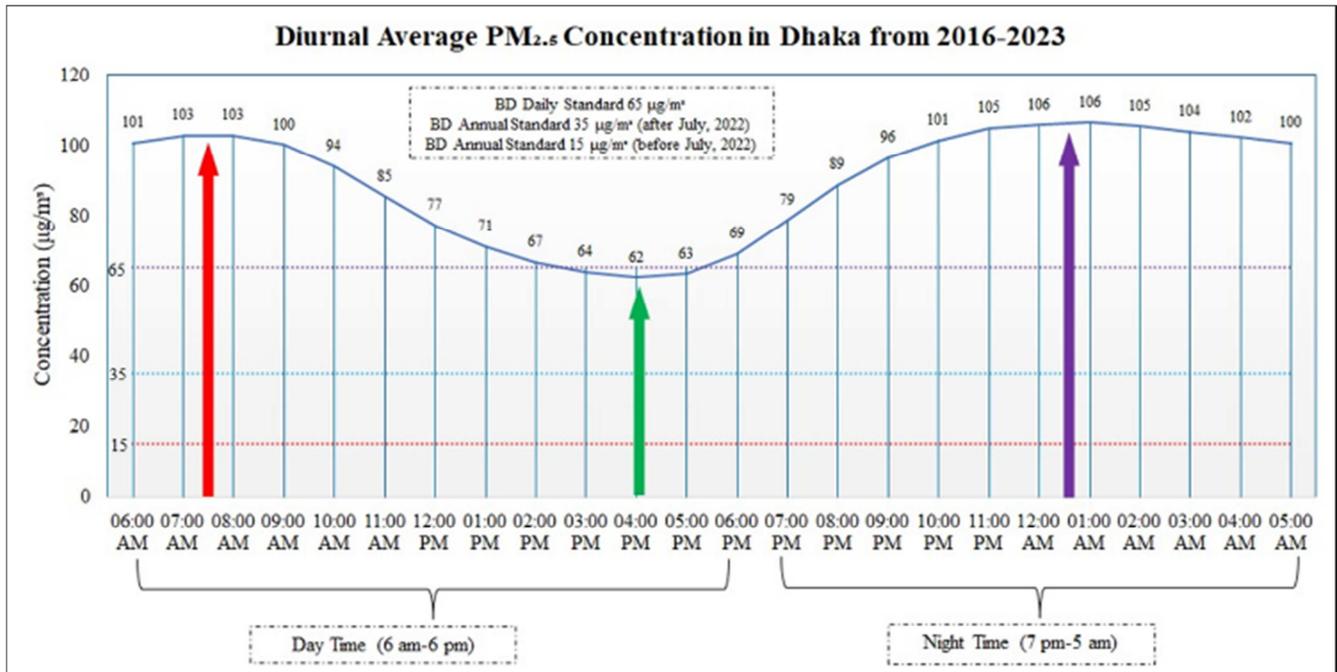


Figure 2. Diurnal Variation PM_{2.5} Concentration in Dhaka from 2016 to 2023.

The figure 2 provides insights into the diurnal variation of PM_{2.5} concentration in Dhaka, Bangladesh over eight years period, from 2016 to 2023. PM_{2.5} concentrations reaches their peaks in the morning and night time where it drops at evening time. The transportation sector, particularly trucks and buses, is one of the main sources of PM_{2.5} emissions in Dhaka City [15]. The fact that trucks and long-distance buses are allowed to operate inside the city from 10 p.m. to 8 a.m. may be a major factor in the morning's greater PM_{2.5} concentrations than in the afternoon and evening. The table 2 provides insights into the shifting variation of PM_{2.5} concentration in Dhaka, In the night time (8pm to 6am), PM_{2.5} concentration reached peak ($119.6 \pm 84 \mu\text{g}/\text{m}^3$), which is almost 2 times higher than the Bangladesh daily air quality standard of $65 \mu\text{g}/\text{m}^3$. During the morning time (6am to 12pm), the concentration found similar which ($99.3 \pm 84.0 \mu\text{g}/\text{m}^3$), also exceed the standard level. The lowest concentration was observed in the afternoon, which was ($67.3 \pm 51.1 \mu\text{g}/\text{m}^3$).

Table 2. Shifting Variation of PM_{2.5} concentration in Dhaka from 2016-2023.

Shift	Duration (GMT +6, Local time)	PM _{2.5} (µg/m ³)
Morning	06:01am – 12:00pm	99.3 ±84.0
Afternoon	12:01pm – 06:00pm	67.3±51.1
Evening	06:01pm – 08:00pm	87.7±66.0
Night	08:01pm – 06:00am	119.6±88.9

The figure 3 illustrates the weekly average PM_{2.5}

concentrations over eight years period, from 2016-2023 in Dhaka City. The findings indicate that both average PM_{2.5} concentrations were higher on Thursday ($91.97 \mu\text{g}/\text{m}^3$), Wednesday ($91.38 \mu\text{g}/\text{m}^3$), Tuesday ($91.19 \mu\text{g}/\text{m}^3$) and lowest on Saturday ($86.3 \mu\text{g}/\text{m}^3$). The average PM_{2.5} concentrations in all the days exceeded the Bangladesh daily standard of $65 \mu\text{g}/\text{m}^3$. The weekly average concentration about 1.38 times higher than daily standard. However, the concentration of PM_{2.5} found in Saturday also exceed the national limit. PM_{2.5} concentrations were found to be maximum on Wednesday and lowest on Saturday. It is expected that local transport services could be reduced on weekends (Friday and Saturday) which could be attributed to low air pollution on Saturday [13]. However, on Thursday there are several factors that can contribute to the highest air pollution compared to other days of the week. The air pollution sources such as vehicle emissions, industrial activities and manufacturing processes, construction works that continue operating throughout the week results in greater pollutant loads in the atmosphere on Thursdays which contributes to highest air pollution on Thursday in Dhaka City. Besides that, due to public holiday on Saturday, the adverse impact on the environment is reduced to a large extent as people's outdoor movement and subsistence activities are reduced. For instance, with less private and public transport, the pollutants emitted by vehicles are dramatically reduced. Although the concentration of

particulate matters on the air due to public holidays (Friday) is not as expected, the amount is the same as other recorded days. The main reason behind which is that people go out to spend

time with their families to get relief from the exhausted days of week.

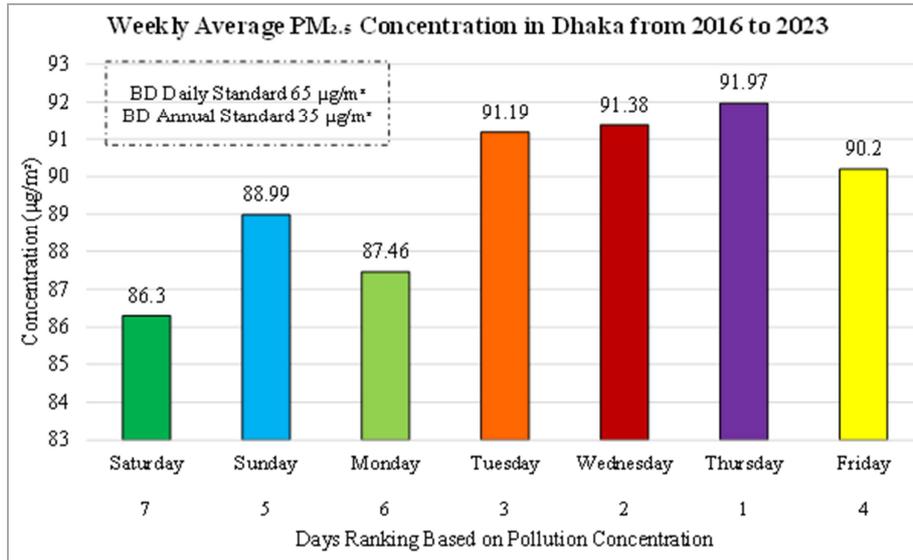


Figure 3. Weekly Variation of PM_{2.5} Concentration in Dhaka from 2016 to 2023.

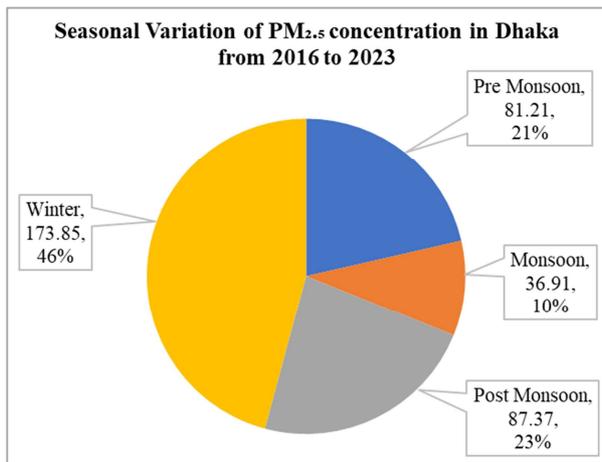


Figure 4. Seasonal Variation of PM_{2.5} concentration in Dhaka from 2016 to 2023.

In The figure 4 demonstrates the seasonal variation of PM_{2.5} concentration in Dhaka over eight years period, from 2016-2023. PM_{2.5} concentrations showed similar trend in descending order: Winter > Post-Monsoon > Pre-Monsoon > Monsoon. The PM_{2.5} concentrations in all seasons exceeded the Bangladesh annual standard of 35 µg/m³. In winter the concentrations were found almost 5 times higher than national annual standard which is 173.85 µg/m³. The average concentration of PM_{2.5} is 87.37 µg/m³ which is almost 2.49 times higher than the annual standard level. Pie chart depicts winter season has the largest concentration, reaching 46% (173.85), whilst the monsoon season has the lowest concentration at 10% (36.91). The concentration during the pre-monsoon period is 21% (81.21), whereas during the post-monsoon period it is 23% (87.37). The results indicate

poor air quality during the winter season. This pollution in winter is caused for a variety of reasons. Less vegetation cover, drier water bodies, greater biomass burning to warm up the body, use of heaters, a lack of rainfall, and leaf burning are the main contributing factors [18]. On the other side, winter is the time of year when crops are harvested, processed for sale, and the trash was burned [22]. Brick fields also continued their operation during winter season. During monsoon, enough rainfall expands the water body and dilutes air pollution. Less use of heaters, fewer activities involving burning crop waste, less biomass burning, more vegetation cover, warmer air mass etc. are some of the common causes of decreased PM_{2.5} concentrations during the monsoon season [24]. Particulate matter, which consists of soil and road dust, absorbs water vapor from the atmosphere and easily get deposited on the ground, reducing pollutant from the atmosphere and AQI as well [23].

The figure 5 illustrates correlation between PM_{2.5} and precipitation in Dhaka from 2016-2023. Both the average PM_{2.5} concentrations in January from 2016 to 2023 were found to be the highest compared to other months. The average PM_{2.5} concentration in January (196.74 µg/m³) was almost three times higher than the Bangladesh daily standard and five times higher than the Bangladesh annual standard. Moreover, according to monthly variation higher concentration found January, February and December. However, July and August were identified as months with relatively good concentrations with average level of 31.23 and 36.24 respectively. The average PM_{2.5} concentrations in July and August were found to be within the Bangladesh daily (65 µg/m³) and annual (35 µg/m³) standard. Data from 8 years shows that apart from January, the average PM_{2.5} concentrations in November, December, February and March

were comparatively higher than other months. Results indicate that from November to March months air pollution is comparatively higher. The main reason behind this is the colder winter season during November-February, which leads to higher concentrations of pollutants due to increased heating activities and reduced dispersion. The phenomenon of temperature inversion during the winter exacerbates the accumulation of pollutants. The burning of solid fuels, especially during the winter season, contributes to the high levels of particulate matter in the air [18]. Factors such as lower temperatures and humidity also contribute to the persistence of pollutants during this time. Brick fields also continue their operation during winter season. Some individuals resort to use biomass for heating purposes, which

further adds to the air pollution in Dhaka. On the other hand, during monsoon (June-August), the reduction in biomass burning and increased amount of rainfall contributes to the improvement in air quality [24]. May to September where the average rainfall in Bangladesh is recorded above 300 mm and results in Particulate Matter deposits. It has been observed that there exists a robust and statistically significant negative relationship between rainfall and the concentration of PM_{2.5}. Precipitation is always associated with the reduction in pollution level from the atmosphere especially during the monsoon [25]. While in the month of December to January average rainfall found below 30 mm, this is mostly in during winter when all the particles travel one place to another.

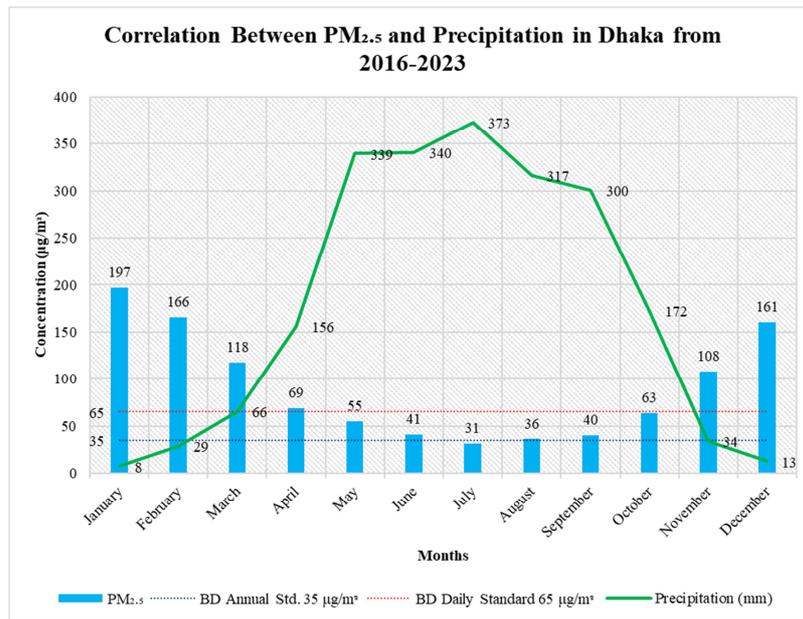


Figure 5. Correlation Between PM_{2.5} and Precipitation in Dhaka from 2016-2023.

The figure 6 demonstrates annual average PM_{2.5} concentrations in Dhaka over eight years period, from 2016-2023. The annual average concentration of PM_{2.5} in Dhaka sharply increased in the year of 2016 to 2018. In 2019 concentration slightly decreased in the year of 2019 and 2020. Again, the concentration fluctuated in the next 3 years where in 2023 the density was at the peak with a number of 103.67. The research findings illustrate that the years 2023 observed the highest pollution levels. The average concentration was 103.67. After that, The higher concentrations of PM_{2.5} were also observed in the years 2018, 2021 and 2022, reaching to an average of 99.44 µg/m³, 98.99 µg/m³, and 95.96 µg/m³ respectively. On the other hand, the lowest average PM_{2.5} concentrations were recorded in the years 2016 and 2017, which were 67.79 µg/m³ and 79.94 µg/m³, respectively. In 2020, due to the lockdown measures, there was a decrease in air pollution sources, resulting in lower PM_{2.5} concentrations compared to 2018-2019. After 2020, PM_{2.5} concentrations began to increase again indicating increased air pollution after the lockdown. During the lockdown, reduction of transport activities, closure of offices, schools, and all types

of industrial activities contributed to a large extent to the decline in the emissions of air pollutants in Dhaka City resulting in lower [21]. However, the overall trend shows that over the years from 2016 to 2023, the air quality in Dhaka city has been consistently poor.

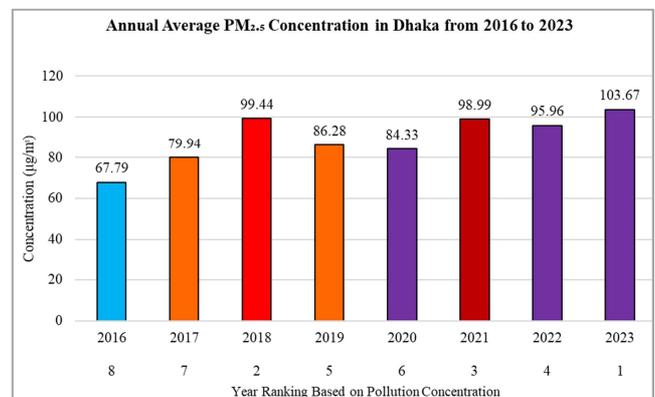


Figure 6. Annual Variation of PM_{2.5} concentrations in Dhaka from 2016-2023.

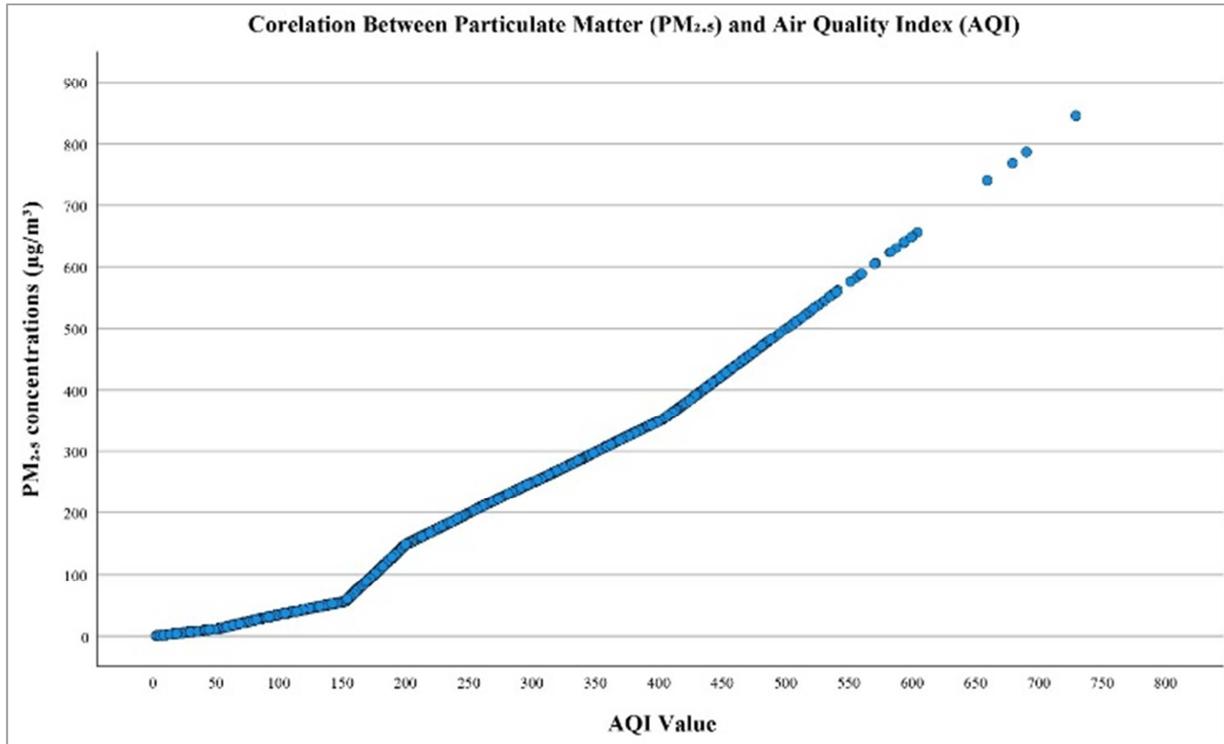


Figure 7. Correlation between Particulate Matter (PM_{2.5}) and Air Quality Index (AQI).

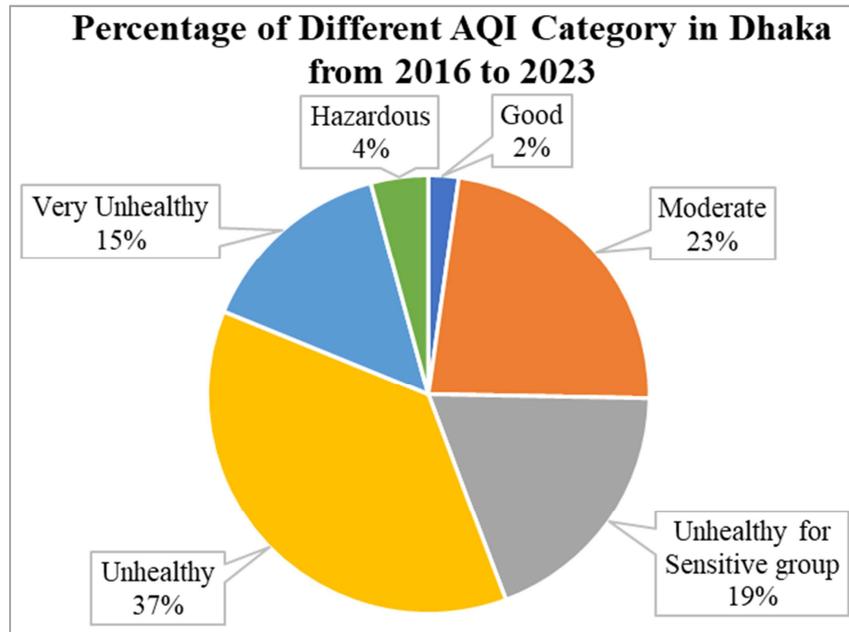


Figure 8. Percentage of Different AQI Category in Dhaka from 2016-2023.

Figure 7 shows the strong correlation between AQI and PM_{2.5} concentrations. It can be seen that when the PM_{2.5} concentrations increased AQI also increased. Again PM_{2.5} concentrations decreased AQI also decreased. Figure 8 (the pie chart) above shows the percentage of different AQI categories over an eight years period (hourly data) from 2016-2023 in Dhaka City. Based on the research findings, it can be observed that in the last 8 years, the people of Dhaka received good air only 2% of the time. However, 23% of the

time receives moderate air, 19% of the time sensitive air, 37% of the time unhealthy, 15% of the time very unhealthy, and 4% of the time hazardous air.

4. Conclusions

The capital of Bangladesh, Dhaka (Latitude: N23°43'40"; Longitude: E90°23'52") is one of the biggest and lead growing cities of south Asia [20]. Moreover, meteorological factors,

along with seasonal influence also contribute to the enhancement of PM_{2.5} concentration, leading to higher AQI [23]. It is found that PM_{2.5} concentration and AQI being more during winter, and the least during monsoon. Between the year, annual average PM_{2.5} concentration in Dhaka city arrange in descending order the years are as followed in 2023 (103.67 µg/m³) > 2018 (99.44 µg/m³) > 2021 (98.99 µg/m³) > 2022 (95.96 µg/m³) > 2019 (86.28 µg/m³) > 2020 (84.33 µg/m³) > 2017 (79.94 µg/m³) > 2016 (67.79 µg/m³). The highest weekly average PM_{2.5} concentration found in Thursday which was 89.65 µg/m³. The weekly average concentration about 1.38 times higher than daily standard. However, the concentration of PM_{2.5} found in Saturday also exceed the national limit. The diurnal average PM_{2.5} concentration in Dhaka city rises after 6:00 pm and gradually decreases after 7:00 am. From this period of years, the highest PM_{2.5} concentration found in the night time around 1:00 am. Due to this constant worsening of air quality, it has become a crucial issue because of the threat it is to human health and the environment [4, 12]. Dhaka City Corporation has a good number of waters sprinkling vehicles which was used to wash the roads to reduce the dust particles in Dhaka city temporarily. We must safeguard trucks transporting sand, soil, or building materials in the capital city by covering the materials. Fitness less vehicles contribute significantly to total air pollution in Dhaka. As a result, strict control of expired and less fit vehicles, as well as seizing vehicles emitting black smoke, could be a useful reduction strategy. The government should take action to shut down all illegal kilns that are not licensed. Instead of Fixed Chimney Kilns, cleaner brick-making technologies such as Vertical Shaft Brick Kilns (VSBKs) and Hybrid Hoffmann Kilns (HHKs) should be introduced (FCKs). Furthermore, massive tire-burning and Used Lead Acid Batteries (ULAB) factories in Dhaka city make Dhaka the worst. As a result, that should also cease to reduce pollution levels. Waste burning must be avoided at the city corporation dumping station as well as on the street sides. To reduce waste volume, both Dhaka North and South city corporations must discontinue open waste burring. Improved cooking stoves and quality fuel in slum areas would eventually contribute to improved air quality in urban areas. The number of Continuous Air Monitoring Stations (CAMS) in urban and semi-urban areas should be increased. CAMS data must be disseminated to the public on a regular basis via a website [19]. Furthermore, the Department of Environment should implement an AQI forecasting and warning system (DoE). Proper tree planting and encouraging rooftop gardening in urban areas may aid in improving air quality. Furthermore, the number of bodies of surface water should be increased. There has been a noticeable improvement in air quality in areas with more greenery and water bodies.

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Conflicts of Interest

The authors declare no conflicts of interest.

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