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Research Article

Spatial Distribution of Air Quality in Narayanganj District Town, Bangladesh

Ahmad Kamruzzaman Majumder[1, *], Tanjir Hossain[2], Marziat Rahman[1], Mohsina Hossain Mita[3], S M Alamgir Hossain[2]

[1]Department of Environmental Science, Stamford University Bangladesh, Dhaka, Bangladesh & Center for Atmospheric Pollution Studies (CAPS), Dhaka, Bangladesh

[2]Department of Environmental Science, Stamford University Bangladesh, Dhaka, Bangladesh

[3]Center for Atmospheric Pollution Studies (CAPS), Dhaka, Bangladesh

Abstract

Globally air pollution is a major concern as it poses serious health risks, damages the environment, contributes to climate change, and incurs substantial economic costs. The objective of this study is to monitor the Particulate Matters (PM_1, $PM_{2.5}$, and PM_{10}) and Carbon Monoxide (CO) concentration based on different land use in Narayanganj District town. This study was conducted in seven land uses, 60 locations of Narayanganj District, a district of Dhaka Division; by using portable Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector (Model: DM106) and CO Meter (Model: AS8700A). Descriptive statistics and whisker box plots were also employed to analyze and visualize the variations in pollutant concentrations across different locations. Additionally, a dendrogram plot was created to classify and interpret data clusters, providing a deeper understanding of the spatial distribution of pollutants. Results indicated that the average concentration of $PM_{2.5}$ of different land-use were found 3.37 times higher than the Bangladesh National Ambient Air Quality Standard (NAAQS) level. NAAQS set for $PM_{2.5}$, and PM_{10} at 65 and 150 $\mu g/m^3$, respectively by Department of Environment (DoE). Consequently, the most polluted location was found in Industrial location with PM_1, $PM_{2.5}$ and PM_{10} concentration of 230, 389 and 496 $\mu g/m^3$, respectively. Also, the concentration of CO was 1.3 to 2.3 times higher than NAAQS level which is 9 ppm (8-hour) set By Department of Environment (DoE). Besides, the study estimated that the average $PM_{2.5}/PM_{10}$ ratio was 77.32%, while the $PM_1/PM_{2.5}$ ratio was 60.85%, which indicated significant presence of finer particles in the air. Therefore, the study underscores the urgent need for enhanced air quality policies and public awareness in Narayanganj District due to critically high levels of air pollution.

Keywords

Particulate Matter, Gaseous Pollutants, Land Use, Meteorological Correlation, Narayanganj District

1. Introduction

According to WHO [1], any chemical, physical, or biological compound that disrupts the atmosphere's fundamental properties and pollutes its inner or external environment can be referred to as air pollution. Seven million premature deaths

*Corresponding author: dk@stamforduniversity.edu.bd (Ahmad Kamruzzaman Majumder)

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are expected to occur each year due to air pollution, which is the biggest environmental danger to public health globally and it has a strong connection to climate change since most significant pollutants have shared origins with greenhouse gases and have a detrimental impact on the climate [2]. Air pollution from sources like household combustion, vehicles, industries, and forest fires includes harmful pollutants such as particulate matter, carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide, all of which can cause serious respiratory issues and other diseases, contributing significantly to illness and death rates [3]. The U. S. Environmental Protection Agency (EPA) [3] states that PM are tiny, airborne liquid and solid particles that fall into two sizes categories: PM_{10}, which are particles with a diameter of less than 10 micrometers, and $PM_{2.5}$, which are particles with a diameter of less than 2.5 micrometers. It is possible to inhale both $PM_{2.5}$ & PM_{10}, but $PM_{2.5}$ is more likely to enter the lung and land on its surface in the deeper regions, whereas PM_{10} is more likely to land on the surfaces of the upper lung's bigger airways [4]. $PM_{2.5}$ is a serious threat to human health; it is linked to oxidative stress and inflammatory reactions in the respiratory system and has been linked to about 4 million deaths globally from cardio-pulmonary diseases [5].

According to IQAir report [6], Bangladesh ranked the number one polluted country where annual average of $PM_{2.5}$ is 79.9 which is more than 15 times higher than the WHO $PM_{2.5}$ annual guideline and Dhaka marked as the most polluted city. As per to the fifth edition of the State of Global Air report, at least 236,000 lives were lost in Bangladesh due to exposure to polluted air [7]. According to a research, the average concentration of $PM_{2.5}$ in Dhaka was found to be 103.67 $\mu g/m^3$, 2.96 times higher than the national ambient air quality regulations threshold [8]. As per World Bank [9] estimated, air pollution accounted for around 20% of all preventable deaths in Bangladesh. Bangladesh's air quality deteriorated, with Dhaka and Narayanganj having the highest pollution [10]. The areas around Dhaka, $PM_{2.5}$ and PM_{10} concentrations revealed that pollution levels in all land uses surpassed WHO standards [11].

The prominent cause of fine particulate matter in urban air pollution is brick kilns [12]. Besides, unfit vehicles, industries, and construction activities are also notable contributors of air pollution in Dhaka [13]. According to the DoE [12], brick kilns are responsible for 58% of fine particles, cars for 10.4%, and dust for 15.3% air pollution in Dhaka. Another study conducted by Majumder et al. [8], identified unplanned urbanization, industrialization, heavy traffic, and biomass burning as key sources of air pollution in Dhaka and these activities, combined with meteorological factors like reduced rainfall, have led to a significant rise in $PM_{2.5}$ levels. However, air pollution is an alarming concern since pollutants can travel long distances from their sources, impacting air quality in regions far from the original emissions [13]. It significantly impacts health, leading to respiratory and cardiovascular diseases like asthma, heart attacks, and strokes, with children and the elderly being particularly vulnerable, while prolonged exposure can result in premature mortality, and emerging evidence suggests it may also contribute to mental health issues like depression and cognitive decline [14]. In Dhaka air pollution is a major public health concern as evidenced by the sharp increase in respiratory illnesses among its population where many of whom had no prior serious health problems [15]. As Narayanganj is a highly populated urban industrial center, it is rife with environmental burdens, one of which is air pollution impacting health and causing respiratory and cardiovascular diseases. Additionally, industrial factors related to local air pollution include emissions from brick kilns and factories. This requirement needs to achieve such spatial variations to manage economic development with environmental enhancement. The results will also provide relevant baseline information necessary for the development of appropriate policies for air quality management and urban planning consistent with the Sustainable Development Goals (SDGs) of Good Health and Well-being (Goal 3), and Sustainable Development for Cities and Communities (Goal 11).

Therefore, the study aimed to assess air pollution in Narayanganj town by examining the relationship between land use and key pollutants (PM_1, $PM_{2.5}$, PM_{10} & CO) as well as their correlation with meteorological factors like temperature and humidity. The rationale behind this research is to better understand how land use patterns impact air quality. Besides, this knowledge could help in formulating targeted strategies to reduce pollution and mitigate its harmful effects on public health and the environment.

2. Materials and Method

2.1. Study Area

Narayanganj District is a district in central Bangladesh which is a part of the Dhaka Division and home to the ancient city of Sonargaon and is one of the oldest industrial districts in the country. Narayanganj located at 23 ° N, 90 ° E, lying on the banks of the Shitalakshya River and the Meghna River.

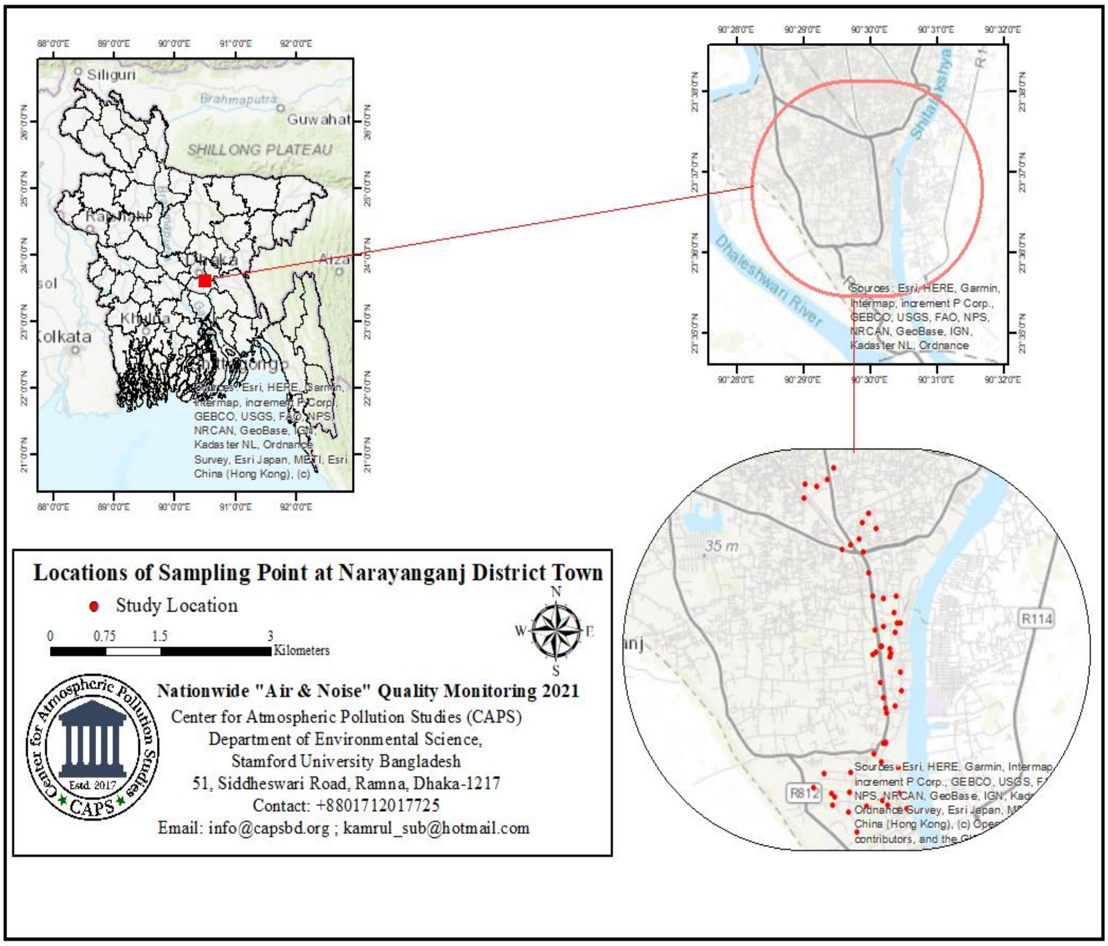


Figure 1. Study Area (Narayanganj District Town and Data Collection Location).

2.2. Flow Diagram of Research Methods

The study was carried out following the depicted flow diagram in Figure 2.

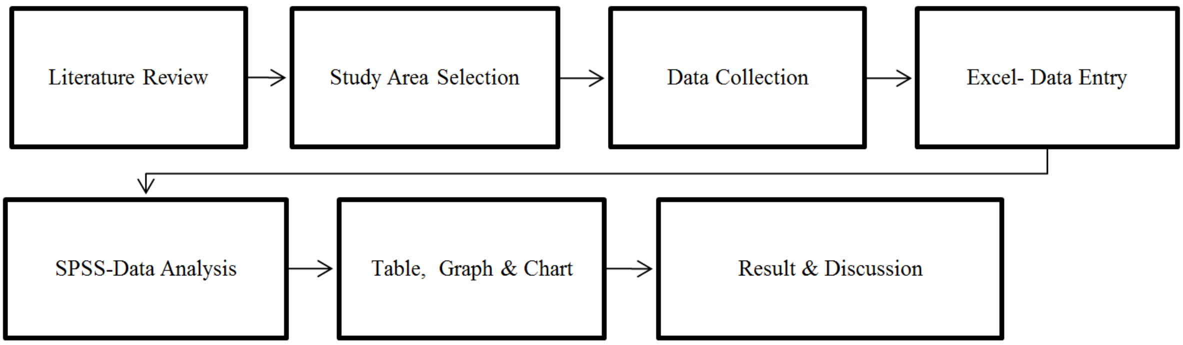


Figure 2. Flow Diagram of Research Methods.

2.3. Area Selection

Sixty locations were selected based on the use of land. After that, all locations were divided according to the use of land into seven types, which are sensitive, residential, mixed, commercial, road intersection, industrial, and village Area [20]. There is total 6 sensitive areas were selected that includes hospitals and clinics, schools, colleges, mosques, madrasas, temples, churches, and administrative buildings. On the other hand, mixed areas contain bazars, buildings, main roads etc. Rest 54 locations were categorized as residential areas; 10 locations, mixed areas; 7 locations, commercial areas; 10 locations; road intersection or busiest road junctions and bends; 7 locations, industrial area; 10 locations and village area; 10 locations.

2.4. Data Collection

As part of the survey, Air Quality was measured in different locations of Narayanganj District town for two days with the help of various automated portable instruments Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector (Model: DM106). GPS data was also collected by software named Garmin ETrex 10. Four individual data of PM_1, $PM_{2.5}$, PM_{10} and CO was collected from each location. Data was collected from 60 different locations, at different times in a day from morning to late night at Narayanganj district town. Instruments used to measure the parameters are depicted in table 1.

Table 1. *Instrument Description for Air Quality Monitor (Particulate Matter) & Carbon Monoxide (CO).*

SL.	Parameters	Instrument	Model
1.	PM_1, $PM_{2.5}$, PM_{10}, HCHO, TVOC, AQI, Temperature, Humidity	Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector	Model: DM106; B07SCM4YN3 (Saiko)
2.	Carbon Monoxide (CO)	Handheld Carbon Monoxide Meter	AS8700A (Smart Sensor / OEM)

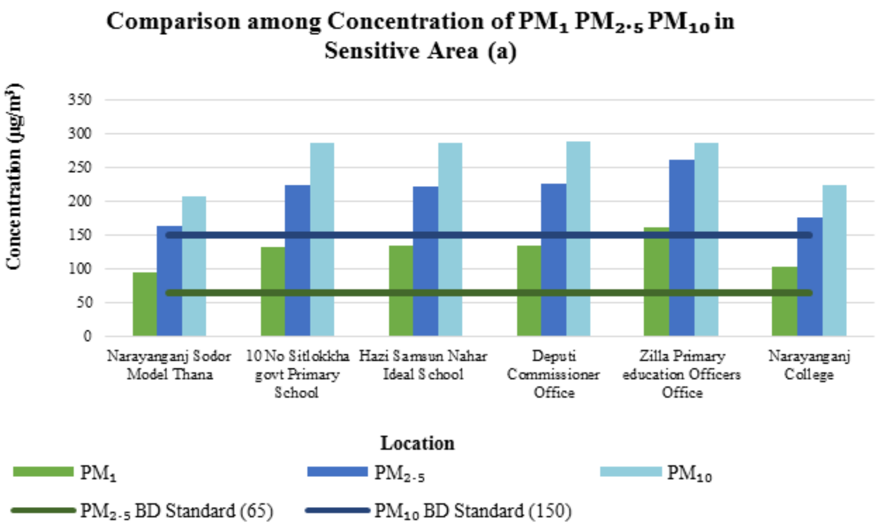
2.5. Data Analysis

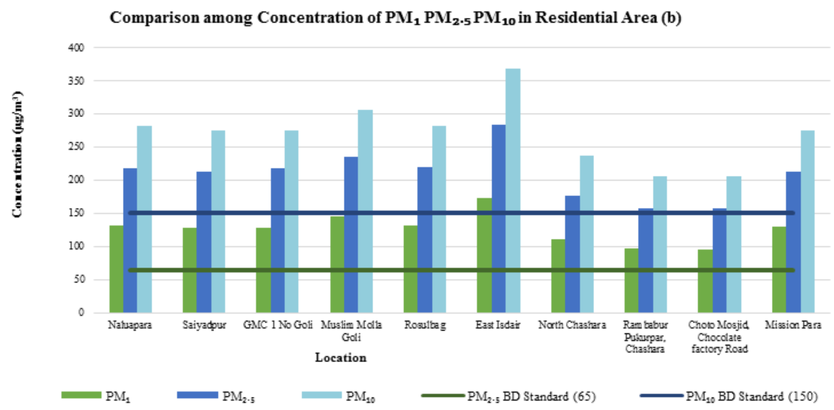
Microsoft Excel 2020 and IBM SPSS V20 were used to analyze the data that was obtained. Besides, multiple graphs, tables, diagrams, and Box-Whisker plots were generated to understand the nature of the data. Descriptive statistics were performed to examine the dispersion of each parameter related to land use. Additionally, an Analysis of Variance (ANOVA) test was conducted to assess the statistical significance of the results. The findings are presented through various graphs and charts, providing a comprehensive overview of the data.

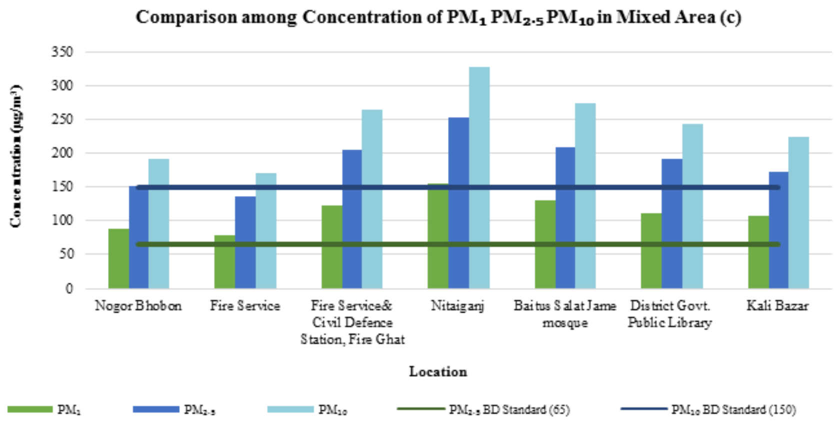
3. Results

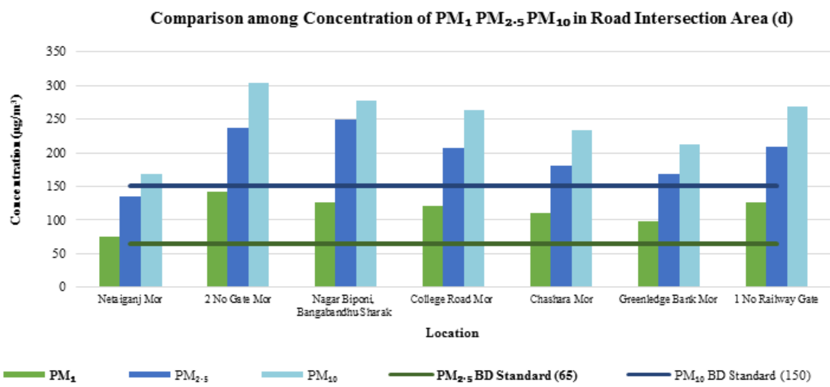
3.1. Comparison among Concentration of PM_1, $PM_{2.5}$ & PM_{10} in Different Areas

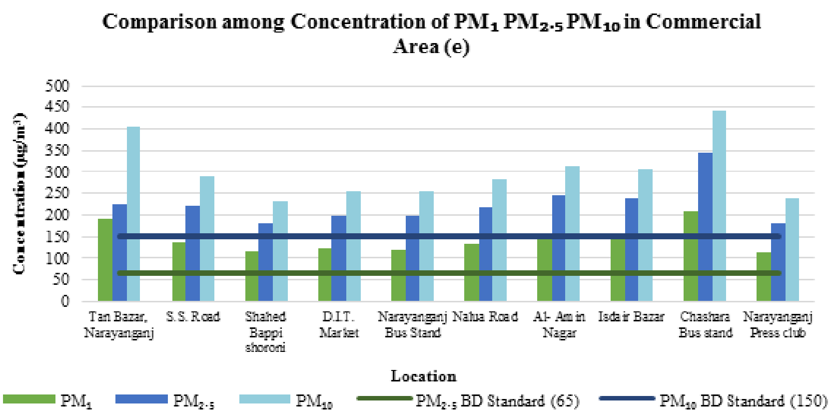
Figure 3 (a), (b), (c), (d), (e), (f) and (g) illustrate the concentration (μg/m^3) of PM_1, $PM_{2.5}$ and PM_{10} of some locations in sensitive, residential, mixed, road intersection, commercial, industrial and village area of Narayanganj District Town. Among the 6 sensitive places, three polluted places regarding PM_1, $PM_{2.5}$ and PM_{10}, were outside of Zilla Primary Education officer's office, near Deputy Commissioner office and in front of 10 No Sitlokkha Govt. Primary School with PM concentration of 162.00, 261.75 and 285.75 μg/m^3, 135.00, 225.75 and 288.75 μg/m and 132.75, 224.25 and 286.50 μg/m^3 respectively. The comparatively less polluted places were outside of Narayanganj Sadar Model Thana and outside of Narayanganj College with $PM_{2.5}$ concentration of 162.75 and 175.50 μg/m^3 respectively. It has been also observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of outside of Zilla Primary education Officers Office and outside of Narayanganj Sadar Model Thana were 162.00, 261.75 and 34.50 μg/m^3 and 96.00, 162.75 and 207.00 μg/m^3 respectively. It was also noted that the concentrations of $PM_{2.5}$ and found in the most polluted place were 4.03 and 1.905 times higher than NAAQS. The study estimated that in all sensitive areas, 191.66% of $PM_{2.5}$ was present in PM_{10} and 59.92% of the PM_1 was present in $PM_{2.5}$. It has been found that out of 10 residential places, three polluted places were East Isdair, Muslim Molla Goli and GMC 1 no. Goli with the $PM_{2.5}$ concentration of 283.50, 234.75and 218.25 μg/m^3 respectively and comparatively less polluted places were Choto Mosjid, Chocolate factory road, Rambabur Pukurpar, Chashara and North Chashara with $PM_{2.5}$ concentration of 158.25, 158.25 and 177.00 μg/m^3 respectively. It has been observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of East Isdair and Choto Mosjid, Chocolate factory road were 174.00, 283.50 and 368.25 μg/m^3 and 96.00, 158.25 and 205.50 μg/m^3 respectively. It was also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted places were 4.5 and 2.455 times higher than NAAQS. The study estimated that in all sensitive areas, 77.09% of $PM_{2.5}$ was present in PM_{10} and 60.80% of the PM_1 was present in $PM_{2.5}$. Among 7 mixed places, three polluted places were Nitaiganj, in front of Baitus Salat Jame Mosque and outside of Fire Service& Civil Defense Station, Fire Ghat with the $PM_{2.5}$ concentration of 253.50, 209.25 and 204.75μg/m^3 respectively. Comparatively less polluted places were near Fire Service Office, outside of Nogor Bhobon and Kali Bazar with the $PM_{2.5}$ concentration of 135.75, 150.75 and 171.75 μg/m^3 respectively. It has been observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of Nitaiganj and Fire Service office were 154.50, 253.50 and 327.75 μg/m^3 and 78.00, 135.75 and 171.00 μg/m^3 respectively. However, it was also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted places were 3.9 and 2.185 times higher than NAAQS. The study estimated that in all sensitive areas, 544.98% of $PM_{2.5}$ was present in PM_{10} and 60.06% of the PM_1 was present in $PM_{2.5}$. Also found that 10 commercial places, three polluted places were Chashara Bus stand, Tan Bazar, Narayanganj and Al- Amin Nagar with the $PM_{2.5}$ concentration of 345.00, 225.50 and 245.25 µg/m^3 respectively and comparatively less polluted places were Shahed Bappi shoroni and Narayanganj Press club with the $PM_{2.5}$ concentration of 181.50 and 182.25 µg/m^3 respectively. It has been observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of Chashara bus stand and Shahed Bappi shoroni were 208.50, 345.00 and 444.00 µg/m^3 and 116.25, 181.50 and 232.50 µg/m^3 respectively. However, it was also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted places were 5.31- and 2.96-times higher NAAQS. The study estimated that in all sensitive areas, 75.32% of $PM_{2.5}$ was present in PM_{10} and 63.56% of the PM_1 was present in $PM_{2.5}$. It has been found that out of 7 road intersection places, three polluted places were Nagar Biponi, Bangabandhu sharak, 2 no. Gate mor and 1 no. Railway Gate with the $PM_{2.5}$ concentration of 249.00, 237.00 and 209.25 µg/m^3 respectively and relatively less contaminated places were Netaiganj mor, Green Ledge Bank mor and Chashara mor with the $PM_{2.5}$ concentration of 134.25, 168.00 and 180.75 µg/m^3 respectively. It has been observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of Nagar Biponi, Bangabandhu sharak and Netaiganj mor were 126.75, 249.00 and 277.50 µg/m^3 and 75.75, 134.25 and 168.75 µg/m^3 respectively. It was also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted places were 3.83 and 1.85 times higher than NAAQS. The study estimated that in all sensitive areas, 79.96% of $PM_{2.5}$ was present in PM_{10} and 57.96% of the PM_1 was present in $PM_{2.5}$. It has been found that out of 10 industrial places, three highly polluted places were outside of Atiqe Knitting, C. S. Colour House and Illako Textile with the $PM_{2.5}$ concentration of 388.50, 351.00 and 316.50 µg/m^3 and relatively less polluted places was outside of Ahasan Knitting mills, Jobayer Cotton mill and Orient Fashion with $PM_{2.5}$ concentration of 244.50, 248.25 and 259.50 µg/m^3 respectively. It was also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted place were 5.98 and 3.305 times higher than NAAQS level. The study estimated that in industrial areas, 77.91% of $PM_{2.5}$ was present in PM_{10} and 60.20% of the PM_1 was present in $PM_{2.5}$. It has been found that out of 10 village locations, the three polluted places were Diayara road, 1 no. Goli, Shahidnagar and outside of Baitul Wakil Jame Masque with the $PM_{2.5}$ concentration of 267.75, 244.50 and 230.25 µg/m^3 respectively. Less polluted places were Sukum potti, Sikdar nagar and Diyara Bank colony with $PM_{2.5}$ concentration of 162.75, 171.75 and 190.50 µg/m^3 respectively. It has been observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of Diayara road and Sukum potti were 171.00, 267.75 and 354.00 µg/m^3 and 94.50, 162.75 and 206.25 µg/m^3 respectively. It was also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted place were 4.12 and 2.36 times higher than NAAQS. The study estimated that in all sensitive areas, 79.85% of $PM_{2.5}$ was present in PM_{10} and 59.17% of the PM_1 was present in $PM_{2.5}$. Figure 3 (h) compares the average PM_1, $PM_{2.5}$, and PM_{10} concentrations of seven different land uses in the town of Narayanganj. According to this study, the average concentration of PM_1, $PM_{2.5}$, and PM_{10} was higher in sensitive areas, commercial areas, and industrial areas, with the highest concentrations observed in the industrial area. The values of these concentrations were 175.43, 291.53, and 374.18 µg/m^3, 142.95, 225.43, and 302.10 µg/m^3, and 127.38, 212.13, and 263 µg/m^3, respectively. On the other hand, Residential areas, areas with traffic intersections, and mixed areas were shown to have comparatively lower PM concentrations. Additionally, it was shown that the mixed area had the lowest average concentrations of PM_1 (113.36 µg/m^3), $PM_{2.5}$ (188.14 µg/m^3), and PM_{10} (242.04 µg/m^3).




Comparison among Concentration of PM_1 $PM_{2.5}$ PM_{10} in Residential Area (b)
Concentration (μg/m³)
400
350
300
250
200
150
100
50
0
Nałuapara
Saiyadpur
GMC 1 No Goli
Muslim Molla Goli
Rosulbag
East Isdair
North Chashara
Ram babur Pukurpar, Chashara
Choto Mosjid, Chocolate factory Road
Mission Para
Location
PM_1
$PM_{2.5}$
PM_{10}
$PM_{2.5}$ BD Standard (65)
PM_{10} BD Standard (150)


Comparison among Concentration of PM_1 $PM_{2.5}$ PM_{10} in Mixed Area (c)
Concentration (μg/m³)
350
300
250
200
150
100
50
0
Nogor Bhobon
Fire Service
Fire Service& Civil Defence Station, Fire Ghat
Nitaiganj
Baitus Salat Jame mosque
District Govt. Public Library
Kali Bazar
Location
PM_1
$PM_{2.5}$
PM_{10}
$PM_{2.5}$ BD Standard (65)
PM_{10} BD Standard (150)


Comparison among Concentration of PM_1 $PM_{2.5}$ PM_{10} in Road Intersection Area (d)
Concentration (μg/m³)
350
300
250
200
150
100
50
0
Netaiganj Mor
2 No Gate Mor
Nagar Biponi, BangabandhuSharak
College Road Mor
Chashara Mor
Greenledge Bank Mor
1 No Railway Gate
Location
PM_1
$PM_{2.5}$
PM_{10}
$PM_{2.5}$ BD Standard (65)
PM_{10} BD Standard (150)


Comparison among Concentration of PM_1 $PM_{2.5}$ PM_{10} in Commercial Area (e)
Concentration (μg/m³)
500
450
400
350
300
250
200
150
100
50
0
Tan Bazar, Narayanganj
S.S. Road
Shahed Bappi shoroni
D.I.T. Market
Narayanganj Bus Stand
Nalua Road
Al- Amin Nagar
Isdair Bazar
Chashara Bus stand
Narayanganj Press club
Location
PM_1
$PM_{2.5}$
PM_{10}
$PM_{2.5}$ BD Standard (65)
PM_{10} BD Standard (150)

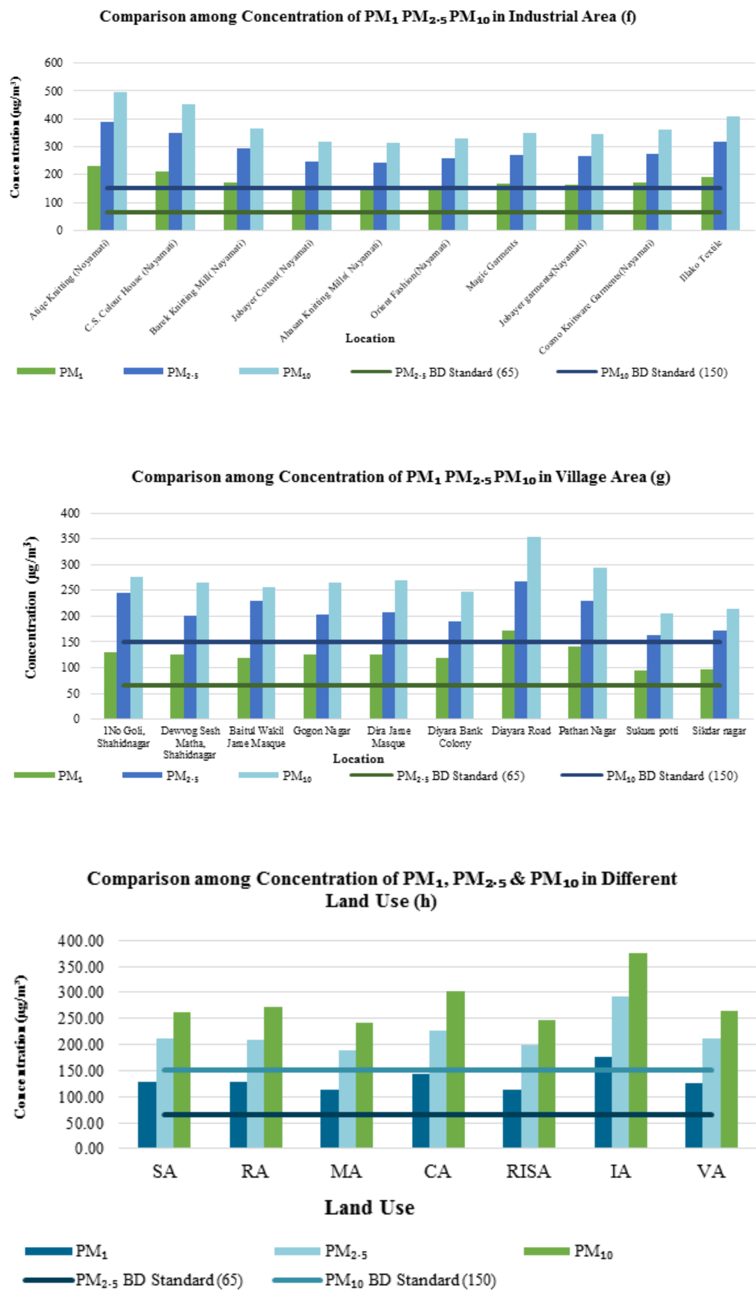


Figure 3. *Concentration of PM_1, $PM_{2.5}$ & PM_{10} in sensitive, residential, mixed, commercial, road intersection, industrial and village area.*

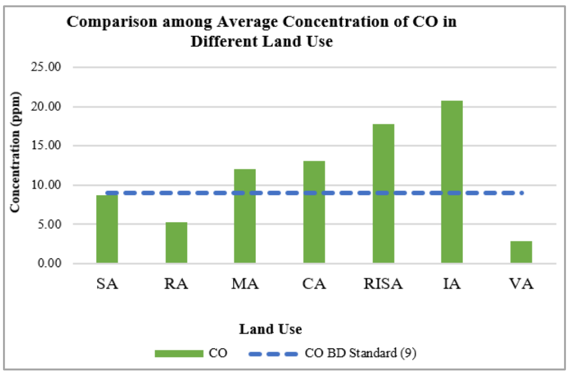


Figure 4. *Average Concentration of CO of Different Land Use.*

3.2. Comparison of Average Concentration of Gaseous Pollutants of Different Land Use

A The average concentration of CO was found to be higher in the industrial, road intersection, commercial, and mixed areas among the seven land uses in the Narayanganj District Town area. These areas also have CO concentrations that are higher than the standard level and can be harmful to living organisms if they are occupied for an extended period. The average CO concentrations in the commercial, mixed, industrial, and road intersection areas were determined to be 20.70, 17.71, 13.10, and 12.00 ppm, respectively. The concentration of CO was 1.3 to 2.3 times higher than NAAQS level which is 9 ppm (8-hour) set by Department of Environment (DoE).

In contrast, sensitive areas, residential areas, and village areas had average CO concentrations that were not above the recommended range. In the village area, the average CO concentrations were lowest.

3.3. Dispersion of PM_1, $PM_{2.5}$, PM_{10} and CO

The following table 2 illustrates the descriptive statistics for PM_1, $PM_{2.5}$, PM_{10} and CO of the studied seven land uses. The highest range of PM_1 was found in commercial area (95.00 µg/m^3) and lowest range was found in road intersection area and sensitive area with same value (66.00 µg/m^3). For $PM_{2.5}$, the highest range was found in commercial area (163.00 µg/m^3) followed by industrial area (144.00 µg/m^3) and lower ranges were found in sensitive area (99.00 µg/m^3) and village area (105.00 µg/m^3). In case of PM_{10} the higher ranges were found in sensitive area (254.00 µg/m^3) followed by commercial area (211.00 µg/m^3) and lower ranges were found in road intersection area (135.00 µg/m^3) and village area (148.00 µg/m^3). However, the highest range was found in road intersection area and commercial (44 ppm) for CO and lowest found in found in village area (10 ppm). The highest mean value of PM was found in industrial area (175.60, 291.70 & 374.20 µg/m^3) followed by commercial area (143.00, 225.50 and 225.50 µg/m^3) and the lowest mean was found in mixed area (113.57 and 188.29 µg/m^3) for PM_1 and $PM_{2.5}$; however, lowest mean of PM_{10} was found in sensitive area (221.33 µg/m^3). Along with that the highest mean value of CO was found in the industrial area (20.70 ppm) and the lowest mean was found in the village area (2.90 ppm). It was observed that the highest coefficient of variation was found in village area (135.47%) followed by sensitive area, residential area, commercial area, mixed area, and road intersection area respectively. The least variation was found in the industrial area, which was 78.03%. The study found that mixed, commercial, and sensitive areas had the highest coefficients of variation for PM_1, $PM_{2.5}$, and PM_{10}, at 22.80%, 21.06%, and 44.27% respectively. However, lowest variations were in industrial (15.79%) and village areas (15.39% for $PM_{2.5}$ and 15.60% for PM_{10}). This highlights how different urban activities like traffic, construction, and industry contribute to variations in particulate matter levels.

The whisker box plot in Figure 5 shows the average concentration of PM_1, $PM_{2.5}$, PM_{10} & CO in different land use. A horizontal black line within the box marks the median; the lower boundary of the box indicates the 25th percentile, the upper boundary of the box indicates the 75th percentile. The whisker represents the maximum (upper whisker) and minimum value (lower whisker) for each land use. Points above the whiskers indicate outliers. Following whisker box plot of PM_1 revealed that industrial area had higher dispersion with positively skewed distribution followed by sensitive area and mixed area with negative skewed values whereas $PM_{2.5}$ revealed that industrial area had the highest dispersion with positively skewed distribution followed by sensitive area and road intersection area with extreme negative to negative distribution. In case of PM_{10} it is observed that industrial area had the highest dispersion with positively skewed distribution followed by sensitive area with one lower outlier which found outside of Narayanganj Sodor Model Thana due to less vehicular movement. However, whisker box plot of CO revealed that industrial area had the highest dispersion with positively skewed distribution which is contradicting to descriptive statistics where village area had shown the highest variation. Therefore, in case of the PM_1, $PM_{2.5}$ & PM_{10} and CO, the higher values observed in Atiqe Knitting (Noyamati) due to industrial activities could be the reason behind the higher dispersion in industrial area.

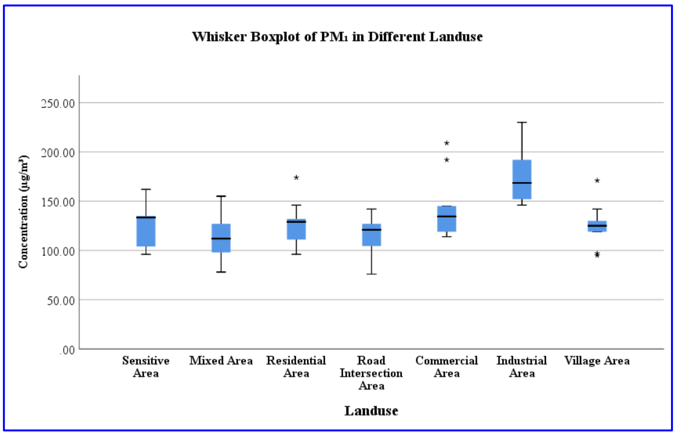
Table 2. *Descriptive Statistics for PM_1, $PM_{2.5}$, PM_{10} and CO.*

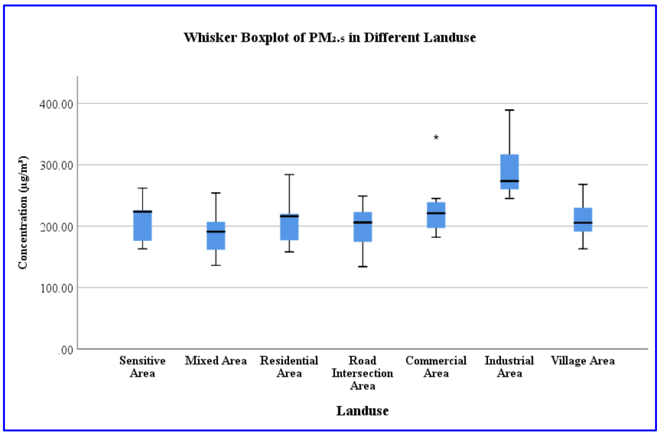
Sl. No.	Land Use	PM_1					$PM_{2.5}$			
		Number of locations	Range (µg/m^3)	Mean (µg/m^3)	Std. Deviation (µg/m^3)	Coefficient of Variation (%)	Range (µg/m^3)	Mean (µg/m^3)	Std. Deviation (µg/m^3)	Coefficient of Variation (%)
1	Sensitive Area	6	66	127.33	23.93	18.79	99	212.33	36.49	17.18
2	Mixed Area	7	77	113.57	25.90	22.80	118	188.29	39.63	21.05
3	Residential Area	10	78	127.30	22.94	18.02	126	209.5	37.78	18.04
4	Road Intersection Area	7	66	114.57	21.90	19.11	115	197.71	39.98	20.22
5	Commercial Area	10	95	143.00	32.49	22.72	163	225.5	47.49	21.06
6	Industrial Area	10	84	175.60	27.73	15.79	144	291.7	47.15	16.16

Sl. No.	Land Use	PM_1					$PM_{2.5}$			
		Number of locations	Range (µg/m³)	Mean (µg/m³)	Std. Deviation (µg/m³)	Coefficient of Variation (%)	Range (µg/m³)	Mean (µg/m³)	Std. Deviation (µg/m³)	Coefficient of Variation (%)
7	Village Area	10	76	124.90	21.57	17.27	105	211.2	32.50	15.39

Table 2. Continued.

Sl. No.	Land Use	PM_{10}					CO			
		Number of locations	Range (µg/m³)	Mean (µg/m³)	Std. Deviation (µg/m³)	Coefficient of Variation (%)	Range (ppm)	Mean (ppm)	Std. Deviation (ppm)	Coefficient of Variation (%)
1	Sensitive Area	6	254	221.33	97.99	44.27	23	8.67	10.58	122.04
2	Mixed Area	7	157	242.14	52.70	21.77	36	12	12.77	106.39
3	Residential Area	10	162	271.5	47.82	17.61	18	5.20	6.34	121.90
4	Road Intersection Area	7	135	247.14	45.39	18.36	44	17.71	15.76	88.94
5	Commercial Area	10	211	302.20	70.18	23.22	44	13.10	13.95	106.47
6	Industrial Area	10	183	374.20	60.10	16.06	40	20.70	16.15	78.03
7	Village Area	10	148	264.60	41.28	15.60	10	2.90	3.93	135.47





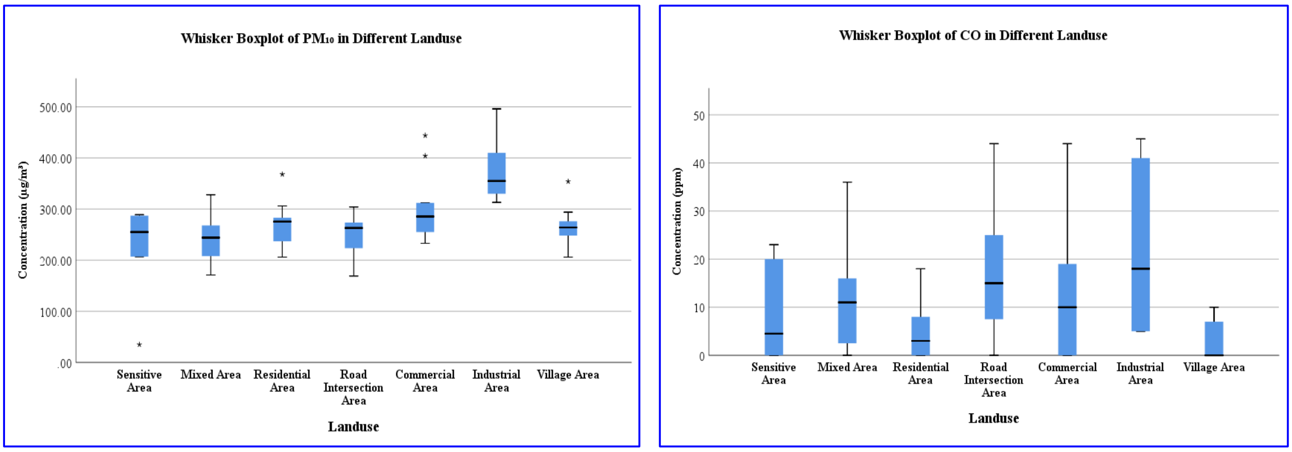


Figure 5. *Whisker Box Plot of the Concentration of PM_1, $PM_{2.5}$, PM_{10} & CO in Different Land use.*

3.4. Significance Test

Table 3 demonstrates ANOVA for significance test. ANOVA is performed to find whether the changes in the concentration of all the parameters between and within land uses are significant. The F values were calculated to be 6.343 for PM_1, 6.406 for $PM_{2.5}$, 6.279 for PM_{10} and 2.695 for CO. The P value of PM_1, $PM_{2.5}$ & PM_{10} and CO were found 0.000, 0.000, 0.000 and 0.023. The following table shows that the concentrations of PM_1, $PM_{2.5}$ & PM_{10} and CO changes significantly as the p value is less than 0.05.

Table 3. *Significance Test.*

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
PM_1	Between Groups	25208.821	6	4201.470	6.343	0.000
	Within Groups	35106.162	53	662.380		
	Total	60314.983	59			
$PM_{2.5}$	Between Groups	64057.693	6	10676.282	6.406	0.000
	Within Groups	88332.890	53	1666.658		
	Total	152390.583	59			
PM_{10}	Between Groups	134897.452	6	22482.909	6.279	0.000
	Within Groups	189785.148	53	3580.852		
	Total	324682.600	59			
CO	Between Groups	2326.721	6	387.787	2.695	0.023
	Within Groups	7626.262	53	143.892		
	Total	9952.983	59			
	Total	.269	59			

3.5. Land Use Based Cluster Analysis

For PM_1, $PM_{2.5}$ & PM_{10} and CO dendrogram plot derived via cluster analysis with Z-score standardization has been shown in Figure 6. From this analysis, the average linkage between groups has been considered. In case of PM_1, three clusters have been found where the first cluster is consisted of sensitive area, residential area, village area, mixed area and road intersection area; second cluster includes commercial area, and third cluster includes industrial area only. The first and second cluster join at the approximate distance of 5. Whereas, $PM_{2.5}$ dendrogram plot revealed two clusters have been found from the graph where first cluster is consisted of sensitive area, village area, residential area, commercial area, mixed area and road intersection area; second cluster includes industrial area respectively. The first and second cluster join at an approximate distance of 25. In terms of PM_{10}, three clusters have been found from below graph. The first cluster consists of mixed area, road intersection area; sensitive area, residential area and village area; second and third clusters includes commercial area and village area respectively. The first and second cluster join at the approximate distance of 6. Three clusters have been found from dendrogram plot of CO. In the case of CO, the first cluster consists of mixed area, commercial area and sensitive area; second cluster involves residential area and village area; third cluster composed of road intersection area and industrial area respectively. The first and second cluster of CO graph joins at the approximate distance of 11.

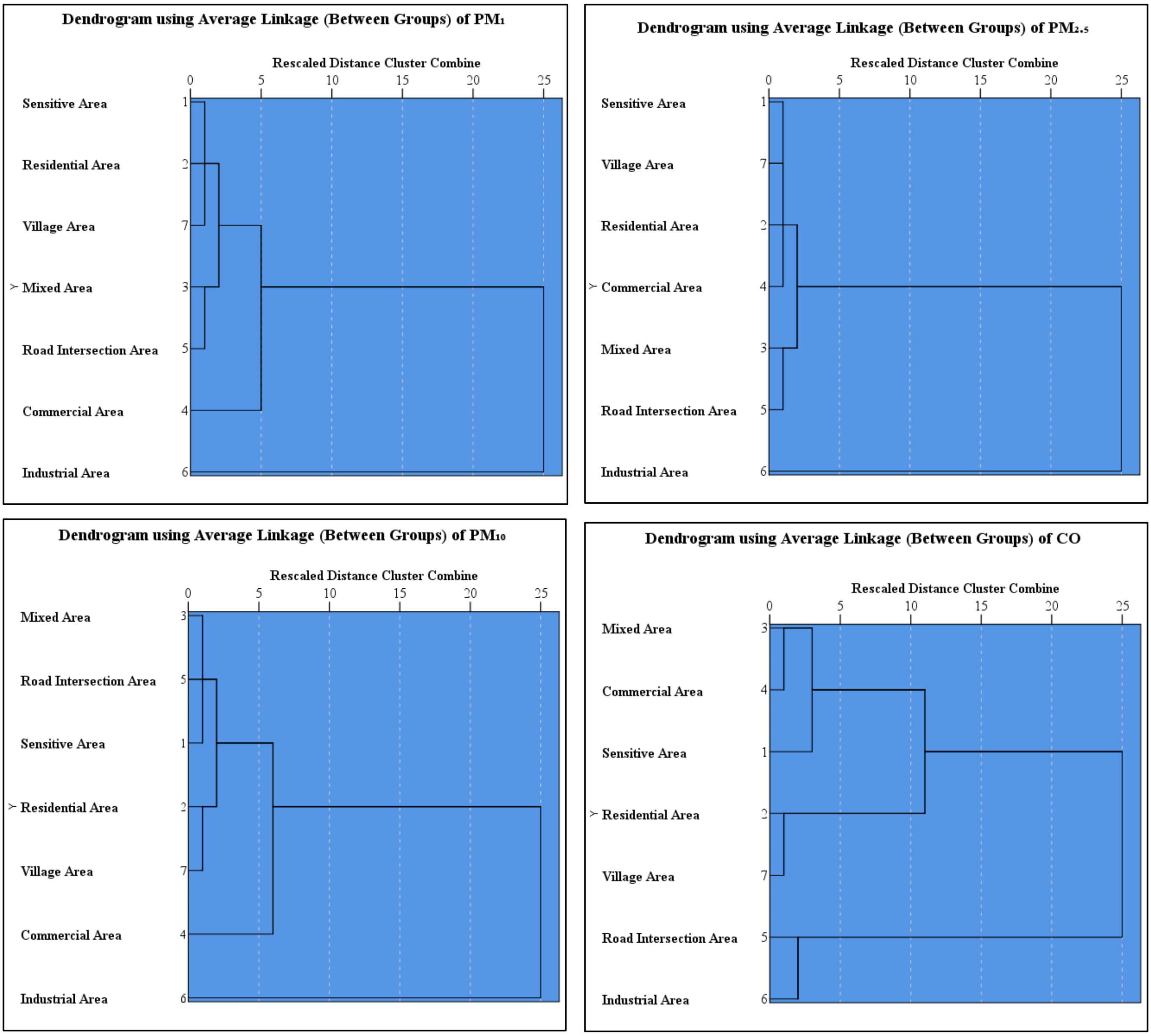


Figure 6. *Rescaled Distance Cluster Combine for PM_1, $PM_{2.5}$, PM_{10} and CO.*

3.6. Correlation Between Parameters

Person correlation demonstrated in table 4 that there were moderate strength relationships exist between all the three PM_1, $PM_{2.5}$ & PM_{10} and humidity which were statistically significant at 0.05 and 0.01 alpha levels respectively. The direction of relationship between PM_1, $PM_{2.5}$ & PM_{10} and humidity was positive. Therefore, any change in the concentration of PM_1, $PM_{2.5}$ & PM_{10} can cause significant change in the percentage of humidity. The strength of the relationship was strong, and direction was negative. Hence a change in concentration of any of these two would change the concentration of the other one in the opposite direction. There was a negative, strong and statistically significant relationship that was also found between temperature and humidity. It can be said that change in any of these two environmental parameters would change the other in the opposite direction.

Table 4. Correlation among PM_1, $PM_{2.5}$, PM_{10} & CO Selected Meteorological Parameters.

Correlations among PM & CO and Selected Meteorological Parameters							
		$PM_{1.0}$	$PM_{2.5}$	PM_{10}	CO	Temperature	Humidity
PM_1	Pearson Correlation	1	.958**	.843**	.341**	-.022	.154
	Sig. (2-tailed)		.000	.000	.008	.865	.242
	N	60	60	60	60	60	60
$PM_{2.5}$	Pearson Correlation	.958**	1	.819**	.362**	-.001	.108
	Sig. (2-tailed)	.000		.000	.004	.995	.412
	N	60	60	60	60	60	60
PM_{10}	Pearson Correlation	.843**	.819**	1	.261*	-.141	.259*
	Sig. (2-tailed)	.000	.000		.044	.282	.046
	N	60	60	60	60	60	60
CO	Pearson Correlation	.341**	.362**	.261*	1	.095	.021
	Sig. (2-tailed)	.008	.004	.044		.472	.875
	N	60	60	60	60	60	60
Temperature	Pearson Correlation	-.022	-.001	-.141	.095	1	-.896**
	Sig. (2-tailed)	.865	.995	.282	.472		.000
	N	60	60	60	60	60	60
Humidity	Pearson Correlation	.154	.108	.259*	.021	-.896**	1
	Sig. (2-tailed)	.242	.412	.046	.875	.000	
	N	60	60	60	60	60	60

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

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

4. Discussion

The study on the spatial distribution of air quality in Narayanganj District Town, Bangladesh, revealed significant spatial variations in air quality parameters, including particulate matters (PM_1, $PM_{2.5}$ & PM_{10}) and carbon monoxide (CO). The results indicate that certain areas within the district town experience higher levels of pollution compared to others, which can be attributed to various anthropogenic factors. The spatial analysis showed that industrial zones and densely populated commercial regions exhibited the highest concentrations of PM_1, $PM_{2.5}$ & PM_{10} as the three most polluted locations Atiqe Knitting (Noyamati), C. S. Color House (Noyamati) and Chashara Bus stand) were categorized by them. This finding aligns with previous studies that have demonstrated the impact of industrial emissions and commercial activities on air quality. For example, A study conducted at Chittagong showed the average $PM_{2.5}$ concentrations was highest in industrial area (175.36 µg/m^3) [16]. Similar results observed from another study conducted at Rajshahi where the highest pollution level observed at industrial zone [17]. Besides, another study conducted by Majumder et al [18] at Lakshmipur revealed that the highest amount of PM_1, $PM_{2.5}$ & PM_{10} found in commercial zones. Conversely, regions with more green spaces and fewer industrial activities recorded lower pollutant levels. The three least polluted areas were Netaiganj Mor, Fire Service and Nagar Bhaban which belonged to the road intersection area and village area. This supports the hypothesis that vegetation and open spaces play a crucial role in mitigating air pollution. A study conducted at Lakshmipur revealed that the least polluted three zones are mixed zone, sensitive zone and village area respectively [18]. Nevertheless, this cannot be claimed for every location. Because each region's locations engage in different activities. For instance, a village area in one location may be surrounded by greenery, while in another, the village area might go through construction activities and deforestation, which raises the pollution level. For example, a study demonstrated that in Rajshahi the three most polluted areas were industrial area, village area and road intersection area respectively [17]. However, this study revealed that CO concentrations were highest in commercial (20.70 ppm), mixed (17.71 ppm), industrial (13.10 ppm), and road intersection (12.00 ppm) areas, exceeding the Bangladesh NAAQS of 9 ppm (8-hour). This result aligns with findings from similar study conducted at Chittagong demonstrated CO concentration was found to be 1.65 times higher than the national standard in the most polluted area and the average concentration of CO is determined to be highest (25.10 ppm) in the mixed zone [16]. But village area was found to have the highest concentration of CO (92 ppm) in another study conducted at Netrokona district [19]. However, this study demonstrated that sensitive, residential, and village areas had CO levels within safe limits, with the lowest in village areas. These results align with findings from similar urban studies where traffic and industrial activities significantly contribute to CO pollution. These findings underscore the need for targeted air quality management in high-risk areas to protect public health.

5. Implication to Research and Practice

The study provides detailed data on PM_1, $PM_{2.5}$, PM_{10}, CO, TVOC, and HCHO across various land uses, forming a basis for future research on pollution sources and health impacts. The baseline data enables future studies to monitor trends and evaluate intervention effectiveness, essential for developing robust pollution control strategies. Besides, integrating environmental science, urban planning, and public health highlights the importance of interdisciplinary approaches for comprehensive pollution control solutions. However, high $PM_{2.5}$ and CO levels, especially in industrial and commercial areas, indicate the need for stricter air quality regulations. Policymakers can use these findings to develop targeted pollution control policies and mitigation efforts. The results can guide urban planners in making zoning decisions and creating green spaces to buffer residential and sensitive areas from pollution sources and health officials can design targeted interventions based on pollution hotspots. Furthermore, the findings can help raise community awareness about air quality issues and health risks, fostering public support for air quality improvement initiatives.

6. Conclusion

The research indicated alarming levels of particulate matter (PM_1, $PM_{2.5}$, and PM_{10}) concentrations across various land uses, far exceeding the NAAQS set by DoE. Industrial zones show the highest levels of pollution, with average $PM_{2.5}$ concentrations reaching 291.53 µg/m^3, followed by commercial and sensitive areas, while the road intersection and mixed-use areas recorded the lowest. Average concentration of $PM_{2.5}$ in descending order follows as industrial area > commercial area > sensitive area > residential area > village area > road intersection area > mixed area. Although, the changes in the concentration of all the selected parameters within land uses were insignificant. The lowest PM concentration observed at Netaiganj Mor (road intersection area) with concentration of 76, 134 and 169 µg/m^3, respectively. However, inconsistent pollution patterns are further shown by the large standard deviation and coefficient of variation in PM concentrations, especially in industrial, commercial, and village areas, which puts locals at risk for unexpected exposure. Particulate matter concentration clustering patterns are shown by the study's dendrogram analysis, which illustrates the intricacy of pollution sources and their interactions among various land uses. Stricter regulations, better urban planning, and the use of mitigation solutions are desperately needed in light of the significant departure from air quality requirements in order to lower pollution levels and safeguard public health.

7. Future Research

While this study provides valuable insights into the spatial distribution of air quality in Narayanganj, several limitations should be acknowledged. The study relied on data from a limited number of monitoring stations, which may not capture the full variability of air quality across the district. Future research should aim to increase the spatial resolution of air quality measurements and investigate the temporal variations in pollutant levels. Additionally, exploring the effectiveness of specific interventions and policies in reducing air pollution can provide actionable insights for policymakers. Longitudinal studies examining the health impacts of air pollution on the local population would also be beneficial.

Abbreviations

AQI	Air Quality Index
CARB	California Air Resources Board
ECA	Energy and Clean Air
EEA	European Environment Agency
DoE	Department of Environment, Bangladesh
NAAQS	National Ambient Air Quality Standard
PM	Particulate Matter
UNEP	United Nations Environment Programme
U.S. EPA	U. S. Environmental Protection Agency
WHO	World Health Organization

Author Contributions

Ahmad Kamruzzaman Majumder: Conceptualization, Investigation, Funding acquisition, Resources, Project administration, Supervision

Marziat Rahman: Conceptualization, Data curation, Resources, Formal Analysis, Validation, Writing – original, Writing – review & editing

Mohsina Hossain Mita: Formal Analysis, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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