Atmospheric Particulate Matter in Bangladesh: Sources, Meteorological Factors and Management Approaches

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1 Introduction

Atmospheric particulate matter (PM) is described as a complex mixture of diverse sizes and chemical compositions of airborne particulates (Hou et al., 2019). PM is not a single quantity, as are the other criteria pollutants, but rather a mixture of solid particulates and liquid droplets that can be inhaled. PM particulate sizes are primarily divided into two categories: finer particulates with an aerodynamic diameter of less than 2.5 micrometers and coarser particulates with an aerodynamic diameter of less than 10 micrometers. They are classified as primary or secondary particulates based on their origin. Vehicles, cooking, forest fires, and other burning activities all emit primary particulates into the atmosphere. Secondary particulates are formed in the air as a result of atmospheric chemical reactions, such as sulfates produced by the oxidation of sulfur dioxide (USEPA, 2018).

Air quality in different cities has deteriorated in parallel with uncontrolled infrastructure development, rapid economic growth, industrialization, and automobile emissions (Hien et al., 2022; Zhao et al., 2020). Bangladesh, like other countries, has experienced severe air pollution throughout the year, particularly during winter, when particulate matter (PM) levels surpass standards by up to 2.5 times (Islam

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et al., 2015; Rouf et al., 2021). The principal sources of PM are anthropogenic activities, which have become a substantial hazard to Dhaka's public health (Rouf et al., 2021). Throughout the winter season, Dhaka becomes one of the world's most polluted cities in terms of air quality, according to the Air Quality Index (IQAir, 2021). In Dhaka, $PM_{2.5}$ (which comprises 30–50% of PM_{10}) is the criterion air pollutant that requires immediate attention if overall air quality is to be addressed (Begum et al., 2014).

Meteorological factors (wind, temperature, precipitation, surface pressure, relative humidity, solar radiation, and various other weather components) have been found to have a significant impact on particulate matter variance (Islam et al., 2022). PM accumulation, clearance effectiveness, and chemical production are all heavily influenced by weather conditions.

Wind speed and direction, ambient surface temperature, boundary layer height, rainfall rate and duration, solar radiation, relative humidity, and other factors can all contribute to an increase or decrease in PM concentration in the air (Asimakopoulos et al., 2022; Islam et al., 2015; Leung et al., 2018; Li et al., 2019; Trivedi et al., 2018). Studying the link between PM and meteorological characteristics is crucial for understanding overall air quality since meteorological variables can influence PM variation. Meteorological parameters may influence particulate matter concentration in Dhaka and other urban areas in Bangladesh, but the extent to which these parameters affect air quality is unknown (Islam et al., 2015). The concentration of particulate matter displays different seasonal trends all over the world. As a result, statistical time series analysis on a seasonal scale may be appropriate for understanding the trends and influences of PM and meteorology. Moreover, the Bangladesh government should investigate the root causes of air pollution in all the city municipalities as the High Court Bench of the Bangladesh Supreme Court asked the relevant agencies to identify the sources of air pollution on November 27, 2019.

2 National Ambient Air Quality Standards

Standards of the six criterion pollutants (important air pollutants with a significant impact on health for which health-based recommendations have been set) such as carbon monoxide, lead, nitrogen oxide (NOx), particulate matter (PM_{10}, $PM_{2.5}$), ozone, and sulfur dioxide) are listed below (Table 1). Standards for these pollutants were established by Bangladesh Environment Conservation Rules (ECR), 1997, which were later revised in 2005 (Hossen and Hoque, 2016).

Bangladesh government has started to use Air Quality Index value to report the daily air quality. This index was first developed by the USEPA (United States Environmental Protection Agency) and has been implemented by many countries. This index is comprised of a range of value 0–500 and the higher value indicates greater public health concern (Table 2).

Table 1 National Ambient Air Quality Standards (NAAQS) for Bangladesh

Pollutant	Limit Value	Averaging Period
CO	9 ppm (10 mgm^{-3})	8 hours
	35 ppm (40 mgm^{-3})	1 hour
Pb	0.5 μgm^{-3}	Annual
NO_x	100 μgm^{-3}	
PM_{10}	50 μgm^{-3} 150 μgm^{-3}	Annual 24 hours
$PM_{2.5}$	15 μgm^{-3} 65 μgm^{-3}	Annual 24 hours
O_3	235 μgm^{-3}	1 hour
	157 μgm^{-3}	8 hours
SO_2	80 μgm^{-3}	Annual
	365 μgm^{-3}	24 hours

Table 2 Air Quality Index (AQI) for Bangladesh

Air Quality Index	Category	Color
0–50	Good	Green
51–100	Moderate	Yellow Green
101–150	Caution	Yellow
151–200	Unhealthy	Orange
201–300	Very Unhealthy	Red
301–500	Extreme Unhealthy	Purple

3 Major Sources of Atmospheric Particulate Matter in Bangladesh

In Bangladesh, there are both manmade and natural sources of air particulate matter. Burning fossil fuels like coal and wood, open burning of trash or agricultural waste, emissions from cars, power plants, and other businesses, using biomass fuel for cooking, and transboundary particulate matter are all examples of anthropogenic causes. Natural sources of air pollution include forest fires, sea spray, and wind-borne dust. While human sources are increasingly broadly dispersed and outnumber natural ones, natural sources largely remain confined (WHO, 2018). For instance, a survey from 2014 in Dhaka revealed that surface dust, vehicle emissions, and brick kilns account for over 85% of the city's local air pollution (Nahar et al., 2021). Open landfills, the burning of plastic trash, and industrial activities are other sources of particulate matter (Nahar et al., 2021). Some of the major sources of atmospheric particulate matter have been explained in the following.

3.1 Brick Kilns

According to CASE (2018), there are 7902 brick kilns in the entire nation, with 1000–1200 of them located close to Dhaka. The rise in urbanization and industrial expansion has led to an increase in brick kilns. As a result, 58% of Dhaka's air pollution is caused by this (Begum et al., 2014). Bricks are burned using coal and wood in the kilns. According to the DOE (2019a), tons of PM, sulfur dioxide, carbon monoxide, volatile organic compounds, and other harmful chemicals including furans and dioxin are produced when 2.2 million tons of coal are burned. If natural gas were to take the place of coal and wood in the brick kiln industries, this emission might be significantly decreased (Begum and Hopke, 2018).

3.2 Motor Vehicles

According to the BRTA's number of registered vehicles, there were about 4.44 million motor vehicles in Bangladesh by 2020, up from 1.49 million in 2010. Most of these cars and trucks were refurbished or old and weren't properly maintained. Air pollution is caused by congested traffic, poor parking management, tainted fuels, overloading, and the dust that is produced when vehicles collide with the road (DOE, 2019a). Fine particulates produced by transportation-related sources account for 30–50% of the PM collected from various parts of Dhaka city (Begum et al., 2013), particularly diesel buses and trucks (45%) and auto rickshaws (40%) (DOE, 2019a). The majority of carbon monoxide (CO) is produced by gasoline-powered light-duty vehicles (cars/vans) and auto rickshaws, whereas the majority of nitrogen oxides (NO_x) is produced by diesel-powered buses and trucks (84%).

3.3 Road Digging and Construction Work

A recent study conducted by CAPS (Center for Atmospheric Pollution Study) concluded that road digging and construction works are responsible for 30% of air pollution in Dhaka. Road construction and repairing; ongoing modern communication development projects such as flyovers, expressways, and metro rail; transportation of sand and soil; and other construction materials in trucks, including construction of multistoried buildings are responsible for air pollution in urban areas of Bangladesh.

3.4 Power Plants

Bangladesh generates 80% of its electricity using gas, with the remaining 20% coming from coal, liquid, and furnace oil. According to Arnab et al. (2021), around 70% of sulfur dioxide (SO_2) and 30% of nitrogen oxides (NO_x) are produced when coal is used in electrical utilities. The Barapukuria thermal power plant is one hydraulic power plant with SO_2, NO_x, and PM emissions under permissible limits. When it comes to air pollutants, notably PM, during the dry season, road dust and soil dust from various power plant-related projects play a significant role (DOE, 2019a).

3.5 Transboundary Air Pollution

Bangladesh is bordered by the heavily polluted nation of India on three sides (Fig. 1). Transboundary pollutants generally come from North-Western India, West Bengal, Nepal, and the surrounding regions, and they travel 200–500 kilometers to Bangladesh. 40% of the air pollution in Bangladesh is caused by transboundary PM from India's coal burning (Sakib, 2021; Rana et al., 2016), particularly between November and January. In addition, during October and November, burning agricultural fields in India produces smoke plumes that almost completely cover the Indo-Gangetic Plain (IGP) from West to East, including Bangladesh (Singh and Kaskaoutis, 2014), and can even travel through the Himalayan foothills (Bonasoni et al., 2020).

4 Link Between Meteorological Parameters and Atmospheric Particulate Matter

It is crucial to look at the properties of PM and their dependencies on other factors since several researches have shown that PM concentration is linked to negative health effects and a subsequent decline in air quality (Rahman et al., 2022). Numerous researches have mainly focused on the wind, temperature, and other meteorological factors for the change of PM levels since atmospheric dispersion is primarily responsible for the accumulation of PM in air. In the subsections that follow, we'll go through how particulate matter depends on meteorological characteristics and how those parameters affect particulate matter.

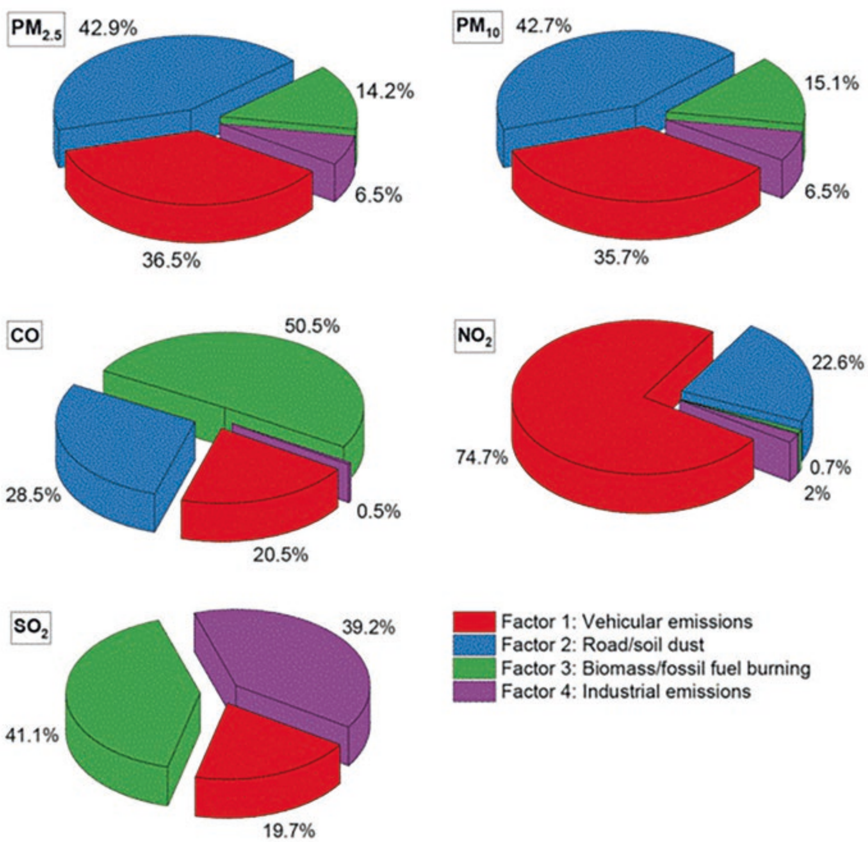

Fig. 1 Contribution of the major sources of air pollutants ($PM_{2.5}$, PM_{10}, CO, NO_2, and SO_2) in Bangladesh (Pavel et al., 2021)

4.1 Seasonal and Diurnal Variation

The seasonal and diurnal change of particulate matter in response to the variability of climatic conditions has been demonstrated by a good number of studies. Urban areas typically have the highest PM concentration in the winter and the lowest in the summer, whereas rural areas experience the highest PM concentration in the spring and the lowest in the winter. Peaks are caused by boundary layer height in urban areas during the winter and dust incidence in rural areas during the spring. Other research (Rahman et al., 2022; Kayes et al., 2019; Islam et al., 2022; Hoque et al., 2020; Hridoy et al., 2021) have found comparable seasonal variations in PM with greater concentrations in winter (December–March). Temporal trend of particulate matter in Dhaka city has been given in Fig. 2 which has been prepared based on six years of data (2013–2018). The lower PM concentrations in warmer months are

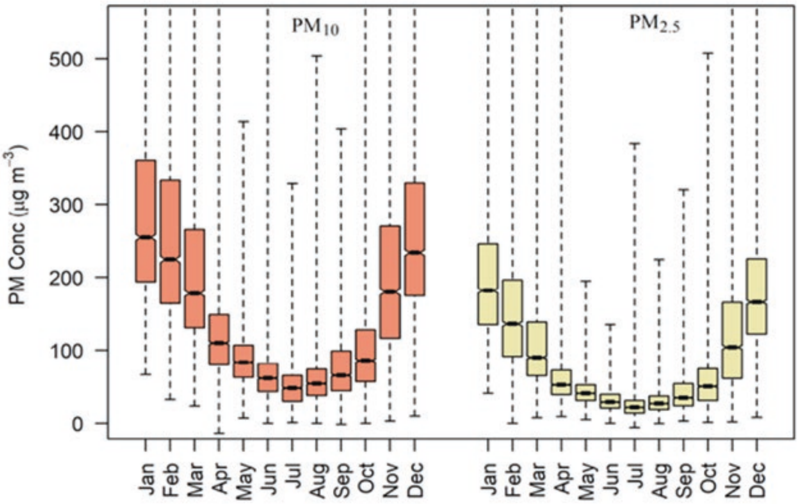

Fig. 2 Box-whisker plots of PM concentration in different months in Dhaka (Department of Environment, 2018)

linked to atmospheric dispersion due to increased wind speeds and wider mixing layer heights (Khan et al., 2016; Ferrero et al., 2010).

4.2 Temperature

Due to increased photochemical activity at higher temperatures, several studies found a positive relationship between temperature and particulate matter (Islam et al., 2022). According to several studies (Rahman et al., 2022; Hridoy et al., 2021; Hoque et al., 2020), the use of coal for space heating, increased household heating, and the production of stagnant air conditions in winter have all been linked to a negative association between PM and temperature. When the temperature regularly surpasses 29 °C and the humidity is high, high summer $PM_{2.5}$ levels are seen.

4.3 Rainfall

Precipitation reduces PM by scavenging (Kayes et al., 2019; Islam et al., 2022). It has been found to have a larger impact on PM_{10} than $PM_{2.5}$ (Islam et al., 2022). According to research, rainfall duration has a greater impact on PM concentration than rainfall volume (Rahman et al., 2022).

4.4 Wind Speed

Wind speed is the most important element in driving PM concentration, particularly at roadside locations (Hridoy et al., 2021; Hoque et al., 2020). Because of dilution, higher wind velocity lowers PM concentration. However, when a threshold value is exceeded, wind speed increases, showing that the diluting impact of wind speed is superseded at this point by the resuspension of road dust (Kayes et al., 2019; Islam et al., 2022). The buildup of $PM_{2.5}$ is shown to be positively influenced by low wind speed, but PM_{10} is influenced by high wind speed that exceeds a threshold due to long-distance transport (Hridoy et al., 2021). According to Cox and Chu (2016), calm winds are related to the highest $PM_{2.5}$ concentration.

4.5 Wind Direction

PM concentration is significantly influenced by both wind direction and speed. According to a number of studies (Begum et al., 2013, 2016; Islam et al., 2022) conducted in Bangladesh, the north-easterly wind in Bangladesh contributes to high PM concentration in the winter, which worsens the air quality.

4.6 Mixing Height

The majority of studies found bimodal diurnal fluctuation, with particulate matter concentration reaching its maximum peak in the morning. The morning's atmospheric stability circumstances (low wind speed and temperature inversion) produce a buildup of air particulates in the lower atmospheric layer that results in a foggy situation (Hridoy et al., 2021).

4.7 Relative Humidity

An indication of atmospheric moisture, such as relative humidity, should be considered when analyzing meteorological factors that impact particulate matter concentrations in atmosphere. According to the majority of research (Rahman et al., 2022; Hridoy et al., 2021), relative humidity continues to be positively linked with PM concentration (Table 3). High humidity levels have been linked to highest PM concentrations (Islam et al., 2022).

Table 3 Summarization of key meteorological factors that drive atmospheric particulate matter concentration and the rationality behind these mechanisms (Islam et al., 2022)

Parameters	Relation within particulate matter	Reasons behind such relation
Temperature	Positively related	High temperatures are conductive to chemical reactions in the atmosphere and cause the creation of SO_X at higher states.
	Negatively related	The creation of stagnant air conditions in the winter, increased space heating.
Rainfall	Negatively related	Moist deposition, scavenging effect.
Wind speed	Negatively related within $PM_{2.5}$	Ultrafine particulates are diluted by high wind speed, whereas ultrafine particulate formation is aided by low wind speed.
	Positively related with coarser particulate at wind speed >9 m/s	Road dust's resuspension imposes the dilution impact and long-range transport's contribution.
Boundary layer height	Negatively related	Greater dispersion is caused by higher mixing/ boundary layer heights.
Solar radiation	Positively related	Nitrate particulate generation, improved photochemical reaction, and secondary aerosol production.
Relative humidity	Positively related to sulfate and nitrate	High humidity speeds up the oxidation of SO_2 inside clouds and accelerates the creation of nitrates (ammonium).
	Inversely related to OC, EC	Reduced OC and EC production at high humidity, absorption of moisture, and subsequent particulate settling down.

5 Management Approaches to Mitigate Air Pollution

Two specific Sustainable Development Goals (SDG) 3 and SDG 11 must be addressed if we want to materialize the importance of air control management because both goals explicitly mention air pollution. These two SDGs are among the 17 Sustainable Development Goals (SDGs). In addition to mentioning the two SDGs, this problem also involves a number of drivers and associated sustainability consequences that link about 14 of the 17 SDGs of the UN (Khuda, 2020). These aims, targets, and indicators are linked to a number of causes, but the best way to ensure clean air is to use an integrated strategy to manage air quality. If not, the SDGs' vision would remain mostly unrealized and useless. The Bangladesh government and all municipal corporations might take into account the following approaches to lessen air pollution in Bangladesh.

- Since air pollution in Dhaka city often reaches dangerous levels between December and March and fluctuates depending on the season, an effective air control plan must be distinct from the government's other general management strategies.

- The key pollutants must be identified quickly for the development plan for air quality control. A solution for a certain region or place may be formed by identifying the pollutants and health risks brought on by poor air quality in that area or location.
- The rising amount of dust particulates, together with other air pollutants, is now posing a substantial health risk to the people living in Dhaka city, which is a major issue. For this reason, a cost-effective management system that incorporates control measures in light of lowering the sources of dust and waste points should be set up right away. Other significant source locations, such as building sites, brickfields, the whole Dhaka city transportation system, etc., should be taken into account in order to satisfy the SDG targets and indicators.
- The residents of a particular area can contribute significantly individually or collectively to the reduction of air pollution. By driving less and more carefully, utilizing fuel-efficient vehicles, public transportation, walking, cycling, and other methods, people may significantly reduce air pollution.
- However, the development of an integrated system is necessary to guarantee a better response in the control of municipal air quality. The Bangladesh government has some good policies and plans for managing air quality, but there aren't any good programs for implementation and monitoring. However, they are crucial not just for reducing air pollution but also for giving source point owners access to the data they want for continued system improvement and monitoring.
- Typically, Bangladeshi decision-makers operate the air control system in accordance with a traditional methodology. This system puts up a set of requirements for pollutants in the manufacturing sectors. This could be a success for the industrial sector alone, but the government can take it a step further by penalizing all polluters and offering incentives to stimulate the economy to reduce emissions.
- While there is now just a limited incentive system in place, it might be expanded to include a wide range of programs and activities, including tax incentives for reducing pollution, subsidies for waste treatment, rebate programs for trash disposal, etc.

6 The Role of the Government in Bangladesh Against Atmospheric Air Pollution

According to the government of Bangladesh's seventh five-year plan, urban $PM_{2.5}$ concentration was planned to reduce from 78 gm/m^3 in 2013 to 73 gm/m^3 in 2020 (Khandker et al., 2022). The government had put in place the Clean Air Program, Cleaner Fuel and Transport Standards, and Strict Brick Kiln Act 2013 enforcement to accomplish this aim.

6.1 Brick Kilns

The Brick Manufacturing and Kiln Construction (Control) Act 2013 changed conventional brick kilns into more energy-efficient ones in order to minimize air pollution, particularly particulate matter (PM), in urban air (DOE, 2019a). Improved Zigzag Kilns (IZKs) can replace Fixed Chimney Kilns (FCK) by burning less coal and emitting less particulate matter, and water scrubber systems can absorb particulate matter to cut emissions. The infrastructure Development Company Limited (IDCOL), the DOE, World Bank, Asian Development Bank (ADB), and other donor organizations have provided financial and technical assistance for this initiative. Additionally, it supports initiatives for solar energy, biogas, home energy, and rural electrification (ESMAP, 2019).

6.2 Motor Vehicles and Fuels

The 2011 motor vehicle legislation regulating car emissions regulations was published by the government of Bangladesh. At roadside checkpoints, vehicles are put through testing to reduce vehicle emissions (DOE, 2019b). In addition, the government decreased import taxes for modern automobiles and prohibited the entry of vehicles older than five years. In order to match the Euro 3 standard, the 1977 car emissions standard was improved in 2005 and again in 2014. The Chittagong oil refinery was updated to reduce the sulfur level in the oil to below 500 ppm, which is important for fuels. Compressed natural gas (CNG) was substituted for gasoline, lowering the amount of sulfur in the air (DOE, 2019b), which improved the air quality in Dhaka.

The government of Bangladesh has implemented "The Air Pollution Rules 2022 under section 20 of the Bangladesh Conservation Act, 1995 to improve the air quality status of Bangladesh."

6.3 Industry

Industries and projects are divided into four classifications for environmental clearance: Green, Amber-A, Amber-B, and Red. The government has exempted equipment and replacement parts for renewable energy projects, including energy audits, from 5% VAT and 5-year income tax. In an effort to lessen industrial pollution and boost electricity supply, Bangladesh Bank, the country's national bank, introduced the Bangladeshi Taka (BDT) 2 billion green banking refinancing program in August 2009 (UNEPA, 2021). As a result, Bangladesh is seeing an uptick in green financing (Rana & Siddique, 2019). According to Macgregor et al. (2016), the Bangladesh government has contributed 7% of public spending toward green development initiatives.

6.4 *Clean Cook Stoves*

1.7 million improved cook stoves have been installed as part of the Bangladesh Improved Cook Stoves Program. People in a chosen coastal hamlet in Bangladesh get technical and financial assistance from the Bangladesh Environment and Development Society (BEDS). The villages now have solar lighting, solar panels, solar dwellings, solar generators, and fuel-efficient cooking stoves (BEDS, 2020).

From 2020, Dhaka routinely placed as the world's highest or the second-most polluted city, and Bangladesh rose to become the most polluted nation in the world (Khandker et al., 2022). In order to reduce air pollution, the government has enacted and revised rules, developed policies and strategic plans, and carried out a number of sector-specific programs and initiatives. The information produced by the Continuous Air Monitoring Stations (CAMS) is used to describe the types and levels of city pollution, to track national pollution trends, to build air models, and to support the Air Quality Index for the general public.

Besides, replacing brick with cement block for construction purpose is one of the best ways to reduce the concentrations of PM as brick kiln are the main sources of PM pollution in Bangladesh. Moreover, introduction of mass transport. especially train, metro, and tram within the metropolitan cities could reduce PM pollution. Running of high-speed trains from the surrounding and distant districts toward Dhaka will eventually reduce the number of vehicles especially buses and private cars, which will help to reduce PM pollution. Sweeping and watering of roads in the morning will help to settle down pollutants. Finally, regular monitoring and inspection, research activities, and public awareness will support to minimize particulate matter pollution.

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