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Status of Gaseous Air Pollutants in Biomass Burning Smoke from Agricultural Field in Bangladesh

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Abstract

This study was carried out to determine the concentrations of gaseous air pollutants (CH_4, $PM_{2.5}$, PM_{10}, CO_2, CO, Cl_2, NH_3, SO_2, NO_2) and its multifaceted effects on human health in various locations in Bangladesh. As Bangladesh is an agricultural country, agricultural biomass burning is a common practice here and this incident typically occurs during the dry season from October to March. Therefore, this study was conducted in seven different areas in dry season where biomass (water hyacinth) was burnt mainly in the river land areas. In this paper, the health impact of biomass burning smoke from agricultural field was examined on the exposed people to the burning pollutants. These pollutants have adverse effects on human health contributing to respiratory problems, cardiovascular diseases, and other health issues. Considering all types of pollutants, excessive amounts of $PM_{2.5}$, PM_{10}, CH_4, and SO_2 are present in the air. In this study, pollutant concentration methods, spatial distribution methods and exposures assessment methods were used to prepare the project work. From the URB AIR guidebook, the mortality and morbidity were calculated and the results of mortality of excess death high exposure were 68, moderate exposure 32 and average exposure 100. Additionally, Pearson correlation was conducted to find out a relationship among the pollutants including positive correlation between $PM_{2.5}$ and SO_2 (r = 0.777, $p < 0.05$) and PM_{10} and SO_2 (r = 0.725, $p < 0.05$) and negative correlation between SO_2 and CO (r = −0.868, $p < 0.05$) and PM_{10} and CH_4 (r = −0.891, $p < 0.01$). Promoting sustainable biomass management, educating communities and providing healthcare facilities with resources and training to recognize and address health issues related to biomass burning exposure may be the best recommendations in the context of reducing pollution level, environmental damage and health risk.

Keywords

Biomass Burning, Air Pollution, Particulate Matter, Health Impact

1. Introduction

Biomass burning refers to the combustion of organic matter, such as wood or crop waste, which can either be burned directly or converted into gaseous or liquid fuels. It is a widespread phenomenon driven by both natural processes and human activities, playing a crucial role in shaping air quality on regional and global scales. Although biomass burning has long been an agricultural practice, the increasing population and demand for agricultural land and food have significantly influenced its extent. Globally, farmers use fire as a tool for removing agricultural waste and excess crop residue from fields. Agricultural biomass burning refers to the intentional burning of crop residues, such as stubble, straw, or other agricultural waste, as a method to clear fields for the next planting season or for disposal purposes. Though Bangladesh is a fast-developing nation in Southeast Asia, the majority of its population about 80% still lives in rural regions. The biomass produced by forestry and agriculture is a significant source of fiber, food, fuel, fodder, and organic fertilizer in rural parts of developing nations. Thus, there is pressure from several sectors on biomass.

Bangladesh is predominantly an agricultural nation, thus burning agricultural waste is a popular practice here, especially during the dry season, which runs from October to March. Significant amounts of pollutants can be produced and released into the atmosphere by biomass burning, which includes peatland fires, wildfires, open-burning agriculture, household biofuel combustion, forest fires, and grass fires. With effects on public health (Johnston et al., 2014; Linares et al., 2015; Yao et al., 2016), air quality (Jacobson, 2014), and climate (Jacobson, 2014), open and agricultural fires are one of the major contributors to primary emissions to the atmosphere. Due to the short duration of these emissions a few weeks to months—they pose a considerable danger to human health as well as have a significant impact on air quality (Koe et al., 2001; Pöschl, 2005; Gustafsson et al., 2009; Choudhury & Dey, 2017).

As biomass burning is a prevalent anthropogenic activity, it significantly contributes to air pollution, posing substantial environmental and public health challenges globally. However, the smoke emissions from these agricultural fires have an immense impact, especially in places like East Asia where burning seems to be very widespread (Streets et al., 2003). These can have a major impact on the ecosystem locally as well as far downwind; they can even have an impact on highly inhabited metropolitan regions that are located far from the agricultural areas itself (Chan & Yao, 2008; Zhang et al., 2011). Increases in concentrations of O_3 (Brook et al., 2002), CO (Bell et al., 2009), NO_2 (Latza et al., 2009), and particulate matter have been associated with detrimental health consequences and increased mortality (Garrett & Casimiro, 2011; Di et al., 2017). The burning of biomass releases gases and particulates that exacerbate respiratory ailments such as lung infections, asthma, and chronic obstructive pulmonary disease (Johnston et al., 2014; Yao et al., 2016). The tiny particles, particularly $PM_{2.5}$, have the greatest chance to harm health since they can penetrate the lungs deeply. There is continuous evidence indicating children and adults who are exposed to biomass smoke have a higher chance of developing common and severe illnesses. Particulate matter is thought to be responsible for around 3% and 5% of deaths from lung cancer and cardiovascular illnesses, respectively (WHO, 2013). Given that black carbon emissions may play a substantial role in aerosol concentrations, it is critical to assess the effects of agricultural and open fires on air pollution levels and the health consequences that follow.

According to Kim et al. (2015), there is strong evidence linking exposure to air pollution to adverse health outcomes, including cardiovascular and respiratory disorders, as well as reduced lung function. Agricultural biomass fire smoke exposure can lead to respiratory disorders, optical irritation, allergic responses, and other health issues, especially in susceptible groups including children, the elderly, and those with previous health issues. Biomass burning may have negative economic effects on nearby towns, farmers, and agriculture-related industries. Analysing these effects aids in locating prospects for diversifying sources of income and sustainable alternatives.

This research aims to enhance the understanding of this pressing environmental issue and provide insights for improved mitigation and management strategies by analysing the complex interactions between biomass burning and air pollution. Efforts are being made to explore alternative waste management techniques—such as composting or utilizing crop residues for bioenergy production—to reduce the harmful environmental impacts of agricultural biomass burning. This study seeks to assess the current state of pollution caused by biomass burning in rural areas and its effects on public health. It is anticipated that the findings will contribute to sustainable biomass management practices and raise awareness about the pollution associated with biomass burning. Given the significant impact of biomass burning on climate and air quality, ongoing research continues to investigate its emissions and their broader environmental consequences.

2. Methods

2.1. Nature of the Study

This study investigates the effects of biomass burning on air quality and health impacts in Madargonj Upazila, Jamalpur, Bangladesh. The study employs quantitative methods, utilizing air quality monitoring, spatial analysis, and health risk estimation. Using an Aeroqual Handheld Air Quality Monitor series 500, the study monitors air contaminants at seven monitoring stations.

2.2. Study Samples

A total of 7 air quality monitoring stations were systematically selected representing diverse biomass burning activities. While the limited number of stations provides a snapshot of pollution levels, it is acknowledged that this sample size may limit generalizability. Future studies are recommended to expand sampling across seasons and larger geographical areas to capture temporal and spatial variability. Data was gathered from December 22, 2024 to December 26, 2024 the selected seven distinct stations. These 7 sample sites were selected in a systematic manner to complete the study efficiently. Data were collected from Shamgonj Kalibari, Nandina, Baromaisha, Krishnopur, Milon Bazar, Jurkhali, Chor Bhatiani at Madargonj upazila in Jamalpur district, Bangladesh.

The selection of seven monitoring stations was based on 1) the homogeneity of biomass burning practices across Madargonj Upazila, 2) logistical feasibility given resource constraints, and 3) the need for spatially distributed data to capture localized pollution hotspots. While this sample size limits extrapolation to larger regions, it provides a robust baseline for future studies in similar rural agricultural contexts.

2.3. Parameters of Interest

The study monitored the following air pollutants:

- Particulate Matter ($PM_{2.5}$, PM_{10})
- Nitrogen Dioxide (NO_2)
- Carbon Dioxide (CO_2)
- Methane (CH_4)
- Chlorine (Cl_2)
- Ozone (O_3)
- Sulfur Dioxide (SO_2)
- Carbon Monoxide (CO).

Monitoring Tools

The Aeroqual Handheld Air Quality Monitor (Series 500) was utilized for real-time measurement (**Figure 1**). To improve data reliability, future studies could incorporate additional validation methods, such as cross-referencing with stationary air quality monitors or secondary datasets.

The portable monitors can be configured with 28 different gas sensors (CH_4, $PM_{2.5}$, PM_{10}, CH_4, CO, Cl_2, NH_3, SO_2, NO_2, CO_2, VOC) and particulate matter. It is possible to measure the target gases in ambient air at different concentrations in outdoor and indoor environments.

2.4. Data Analysis

A GPS device was used to record the longitude and latitude in the field, and the data was subsequently entered into ArcGIS 10.8.2, a geographic information system application. After data collection, Microsoft Word 2007 and Microsoft Excel 2007 were used to organize and evaluate the data. The Aeroqual Series 500 is used to collect the data from the machine, and it is then used to present the data

Figure 1. Aeroqual handled air quality monitor with sensors. ($PM_{2.5}$, PM_{10}, CH_4, CO, Cl_2, NH_3, SO_2, NO_2, CO_2).

using simple statistical approaches and methodologies, including a variety of tables, diagrams, graphs, and flow charts, among other things. Data on (CH_4, $PM_{2.5}$, PM_{10}, CH_4, CO, Cl_2, NH_3, SO_2, NO_2, CO_2) has been collected from the device. The facts obtained for the research paper's major portion are explained using tables and graphs, which are also used to highlight the theme of the study.

Inverse Distance Weighted (IDW) interpolation was selected for its simplicity and effectiveness in visualizing spatial trends with limited monitoring points. However, IDW assumes uniform spatial dependence, which may not fully capture micro-scale variability. Future work could validate these results with kriging or land-use regression models.

2.5. The Spatial Distribution Method for Showing (CH_4, $PM_{2.5}$, PM_{10}, CH_4, CO, Cl_2, NH_3, SO_2, NO_2, CO_2)

ArcGIS 10.8.2 was used to analyze the geographical distribution of particular air pollutants in Madargonj Upazila's biomass burning pollution. GIS-based pollution mapping makes use of interpolation techniques. The interpolation method employed in the study was Inverse Distance Weighted (IDW). The IDW interpolation approach is a multivariate interpolation analysis that uses a known set of scattered points to identify unknown points. The weighted average of the known points is used to identify the data for the unknown points. The weights, which are a function of the distance between the sampled and unsampled locations, can be calculated using the IDW power coefficient.

The IDW-derived spatial distributions should be interpreted with caution, as the small number of stations may oversimplify pollution gradients. Ground-truthing with additional sensors or hybrid modeling approaches would improve accuracy.

2.6. Methods to Identify the Health Impacts on People

We use survey unit-level and regional-level pollution data to evaluate the extent of exposure to the following pollutants: (CH_4, $PM_{2.5}$, PM_{10}, CO, Cl_2, NH_3, SO_2, NO_2, CO_2). Next, by assigning to each survey unit's occupants a distance-weighted average of pollutant concentrations (CH_4, $PM_{2.5}$, PM_{10}, CO, Cl_2, NH_3, SO_2, NO_2, CO_2) predicted by the Ostro (1994), we utilize the concentration response to evaluate the health effects of this exposure. In this investigation, the following air pollutants are the focus: $PM_{2.5}$, PM_{10}, CH_4, CO, Cl_2, NH_3, SO_2, NO_2, CO_2. Particles containing a mixture of solid and liquid droplets exist in the atmosphere for a longer period of time than larger particles due to their smaller size and light weight. This is small enough to be breathed and enter the respiratory system profoundly after being absorbed into the bloodstream.

Health impact estimates were derived from pollutant exposure levels but do not account for individual-level confounders (e.g., pre-existing respiratory conditions, access to healthcare, or concurrent exposure to indoor air pollution). These factors may modify risk and should be investigated in future longitudinal studies.

2.6.1. Dose-Response Assessment

All people are not exposed to equal concentration. However, three categories of concentration may be taken such as

1) Average exposure concentration.
2) Moderate exposure concentration.
3) High exposure concentration.

According to the World Bank, WHO, the average exposure concentration and value is 122.7 μg/m^3. They proposed that the population who are overexposed should be exposed three times.

1) Average exposure concentration 122.7 μg/m^3.
2) Moderate exposure concentration 245.4 μg/m^3.
3) High exposure concentration 368.4 μg/m^3.

2.6.2. Estimation of Excess Death Resulting from Exposure to Pollutants (CH_4, $PM_{2.5}$, PM_{10}, CO, Cl_2, NH_3, SO_2, NO_2, CO_2)

The "URB AIR" urban air quality management plan in Asia, greater Mumbai report, provides a dose-response relationship that can be used to estimate the excess fatality caused by exposure to pollutants (CO_2, $PM_{2.5}$, PM_{10}, CH_4, CO, Cl_2, NH_3, SO_2, NO_2).

A World Bank publication, as indicated below,

$$\text{Excess death} = 0.00112 \times [\text{Pollutants} - 41] \times P \times C$$

where,

P = number of people exposed

C = Crude mortality rate 0.00535 (according to World Atlas Data, 2015)

$$\text{High exposure} = 0.00112 \times [368.4 - 41] \times P \times C$$

$$\text{Moderate exposure} = 0.00112\ [245.4 - 41] \times P \times C$$

$$\text{Average exposure} = 0.00112 \times [122.7 - 41] \times P \times C$$

$$\text{Excess death} = 0.00112 \times [\text{Pollutants} - 41] \times P \times C$$

where,

P = number of people exposed

C = Crude mortality rate 0.00756 (according to world Atlas Data, 2015)

$$\text{High exposure} = 0.00112 \times [368.4 - 41] \times P \times C$$

$$\text{Moderate exposure} = 0.0012 \times [245.4 - 41] \times P \times C$$

$$\text{Average exposure} = 0.00112 \times [122.7 - 41] \times P \times C$$

a) Bronchitis

Change in yearly cases of chronic bronchitis per 100,000 people is estimated at 6.12 pollutants (CO_2, CH_4, CO, Cl_2, NH_3, SO_2, NO_2).

The number of cases = 6.12 × [Pollutants − 41] < P

$$\text{High exposure} = 6.12 \times [368.4 - 41] \times P$$

$$\text{Moderate exposure} = 6.12 \times [245.4 - 41] \times P$$

$$\text{Average exposure} = 6.12 \times [122.7 - 41] \times P$$

b) Restricted Activity Days

Change in yearly cases of restricted activity days per person estimate pollutants. If the WHO standards are used, the change = 0.0575 × [Pollutants − 41] × P

$$\text{High exposure} = 0.0575 \times [368.4 - 41] \times P$$

$$\text{Moderate exposure} = 0.0575 \times [245.4 - 41] \times P$$

$$\text{Average exposure} = 0.0575 \times [122.7 - 41] \times P$$

c) Respiratory Hospital Diseases

Change respiratory hospital diseases per 100,000 people estimated at 1.2 using WHO standard.

Respiratory hospital diseases per 100,000 are estimated at 1.2 × [Pollutants − 41] × P/100,000

$$\text{High exposure} = 1.2 \times [368.4 - 41] \times P/100{,}000$$

$$\text{Moderate exposure} = 1.2 \times [245.4 - 41] \times P/100{,}000$$

$$\text{Average exposure} = 1.2 \times [122.7 - 41] \times P/10{,}000$$

d) Emergency Room Visits

Change Emergency room visits per 10,000 people estimated at 23.54 μg/m^3 PM using WHO standard, Emergency room visit per 100,000 are estimated at 23.54 [pollutants – 41] P/100,000

$$\text{High exposure} = 23.54 \times [368.4 - 41] \times P/10{,}000$$

$$\text{Moderate exposure} = 23.54 \times [245.4 - 41] \times P/100{,}000$$

$$\text{Average exposure} = 23.54 \times [122.7 - 41] \times P/10{,}000$$

e) Asthma Attack

Change in daily asthma attack per cases of Asthmatic person is estimated.

The number of asthmatic persons is estimated at 7% of the population.

$$\text{The number of asthma attack} = 0.0326 \times [\text{pollutants} - 41]$$

$$\text{High exposure} = 0.0326 \times [368.4 - 41]$$

$$\text{Moderate exposure} = 0.0326\ [245.5 - 41]$$

$$\text{Average exposure} = 0.0326 \times [122.7 - 41]$$

f) Respiratory Symptom Days

Respiratory symptom days per person estimated per year are estimated at 0.183 × [pollutants − 41] < h

$$\text{High exposure} = 0.183 \times [368.4 - 41] \times h$$

$$\text{Moderate exposure} = 0.183 \times [245.4 - 41] \times h$$

$$\text{Average exposure} = 0.183 \times [122.7 - 41] \times h$$

3. Result

3.1. Types and Amount (kg) of Biomass Used in the Study Area, 2023

The quality, quantity and kind of biomass used for burning in agricultural land are significant as they have varying energy content, combustion characteristics, and environmental and health impacts. Different types of biomasses such as water hyacinth, grass and weeds, dried leaves are mainly used for burning in the study area. Here, we indicate the sampling locations Shamgonj Kalibari, Milon Bazar, Jorkhali, Nandina, Baromaisha, Chor Bhatiani, Krisnopur respectively with the number of 1, 2, 3, 4, 5, 6, 7.

Table 1. Types and amount (kg) of biomass used in the study area, 2023.

No of sampling location	Using type of biomass used in the study area	Amount of biomass used (kg) in the study area	Percentage of biomass uses as amount
1, 2, 3, 4, 5, 6, 7	Water hyacinth	1680	60%
2, 3, 5, 7	Grass and weeds	750	26%
1, 4, 6	Dried leaves	400	14%

(Source: Field survey, 2023).

As shown in "**Table 1**" among the different biomass sources, water hyacinth was the most commonly used, accounting for 60% of the total biomass consumption, with 1680 kg utilized across sampling locations 1, 2, 3, 4, 5, 6, and 7. Grass and weeds were the second most used biomass type, comprising 26% of the total, used mainly in locations 2, 3, 5, and 7, with a total consumption of 750 kg. The least used biomass was dried leaves, contributing 14% (400 kg) and utilized in locations 1, 4, and 6. This distribution reflects the availability and preference of local communities for specific biomass resources in their daily activities.

As shown in "**Figure 2**" this distribution is also visually represented by the percentage of different biomass types used, reflecting the availability and preference of local communities for specific biomass resources in their daily activities. It is clearly visualized the dominance of water hyacinth in the study area.

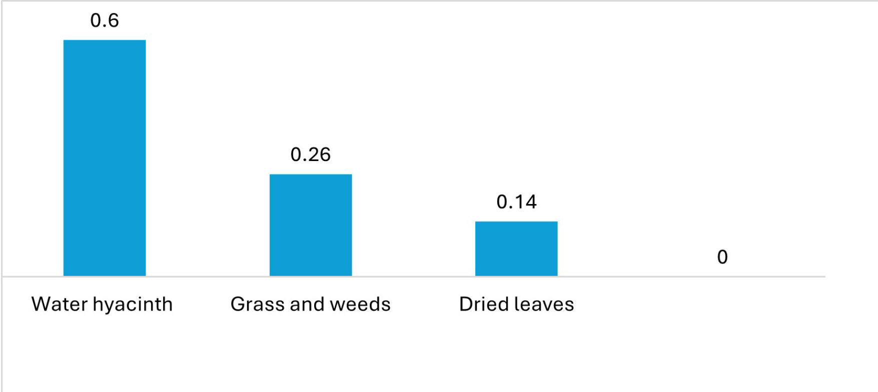

Figure 2. Percentage of different types of biomasses used in the study area, 2023.

3.2. The Spatial Distribution Method for Showing (CH_4, $PM_{2.5}$, PM_{10}, CO, Cl_2, NH_3, SO_2, NO_2, CO_2)

3.2.1. Spatial Distribution of CH_4 Concentration in the Study Area

As shown in **Table 2** the concentration of CH_4 ranges from 76 - 230 mg/m^3 with the mean value of 139.36 mg/m^3 (212. 96 ppm). The mean concentration of CH_4 in this study is found higher than the study of Gazipur City ranging from 0 to 4.66 mg/m^3 (Rehnuma et al., 2023), a combined study of Dhaka, Narayanganj, Munshiganj, Narsingdi and Gazipur ranging from 0.63 - 0.67 ppb (Hassan & Bhuiyan, 2021), Chittagong City with the mean value of 4.85 ppm (Rouf et al., 2012), and Shanghai, China 2.154 ppm (Wei et al., 2020). However, the spatial distribution (**Figure 3**) showed the highest concentration of CH_4 in Shamgonj Kalibari which is about 228.98 mg/m^3 and the lowest concentration is 76 mg/m^3 which was found at Milon Bazar.

3.2.2. Spatial Distribution of SO_2 Concentration in the Study Area

As shown in **Table 2**, the concentration of SO_2 ranges from 4.2 - 13 mg/m^3 with the mean value of 7.05 mg/m^3 (2.69 ppm). The mean concentration of SO_2 in this study was found higher than the study of Nanjing, China (0.005 ppm) (Hasnain et al., 2023) Shijiazhuang, China (0.008 ppm) (Tui et al., 2021), Delhi, India (0.002 ppm) (Tyagi et al., 2016), Narayanganj, Bangladesh (0.006 ppm) (Rahman et al., 2019), Chittagong, Bangladesh (0.0032 - 0.0128 ppm) (Hoque et al., 2022), and Dhaka (0.0102 - 0.0234 ppm) (Hoque et al., 2020). However, the spatial distribution (**Figure 4**) showed the highest concentration of SO_2 in Jorkhali which is about 12.6 mg/m^3 and the lowest concentration is 4.2 mg/m^3 which was found at Shamgonj Kalibari.

3.2.3. Spatial Distribution of NO_2 Concentration in the Study Area

As shown in **Table 2** the concentration of NO_2 ranges from 0.087 - 0.095 mg/m^3 with the mean concentration of 0.092 mg/m^3 (0.049 ppm). The mean concentration

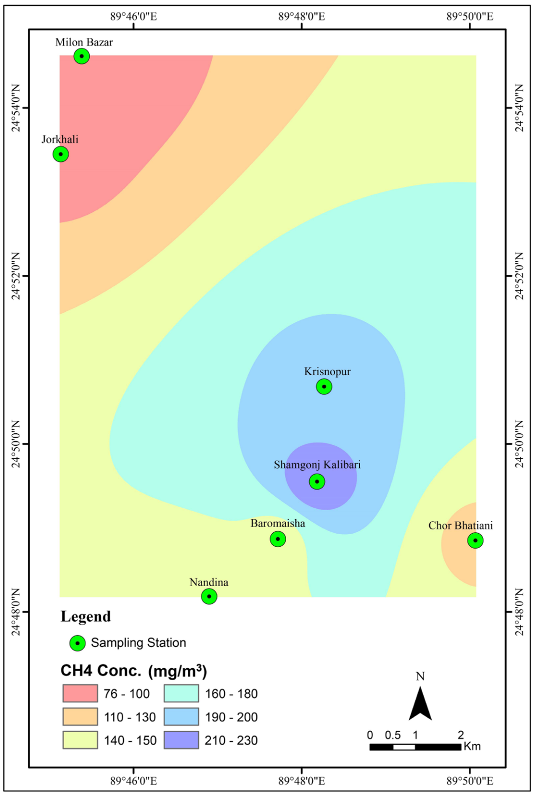

Figure 3. Spatial distribution of CH_4 concentration in the study area.

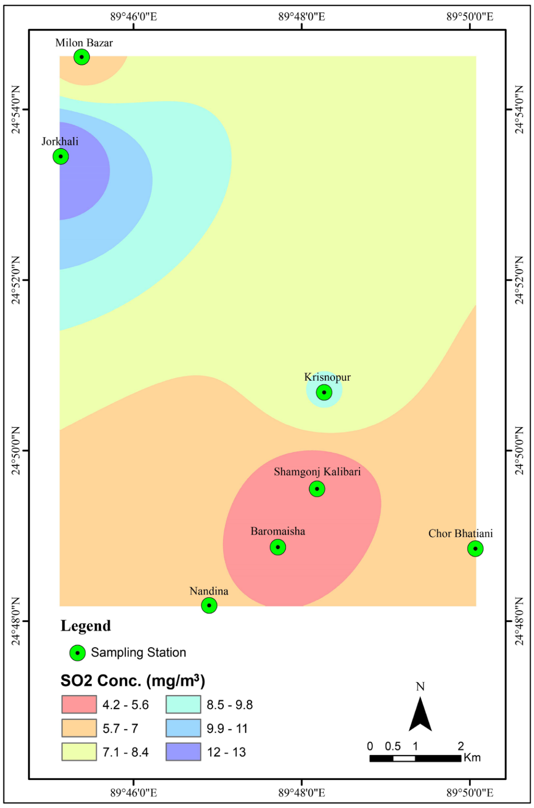

Figure 4. Spatial distribution of SO_2 concentration in the study area.

of NO_2 in this study was found higher than the study of Nanjing, China (0.03 ppm) (Hasnain et al., 2023) Shijiazhuang, China (0.02 ppm) (Tui et al., 2021), Narayanganj, Bangladesh (0.01 ppm) (Rahman et al., 2019), Chittagong, Bangladesh (0.024 - 0.065 ppm) (Hoque et al., 2022), Dhaka (0.016 - 0.055 ppm) (Hoque et al., 2020) and Barapukuria (0.034 mg/m^3) and lower than the study of Delhi, India (0.400 ppm) (Tyagi et al., 2016). However, the spatial distribution (**Figure 5**) showed the highest concentration at Chor Bhatiani which is about 0.095 mg/m^3 and the lowest concentration is 0.087 mg/m^3 which was found at Milon Bazar.

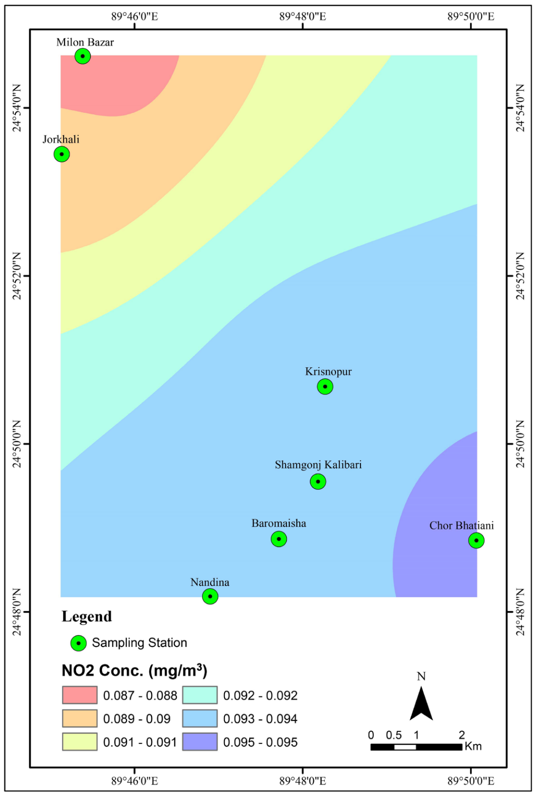

Figure 5. Spatial distribution of NO_2 concentration in the study area.

3.2.4. Spatial Distribution of CO_2 Concentration in the Study Area

As shown in **Table 2** the concentration of CO_2 ranges from 1185.58 - 1658.22 mg/m^3 where the average value is 1392.54 mg/m^3 (773.81 ppm). The mean concentration of CO_2 in this study was found higher than the study of Shanghai, China (428.36 pm) (Wei et al., 2020), Dhaka (427 ppm) (Pavel et al., 2020) and Rehnuma, Riad, and Shakur (2020) observed the average concentration of CO_2 ranged from 920 to 1238 mg/m^3 from different locations of Tangail Sadar Upazila which was mostly similar range to the findings to this present study and also with the similar range of Gazipur City ranging from 1103 to 1507.67 mg/m^3 (Rehnuma et al., 2023) and lower than the study of Jessore, Bangladesh (1061 - 2459 mg/m^3) (Akteruzzaman et al., 2023) and Rajshahi (1020 ppm) (Mahmud, Bari, & Rahman, 2017). However, the spatial distribution (**Figure 6**) showed the highest concentration of CO_2 in Krisnopur which is about 1658.22 mg/m^3 and the lowest concentration is 1185.6 mg/m^3 which was found at Chor Bhatiani.

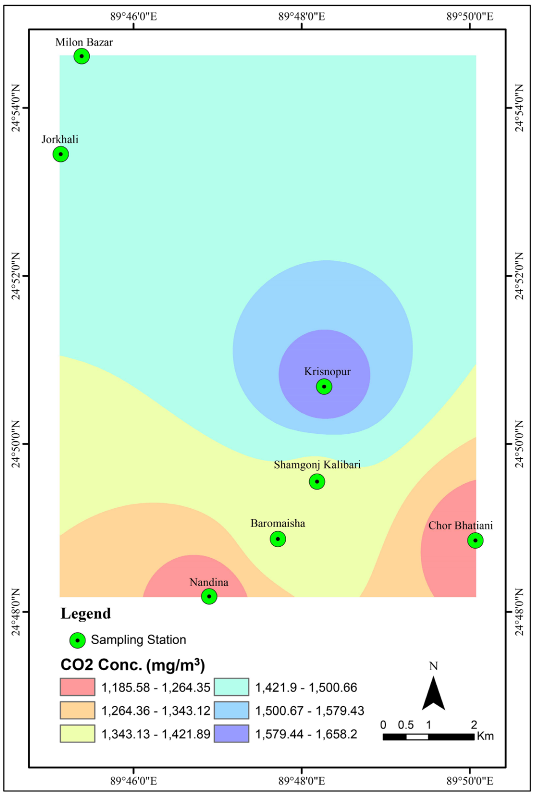

Figure 6. Spatial distribution of CO_2 concentration in the study area.

3.2.5. Spatial Distribution of Cl_2 Concentration in the Study Area

As shown in **Table 2** the concentration of Cl_2 ranges from (0 - 0.54) mg/m^3 where the average value is 0.11 mg/m^3. However, the spatial distribution (**Figure 7**) showed the highest concentration of Cl_2 in Baromaisha, which is about 0.54 mg/m^3 and the lowest concentration is 0 mg/m^3 was found at Shamgonj Kalibari and Milon Bazar. Hydroxyl and ozone are the most abundant tropospheric oxidants, but chlorine atoms are much more reactive and can oxidize functional groups or whole molecules that are resistant to the weaker common oxidants. This can increase the formation of harmful secondary pollutants including particulate matter (PM) and ozone (Ediagbonya & Tobin, 2020).

3.2.6. Spatial Distribution of NH_3 Concentration in the Study Area

As shown in **Table 2** the concentration of NH_3 ranges from (0.067 - 0.28) mg/m^3 where the average value is 0.217 mg/m^3. Rehnuma et al. (2020) observed the average concentration of NH_3 ranged from 0.06 - 0.30 mg/m^3 from different locations of Gazipur City which was mostly similar range to the findings to this present study and Kawashima et al. (2022) also observed NH_3 in Dhaka city where average concentration of NH_3 was found accounting 40.8 μg/m^3 (3.0 - 154.6 μg/m^3). However, the spatial distribution (**Figure 8**) showed the highest concentration of NH_3

in Chor Bhatiani which is about 0.277 mg/m^3 and the lowest concentration is 0.067 mg/m^3 which was found at Nandina.

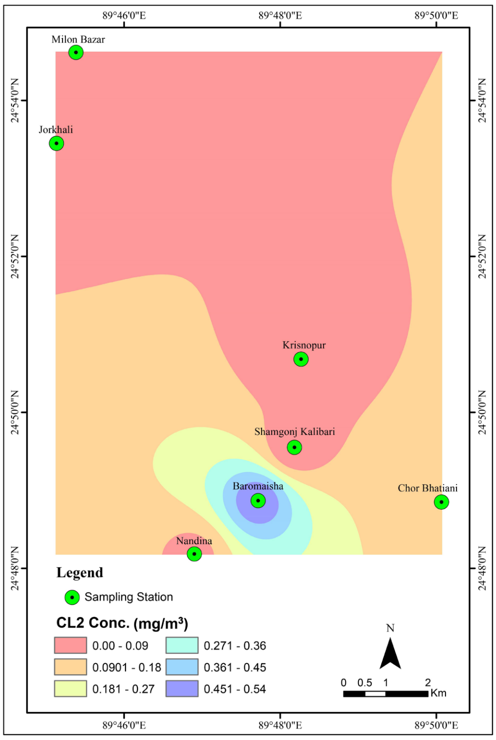

Figure 7. Spatial distribution of Cl_2 concentration in the study area.

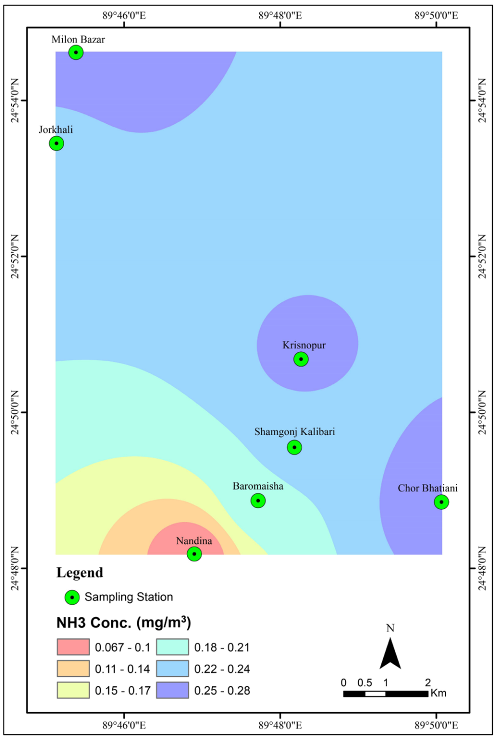

Figure 8. Spatial distribution of NH_3 concentration in the study area.

3.2.7. Spatial Distribution of CO Concentration in the Study Area

As shown in Table 2 the concentration of CO ranges from (0.47 - 0.5) mg/m^3 where the mean concentration is 0.490 mg/m^3 (0.428 ppm). The mean concentration of CO in this study was found lower than the study of Nanjing, China (0.89 ppm) (Hasnain et al., 2023) Shijiazhuang, China (1.21 ppm) (Tui et al., 2021), Delhi, India (2.3 ppm) (Tyagi et al., 2016), Narayanganj, Bangladesh (1.4 ppm) (Rahman et al., 2019), Chittagong, Bangladesh (0.6 - 1.2 ppm) (Hoque et al., 2022), and higher than the study of Dhaka (0.0012 - 0.0037 ppm) (Hoque et al., 2020), Barapukuria (0.0093 mg/m^3) and with the similar range of Serbia (0.69 ppm) (Davidovic et al., 2021). However, the spatial distribution (Figure 9) showed the highest concentration of CO in Shamgonj kalibari, Milonbazar, Nandina, Baromaisha, Chor Bhatiyani which is about 0.5 mg/m^3 and the lowest concentration is 0.47 mg/m^3 which was found at Krisnopur and Jorkhali.

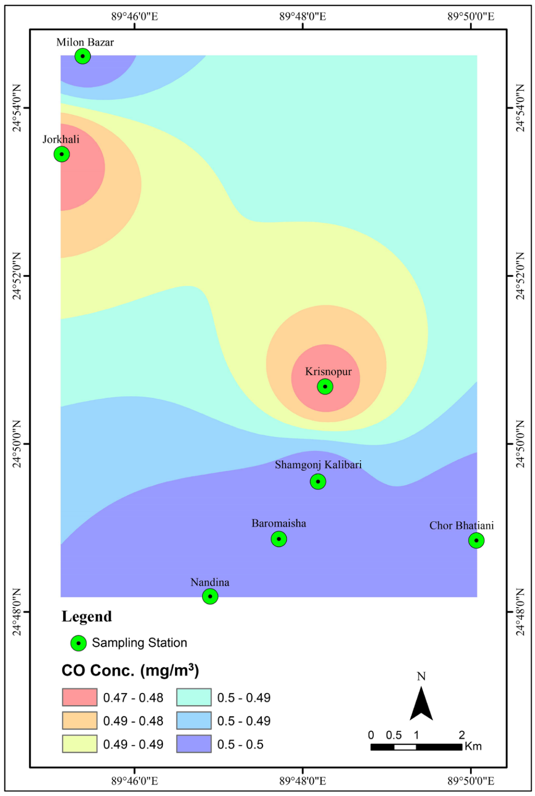

Figure 9. Spatial distribution of CO concentration in the study area.

3.2.8. Spatial Distribution of PM$_{2.5}$ Concentration in the Study Area

As shown in Table 2 the concentration of ranges PM$_{2.5}$ from (0.65 - 1.3) mg/m^3 with the mean value of 0.880 mg/m^3 (880 µg/m^3). The mean concentration of PM$_{2.5}$ in this study was found higher than the study of Nanjing, China (65.36 µg/m^3) (Hasnain et al., 2023) Shijiazhuang, China (70.64 µg/m^3) (Tui et al., 2021), Delhi, India (134 µg/m^3) (Tyagi et al., 2016), Narayanganj, Bangladesh (203.2 µg/m^3) (Rahman et al., 2019), Serbia (100 µg/m^3) (Davidovic et al., 2021), Chittagong, Bangladesh (14.6 - 93.5 µg/m^3) (Hoque et al., 2022), Dhaka (39.65 - 125.66

μg/m³) (Hoque et al., 2020), Jessore, Bangladesh (20.63 - 23.72 μg/m³) (Akteruzzaman et al., 2023), Gazipur (37.5 - 208 μg/m³) (Mukta et al., 2020) and Chittagong City with the mean value of 327 μg/m³ (Rouf et al., 2012). However, the spatial distribution (**Figure 10**) showed the highest concentration of $PM_{2.5}$ was at Jorkhali, which is about 1.256 mg/m³ and the lowest concentration was 0.65 mg/m³ which was found at Baromaisha.

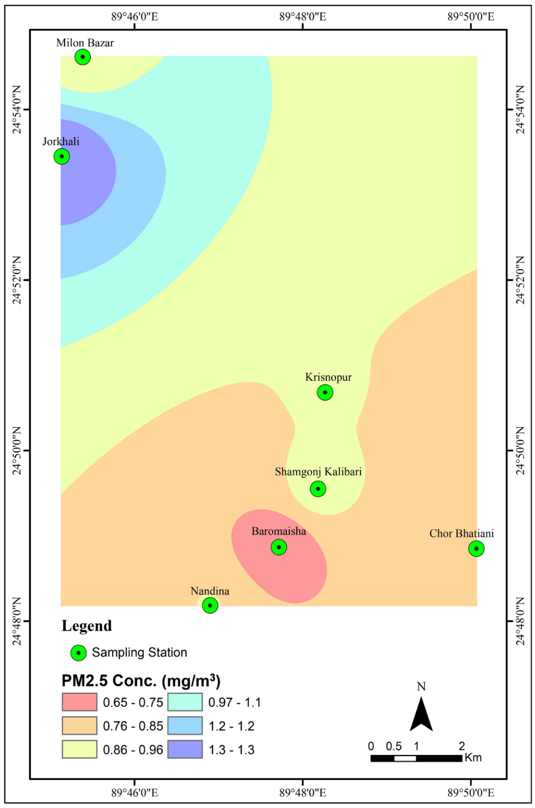

Figure 10. Spatial distribution of $PM_{2.5}$ concentration in the study area.

3.2.9. Spatial Distribution of PM_{10} Concentration in the Study Area

The concentration of PM_{10} ranges from (0.72 - 1.5) mg/m³ where the mean value is 1.14 mg/m³ (1140 μg/m³). The mean concentration of PM_{10} in this study was found higher than the study of Gazipur (85.6 - 300 μg/m³) (Mukta et al., 2020), Dhaka 139.1 - 195.3 μg/m³) (Rahman et al., 2019), Nanjing, China (102.75 μg/m³) (Hasnain et al., 2023), Shijiazhuang, China (132.77 μg/m³) (Tui et al., 2021), Delhi, India (378 μg/m³) (Tyagi et al., 2016), Narayanganj, Bangladesh (358 μg/m³) (Rahman et al., 2019), Malaysia (65.86 μg/m³) (Mohtar et al., 2018), Serbia (250 μg/m³) (Davidovic et al., 2021), Chittagong, Bangladesh (26.9 - 210 μg/m³) (Hoque et al., 2022), Dhaka (76.5 - 219 μg/m³) (Hoque et al., 2020), Dhaka (87.1 μg/m³) (Pavel et al., 2020), and Chittagong City with the mean value of 545 μ μg/m³ (Rouf et al., 2012). However, the spatial distribution (**Figure 11**) showed the highest concentration of PM_{10} was found at Jorkhali, which is about 1.457 mg/m³ and the lowest concentration was 0.721 mg/m³ which was found at Shamgonj Kalibari.

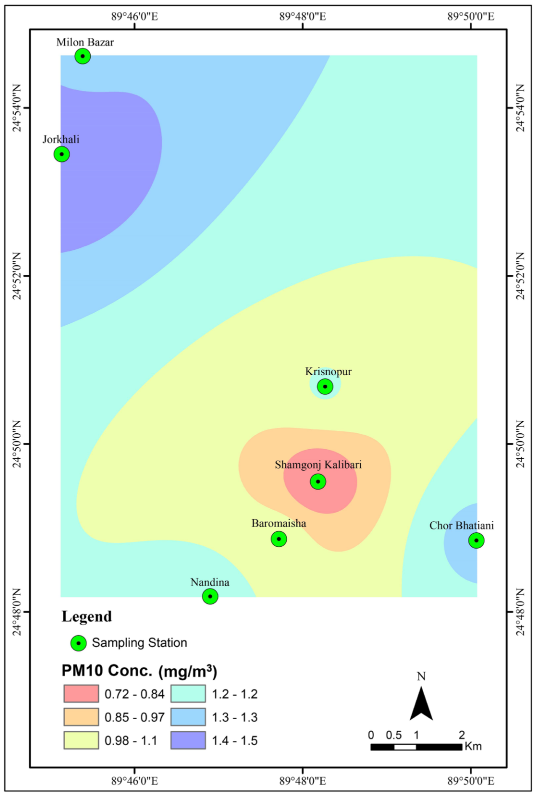

Figure 11. Spatial distribution of PM_{10} concentration in the study area.

Table 2. Pollutants concentration in the study area.

Pollutants concentration in the study area (mg/m^3)												
Parameter name	Time	Location							min avg	Max avg	Mean	Mean (ppm)
		Shaymgonj kalibari	Milon Bazar	Jorkhali	Nandina	Baromaisha	Chor Bhatiyani	Krishnopur				
CO_2	Morning	1185	1490	1206	1133	1217	1140	1520	1133	1520	1392.5	773.81
	Noon	1700	1521	1542	1175	1619	1235	1732.66	1175	1732.66		
	Evening	1322	1374	1616	1290	1322	1181.74	1722	1181.74	1722		
	Average	1402.33	1461.67	1454.67	1199.33	1386	1185.58	1658.22	1185.58	1658.22		
CO	Morning	0.5	0.5	o.47	0.5	0.5	0.5	0.47	0.47	0.5	0.49	0.428
	Noon	0.5	0.5	0.47	0.5	0.5	0.5	0.47	0.47	0.5		
	Evening	0.5	0.5	0.47	0.5	0.5	0.5	0.47	0.47	0.5		
	Average	0.5	0.5	0.47	0.5	0.5	0.5	0.47	0.49	0.49		
SO_2	Morning	0.8	3.6	2.9	0.9	0.8	4.5	5.9	0.47	4.5	7.05	2.69
	Noon	6.2	9.5	13.1	8.7	8.5	8.4	11.6	6.2	13.1		
	Evening	5.6	5.5	21.8	7.2	7.2	7.2	8.3	5.5	21.8		
	Average	4.2	6.2	12.6	5.6	5.5	6.7	8.6	4.2	12.6		
NO_2	Morning	0.091	0.086	0.089	0.091	0.09	0.092	0.091	0.086	0.092	0.92	0.049
	Noon	0.094	0.087	0.089	0.092	0.095	0.095	0.093	0.087	0.095		

Continued

	Evening	0.095	0.087	0.089	0.096	0.096	0.098	0.095	0.087	0.098		
	Average	0.093	0.087	0.089	0.093	0.093	0.095	0.093	0.087	0.92		
$PM_{2.5}$	Morning	1.044	0.983	1.159	1.036	0.606	0.879	0.637	0.606	1.159	0.88	880 µg/m^3
	Noon	1.134	1.02	1.777	1.013	0.849	0.779	1.054	0.779	1.777		
	Evening	0.523	0.625	0.833	0.527	0.509	0.613	0.886	0.509	0.886		
	Average	0.9	0.876	1.256	0.858	0.654	0.757	0.859	0.65	1.25		
PM_{10}	Morning	1.116	1.82	1.167	1.48	0.796	0.899	0.769	0.769	1.82	1.14	1140 µg/m^3
	Noon	0.21	1.117	1.88	1.182	1.439	1.641	1.135	0.21	1.88		
	Evening	0.838	0.992	1.326	0.833	0.804	1.201	1.387	0.804	1.387		
	Average	0.721	1.309	1.457	1.165	1.013	1.249	1.097	0.721	1.45		
CH_4	Morning	64	59	54	62	54	180	120	54	180	139.36	212.96
	Noon	299	66	92	152	174	120	268.06	66	299		
	Evening	324	103	138	174	192	55.68	176	55.68	224		
	Average	229	76	94.67	129.33	140	118.56	188.02	76	229		
CI	Morning	0	0	0.05	0.05	0.05	0.035	0.02	0	0.05	0.11	0.037
	Noon	0	0	0.06	0.06	0.06	0.131	0.02	0	0.131		
	Evening	0	0	0.06	0.06	0.06	0.155	0.02	0	0.155		
	Average	0	0	0.056	0.056	0.54	0.131	0.02	0	0.54		
NH_3	Morning	0.2	0.2	0.1	0	0	0.3	0.2	0	0.3	0.217	0.31
	Noon	0.2	0.3	0.3	0	0.3	0.2	0.3	0	0.3		
	Evening	0.2	0.3	0.3	0.2	0.3	0.31	0.268	0.2	0.3112.6		
	Average	0.22	0.267	0.233	0.067	0.2	0.277	0.256	0.067	0.277		

3.3. Correlation Analysis among the Pollutants (CH_4, $PM_{2.5}$, PM_{10}, CO, Cl_2, NH_3, SO_2, NO_2, CO_2) of the Study Area

Pearson's correlation analysis was performed in order to determine the relationships among the gaseous air pollutants (CH_4, $PM_{2.5}$, PM_{10}, CH_4, CO, Cl_2, NH_3, SO_2, NO_2, CO_2) in different areas of Madargonj which has been shown in Table 3.

Based on the experimental settings, $PM_{2.5}$ and SO_2 are positively correlated (r = 0.777, $p < 0.05$). This relationship designates with a concentration increase of $PM_{2.5}$ in the air, it is expected to see a rise in the value of SO_2. PM_{10} and CH_4 (r = −0.891, $p < 0.01$) are also strongly correlated, but their relationship is in a negative direction. It implies with the increase of PM_{10} the value of CH_4 would likely decrease.

Other than the two mentioned significant relationships between pollutants, A Positive correlation between PM_{10} and SO_2 (r = 0.725, $p < 0.05$). A positive correlation between PM_{10} and SO_2 means that as the levels of $PM_{2.5}$ increase, the levels of SO_2 also tend to increase, and vice versa. Again, this analysis shows that the negative correlation between SO_2 and CO (r = −0.868, $p < 0.05$). This might suggest different emission sources or atmospheric processes affecting the two pollutants inversely.

Table 3. Pearson Correlation Analysis among the pollutants (CH_4, $PM_{2.5}$, PM_{10}, CO, Cl_2, NH_3, SO_2, NO_2, CO_2).

pollutants	CO_2	NO_2	CO	CH_4	NH_3	SO_2	Cl_2	$PM_{2.5}$	PM_{10}
CO_2	1								
NO_2	−0.394	1							
CO	−0.687	0.210	1						
CH_4	0.248	0.581	−0.025	1					
NH_3	0.451	−0.203	−0.261	−0.065	1				
SO_2	0.378	−0.379	−0.868*	−0.397	0.268	1			
Cl_2	−0.147	0.272	0.260	−0.065	−0.116	−0.192	1		
$PM_{2.5}$	0.268	−0.552	−0.650	−0.220	0.060	0.777*	−0.537	1	
PM_{10}	−0.046	−0.512	−0.383	−0.891**	0.153	0.725*	−0.154	0.475	1

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

3.4. Health Impact of People in the Study Area

Exposure assessment

Exposure assessment involves a determination of the size and nature of the population that has been exposed to the toxicant under consideration, and the length of time and toxicant concentration to which they have been exposed.

A) High exposure Population

Total farmers within the study area = 15,725.

The number of people in around one km radius of the study area = 3575.

The number of students within the study area = 5375.

Therefore, the total number of high exposures = 24,675.

B) Moderate Exposure Population

The people outside of the study area = 5750.

The people who live 500 m away around the study area are = 12,875.

Hence, the total number of moderate exposure people = 18,625.

C) Average Exposure

The rest of the people are on average exposure. The number of people = 20,075.

Estimation of Excess Death Resulting from Exposure to Pollutants

Excess death resulting from exposure to pollutants can be estimated from dose response lap provided by URB ADR urban or quality management strategy in Asus greater Mumbai report-A publication World Bank, shown below.

$$\text{Excess death} = 0.00112 \times [\text{pollutants} - 41] \times P \times C$$

where,

P = number of people exposed.

C = Crude mortality rate.

$$\text{High exposure} = 0.00112 \times [368.4 - 41] \times 24{,}675 \times 0.0076 = 68$$

$$\text{Moderate exposure} = 0.00112 \times [245.\ 4 - 41] \times 18{,}625 \times 0.0076 = 32$$

$$\text{Average exposure} = 0.00112 \times [122.7 - 41] \times 20{,}075 \times 0.0076 = 13$$

a) Bronchitis

Change in yearly cases of chronic bronchitis per 100,000 people is estimated at 6.12 μg/m³ pollutants. The number of cases = 6.12 × [pollutants − 41] × 15,000

$$\text{High exposure} = 6.12 \times [368.4 - 41] \times 0.24 = 480$$

$$\text{Moderate exposure} = 6.12 \times [245.4 - 41] \times 0.18 = 225$$

$$\text{Average exposure} = 6.12 \times [122.7 - 41] \times 0.20 = 100$$

b) Restricted activity days

Change in yearly cases of Restricted activity days per person estimate PM. If the WHO standards are used the change = 0.0575 × [pollutants − 41] p

$$\text{High exposure} = 0.0575 \times [368.4 - 41] \times 24{,}675 = 464{,}519$$

$$\text{Moderate exposure} = 0.0575 \times [245.4 - 41] \times 18{,}625 = 218{,}899$$

$$\text{Average exposure} = 0.0575 \times [122.7 - 41] \times 20{,}075 = 94{,}307$$

C) Respiratory hospital diseases

Change respiratory hospital diseases per 100,000 people are estimated at 1.2 using WHO standard, respiratory hospital diseases per 100,000 are estimated at 1.2 × [pollutant − 41] × P/100,000

$$\text{High exposure} = 1.2 \times [368.4 - 41] \times 0.24 = 94$$

$$\text{Moderate exposure} = 1.2 \times [245.4 - 41] \times 0.18 = 44$$

$$\text{Average exposure} = 1.2 \times [122.7 - 41] \times 0.20 = 19$$

d) Emergency room visits

Change respiratory hospital diseases per 100,000 people are estimated at 1.2 per μg/m³ pollutants using WHO standard, Emergency room visits per 100,000 are estimated at 23.54 [pollutant − 41] × P/100,000

$$\text{High exposure} = 23.54 \times [368.4 - 41] \times 0.24 = 1849$$

$$\text{Moderate exposure} = 23.54 \times [245.4 - 41] \times 0.18 = 866$$

$$\text{Average exposure} - = 23.54 \times [122.7 - 41] \times 0.20 = 384$$

e) Asthma attack

Change in daily asthma attacks per case of Asthmatic person is estimated at the number of asthmatic persons is estimated at 7% of the population.

The number of asthma attack = 0.0326 × [pollutants − 41]

$$\text{High exposure} = 0.0326 \times [368.4 - 41] \times 1727 = 18{,}432$$

$$\text{Moderate exposure} = 0.0326 \times [245.4 - 41] \times 1303 = 8682$$

$$\text{Average exposure} = 0.0326 \times [122.7 - 41] \times 1405 = 3742$$

f) Respiratory symptom days

Respiratory symptom days per person estimated per year are estimated at 0.183

$$[\text{pollutants} - 41] \times p]$$

$$\text{High exposure} = 0.183 \times [368.4 - 41] \times 24{,}675 = 1{,}478{,}382$$

$$\text{Moderate exposure} = 0.183 \times [245.4 - 41] \times 18{,}625 = 696{,}671$$

$$\text{Average exposure} = 0.183 \times [122.7 - 41] \times 20{,}075 = 300{,}143$$

Table 4. Exposure assessment of population in the study area.

Number of populations exposed in the study area										
Exposure type	Type of population in the study area	Survey (No.) from farmers	Shamgonj kalibari	Milon Bazar	Jorkhali	Nandina	Baromaisha	Chor Bhatiyani	Krisnopur	Total
		1	3000	2500	2200	2000	2500	2000	2000	
		2	2000	3000	1500	2500	3000	2500	2000	15,725
	Farmers	3	2500	3200	2500	1500	2000	2000	1500	
		4	2000	2000	3000	1500	2500	1500	2500	
			Avg = 2375	Avg = 2675	Avg = 2350	Avg = 1875	Avg = 2500	Avg = 2000	Avg = 2000	
		1	500	500	500	500	300	800	500	
		2	200	500	500	300	700	500	500	3575
High exposure	People in 1 km Radius	3	300	800	500	200	300	1000	700	
		4	300	600	800	700	500	500	500	
			Avg = 325	Avg = 600	Avg = 575	Avg = 425	Avg = 450	Avg = 700	Avg = 550	
		1	1500	300	800	500	800	500	500	
		2	1500	500	800	500	800	300	500	
		3	2000	500	1000	800	500	500	700	5375
	Students	4	1500	500	1000	500	700	1000	500	
			Avg = 1625	Avg = 450	Avg = 900	Avg = 575	Avg = 700	Avg = 575	Avg = 550	
										Total = 24,675
		1	2000	1200	1000	500	600	700	1200	
		2	1500	700	500	700	800	500	1000	5750
Moderate exposure	Outside people	3	1000	500	500	300	1000	500	700	
		4	1000	1000	1000	500	600	800	700	
			Avg = 1375	Avg = 850	Avg = 750	Avg = 500	Avg = 750	Avg = 625	Avg = 900	
		1	3000	2500	2000	1500	2500	2000	1000	
		2	4000	2000	1500	1000	1800	1500	700	12,875
		3	3000	1800	2500	1200	2000	1000	800	
	People of 500 m away around the study area	4	2500	2000	1500	1500	2200	1500	1000	
			Avg = 3125	Avg = 2075	Avg = 1875	Avg = 1050	Avg = 2125	Avg = 1500	Avg = 1125	
										Total = 18,625

Continued

Average exposure	Rest of the people	1	5000	4500	4000	1800	3000	2500	1800	20,075
		2	4500	4000	2500	2000	2500	2200	2000	
		3	3000	3000	3500	2500	3200	2500	2500	
		4	3500	3000	2800	2500	2000	2000	2000	
			Avg = 4000	Avg = 3625	Avg = 3200	Avg = 2200	Avg = 2675	Avg = 2300	Avg = 2075	

As shown in "Table 4", the exposure assessment reveals that a significant portion of the study area's population is subject to varying degrees of pollution exposure. High exposure groups—comprising farmers, students, and residents within a 1 km radius—total 24,675 individuals. Meanwhile, 18,625 people fall under moderate exposure, including those living 500 meters around the area and those residing outside the immediate vicinity. The remaining 20,075 individuals experience average exposure. This categorization forms the basis for estimating potential health impacts such as excess deaths, bronchitis cases, respiratory hospital admissions, emergency room visits, asthma attacks, and respiratory symptom days.

Table 5. Valuation of health impacts due to pollutants.

Case	Item	High exposure	Moderate Exposure	Average exposure	Total exposure
Mortality	Excess death	68	32	100	200
Morbidity	Bronchitis	480	225	100	805
	Restricted activity day	464,519	218,899	94,307	777,725
	Respiratory hospital diseases	94	44	19	157
	Emergency Room visits	1849	866	384	3099
	Asthma attack	18,432	8682	3742	30,856
	Respiratory Symptom days	1,478,382	696,671	300,143	2,475,196

(Source: Field survey, 2023).

Table 5 presents the estimated health impacts caused by pollution across varying exposure levels. High exposure areas recorded the highest number of cases across all health indicators. Excess deaths occurred in the high exposure group, indicating a direct link between pollution levels and mortality. There were 68 excess deaths and 805 bronchitis cases, with over 1,478,382 respiratory symptom days in highly exposed groups. Moderate and average exposure areas also showed significant health burdens, though comparatively lower. Overall, pollution exposure is directly linked to increased mortality, morbidity, hospital visits, and respiratory problems.

4. Discussion

A portable sensor-based air quality measurement system was used in this study to assess the levels of the main air pollutants ($PM_{2.5}$, PM_{10}, CH_4, CO, Cl_2, NH_3, SO_2, NO_2, CO_2). For this purpose, a total of seven sampling locations were studied on the biomass burning impact in Jamalpur. In this study, it is noteworthy to mention that the concentration of O_3, H_2S were so negligible in the Jamalpur air that the sensors of the portable monitoring station could not record any values. Also, through spatial distribution, it was remarked the station number containing the highest and the lowest concentration of the pollutants by using various colors whereas red color denotes the lowest concentration and purple color denotes the lowest concentration range of pollutants. Comparing with other studies we found that the concentration of SO_2 is comparatively higher than in the study of Nanjing, China (Hasnain et al., 2023); Delhi, India (Tyagi et al., 2016); Dhaka (Hoque et al., 2020). Again CO_2 is relatively similar range in the study of Tangail (Rehnuma et al., 2023), and higher than Dhaka (Pavel et al., 2020) and NO_2 is comparatively lower than Delhi, India (Tyagi et al., 2016), CH_4 is relatively higher than the study of Gajipur city (Rehnuma et al., 2023), Chittagong (Rouf et al., 2012) and Shanghi, China (Wei et al., 2020); $PM_{2.5}$ is relatively higher than Gajipur (Mukta et al.,2020), Narayangonj (Rahman et al., 2019). And PM_{10} is higher than Gajipur (Mukta et al., 2020), Chittagong (Hoque et al., 2022), Malaysia (Mohtar et al., 2018). The elevated $PM_{2.5}$ and SO_2 levels in Madargonj (880 μg/m^3 and 7.05 mg/m^3, respectively) exceed those in urban Dhaka (125.66 μg/m^3) and Gazipur (208 μg/m^3), underscoring the acute pollution burden from agricultural burning. The strong $PM_{2.5}$-SO_2 correlation (r = 0.777) suggests shared combustion-driven emission pathways, while the negative PM_{10}-CH_4 correlation (r = −0.891) may reflect dispersion dynamics or methane oxidation processes. Additionally, Pearson correlation was conducted to find out a relationship among the pollutants including positive correlation between $PM_{2.5}$ and SO_2 (r = 0.777, $p < 0.05$) and PM_{10} and SO_2 (r = 0.725, $p < 0.05$) and negative correlation between SO_2 and CO (r = −0.868, $p < 0.05$) and PM_{10} and CH_4 (r = −0.891, $p < 0.01$). It was measured that CO_2, CH_4 and SO_2 are densely concentrated in the sampling location's air of the observed area causing frequent health hazards of the villagers. From the study, it was estimated various risk factors including bronchitis, restricted activity days, respiratory hospital disease, emergency room visits, asthma attack and respiratory symptom days. At the case of bronchitis, high exposure 480, moderate exposure 225, average exposure 100 and the total exposure 805. Restricted activity days: high exposure 464,519, moderate exposure 218,899, average exposure 94,307 and the total exposure 777,725, Respiratory hospital disease high exposure 94, moderate exposure 44, average exposure 19 and total exposure 157. Emergency room visits, high exposure 1849, moderate exposure 866, average exposure 384 and total exposure 3099. Asthma attack: high exposure 18,432, moderate exposure 8682, average exposure 3742 and total exposure 30,856. For Respiratory symptom days high exposure 1,478,382, moderate exposure 696,671, average exposure 300,143 and total exposure 2,475,196. In case, the people of this area are risked at these air pollutants. This can be minimized by raising awareness about the health risks associated with biomass burning, such as respiratory issues due to air pollution and exposure to hazardous particulate matter and encouraging the use of cleaner burning technologies and the implementation of smoke-free zones. We should encourage the adoption of sustainable biomass burning practices to minimize air pollution. This includes promoting controlled burning techniques and using biomass waste for energy production.

The spatial concentration of monitoring stations within Madargonj Upazila, while sufficient to characterize local pollution patterns, may not fully represent variability in other regions with differing agricultural practices or meteorological conditions. Future studies should incorporate broader geographical coverage and multi-seasonal sampling to enhance generalizability.

Limitations

This study has several limitations: 1) short sampling duration (5 days), 2) reliance on a single sensor model without cross-calibration, and 3) lack of source apportionment to distinguish biomass burning from other emission sources. Addressing these in future work would strengthen causal inferences.

5. Conclusion

This study indicates that similar types of research can be carried out in other regions of the world to mitigate health risks, we recommend: 1) piloting community-based composting of water hyacinth to reduce burning, 2) distributing low-cost particulate masks during burning seasons, and 3) integrating air quality alerts into local healthcare programs. These interventions should be coupled with longitudinal health monitoring to evaluate effectiveness. Future studies should expand to multi-seasonal sampling and incorporate socio-economic confounders to refine policy recommendations. With the help of reliable data being available, more investigation into the pollution caused by burning biomass and its consequences on the environment across our country will be possible. The direction of future research will be decided by the findings of this investigation. It is intended that the information obtained in this study will be helpful in subsequent studies on this subject. In addition, when trustworthy data becomes available, it will support our efforts to carry out additional studies on the pollution caused by burning biomass and its effects on the ecosystem throughout our nation.

Future studies in the realm of meteorology are possible. Future studies can concentrate on determining the primary causes of human interaction with air pollution, as well as the indoor and outdoor air pollution control index of a specific location and a large-scale region, as well as relationships within various atmospheric parameters. Future research on these studies is recommended.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Akteruzzaman, M., Rahman, M. A., Rabbi, F. M., Asharof, S., Rofi, M. M., Hasan, M. K., Rahaman, M. H. et al. (2023). The Impacts of Cooking and Indoor Air Quality Assessment in the Southwestern Region of Bangladesh. *Heliyon, 9*, e12852. https://doi.org/10.1016/j.heliyon.2023.e12852

Bell, A. M., Hankison, S. J., & Laskowski, K. L. (2009). The Repeatability of Behaviour: A Meta-Analysis. *Animal Behaviour, 77*, 771-783. https://doi.org/10.1016/j.anbehav.2008.12.022

Brook, D. W., Brook, J. S., Zhang, C., Cohen, P., & Whiteman, M. (2002). Drug Use and the Risk of Major Depressive Disorder, Alcohol Dependence, and Substance Use Disorders. *Archives of General Psychiatry, 59*, 1039-1044. https://doi.org/10.1001/archpsyc.59.11.1039

Chan, C. K., & Yao, X. (2008). Air Pollution in Mega Cities in China. *Atmospheric Environment, 42*, 1-42. https://doi.org/10.1016/j.atmosenv.2007.09.003

Choudhury, R., & Dey, B. (2017). Impact of Visco-Elasticity of Mhd Free Convective Flow Past a Vertical Surface Embedded in a Porous Medium. *Advances and Applications in Fluid Mechanics, 20*, 211-228. https://doi.org/10.17654/fm020020211

Davidovic, L. M., Laketic, D., Cumic, J., Jordanova, E., & Pantic, I. (2021). Application of Artificial Intelligence for Detection of Chemico-Biological Interactions Associated with Oxidative Stress and DNA Damage. *Chemico-Biological Interactions, 345*, Article ID: 109533. https://doi.org/10.1016/j.cbi.2021.109533

Di, Q., Wang, Y., Zanobetti, A., Wang, Y., Koutrakis, P., Choirat, C. et al. (2017). Air Pollution and Mortality in the Medicare Population. *New England Journal of Medicine, 376*, 2513-2522. https://doi.org/10.1056/nejmoa1702747

Ediagbonya, T. F., & Tobin, A. E. (2020). Toxicological Assessment of Chlorine Concentration in Atmospheric Particulate Matter in Benin City, Nigeria. *Air Quality, Atmosphere & Health, 13*, 885-891. https://doi.org/10.1007/s11869-020-00848-0

Garrett, P., & Casimiro, E. (2011). Short-Term Effect of Fine Particulate Matter ($PM_{2.5}$) and Ozone on Daily Mortality in Lisbon, Portugal. *Environmental Science and Pollution Research, 18*, 1585-1592. https://doi.org/10.1007/s11356-011-0519-z

Gustafsson, O., Kruså, M., Zencak, Z., Sheesley, R. J., Granat, L., Engström, E. et al. (2009). Brown Clouds over South Asia: Biomass or Fossil Fuel Combustion? *Science, 323*, 495-498. https://doi.org/10.1126/science.1164857

Hasnain, M., Abideen, Z., Naz, S., Roessner, U., & Munir, N. (2023). Biodiesel Production from New Algal Sources Using Response Surface Methodology and Microwave Application. *Biomass Conversion and Biorefinery, 13*, 6213-6228. https://doi.org/10.1007/s13399-021-01560-4

Hassan, S., & Bhuiyan, M. A. (2021). Probable Nexus between Methane and Air Pollution in Bangladesh Using Machine Learning and Geographically Weighted Regression Modeling. *Journal of Hyperspectral Remote Sensing, 11*, 136-145. https://doi.org/10.29150/2237-2202.2021.251959

Hoque, M. Z., Islam, I., Ahmed, M., Hasan, S. S., & Prodhan, F. A. (2022). Spatio-Temporal

Changes of Land Use Land Cover and Ecosystem Service Values in Coastal Bangladesh. *The Egyptian Journal of Remote Sensing and Space Science*, *25*, 173-180. https://doi.org/10.1016/j.ejrs.2022.01.008

Hoque, R., Ahmed, S. M., Naher, N., Islam, M. A., Rousham, E. K., Islam, B. Z., & Hassan, S. (2020). Tackling Antimicrobial Resistance in Bangladesh: A Scoping Review of Policy and Practice in Human, Animal and Environment Sectors. *PLOS One*, *15*, e0227947. https://doi.org/10.1371/journal.pone.0227947

Jacobson, T. A. (2014). NLA Task Force on Statin Safety—2014 Update. *Journal of Clinical Lipidology*, *8*, S1-S4. https://doi.org/10.1016/j.jacl.2014.03.003

Johnston, I. D., McCluskey, D. K., Tan, C. K. L., & Tracey, M. C. (2014). Mechanical Characterization of Bulk Sylgard 184 for Microfluidics and Microengineering. *Journal of Micromechanics and Microengineering*, *24*, Article ID: 035017. https://doi.org/10.1088/0960-1317/24/3/035017

Kawashima, H., Yoshida, O., Joy, K. S., Raju, R. A., Islam, K. N., Jeba, F. et al. (2022). Sources Identification of Ammonium in $PM_{2.5}$ during Monsoon Season in Dhaka, Bangladesh. *Science of the Total Environment*, *838*, Article ID: 156433. https://doi.org/10.1016/j.scitotenv.2022.156433

Kim, P. S., Jacob, D. J., Mickley, L. J., Koplitz, S. N., Marlier, M. E., DeFries, R. S., Myers, S. S., Chew B. N., & Mao, Y. H. (2015). Sensitivity of Population Smoke Exposure to Fire Locations in Equatorial Asia. *Atmospheric Environment*, *102*, 11-17. https://doi.org/10.1016/j.atmosenv.2014.09.045

Koe, L. C. C., Arellano, A. F., & McGregor, J. L. (2001). Investigating the Haze Transport from 1997 Biomass Burning in Southeast Asia: Its Impact Upon Singapore. *Atmospheric Environment*, *35*, 2723-2734. https://doi.org/10.1016/s1352-2310(00)00395-2

Latza, U., Gerdes, S., & Baur, X. (2009). Effects of Nitrogen Dioxide on Human Health: Systematic Review of Experimental and Epidemiological Studies Conducted between 2002 and 2006. *International Journal of Hygiene and Environmental Health*, *212*, 271-287. https://doi.org/10.1016/j.ijheh.2008.06.003

Linares, V., Bellés, M., & Domingo, J. L. (2015). Human Exposure to PBDE and Critical Evaluation of Health Hazards. *Archives of Toxicology*, *89*, 335-356. https://doi.org/10.1007/s00204-015-1457-1

Mahmud, I., Bari, S. H., & Rahman, M. T. U. (2017). Monthly Rainfall Forecast of Bangladesh Using Autoregressive Integrated Moving Average Method. *Environmental Engineering Research*, *22*, 162-168. https://doi.org/10.4491/eer.2016.075

Mohtar, A. A. A., Latif, M. T., Baharudin, N. H., Ahamad, F., Chung, J. X., Othman, M. et al. (2018). Variation of Major Air Pollutants in Different Seasonal Conditions in an Urban Environment in Malaysia. *Geoscience Letters*, *5*, Article No. 21. https://doi.org/10.1186/s40562-018-0122-y

Mukta, T. A., Hoque, M. M. M., Sarker, M. E., Hossain, M. N., & Biswas, G. K. (2020). Seasonal Variations of Gaseous Air Pollutants (SO_2, NO_2, O_3, CO) and Particulates ($PM_{2.5}$, PM_{10}) in Gazipur: An Industrial City in Bangladesh. *Advances in Environmental Technology*, *6*, 195-209.

Pavel, M. R. S., Salam, A., Yesmin, M., Ahsan, N., Zaman, S. U., & Jeba, F. (2020). Impact and Correlation of Air Quality and Climate Variables with Covid-19 Morbidity and Mortality in Dhaka, Bangladesh. *Advances in Clinical Toxicology*, *5*, 195-209. https://doi.org/10.23880/act-16000197

Pöschl, U. (2005). Atmospheric Aerosols: Composition, Transformation, Climate and Health Effects. *Angewandte Chemie International Edition*, *44*, 7520-7540. https://doi.org/10.1002/anie.200501122

Rahman, M. S., Khan, M. D. H., Jolly, Y. N., Kabir, J., Akter, S., & Salam, A. (2019). Assessing Risk to Human Health for Heavy Metal Contamination through Street Dust in the Southeast Asian Megacity: Dhaka, Bangladesh. *Science of the Total Environment*, *660*, 1610-1622. https://doi.org/10.1016/j.scitotenv.2018.12.425

Rehnuma, M., Ahmed, M., Haque, M. A., Tori, H. R., & Habiba, U. (2023). Assessment of Ambient Air Qualities at Some Locations of Gazipur City. *Bangladesh Journal of Environmental Science*, *45*, 37-44.

Rehnuma, M., Riad, A., & Shakur, R. (2020). Assessment of Air Quality Parameters at Different Locations of Tangail Sadar Upazila, Tangail. *Journal of Environmental Science and Natural Resources*, *13*, 118-122. https://doi.org/10.3329/jesnr.v13i1-2.60699

Rouf, K., White, L., & Evans, K. (2012). A Qualitative Investigation into the Maternal Experience of Having a Young Child with Severe Food Allergy. *Clinical Child Psychology and Psychiatry*, *17*, 49-64. https://doi.org/10.1177/1359104511415636

Streets, D. G., Yarber, K. F., Woo, J., & Carmichael, G. R. (2003). Biomass Burning in Asia: Annual and Seasonal Estimates and Atmospheric Emissions. *Global Biogeochemical Cycles*, *17*, Article ID: 1099. https://doi.org/10.1029/2003gb002040

Tui, S. H., Descheemaeker, K., Valdivia, R. O., Masikati, P., Sisito, G., Moyo, E. N. et al. (2021). Climate Change Impacts and Adaptation for Dryland Farming Systems in Zimbabwe: A Stakeholder-Driven Integrated Multi-Model Assessment. *Climatic Change*, *168*, Article No. 10. https://doi.org/10.1007/s10584-021-03151-8

Tyagi, A., Tripathi, K. M., Singh, N., Choudhary, S., & Gupta, R. K. (2016). Green Synthesis of Carbon Quantum Dots from Lemon Peel Waste: Applications in Sensing and Photocatalysis. *RSC Advances*, *6*, 72423-72432. https://doi.org/10.1039/c6ra10488f

Wei, C. F., Yu, J., & Huang, T. L. (2020). Exploring the Drivers of Conscious Waste-Sorting Behavior Based on SOR Model: Evidence from Shanghai, China. In *2020 Management Science Informatization and Economic Innovation Development Conference (MSIEID)* (pp. 21-24). IEEE. https://doi.org/10.1109/MSIEID52046.2020.00012

World Health Organization (WHO) (2013). *WHO Report on the Global Tobacco Epidemic, 2013: Enforcing Bans on Tobacco Advertising, Promotion and Sponsorship.* World Health Organization.

Yao, H., Ye, L., Zhang, H., Li, S., Zhang, S., & Hou, J. (2016). Molecular Design of Benzodithiophene-Based Organic Photovoltaic Materials. *Chemical Reviews*, *116*, 7397-7457. https://doi.org/10.1021/acs.chemrev.6b00176

Zhang, F., Pant, D., & Logan, B. E. (2011). Long-Term Performance of Activated Carbon Air Cathodes with Different Diffusion Layer Porosities in Microbial Fuel Cells. *Biosensors and Bioelectronics*, *30*, 49-55. https://doi.org/10.1016/j.bios.2011.08.025