

Assessment of Air Quality in Dhaka: Continuous Measurement and Spatial- Temporal Analysis of SO₂, NO, and NO₂ Pollutants across Multiple Urban Zones

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Abstract

Air pollution is now a major public health problem in both rural and urban areas of Bangladesh and the situation is worst in the capital city of Dhaka, which is considered to be among the top cities with the worst air quality in the world. The objectives of this study were to demonstrate continuous, real-time measurements of SO₂, NO and NO₂ at a single site in Dhaka, to analyse each's spatial and temporal variations, and to estimate resultant health risks. The spatial profiles of air pollutant concentrations were measured using the TG-501 and TG-502 probes and related health effects were determined by a structured questionnaire. GIS was used for spatial variation and mapping, and the outcomes were compared between homes and parks. Concentrations of NO (178 µg/m³), NO₂ (264 µg/m³) and SO₂ (239 µg/m³), were measured at various hot spots in Dhaka which are above the WHO (2005) guideline values for SO₂ (80 µg/m³) and NO/NO₂ (120 µg/m³). Maximum concentrations of NO (178µg/m³) and NO₂ (264µg/m³) were recorded at Farmgate with SO₂(239 µg/m³) at Amin Bazaar for three years. Strong positive correlations were detected between CO and NO ($r = 0.65$) as well as CO and NO₂ ($r = 0.84$), but there were strong negative correlations for NO and TVOC ($r = -0.70$) and SO₂ and TVOC ($r = -0.50$). In the survey, more than 55% of the students and drivers had a history of eye irritation, cough, asthma, vomiting, headache, and other respiratory diseases. The results underline the necessity for implementing appropriate air quality management policies in Dhaka to reduce health hazards.

Key word: Air pollution, Dhaka, Health Effects, Spatial and Temporal Variations, and WHO

1.1 Introduction

Bangladesh ranked second among 91 countries with the worst urban air quality in the latest air pollution monitoring report by the World Health Organization (WHO, 2023). Data from the National Institute of Diseases of the Chest and Hospital shows that nearly seven million Bangladeshis suffer from asthma and more than half of them are children. Dhaka, Bangladesh's capital, is invariably listed as one of the world's worst cities for air pollution, and the quality of its air is regularly unsafe for the public. Concentration of PM_{2.5} and PM₁₀ have been observed to exceed national as well as WHO standards frequently particularly in dry season as a result of unplanned urbanization, industrialization and vehicular congestion (Pavel et al., 2021; Rahaman et al., 2023; Siddiqui et al., 2020). In Dhaka alone, an estimated 15,000 premature deaths, as well as several million cases of pulmonary, respiratory and neurological illness are attributed to poor air quality. The atmosphere is a thin blanket of air which envelops earth sustaining life in it and protecting it from the adverse effects of outer space. It contains a large amount of N₂ and O₂, smaller amounts of Ar and CO₂ as well as traces of other gases- He, Ne, CH₄, H₂S, O₃, NH₃, SO₂, NO, NO₂, TVOCs etc. On an average about 50 lbs (irritable bowel syndrome) of air are required per person per day to meet O₂ requirement. Clean air is necessary for healthy environment and to sustain biodiversity. Unfortunately, atmosphere is used as dumping site for varieties of toxic organic and inorganic gases, particulate matter, and aerosols etc. which contaminate the atmosphere. The concentrations measured for SO₂, 239 µg/m³ exceeded the limit values as mentioned in the WHO guideline 120 µg/m³, 2005 and

EPA 120 $\mu\text{g}/\text{m}^3$, 2009. The concentration of NO, 178 $\mu\text{g}/\text{m}^3$ and NO₂, 264 $\mu\text{g}/\text{m}^3$ exceeded the limit values as mentioned in the WHO guideline 80 $\mu\text{g}/\text{m}^3$, 2005; EPA 120 $\mu\text{g}/\text{m}^3$, 2009 and EU 120 $\mu\text{g}/\text{m}^3$, 2008.

Sulfur dioxide (SO₂), nitric oxide (NO) and nitrogen dioxide (NO₂) are the important pollutants in the air of Dhaka city, which are mainly released by vehicles, industries and brick kilns. These gases are precursors of secondary pollutants and aggravate the pollution with particulate matter being particularly dangerous in cities with heavy traffic and industry (Pavel et al., 2021; Jion et al., 2023). High concentrations of SO₂, NO_x (NO + NO₂) result in increased prevalence of respiratory and cardiovascular diseases and early death. In Bangladesh, air pollution is known to contribute to considerable health burdens especially among children and the susceptible groups of the population (Pavel et al., 2021; Rahman et al., 2025; Siddiqui et al., 2020; Chen et al., 2022). Environmental pollution has wide-ranging and serious impacts on human society, affecting health, economy and on climate change is a major concern for the people's survival and lifestyle in the future.

In particular, Dhaka city has become an endangered area in the country. Recently, Dhaka came in second on the list of cities with one of the worst air qualities (WHO, 2023). The average air quality index (AQI) for the city was 162, which is deemed unhealthy. The lives of the city dwellers have been hampered due to air contamination, particularly atmospheric gaseous pollution. Largely as a result of increased mortality from stroke, heart disease, chronic obstructive, pulmonary disease, lung cancer and acute respiratory infections, breathing problem, tuberculosis and skin diseases. Air pollution alone accounts for 17.6% of the risk of death and disability in Bangladesh (Ahmad, S. A. et. Al., 2008). The annual economic burden of air pollution in Dhaka has been estimated at USD 192 million (DoE, 2021). Bangladesh's air unhealthy to breath since 2017 (WHO, 2020). One of our era's greatest scourges is air pollution, on account not only of its impact on climate change but also its impact on public and individual health due to increased morbidity and mortality. There are many pollutants that are major factors in disease in humans. The World Health Organization (WHO, 2022) describes air pollution as a major environmental risk to health and estimates that it causes around seven million premature deaths worldwide every year, and Dhaka is one of the hard-hit cities. Diseases occurring from the aforementioned substances include principally respiratory problems such as Chronic Obstructive Pulmonary Disease (COPD), asthma, bronchiolitis, and also lung cancer, cardiovascular events, central nervous system dysfunctions, and cutaneous diseases (Mehedi, H., 2010). Last but not least, climate change resulting from environmental pollution affects the geographical distribution of many infectious diseases, as do natural disasters. The only way to tackle this problem is through public awareness coupled with a multidisciplinary approach by scientific experts; national and international organizations must address the emergence of this threat and propose sustainable solutions. Air pollution in Dhaka is so severe, yet monitoring of major pollutants on a continuous and comprehensive basis is very limited, and the data are mostly taken from a few monitoring sites. The absence of strong and timely data impedes policy development and implementation-specific measures (Pavel et al., 2021; Khan et al., 2023). The objectives of this study are to demonstrate continuous, on-site monitoring of SO₂, NO and NO₂ in Dhaka, to study their spatial and temporal variations and to assess the associated health risk.

2. Methodology

2.1 Justification for Sampling Point Selection

Sampling sites within Dhaka were selected so as to represent different land use/land cover (LULC) category such as commercial, residential, institutional, green and peri-urban/industrial areas. Such a procedure is crucial for characterizing spatial variation of air pollutant concentration since it has been demonstrated that densely built-up and industrial areas are more polluted while vegetated and waterbody areas are less polluted (Saha et al., 2024; Douglas et al., 2023; Gheshlaghpoor et al., 2022) mentioned in table 1. These include (Farmgate, Science Laboratory, Mouchak, Curzon Hall, Topkhana, Ramna Park, Baily Road, Dhaka University residential areas, Amin Bazar, Ashulia) which cover this range from rural to urban. From figure 1, Dhaka City, the capital of Bangladesh, is the area of study for this study. It is a region that is densely populated and highly urbanized,

with heavy traffic and commercial areas and mixed land use. This sets the stage for a critical area to study spatial differences in air pollutants and temperature.

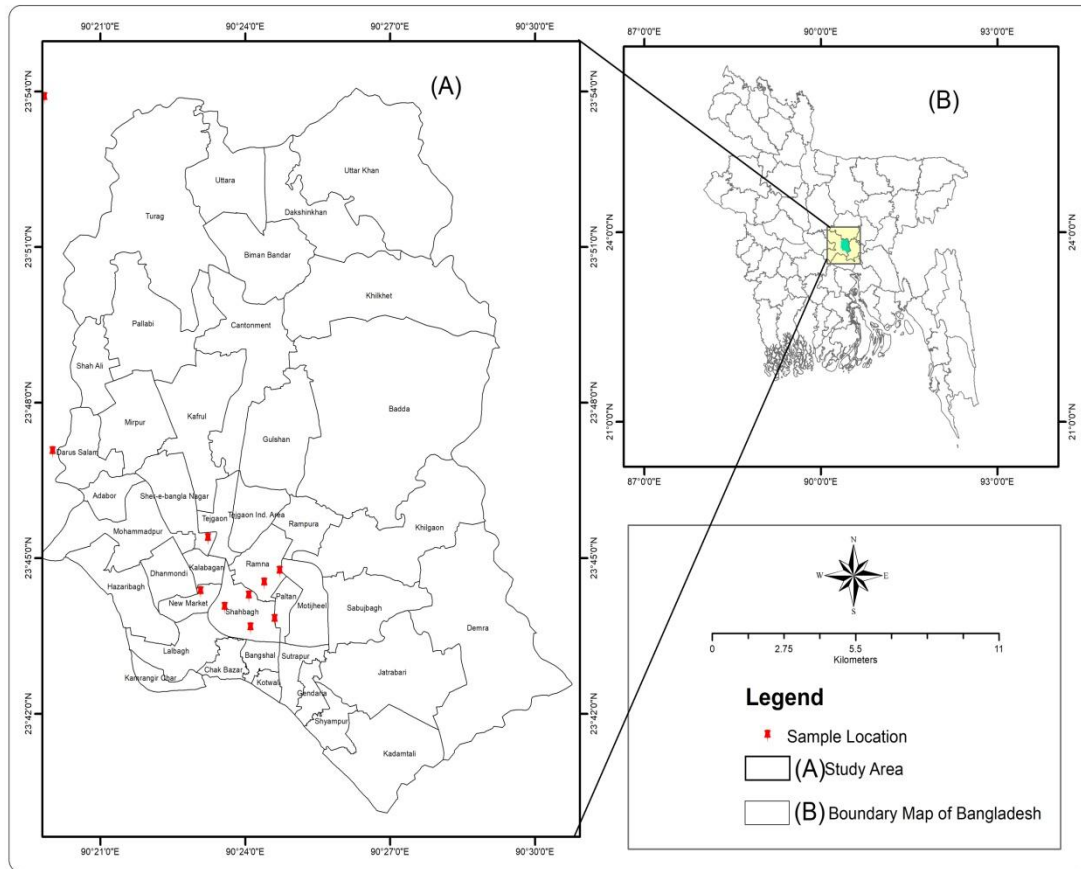


Figure1: Study Area

Table1: Timing of Data Collection and Site Selection

Site Name	LULC/Area Characteristic	Rationale for Selection	Data Collection Timing	Supporting Literature
<i>Farmgate</i>	High-traffic commercial	Urban traffic emissions hotspot	15, 30, 60 min, 8 hr, year-round	Kim et al., 2023; Zhou et al., 2022
<i>Science Laboratory</i>	Institutional/urban core	Central city, mixed traffic and institutional activity	15, 30, 60 min, 8 hr, year-round	Kim et al., 2023; Zhou et al., 2022
<i>Mouchak</i>	Commercial/residential mix	Dense population, mixed land use	15, 30, 60 min, 8 hr, year-round	Kim et al., 2023; Zhou et al., 2022
<i>Curzon Hall</i>	Institutional/green space	Proximity to green space, lower expected pollution	15, 30, 60 min, 8 hr, year-round	Kim et al., 2023; Zhou et al., 2022
<i>Topkhana</i>	Urban core	Central business district, high human activity	15, 30, 60 min, 8 hr,	Kim et al., 2023; Zhou et

			year-round	al., 2022
<i>Ramma Park</i>	Urban Park/green space	Represents vegetated area, expected lower pollution	15, 30, 60 min, 8 hr, year-round	Kim et al., 2023; Zhou et al., 2022
<i>Baily Road</i>	Residential	Typical urban residential exposure	15, 30, 60 min, 8 hr, year-round	Kim et al., 2023; Zhou et al., 2022
<i>Dhaka University Residential Area</i>	Institutional/residential	University housing, moderate traffic, mixed exposure	15, 30, 60 min, 8 hr, year-round	Kim et al., 2023; Zhou et al., 2022
<i>Amin Bazar</i>	Peri-urban/industrial	Edge of city, industrial influence, urban-rural transition	15, 30, 60 min, 8 hr, year-round	Fattoruso et al., 2020; Zhou et al., 2022
<i>Ashulia</i>	Peri-urban/expanding residential	Rapid urbanization, new development, changing LULC	15, 30, 60 min, 8 hr, year-round	Fattoruso et al., 2020; Zhou et al.

2.2 Data Collection Procedure

Atmospheric SO₂, NO, and NO₂ were sampled with battery-operated, calibrated TG-501 and TG-502 probes and data logged to a pocket PC. Temperature and humidity were recorded at the same time because meteorological conditions have a profound effect on the dispersion of pollutant (Garsa et al., 2023; Zghaid et al., 2025). At 15, 30, 60 min, 8 h intervals during the years 2023–2024, measurements were performed, allowing the investigation of diurnal, monthly and annual variations (Zhao et al., 2015).

2.3 Survey of Public Opinion

A structured questionnaire was conducted with some of the residents in each community to collect information on their perceptions of air quality and associated health effects. The answers were examined as a percentage in order to compare them with instrumental data.

2.4 Data Analysis

The data analysis was performed by adopting GIS-based, statistical, and survey procedures. All the figures were calculated and formatted in Microsoft Excel at different stages, such as after the checks for gaps and cleaning and before further analysis. SO₂, NO₂, NO, and temperature were also spatially interpolated and classified thematically in ArcGIS 10.8 by means of IDW to produce continuous spatial surfaces and to identify the spatial patterns of pollutants over Dhaka City. Statistical analysis was performed, including descriptive statistics and Pearson's correlation, to assess the associations among the pollutants and temperature. Statistical analysis, including descriptive statistics and Pearson's correlation, was used to evaluate the associations between the pollutants and temperature. Furthermore, the health effects module was studied based on responses from both interview and questionnaire surveys, where symptoms associated with exposure were reported in a summarized, categorized manner, and interpreted for linkages between exposure to air pollution and public health outcomes.

3 Results

3.1 Sulphur dioxide (SO₂)

Sulphur dioxide (SO₂) contributes to air pollution by forming acid rain, which damages ecosystems, buildings, and water sources, and by contributing to fine particulate matter (PM), which causes serious human health

problems, including asthma and bronchitis. SO_2 is primarily released into the atmosphere from the combustion of sulphur-containing fossil fuels in power plants, industrial processes, and vehicles, as well as from natural volcanic activity. Sulphur dioxide (SO_2) concentrations ($\mu\text{g}/\text{m}^3$) measured for Dhaka city at different hot spots. The concentrations varied from $99 \mu\text{g}/\text{m}^3$ to $239 \mu\text{g}/\text{m}^3$ in the hot spots. Among the hot spots the maximum concentrations $239 \mu\text{g}/\text{m}^3$ was measured at Amin bazar in 2023 followed by Ashulia $237 \mu\text{g}/\text{m}^3$, Farmgate $161 \mu\text{g}/\text{m}^3$, Mohakhali $151 \mu\text{g}/\text{m}^3$ Science laboratory $149 \mu\text{g}/\text{m}^3$, Topkhana $133 \mu\text{g}/\text{m}^3$, Mouchak $141 \mu\text{g}/\text{m}^3$ and Curzon Hall $121 \mu\text{g}/\text{m}^3$, Ramna park $95 \mu\text{g}/\text{m}^3$, Baily Road residential $82 \mu\text{g}/\text{m}^3$. Dhaka university residential area $77 \mu\text{g}/\text{m}^3$. The concentrations of SO_2 measured in the present investigation is higher than the concentrations reported for Dhaka city (Mehedi, 2010).

Continuous assessment of exposure levels of SO_2 in Dhaka city for two years from 2023 to 2024 (January – December) and a generalized analysis of the data depict that the concentration varied from $106 - 136 \mu\text{g}/\text{m}^3$. The highest level $136 \mu\text{g}/\text{m}^3$ was measured in the months of December (in winter) and the lowest level $106 \mu\text{g}/\text{m}^3$ in the month of October with an average of $122 \mu\text{g}/\text{m}^3$. The registered average natural background SO_2 concentration is around $80-120 \mu\text{g}/\text{m}^3$. Short-term (one-hour) mean ambient concentrations in urban areas may exceed $350 \mu\text{g}/\text{m}^3$ (DoE, 2002). The SO_2 measured for Dhaka city and the exposure level is high and passed the limit values set by EPA, 2002 and Bangladesh standards $80 \mu\text{g}/\text{m}^3$ (DoE, 2002). Sulphur dioxide (SO_2) is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NO_x), facilitated by a variety of volatile organic compounds (VOCs), which are photochemically reactive hydrocarbons. One of the major anthropogenic sources of SO_2 precursors is motor vehicles. It is possible that the increasing number of motor vehicles plying in the streets of Dhaka city at present is contributing in the SO_2 precursors. A strong negative correlation ($r = -0.50$) between SO_2 and TVOC, positive correlation ($r = 0.91$) between SO_2 and CO and positive correlation ($r = 0.81$) between SO_2 and O_3 obtained in the present investigation. That is SO_2 concentration increased with a concomitant decrease in TVOC. Whereas, the concentration increased with increasing concentration of NO. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which SO_2 is converted to SO_3 during day time period. The SO_2 concentrations also varied with relative humidity. A significant positive correlation ($r = 0.698$) was obtained for SO_2 and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level SO_2 accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (Chilton and Sholtz, 1989). Mean concentrations are generally highest in the winter. Peak concentrations of SO_2 rarely last longer than two to three hours (WHO, 1979).

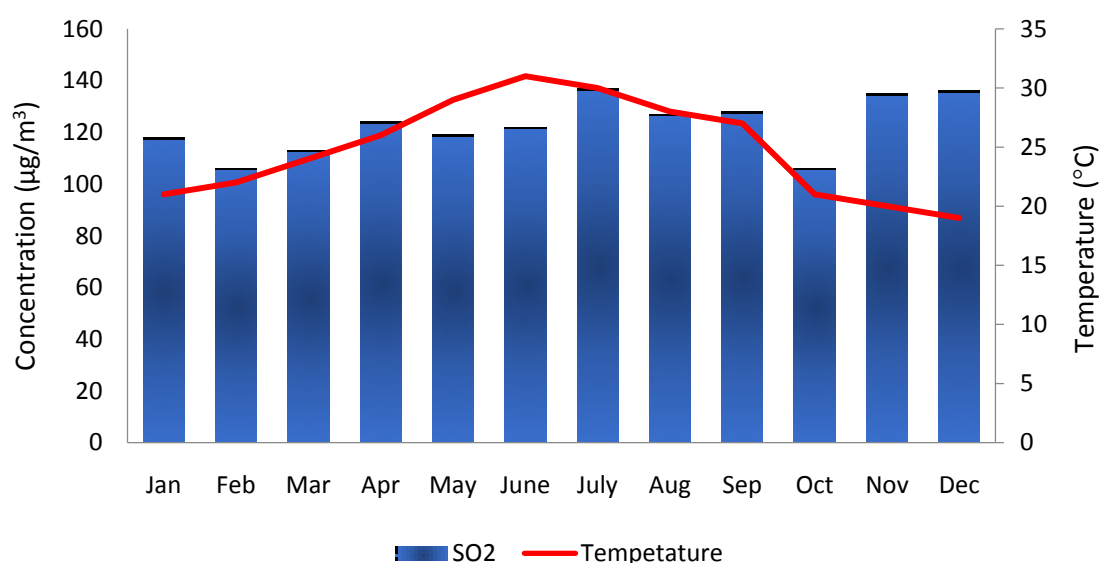


Fig. 2: SO_2 variation along with temperature $^{\circ}\text{C}$ in Dhaka city (2023-2024).

The concentrations of SO₂ increased as the temperature decreased between September to January (Fig. 2). When the temperature starts increasing the value of SO₂ is decreasing in March to August. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of SO₂. The highest SO₂ concentration was measured in winter followed by rainy, summer season respectively. The SO₂ concentrations also varied with relative humidity. A significant correlation ($r= 0.698 \%$) was obtained for SO₂ and relative humidity. SO₂ concentrations increase with increasing hydrocarbons and decrease with increasing Sox. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of SO₂. An air mass trajectory analysis using HYSPLIT model (NOAA, 2023) showed that a substantial amount of SO₂ are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution.

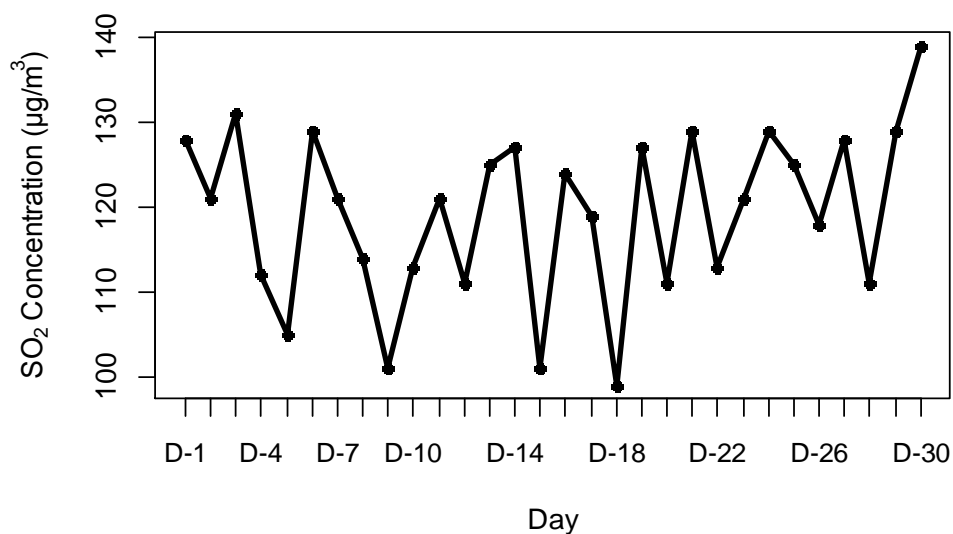


Fig. 3: Monthly variations in SO₂ Concentrations (µg/m³) in Dhaka city (June, 2023).

Sulphur dioxide (SO₂) concentrations (µg/m³) measured for 30 days in June, 2023 in Dhaka city presented in Fig 3 shows that the concentrations varied significantly from 1st June to 30th June. The Concentrations measured on 1st, 2nd, 3rd, 4th, 5th, 6th June were 128 µg/m³, 121 µg/m³, 131 µg/m³, 112 µg/m³, 105 µg/m³, 129 µg/m³ presented table 4.5. The highest value was 139 µg/m³ in 30th June and the lowest value was 99 µg/m³ in 18th June. The reason behind the variation can be explained by the vehicular emissions of SO₂ during the holiday, rainy day, cloudy day in this time period. The average value is significantly different as the 95% confidence between 6th, 21st June and 30th June. The lowest value was found in 9th and 15th and 18th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays and for these reason the concentrations of SO₂ were low than the other days.

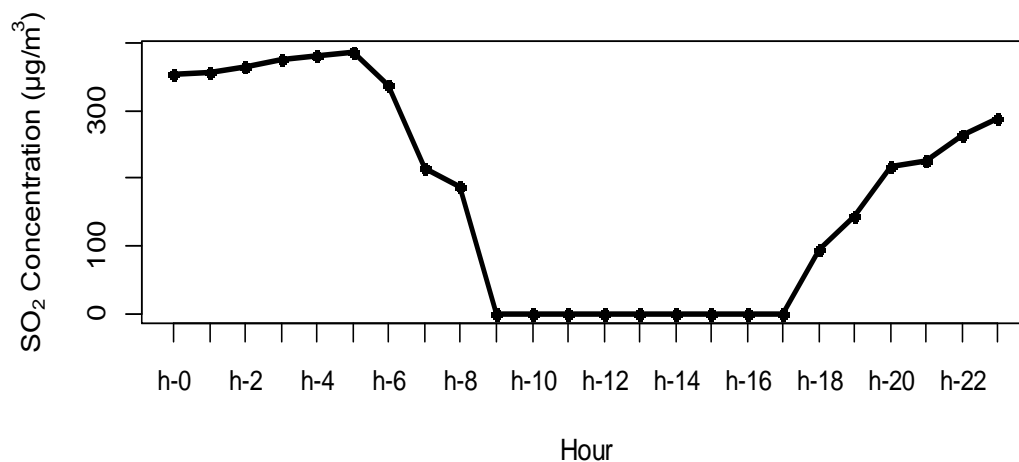


Fig. 4: Diurnal variation in SO₂ Concentrations (µg/m³) in Dhaka city (5 June, 2023).

Sulphur dioxide (SO₂) concentrations (µg/m³) measured for 24 hours on 5 June, 2024 in Dhaka city Fig. 4 shows that the concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 0 hour to 8 hours were 352 µg/m³, 356 µg/m³, 365 µg/m³, 376 µg/m³, 379 µg/m³, 386 µg/m³, 337 µg/m³, 214 µg/m³, 187 µg/m³ presented table 4.6 and then declined to 0 µg/m³ concentrations between 9h -17h and then again regain concentrations slowly increasing 18h -24h. The highest value was 386 µg/m³ in 5 hours and the lowest value was 0 µg/m³ in 9 hours to 17 hours. The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction SO₂ is converted to SO₃ during this day time period. The SO₂ concentrations also varied with relative humidity. A significant negative correlation ($r = -0.698$) was obtained for SO₂ and relative humidity. The average value is significantly different as the 95% confidence between 0 hour to 8 hours and 9 hours to 17 hours. The average value is also significantly different as the 95% confidence between 0 hour to 8 hours and 18 hours to 23 hours.

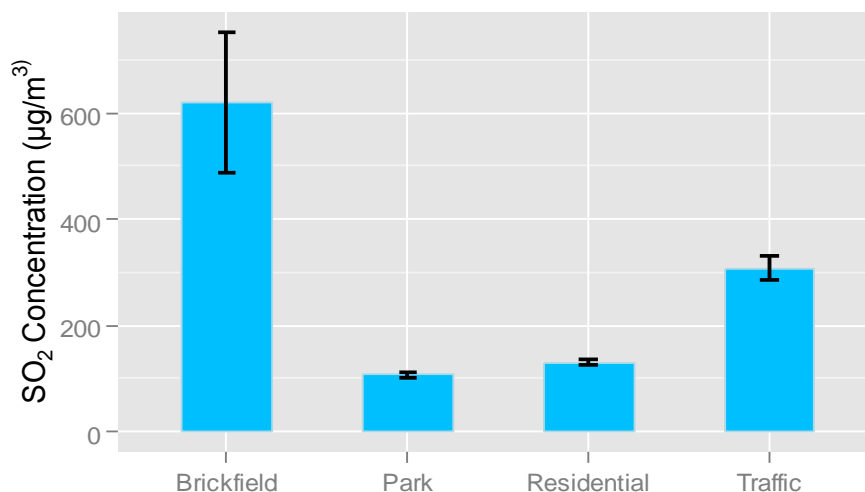


Fig. 5: Comparison of SO₂ Concentrations (µg/m³) measured for different locations in and around Dhaka city from 2023-2024.

Sulphur dioxide (SO₂) concentrations (µg/m³) determined at residential area, traffic area, park, brick-field etc. to observe the locational variation presented in Fig. 5 shows that the concentrations varied significantly from place to place. The highest concentrations measured in brick-field area 1243 µg/m³ followed by traffic 423 µg/m³, residential area 151 µg/m³ and park area 141 µg/m³. The SO₂ concentration measured for brick-fields areas were

significantly higher than that measured for park and residential areas at 95% confidence level. Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. are produce a huge amount of SO₂. Huge amount of running vehicles, long time traffic jam produced SO₂ resulting in an air pollution. To use low quality coal, wood in brick-kilns to produced SO₂ (EPA, 2009).

3.2 Nitric oxide (NO)

Nitric oxide (NO) concentrations ($\mu\text{g}/\text{m}^3$) measured for Dhaka city at different hot spots during 2023 to 2024. The concentrations varied from 124 $\mu\text{g}/\text{m}^3$ to 178 $\mu\text{g}/\text{m}^3$ in the hot spots. Among the hot spots the maximum concentrations were measured for Farm-gate 178 $\mu\text{g}/\text{m}^3$ followed by Ashulia 167 $\mu\text{g}/\text{m}^3$, Amin bazar 166 $\mu\text{g}/\text{m}^3$, Mouchak 159 $\mu\text{g}/\text{m}^3$, Science laboratory 155 $\mu\text{g}/\text{m}^3$, Topkhana 144 $\mu\text{g}/\text{m}^3$, Curzon hall 141 $\mu\text{g}/\text{m}^3$, Ramna park 129 $\mu\text{g}/\text{m}^3$, Baily road residential 126 $\mu\text{g}/\text{m}^3$, Dhaka university residential area 122 $\mu\text{g}/\text{m}^3$. NO nitric oxide (NO) however, was detected in any of the spots between 9 hours to 17 hours. The concentrations of NO measured in the present investigation is higher than the concentrations reported for Dhaka city (Mehedi, 2010).

Continuous assessment of exposure levels of NO in Dhaka city for three years from 2023 to 2024 (January – December) and a generalized analysis of the data depict that the concentration varied from 101- 135 $\mu\text{g}/\text{m}^3$. The highest levels 135 $\mu\text{g}/\text{m}^3$ was measured in the month of January (in winter) and the lowest level was 101 in the month of June (in rainy season) with an average 121 $\mu\text{g}/\text{m}^3$. Nitric oxide concentrations are influenced by the intensity of solar radiation, the absolute concentration of NO_x and VOCs, and the ratio of NO_x and VOCs. A strong negative correlation ($r = -0.70$) between NO and TVOC, positive correlation ($r = 0.76$) between NO and H₂S and positive correlation ($r = 0.81$) between NO and O₃ obtained in the present investigation. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which NO are converted to O₂ during day time period. The NO concentrations also varied with relative humidity. A significant positive correlation ($r = 0.698$) was obtained for NO and relative humidity.

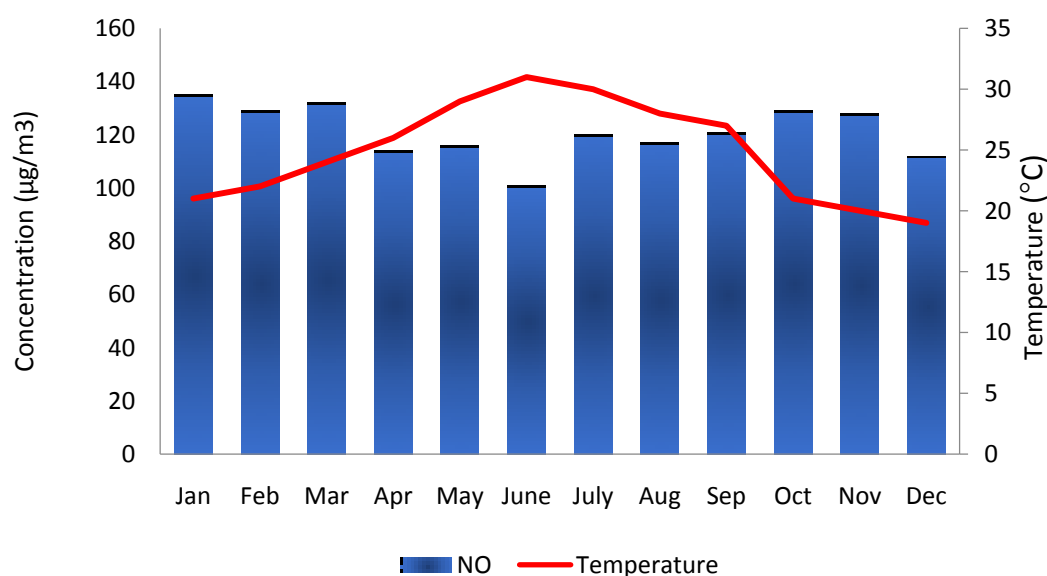


Fig. 6 NO variation along with temperature $^{\circ}\text{C}$ in Dhaka city (2023-2024).

The concentrations of NO increased as the temperature decreased between September to March (Fig. 6). When the temperature starts increasing the value of NO is decreasing in March to August. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of NO. The highest SO₂ concentration was measured in winter followed by rainy, summer season respectively.

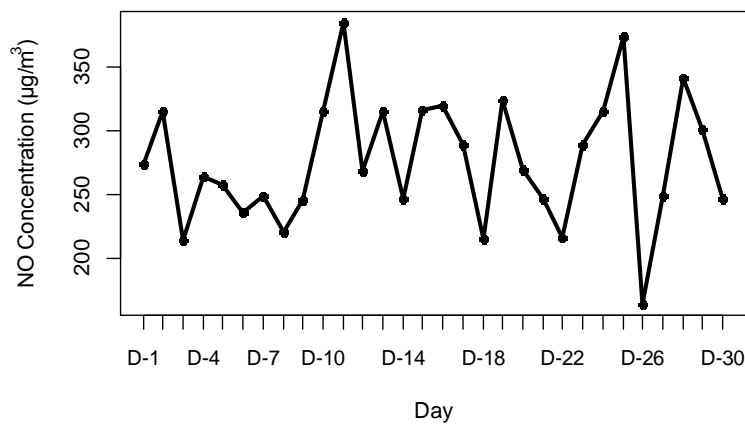


Fig. 7: Monthly variations in NO Concentrations ($\mu\text{g}/\text{m}^3$) in Dhaka city (June, 2023).

Nitric oxide (NO) concentrations ($\mu\text{g}/\text{m}^3$) measured for 30 days on June, 2023 in Dhaka city. The Concentrations measured on 1st, 2th, 3th, 4th, 5th, 6th June were $274 \mu\text{g}/\text{m}^3$, $315 \mu\text{g}/\text{m}^3$, $214 \mu\text{g}/\text{m}^3$, $264 \mu\text{g}/\text{m}^3$, $258 \mu\text{g}/\text{m}^3$, $236 \mu\text{g}/\text{m}^3$. The highest value was $384 \mu\text{g}/\text{m}^3$ in 11th June and the lowest value was $164 \mu\text{g}/\text{m}^3$ in 26th June. The reason behind the variation can be explained by the vehicular emissions of NO during the holiday, rainy day, cloudy day in this time period. The average value is significantly different as the 95% confidence between 26th, 11th June and 5th June. The lowest value was found in 26th and 3th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays (Fig. 7). For this reason, the concentrations of NO were low than the other days.

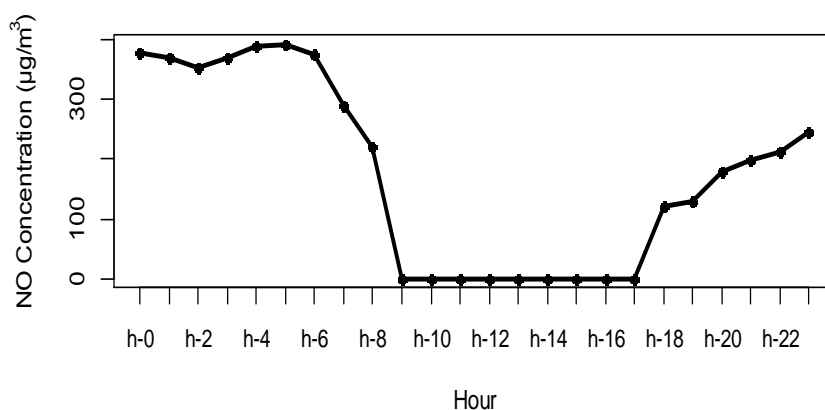


Fig. 8: Diurnal variation in NO Concentrations ($\mu\text{g}/\text{m}^3$) in Dhaka city (5 June, 2023).

Nitric oxide (NO) concentrations ($\mu\text{g}/\text{m}^3$) measured for 24 hours on 5 June, 2023 in Dhaka city. The concentrations measured a peak between 0 hour to 8 hours were $378 \mu\text{g}/\text{m}^3$, $368 \mu\text{g}/\text{m}^3$, $352 \mu\text{g}/\text{m}^3$, $368 \mu\text{g}/\text{m}^3$, $389 \mu\text{g}/\text{m}^3$, $391 \mu\text{g}/\text{m}^3$, $373 \mu\text{g}/\text{m}^3$, $289 \mu\text{g}/\text{m}^3$, $219 \mu\text{g}/\text{m}^3$ and then declined to $0 \mu\text{g}/\text{m}^3$ concentrations between 9h -17h and then again regain concentrations slowly increasing 18h -24h. The highest value was $378 \mu\text{g}/\text{m}^3$ in 0 hour and the lowest value was $0 \mu\text{g}/\text{m}^3$ in 9 hours to 17 hours. The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction NO convert to another gases during this day time period. The NO concentrations also varied with relative humidity. A significant negative correlation (r

= 0.698 %) was obtained for NO and relative humidity. NO concentrations increase with increasing hydrocarbons and decrease with increasing NO_x. The average value is significantly different as the 95% confidence between 0 hour to 8 hours and 9 hours to 17 hours. The average value is also significantly different as the 95% confidence between 0 hour to 8 hours and 18 hours to 23 hours from figure 8.

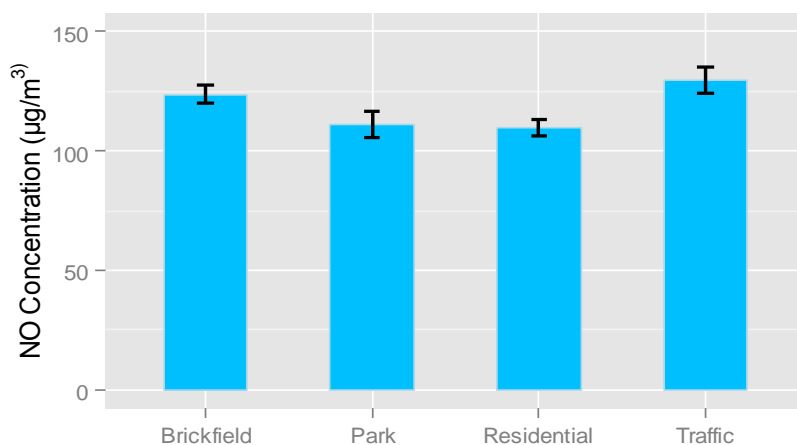


Fig. 9: Comparison of NO Concentrations (µg/m³) measured for different locations in and around Dhaka city from 2023-2024.

Nitric oxide (NO) concentrations determined at residential area, traffic area, park, brick-field etc. to observe the locations variation. The highest concentrations measured in traffic area 171 µg/m³ followed by brick-field 139 µg/m³, residential area 217 µg/m³ and park area 198 µg/m³. Although the difference between traffic and residential area, the average value is significantly different as the 95% confidence. The average value is significantly different as the 95% confidence between brickfield and park. The average value is significantly different as the 95% confidence between traffic and park which is presented in fig 9.

3.3 Nitrogen di oxide (NO₂)

Nitrogen di oxide (NO₂) concentrations (µg/m³) measured for Dhaka city at different hot spots during 2023 to 2024. The concentrations varied from 157 µg/m³ to 264 µg/m³ in the spots. Among the hot spots the maximum concentrations were measured for Farmgate 274 µg/m³ followed by Amin bazaar 261 µg/m³, Ashulia 252 µg/m³, Science laboratory 257 µg/m³, Mohakhali 259 µg/m³, Mouchak 244 µg/m³, Topkhana 229 µg/m³, Curzon Hall 155 µg/m³, Ramna park 132 µg/m³, Baily Road residential 128 µg/m³, Dhaka university residential area 121 µg/m³. Nitrogen di oxide (NO₂) however, was detected in any of the spots between 0 hours to 5 hours. The concentrations of NO₂ measured in the present investigation is higher than the concentrations reported for Dhaka city (Mehedi, 2010). A strong negative correlation ($r = -0.70$) between NO₂ and TVOC, positive correlation ($r = 0.81$) between NO₂ and O₃ and negative correlation ($r = 0.27$) between H₂S and NO₂ obtained in the present investigation. That is NO₂ concentration increased with a concomitant decrease in TVOC and NO₂. Whereas, the concentrate in increased with increasing concentration of NO. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which NO₂ is converted to O₂ during day time period. The NO₂ concentrations also varied with relative humidity. A significant positive correlation ($r = 0.698$) was obtained for NO₂ and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level NO₂ accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (Chilton and Sholtz, 1989). Peak ground-level NO₂ concentrations are measured in the afternoon. Mean concentrations are generally highest in the summer. Peak concentrations of ground-level NO₂ rarely last longer than two to three hours (WHO, 1979).

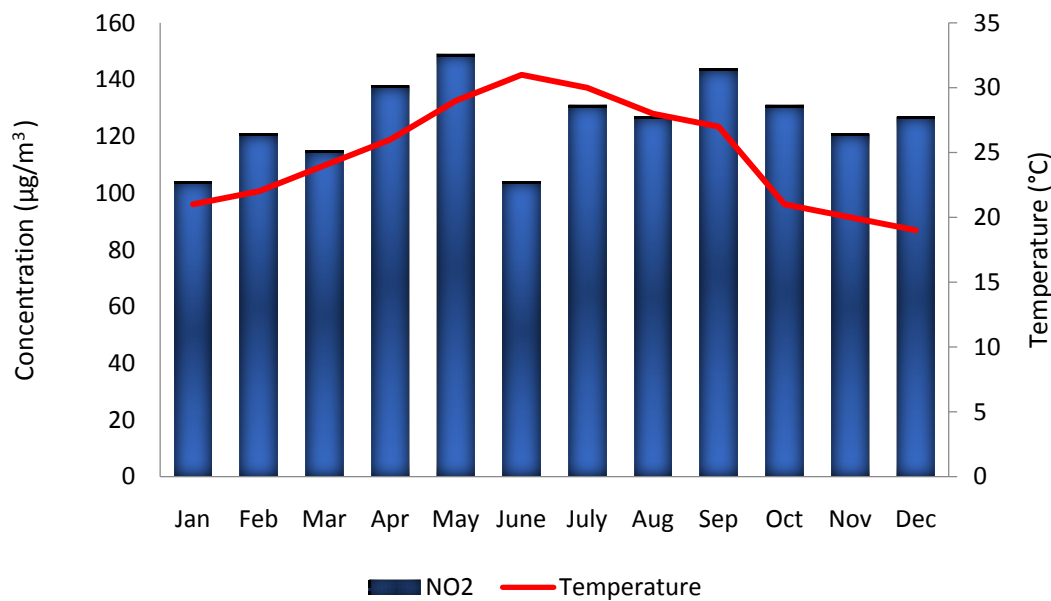


Fig. 10: NO₂ variation along with temperature °C in Dhaka city (2023-2024).

The concentrations of NO₂ increased as the temperature decreased from September to March (Fig. 10). When the temperature starts increasing the value of NO₂ is decreasing in June to August. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of NO₂.

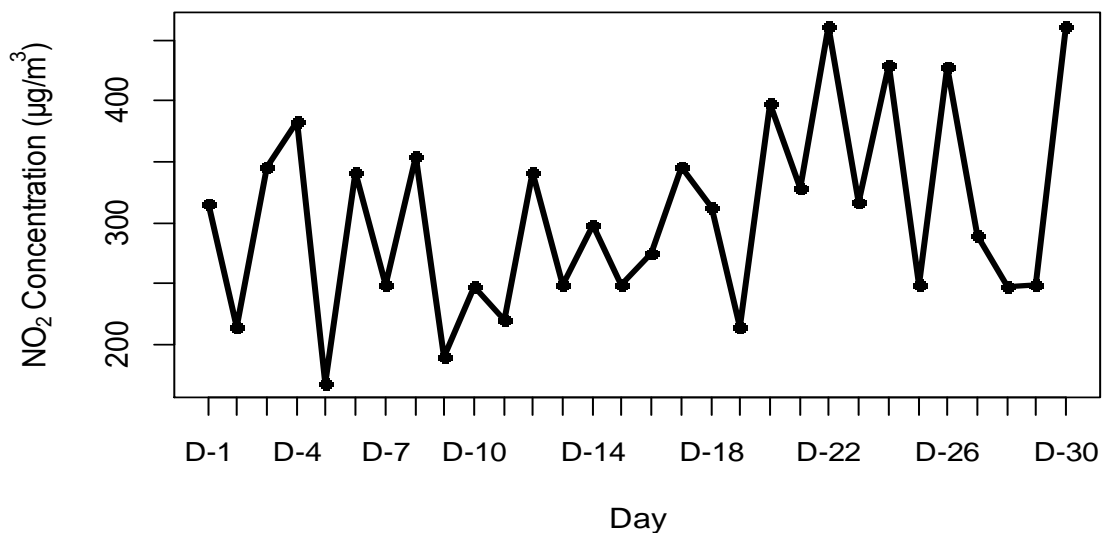


Fig. 11: Monthly variations in NO₂ Concentrations (µg/m³) in Dhaka city (June, 2023).

Nitrogen di oxide (NO₂) concentrations (µg/m³) measured for 30 days on June, 2023 in Dhaka city. The concentrations varied significantly from 1st June to 30th June. The Concentrations measured on 1st, 2nd, 3rd, 4th, 5th, 6th June were 315 µg/m³, 214 µg/m³, 345 µg/m³, 384 µg/m³, 167 µg/m³, 341 µg/m³. The highest value was 461 µg/m³ in 30th June and the lowest value was 167 µg/m³ in 5th June. The reason behind the variation can

be explained by the vehicular emissions of NO_2 during the holiday, rainy day, cloudy day in this time period. The average value is significantly different as the 95% confidence between 26th, 11th June and 5th June. The lowest value was found in 26th and 3th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays. For this reason, the concentrations of NO_2 were low than the other days from fig 11.

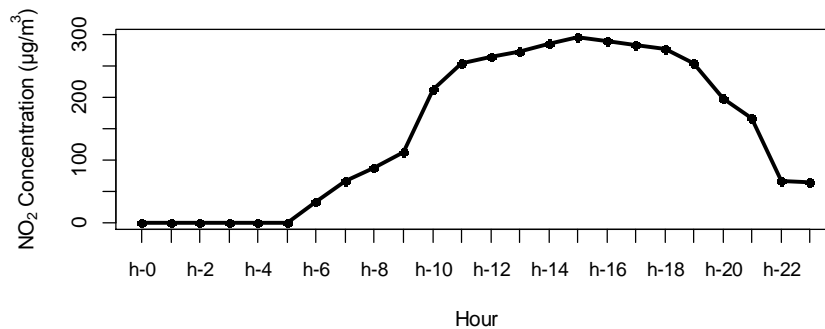


Fig. 12: Diurnal variation in NO_2 Concentrations ($\mu\text{g}/\text{m}^3$) in Dhaka city (5 June, 2023).

Nitrogen di oxide (NO_2) concentrations ($\mu\text{g}/\text{m}^3$) measured for 24 hours on 5 June, 2023 in Dhaka city. The concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 10 hours to 18 hours were $213 \mu\text{g}/\text{m}^3$, $254 \mu\text{g}/\text{m}^3$, $265 \mu\text{g}/\text{m}^3$, $272 \mu\text{g}/\text{m}^3$, $286 \mu\text{g}/\text{m}^3$, $296 \mu\text{g}/\text{m}^3$, $289 \mu\text{g}/\text{m}^3$, $283 \mu\text{g}/\text{m}^3$, $278 \mu\text{g}/\text{m}^3$ and then declined to $0 \mu\text{g}/\text{m}^3$ concentrations between 9h -17h and then again regain concentrations slowly increasing 18h -24h. The highest value was $296 \mu\text{g}/\text{m}^3$ in 15 hours and the lowest value was $0 \mu\text{g}/\text{m}^3$ in 0 hour to 5 hours. The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction NO_2 convert to other gases during this day time period. The NO_2 concentrations also varied with relative humidity. A significant correlation ($r= 0.698 \%$) was obtained for NO_2 and relative humidity. The average value is significantly different as the 95% confidence between 0 hour to 9 hours and 10 hours to 23 hours. The average value is also significantly different as the 95% confidence between 0 hour to 18 hours and 18 hours to 23 hours mentioned in fig 12.

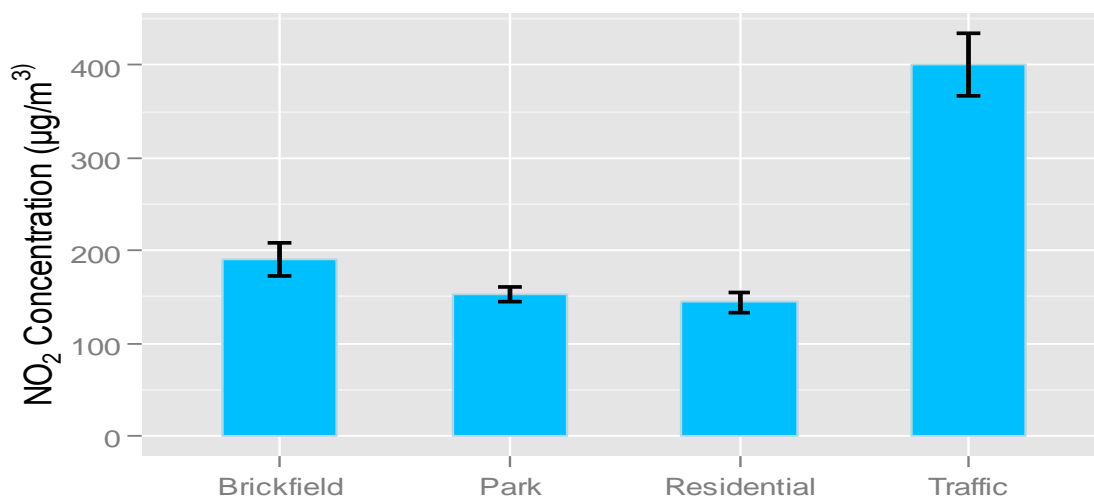


Fig. 13: Comparison of NO_2 Concentrations ($\mu\text{g}/\text{m}^3$) measured for different locations in and around Dhaka city from 2023-2024.

Nitrogen di oxide (NO_2) concentrations determined at residential area, traffic area, park, brick-field etc. to observe the locations variation. The highest concentrations measured in traffic area $542 \mu\text{g}/\text{m}^3$ followed by brick-field $295 \mu\text{g}/\text{m}^3$, residential area $217 \mu\text{g}/\text{m}^3$ and park area $198 \mu\text{g}/\text{m}^3$. Although the difference between traffic and residential area, the average value is significantly different as the 95% confidence. The average value is significantly different as the 95% confidence between brickfield and park. The average value is significantly different as the 95% confidence between traffic and park. Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. are produce a huge amount of NO_2 . Huge amount of running vehicles, long time traffic jam produced NO_2 resulting in an air pollution. To use low quality coal, wood in brick-kilns to produced NO_2 from figure 13.

3.4 Spatial Pattern Analysis

The spatial variation in AOD and total columns of SO_2 , NO_2 , NO , and surface temperature over Dhaka City, representing a well-defined northwest–southeast pattern in pollutant levels. The levels of SO_2 , NO_2 and NO also ranges between Very High to High in north western to northern part of the city specially at Mirpur, Pallabi, Kafrul and its vicinities due to the dense traffic, industrial areas and combustion related activities.

Table 2: Classification of (NO , NO_2 , SO_2 , Temperature)

Parameter	Class	Range (Value)	Category
$\text{NO} (\mu\text{g}/\text{m}^3)$	1	<144.81	Very Low
	2	146.46 – 148.12	Low
	3	148.12 – 149.77	Moderate
	4	149.77 – 151.43	High
	5	>153.08	Very High
$\text{NO}_2 (\mu\text{g}/\text{m}^3)$	1	< 146.652	Very Low
	2	146.652 – 150.895	Low
	3	150.895 – 155.578	Moderate
	4	155.578 – 160.460	High
	5	> 160.460	Very High
$\text{SO}_2 (\mu\text{g}/\text{m}^3)$	1	<150.6877	Very Low
	2	160.9077 – 171.1157	Low
	3	171.1157 – 181.3298	Moderate
	4	181.3298 – 191.5438	High
	5	>201.7577	Very High
Temperature ($^{\circ}\text{C}$)	1	<23.8528	Very Low
	2	24.0149 – 24.9504	Low
	3	24.9504 – 25.0497	Moderate
	4	25.0497 – 26.0497	High
	5	>26.5967	Very High

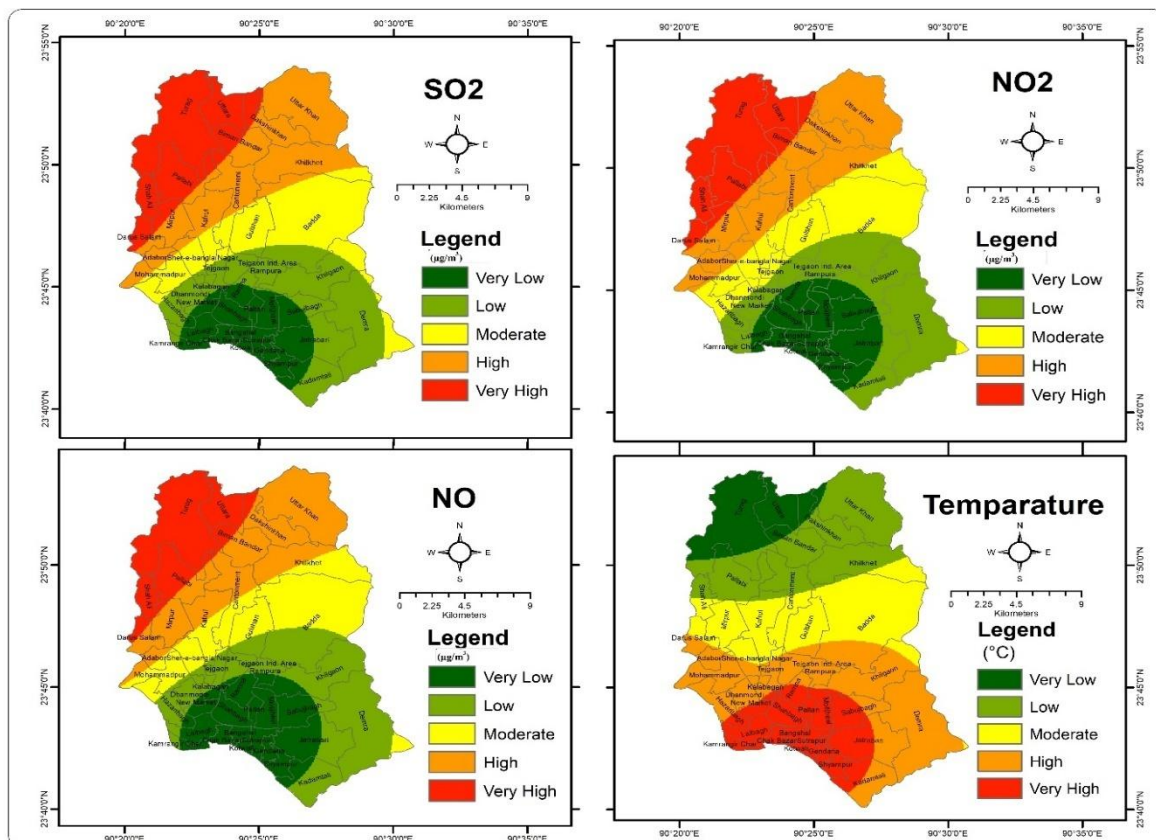


Figure 14: Spatial pattern in the Dhaka city

The levels are decreasing gradually in central, south and southeast parts with Low to Very Low levels. On the other hand, temperature map reveals reverse trend with Very High temperatures prevailing in the south and southwest of Hazaribagh, Kamrangirchar and Bangshal, Low to Very Low temperatures in northern and northeastern parts are primarily attributed to variation in urban heat-island intensity, percentage of vegetation cover and the density of built-up area in each sector of the city mentioned in fig14 and table 2.

3.5 Correlation co-efficient (R^2) and mean ratios

Since the toxic gases such as - SO₂, NO, NO₂ were measured in Dhaka city (Farm-gate, Science-Laboratory, Mouchak, Curzon Hall, Topkhana, Ramna park, Baily road residential, Dhaka university residential areas, Amin bazar, Ashulia) and the temperature and humidity were also recorded along with the above gases with the help of TG- 501 and TG-502 probes. Linear regression analyses between Temperature and Relative humidity were also carried out to determine any relationship.

The correlation between temperature ⁰C and relative humidity% during sampling periods are shown in Fig. 15.

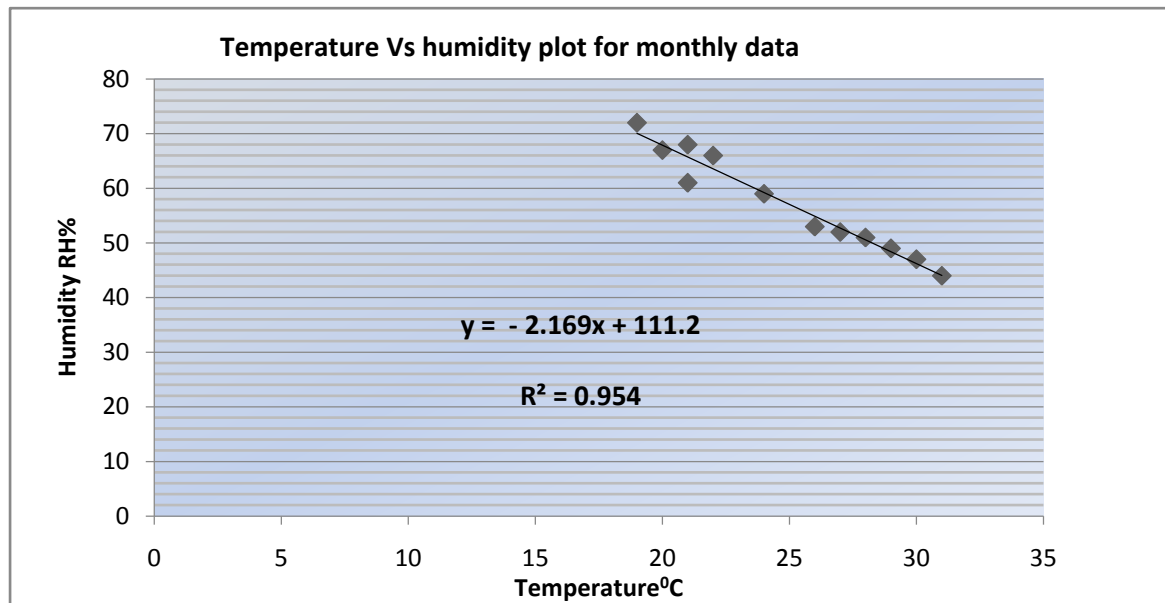


Fig 15: Relationship between temperature ^{°C} and relative humidity% during sampling periods.

3.6 Impacts of Air Pollution on Health

Findings demonstrate that both children and young people in Dhaka city are vulnerable to a diversity of health problems as a consequence of breathing in toxic air. Among the 5–10 years affected, many complained of difficulty in breathing, eye irritation and cough, suggesting early respiratory distress and high susceptibility of the young children. Illnesses were still prevalent in the 10–15 age group, with breathing problems and eye irritation as the most common symptoms. The 15–20 age group experienced more severe symptoms, many of them with breathing difficulties, eye irritation, and skin problems, indicating that the range of ailments experienced by this group is more diverse than that of young children, and that long-term exposure in adolescence results in more serious health problems. Severe health problems were identified at the age of 20–25, including eye irritation, skin diseases, bronchitis and asthma experienced by the respondents mentioned in table 3. This trajectory indicates that the number and severity of health problems relating to air pollution increase from childhood to young adulthood, illustrating that the harmful effects of prolonged exposure in critical stages of development continue to escalate, not just in this study, but in others as well.

Table 3: Students are exposed by toxic gases in Dhaka city

Age-group	Number of persons	Health Problem
5-10	200	Breathing Problem, Eye-irritation, Caught
10-15	310	Breathing Problem, Eye-irritation.
15-20	750	Breathing Problem, Eye-irritation, Skin diseases.
20-25	100	Eye-irritation, Skin diseases, Bronchitis, Asthma.

Source: Field survey, 2025

Table 4: Traffic Polices, Drivers are exposed by toxic gases in Dhaka city

Age-group	Number of persons	Health Problem
30-35	70	Breathing Problem, Eye-irritation.
35-40	35	Breathing Problem, Eye-irritation, Bronchitis.
40-45	65	Breathing Problem, Eye-irritation, Skin diseases.
45-50	35	Lung- cancer, Bronchitis, Skin diseases.

Source: Field survey, 2025

The findings show an increase in respiratory and skin disorders with age and length of exposure. In the 30–35 age demonstration, breathing problems and eye irritation were the most frequent symptoms, indicating the early consequences for the eyes and lungs of continuous exposure to contaminated air. Ages 35–40 have seen their symptoms increase with respondents also citing bronchitis in addition to breathing difficulties and eye irritation as the predominant symptoms, moving towards more chronic respiratory problems. Among the 40–45-year-olds, respiratory disorders, eye irritation, and skin diseases were seen to have further widened, representing the long-term exposure to toxic gases and dust as well as a mother's love of its offspring. In the 45–50 age group, that is who people in this group suffered from lung cancer, bronchitis and many other problems with the skin and they own cases were the worst mentioned in table 4. This trend reveals the age-increasing severity of problems related to air pollution exposure, implying the increased susceptibility of traffic police and drivers, who are long-time exponents of Dhaka's polluted air among the city dwellers.

3.7 Discussion:

Concentrations of SO₂ and NO₂ in Dhaka are Indicator BMP areas in the southeast and southwest close to the WHO 24-hour guideline for SO₂ (36.67 versus 40 g/m³), but the SO₂ in traffic and brick- field exceeded the limit (49.67 g/m³ and 76 g/m³, respectively). The NO₂ concentrations are higher than the WHO guideline (25 g/m³) in all sites, having the maximum concentrations in traffic and brick-field areas (83 g/m³ and 80 g/m³) respectively mentioned in table 5. There is a clear age-dependent and exposure-dependent increase in respiratory and skin problems about health reports, and symptoms reported by children and young adults include breathing difficulties, eye irritation, and skin diseases, while more severe outcomes such as bronchitis and lung cancer are seen in older, long- term exposed groups (e.g., traffic police, drivers; Pavel et al., 2021; Rahman et al., 2025; Siddiqui et al., 2020; Chen et al., 2022). These are in line with recent findings reporting Dhaka were usually hazardous, particularly in high traffic and industrial areas. Sium et al. (2024) highlights the unwanted soaring concentrations of NO₂ and SO₂ in urban hotspots such as Gulistan and Savar exceeding permissible limits, while brick kilns and vehicular emissions are dominant sources. Also, long-term increasing trends of NO₂ and SO₂ were noted by Pavel et al. (2021), with chronic exposure leading to considerable public health risk, especially for children, as they are the most vulnerable group. Salam et al. (2008) concluded that although mean SO₂ and NO₂ concentrations occasionally fall under the annual guidelines recommended by the WHO, maximum concentrations in traffic-related and industrial areas can be significantly higher, consistent with the present findings.

Table 5: Comparison of Pollutant Concentrations with WHO Limits

Pollutant	WHO 24-h Standard ($\mu\text{g}/\text{m}^3$)	Residential	Traffic Area	Brick-Field
SO ₂	40	36.67 (✓ Below)	49.67 (X Above)	76 (X Above)
NO	No standard	41.33	54.67	48
NO ₂	25	52.33 (X Above)	83 (X Above)	80 (X Above)

The AHRs for health effects that ranged from respiratory symptoms in children to chronic diseases in adults were also found in the literature. Pavel et al. (2021) pointed out that chronic exposure to these pollutants poses a high risk to health, in particular, for infants and children. Among the rank list, Gurjar et al. (2010) identified Dhaka as one of the megacities experiencing the highest excess mortality and morbidity from air pollution and called for the urgent need to address this issue. Seasonal and spatial variations such as high levels in winter and around brickfields are not new phenomena (Hoque, 2020; Rahman et al., 2019). Integration of policies to manage air pollution in Dhaka and other comparable cities should be based on cross-sectoral, evidence-based approaches which consider the multifarious sources of emissions and related health outcomes. Stricter emissions controls need to be put in place, particularly for vehicles and brick kilns, which contribute largely to the SO₂ and NO₂ pollution, and airborne discharges from these industries as well as augmenting the use of cleaner technologies in these sectors have led to significant reductions in emissions and to a positive impact on the public health (Brooks et al., 2025; Sofia et al., 2020). Robust air quality monitoring, along with transparent data sharing, is also needed to inform policy, monitor progress, and support adaptive management (Sofia et al., 2020). International proof indicates that policy packages (a combination of regulatory, technological, and behaviour intervention) tend to be more effective than single policy system approaches, and that cooperation across sectors and cross-regional is a precondition for long-term improvement of air quality and public health (Khreis et al., 2023; Feng et al., 2025). Urban planning measures such as enhancing urban greening and developing buffer zones around residential and school areas can further mitigate exposure and improve air quality (Ahmed et al., 2024). Public health interventions such as periodic health evaluations and distribution of protective equipment to populations in high-risk occupations are critical in reducing the health burden associated with chronic exposure to airborne pollutants (Pavel et al., 2021). 9 Co-benefits / Nexus: policies and strategies Solidly integrated air quality management within climate and public health-targeted policy instruments (co-beneficial policy instruments) are suggested to be more effective than focusing only on one policy instrument due to exploiting synergies and avoiding policy trade-offs (Kuylenstierna et al., 2020; Feng et al., 2025).

4. Conclusion

The present research was able to generate significant level of information regarding concentrations of some of the toxic gases in the ambient air of Dhaka and the probable sources. The number of automobiles has been increasing in Dhaka city at the rate of at least 10 percent annually, which has been contributing to air pollution on one hand and traffic congestion on the other. The results of this study highlight that while significant progress has been made in understanding air pollution and its health impacts. It was however, not possible to link any of the particular toxic gases measured affecting human health. Significantly high levels of some of the toxic gases measured compared to different areas are indicative of deteriorating air quality in Dhaka and deserves continuous monitoring and policy framing for curbing production and emission of the gases. The results of the discussion of contamination in Dhaka are apparent in expanded respiratory issues, cardiovascular infections, and other well-being issues among the inhabitants. The financial effect is imminent, with higher healthcare costs, diminished efficiency, and expanded costs related to relieving the impacts of contamination. The particulate matter not as it were influences human well-being but also contributes to natural corruption,

affecting environments and biodiversity. One key limitation is the narrow scope of current data collection, which often relies on a limited number of monitoring stations or focuses on specific urban areas. Moving forward, it is essential to expand air quality monitoring networks to cover a wider range of locations, including both urban and rural areas, and to integrate advanced technologies such as low-cost sensors and remote sensing for more comprehensive data. Social surveys should also be broadened in scope, employing inclusive and representative sampling strategies to ensure that the voices and experiences of all community members are captured. Furthermore, fostering community engagement and participatory approaches in both data collection and policy development can enhance the relevance and effectiveness of interventions. By addressing these limitations and adopting a more holistic, inclusive approach, future research and policy can better inform targeted actions to reduce air pollution and protect public health.

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