

Research Article

Urban Land Use and Particulate Matter Distribution During Winter: A Case Study of Pabna District Town, Bangladesh

Ahmad Kamruzzaman Majumder^{1, 2, *} , Mohammad Tariq Ali¹

¹Department of Environmental Science, Stamford University Bangladesh, Dhaka, Bangladesh

²Center for Atmospheric Pollution Studies (CAPS), Dhaka, Bangladesh

Abstract

Air pollution is a major public health concern in Bangladesh, contributing to significant respiratory and cardiovascular issues. The objective of this study is to monitor the Particulate Matters (PM₁, PM_{2.5} & PM₁₀) and Carbon Monoxide (CO) concentration based on different land use in Pabna district town. This study was conducted in 40 locations of Pabna district town, by using portable Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector (Model: DM106) and CO Meter (Model: AS8700A). It was found that, the average concentrations of PM₁, PM_{2.5} & PM₁₀ of 40 places in Pabna district town were 34.50, 57.02 and 73.43 $\mu\text{g}/\text{m}^3$ respectively. The average concentration of PM_{2.5} and PM₁₀ were found 2.28 and 1.49 times higher than World Health Organization (WHO) which is respectively. It is estimated that the average PM_{2.5}/PM₁₀ was 77.63%, PM₁/PM_{2.5} was 60.46%. From the outcome of this research the studied land uses are arranged in descending order based on average concentration PM which follows as road intersection area > commercial area > mixed area > industrial area > residential area > sensitive area. Therefore, the findings underscore the urgent need for targeted air quality management strategies in Pabna district, particularly in high-pollution areas, to mitigate health risks associated with elevated particulate matter concentrations.

Keywords

Particulate Matter, Gaseous Pollutants, Descriptive Statistic, Pabna District Town

1. Introduction

Air pollution is any chemical, physical, or biological substance that modifies the basic characteristics of the atmosphere and contaminates its interior or exterior surroundings [1]. Approximately 7 million people worldwide lose their lives to air pollution every year; most of these deaths take place in low- and middle-income countries, and nine out of ten breathe air that is more polluted than what the World Health Organization considers safe [2]. Air pollution is the leading environmental threat to public health worldwide, resulting in seven million premature deaths annually [3]. It is closely linked to climate change, as the

majority of major pollutants have origins that are shared with greenhouse gases, which negatively affect the climate. A World Bank estimate for 2019 states that the yearly cost of health damage caused by air pollution is \$8.1 trillion, or 6.1% of global GDP [4]. Hazardous pollutants like particulate matter, carbon monoxide, ozone layer, nitrogen dioxide, and sulfur dioxide are among the air pollutants that come from sources like home combustion, automobiles, industries, and forest fires. These pollutants can all lead to severe respiratory problems and other illnesses, which greatly increase the rates of illness and death [1].

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

Received: 29 June 2025; Accepted: 28 July 2025; Published: 9 September 2025



Copyright: © The Author(s), 2025. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

The majority of life years lost due to pollution (92.7%) are in Asia and Africa, with the US and Canada contributing for 4.2% of these losses. Particulate pollution, or PM_{2.5}, is continuously the world's greatest external risk to human health, pollution is expected to shorten average life expectancy by 2.3 years worldwide [5]. As per a report, non-communicable diseases like diabetes, lung cancer, heart disease, stroke, and chronic obstructive pulmonary disease (COPD) account for nearly 90% of the illness burden caused by air pollution. In 2021, air pollution accounted for 8.1 million fatalities worldwide, including those of children under five [11]. PM are microscopic liquid and solid particles that are airborne and can be divided into two sizes: PM₁₀, or particles less than 10 micrometers, and PM_{2.5}, or particles smaller than 2.5 micrometers [8]. PM_{2.5} poses a significant risk to human health due to its association with oxidative stress and inflammatory reactions in the respiratory system. It has also been connected to around 4 million deaths worldwide from cardiopulmonary disorders [10].

Dhaka was identified as the most polluted city, and Bangladesh was classified as the most polluted country with an annual average of PM_{2.5} of 79.9, which is about 15 times higher than the WHO PM_{2.5} yearly guideline [9]. According to a study, the average PM_{2.5} concentration in Dhaka in 2023 was 2.96 times higher than the limit of the country's ambient air quality guidelines, at 103.67 µg/m³ [15]. About 20% of all premature deaths in Bangladesh are attributed to air pollution, according to a World Bank report from 2023. The WHO Air Quality Guidelines are, on average, 150 percent higher than the levels of fine particulate matter (PM_{2.5}) in Dhaka City's heavily developed and continuously trafficked areas which is roughly equivalent to smoking 1.7 cigarettes per day [7]. A study that investigated the concentrations of PM_{2.5} and PM₁₀ in 82 different locations in Dhaka found that pollution levels are greater than WHO limits in all land uses, and marked unfit vehicles, industries, and construction activities as key sources of air pollution [16]. The Global Liveability Index for 2024, the top livable cities are dominated by those in Europe, Australia, and Canada due to factors such as healthcare, education, culture, environment, and infrastructure. However, Bangladesh ranked 168 in the Global Liveability Index out of 173 countries [12]. The latest State of Global Air 2024 report highlights that air pollution causes the

greatest disease burdens in South Asia and several African countries, with Bangladesh reporting over 235,000 air pollution-related fatalities in 2021 [6]. In Dhaka, there has been a significant increase in the number of people diagnosed with respiratory disorders, having no severe prior health issues, suggesting a strong link between these ailments and exposure to polluted air [17].

However, in Bangladesh, localized data on pollutant concentrations and spatial distribution in semi-urban towns like Pabna remain limited. The objective of this study is to assess the spatial variation and concentration of particulate matter (PM₁, PM_{2.5} & PM₁₀) and carbon monoxide (CO) across 61 locations Pabna district town. Therefore, this study aims to bridge this knowledge gap by systematically assessing air quality levels across different land-use zones within Pabna, providing critical insights for policy-making and urban planning to mitigate the adverse effects of air pollution. The objectives of this study are: a) To identify the status of air pollution in Pabna District Town. b) To assess the relationship between land use and all parameters (PM₁, PM_{2.5}, PM₁₀, and CO) and c) Geospatial mapping on the concentration of PM₁, PM_{2.5}, PM₁₀, and CO.

2. Methodology

2.1. Study Area

Pabna District (rajshahi division) area 2376.13 sq km, located in between 23°48' and 24°21' north latitudes and in between 89°00' and 89°44' east longitudesh [18]. The district is bounded by Natore and Sirajganj districts to the north; the Padma River, Rajbari, and Kushtia districts to the south; Manikganj and Sirajganj districts and the Jamuna River to the east; and the Padma River, Natore, and Kushtia districts to the west. A total of 40 locations were selected across the district for air quality monitoring, based on land use characteristics. These locations were categorized into seven land use types: sensitive, residential, mixed, commercial, road intersection, industrial, and village areas [14]. Table 1 shows the description of land use and sample locations.

Table 1. Location and Land Use of Study.

S. N.	Land Use Type	Description	Number of Locations
1	Sensitive Area	Hospitals, clinics, schools, colleges, mosques, madrasas, temples, churches, administrative buildings	9
2	Residential Area	Primarily housing zones and residential neighborhoods	3
3	Mixed Area	Combination of markets, buildings, and main roads	6
4	Commercial Area	Business centers, shopping areas, and local markets	6
5	Road Intersection Aarea	Busy road junctions, bends, and high traffic zones	5

S. N.	Land Use Type	Description	Number of Locations
6	Industrial Area	Locations near factories and industrial establishments	11
	Total		40

2.2. Instrument Description

Table 2. 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, 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)

2.3. Data Collection & Data Processing and Result Interpretation

As part of the survey, air quality was measured at 40 different locations across the Pabna district town area over the course of a single day using automated portable instruments, including a portable Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector (Model: DM106) and a Handheld Carbon Monoxide Meter. GPS data was recorded using an Android application called Garmin ETrex 10. At each location, four parameters PM₁, PM_{2.5}, PM₁₀, and CO were measured at various times from morning to late evening to capture temporal variation. Data analysis was conducted using MS Excel, IBM SPSS V20, and MS Excel 2020. A range of visualizations, including graphs, tables, diagrams, and box-whisker plots, were generated to illustrate data distribution. Descriptive statistics were used to assess parameter dispersion, and ANOVA was performed to test statistical significance. ArcGIS 10.4.1 was used to develop concentration, with different color schemes applied to visually represent pollutant concentration levels across locations.

3. Analysis of Concentration of PM₁, PM_{2.5}, PM₁₀ and CO

3.1. Status of Air Quality in Pabna District Town

The concentration of PM₁, PM_{2.5} & PM₁₀ in 7 different land

use are shown in Figure 1(a), (b), (c), (d), (e), (f) and (g). Figure 1(a) illustrates the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5} & PM₁₀ of some locations in sensitive areas in Pabna district town. These particular locations included administrative offices, educational institutes and mosques. As we could see, among these 9 sensitive places, three highly polluted places were in front of APS Office, Circuit House and besides Executive Engineers Office with PM concentration of 30, 50 and 64 $\mu\text{g}/\text{m}^3$, 28.75, 49.25 and 61.75 $\mu\text{g}/\text{m}^3$ and 28.5, 47.5 and 615 $\mu\text{g}/\text{m}^3$ respectively and comparatively less polluted places were Chief Judicial Magistrate Court, Pabna Powroshova and Pabna Mental Hospital with PM_{2.5} concentration of 21, 41.5 and 41.25 $\mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentrations of PM_{2.5} and PM₁₀ found in the most polluted place were 2.00 and 2.58 times higher than World Health Organization (WHO) which are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively. The study estimated that in all sensitive areas, 78.03% of PM_{2.5} was present in PM₁₀ and 60.19% of the PM₁ was present in PM_{2.5}.

Figure 1(b) shows the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5} & PM₁₀ of some locations in mixed areas in Pabna district town. It has been found that out of 6 mixed places, three highly polluted places were Pabna Medical College, Public Works Division and Ataikul Road with PM concentration of 51.25, 85 and 108.75 $\mu\text{g}/\text{m}^3$, 50.25, 81.5 and 105.75 $\mu\text{g}/\text{m}^3$ and 43.5, 70.5 and 91.75 $\mu\text{g}/\text{m}^3$ respectively and comparatively least polluted places were Public Library Pabna, Civil Surgeon Office Pabna and LGED PM concentration of 33, 44.25 and 50.25 $\mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentrations of PM_{2.5} and PM₁₀ found in the most polluted places were 3.4 and 2.18 times higher than World Health Organization (WHO) which are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively. The study estimated that in all mixed areas, 77.75% of PM_{2.5} was present in PM₁₀ and 60.24% of the PM₁

was present in $PM_{2.5}$.

Figure 1(c) shows the concentration ($\mu\text{g}/\text{m}^3$) of PM_1 , $PM_{2.5}$ & PM_{10} of some locations in residential areas in Pabna district town. It has been found that out of 3 residential places, the most polluted place was Himayetpur with PM concentration of 133.25, 54.5 and $71 \mu\text{g}/\text{m}^3$ respectively. Comparatively less polluted places were Dolilpur and Bus Stand Goli with $PM_{2.5}$

concentration of 46.75 and $43.5 \mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted places were 2.18 and 1.42 times higher than World Health Organization (WHO) which are 25 and $50 \mu\text{g}/\text{m}^3$ respectively. The study estimated that the ratio of $PM_{2.5}/PM_{10}$ was 77.63%. It was also found that 60.34% of PM_1 mass was present in $PM_{2.5}$.



Figure 1. Comparison among average Concentration of PM_1 , $PM_{2.5}$ & PM_{10} in Different Land Use.

Figure 1(d) shows the concentration ($\mu\text{g}/\text{m}^3$) of PM_1 , $PM_{2.5}$ & PM_{10} of some locations in commercial areas in Pabna dis-

trict town. It has been found that out of 6 commercial places, three highly polluted places were near Tula Potti, Pabna Big

Bazar and Government Duck-Chicken Fram with PM concentration of 54, 85.5 and 112.25 $\mu\text{g}/\text{m}^3$, 49.25, 81.5 and 105 $\mu\text{g}/\text{m}^3$ and 44, 72.5 and 93.75 $\mu\text{g}/\text{m}^3$ respectively and comparatively less polluted places were Kashipur Bazar, Powro Hawkars Market and A Hamid Road (AL-Aksa Super Market) with PM concentration of 27.5, 44 and 58 $\mu\text{g}/\text{m}^3$, 28.25, 47.25 and 60.75 $\mu\text{g}/\text{m}^3$ and 40.75, 64.5 and 84.5 $\mu\text{g}/\text{m}^3$ respectively. It was also observed that the concentrations of $\text{PM}_{2.5}$ and PM_{10} found in the most polluted places were 3.42 and 2.25 times higher than World Health Organization (WHO) which are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively. The study estimated that the ratio of $\text{PM}_{2.5}/\text{PM}_{10}$ was 76.85%. It was also found that 61.62% of PM_1 mass was present in $\text{PM}_{2.5}$.

Figure 1(e) demonstrates the concentration ($\mu\text{g}/\text{m}^3$) of PM_1 , $\text{PM}_{2.5}$ & PM_{10} of some locations in road intersection areas in Pabna district town. It has been found that out of 5 road intersection places, three highly polluted places were Chadmari Moor, Indra Moor and Poilanpur Moor with PM concentration of 78.25, 132.25 and 169 $\mu\text{g}/\text{m}^3$, 41.5, 70.5 and 90 $\mu\text{g}/\text{m}^3$, 43.5, 71 and 90.5 $\mu\text{g}/\text{m}^3$ respectively and relatively less polluted places were College Road, Robeul Market Moor Academy with PM concentration of 28.25, 46.25 and 60 $\mu\text{g}/\text{m}^3$ and 37.75, 63 and 81 $\mu\text{g}/\text{m}^3$ respectively. It was also observed that the concentrations of $\text{PM}_{2.5}$ and PM_{10} found in the most polluted places were 5.29 and 3.38 times higher than World Health Organization (WHO) which are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively. The study estimated that the ratio of $\text{PM}_{2.5}/\text{PM}_{10}$ was 77.98%. It was also found that 60.06% of PM_1 mass was present in $\text{PM}_{2.5}$.

Figure 1(f) shows the concentration ($\mu\text{g}/\text{m}^3$) of PM_1 , $\text{PM}_{2.5}$ & PM_{10} of some locations in industrial locations in Pabna district town. It has been found that out of 11 industrial places,

three highly polluted places are in Mita Oil & Food Industries, A. R. Specialized Auto Rice Mills and Tushar Flour Mill with PM concentration of 39.5, 65.5 and 84.25 $\mu\text{g}/\text{m}^3$, 34.5, 57.75 and 74.25 $\mu\text{g}/\text{m}^3$ and 32, 53.25 and 68.75 $\mu\text{g}/\text{m}^3$ respectively and comparatively less polluted places were SSOM, Kiishan Food Production Dipo-1 and Square Pharmaceuticals with $\text{PM}_{2.5}$ concentration of 38.25, 40.25 and 41 $\mu\text{g}/\text{m}^3$ respectively. It was also observed that the concentrations of $\text{PM}_{2.5}$ and PM_{10} found in the most polluted places were 2.62 and 1.68 times higher than World Health Organization (WHO) which are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively. The study estimated that the ratio of $\text{PM}_{2.5}/\text{PM}_{10}$ was 78.00%. It was also found that 60.12% of PM_1 mass was present in $\text{PM}_{2.5}$.

3.2. Comparison of Average Concentration of CO of Different Land Use

Figure 2 illustrates a comparison of average concentration of CO among seven lands use in Pabna district town. The graph shows that the average of CO was found to be highest in the road intersection area (20 ppm) followed by commercial area (15 ppm) and industrial area (12.73) which were higher than the standard level. It is harmful for the living organism if anyone stays for long time in that concentration. The concentration of CO in the most polluted area was 2.22 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) level which is 9 ppm (8-hour) respectively. The average concentration of CO was found to be relatively lower sensitive area, residential area and mixed area where the concentration did not exceed the standard level. Due to one sample collected area in village area the concentration is not presented here.

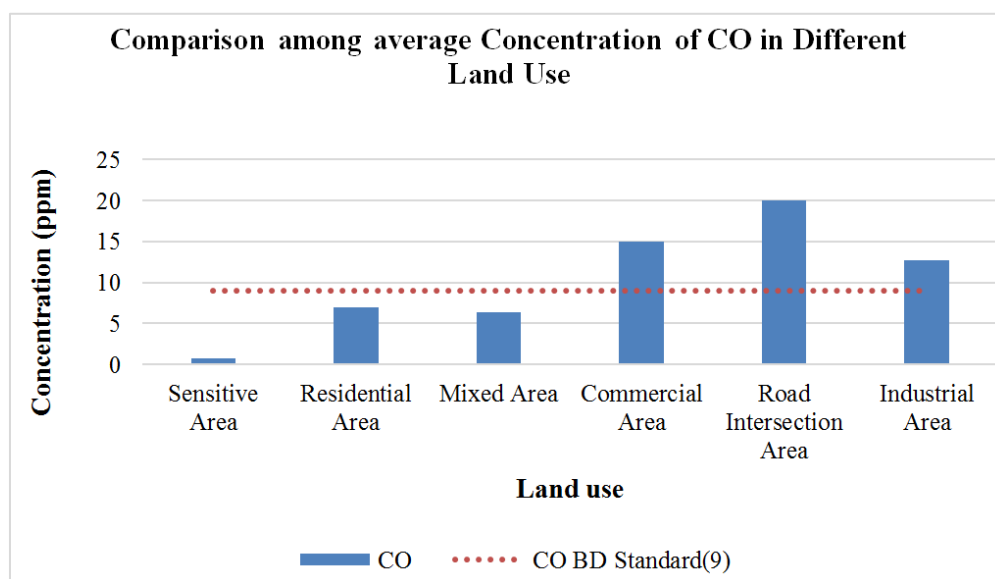


Figure 2. Comparison among average Concentration of CO in Different Land Use.

3.3. Dispersion of PM₁, PM_{2.5}, PM₁₀ and CO

Table 3. Descriptive Statistics for PM₁, PM_{2.5}, PM₁₀ and CO.

PM ₁						
S. N.	Land Use	NoL	Range (µg/m ³)	Mean (µg/m ³)	Std. Deviation (µg/m ³)	Coefficient of Variation (%)
1	Sensitive Area	9	15.25	25.64	4.65	18.12
2	Mixed Area	6	32.50	36.83	13.47	36.58
3	Residential Area	3	8.50	29.17	4.26	14.61
4	Road Intersection Area	5	50.00	45.85	19.04	41.52
5	Commercial Area	6	26.50	40.63	10.86	26.74
6	Industrial Area	11	17.50	28.89	4.93	17.08

PM _{2.5}						
S. N.	Land Use	NoL	Range (µg/m ³)	Mean (µg/m ³)	Std. Deviation (µg/m ³)	Coefficient of Variation (%)
1	Sensitive Area	9	25.00	42.61	7.88	18.49
2	Mixed Area	6	52.00	60.75	21.29	35.04
3	Residential Area	3	11.00	48.25	5.65	11.71
4	Road Intersection Area	5	86.00	76.60	32.68	42.66
5	Commercial Area	6	41.50	65.88	17.32	26.30
6	Industrial Area	11	27.25	48.05	8.11	16.88

PM ₁₀						
S. N.	Land Use	NoL	Range (µg/m ³)	Mean (µg/m ³)	Std. Deviation (µg/m ³)	Coefficient of Variation (%)
1	Sensitive Area	9	32.00	54.58	9.92	18.18
2	Mixed Area	6	67.00	78.29	27.74	35.43
3	Residential Area	3	16.50	62.25	8.30	13.33
4	Road Intersection Area	5	109.00	98.10	41.52	42.32
5	Commercial Area	6	54.25	85.71	22.51	26.26
6	Industrial Area	11	36.25	61.66	10.70	17.36

The descriptive statistics for PM₁, PM_{2.5}, and PM₁₀ across seven land use types show that the road intersection area

consistently had the highest pollution levels in Table 3. For PM_1 , the maximum concentration was $78.25 \mu\text{g}/\text{m}^3$, with a mean of $45.85 \mu\text{g}/\text{m}^3$, standard deviation of $19.04 \mu\text{g}/\text{m}^3$, and coefficient of variation (CV) of 41.61%. In contrast, the sensitive area had the lowest mean ($25.64 \mu\text{g}/\text{m}^3$) and minimum value ($14.75 \mu\text{g}/\text{m}^3$). For $PM_{2.5}$, road intersections again recorded the highest values: maximum of $132.25 \mu\text{g}/\text{m}^3$, mean of $76.60 \mu\text{g}/\text{m}^3$, standard deviation of $32.68 \mu\text{g}/\text{m}^3$, and CV of 42.66%. The lowest mean was in the sensitive area (42.61

$\mu\text{g}/\text{m}^3$), and the lowest CV was in the village area (12.22%). Regarding PM_{10} , the road intersection area had a maximum of $169.00 \mu\text{g}/\text{m}^3$, mean of $98.10 \mu\text{g}/\text{m}^3$, standard deviation of $41.52 \mu\text{g}/\text{m}^3$, and CV of 42.32%. The sensitive area recorded the lowest mean ($54.58 \mu\text{g}/\text{m}^3$), and the residential area had the lowest CV (13.33%). These results highlight significantly higher particulate matter concentrations and variability in road intersections, while residential and sensitive areas show relatively lower and more stable pollution levels.

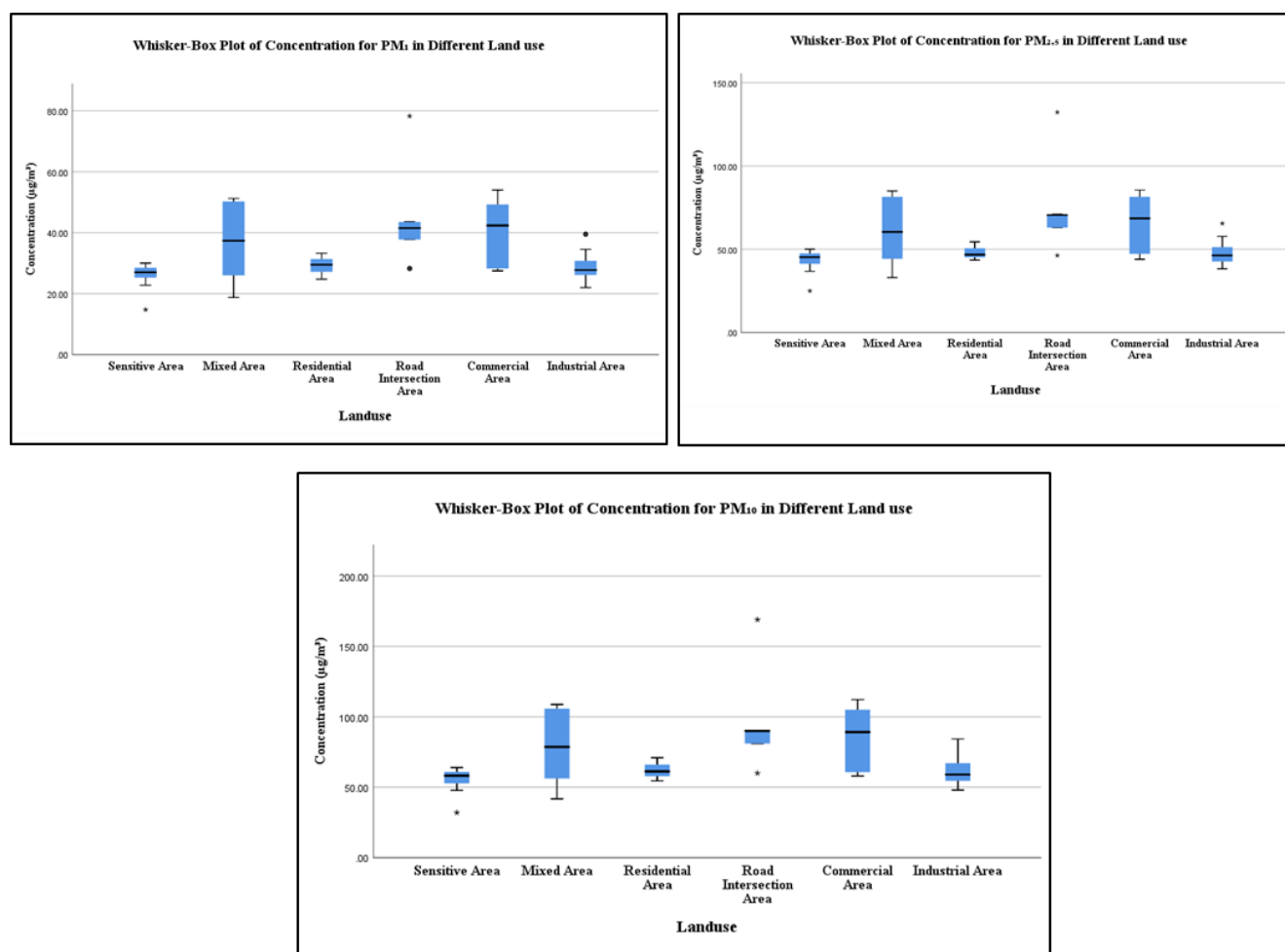


Figure 3. Whisker Box Plot of the Concentration of PM_1 , $PM_{2.5}$ & PM_{10} in Different Land use.

The box-whisker plots for PM_1 , $PM_{2.5}$, and PM_{10} across seven land use types illustrate variations in concentration, dispersion, and outliers in Figure 3(a), (b) and (c). In all three pollutants, the mixed area showed the highest dispersion, with positive skewness in $PM_{2.5}$ and PM_{10} , and normal skewness in PM_1 . Moreover, Commercial areas showed relatively high dispersion, with a negative skewness. A similar pattern of dispersion and skewness was observed in the Netrokona district [13]. Road intersection and industrial areas exhibited moderate dispersion, each with two and one outlier(s), respectively primarily due to heavy traffic (e.g., Chadmari Moor) or industrial activity (e.g., Mita Oil & Food Industries). Res-

idential and sensitive areas had more compact concentrations: residential areas with positive skewness, and sensitive areas with negative skewness, though one outlier was found near the Chief Judicial Magistrate Court, likely due to reduced dust levels. The plots collectively highlight significant spatial variation and pollution sources across land use types.

3.4. Dispersion of CO

The following Table 4 shows the descriptive statistics for CO of the seven land uses studied. The highest ranges were found in road intersection area (37 ppm) and the lowest ranges

was found in residential areas (4 ppm). Among all those land uses the minimum concentration (0 ppm) was seen in all of those zones except residential area (5 ppm) and maximum concentration was seen in road intersection area (37 ppm). The highest mean value of CO was found in road intersection

area (20 ppm) and lowest mean found in sensitive area (0.78 ppm). It was observed that the highest coefficient of Variation was found in sensitive area (300.00%) and the least variation was found in residential area which was 28.57%.

Table 4. Descriptive Statistics for CO.

SI No	Land Use	Number of locations	Range (ppm)	Min. (ppm)	Max. (ppm)	Mean (ppm)	Std. Deviation (ppm)	Coefficient of Variation (%)
1	Sensitive Area	9	7.00	0.00	7.00	0.78	2.33	300.00
2	Mixed Area	6	15.00	0.00	15.00	6.33	5.89	92.97
3	Residential Area	3	4.00	5.00	9.00	7.00	2.00	28.57
4	Road Intersection Area	5	37.00	0.00	37.00	20.00	15.72	78.58
5	Commercial Area	6	33.00	0.00	33.00	15.00	11.85	78.99
6	Industrial Area	11	31.00	0.00	31.00	12.73	9.26	72.79

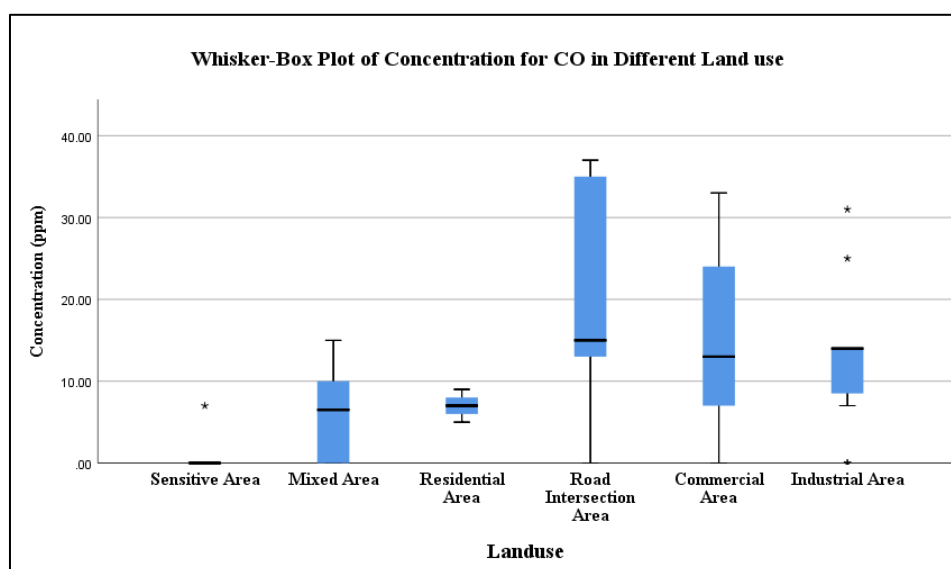


Figure 4. Whisker Box Plot of the Concentration of CO in Different Land use.

The whisker box plot shows the average CO concentrations in seven land uses in Figure 4. 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 CO revealed that the road intersection area had higher dispersion followed by commercial area with positively skewed values. The moderate distribution was seen in industrial area with two outliers. This outlier was found outside of Mita Oil & Food Industries and A. R. Specialized Auto Rice Mills area due to industrial activities. The residential area had less

moderate distribution with normally skewed distribution. The sensitive area had the most clustered concentration with one outlier; the situation was found outside of APS Office due to sudden movements of vehicles.

3.5. Land Use Based Cluster Analysis

Figure 5(a) illustrates the dendrogram plot obtained from cluster analysis in terms of PM₁ with Z-score normalization. For this analysis average linkage between groups has been considered. Three clusters have been found from the graph below. First cluster consists of residential area, industrial area and sensitive area; second cluster includes mixed area and

commercial area; and third cluster includes road intersection area alone. First and second cluster join at the approximate distance of 10 which joins with third cluster the approximate distance of 25.

Figure 5(b) shows the dendrogram plot obtained from cluster analysis in terms of $PM_{2.5}$ with Z-score normalization. For this analysis average linkage between groups has been considered. Three clusters have been found from the graph below. First cluster consists of residential area, industrial area and sensitive area; second cluster includes mixed area and commercial area; and third cluster includes road intersection area alone. First and second cluster joins at the approximate distance of 8 which joins with third cluster the approximate distance of 25. Figure 5(c) shows the dendrogram plot obtained from cluster analysis in terms of PM_{10} with Z-score normalization. For this analysis average linkage between groups has been considered. Three clusters have been found

from the graph below. First cluster consists of residential area, industrial area and sensitive area; second cluster includes mixed area and commercial area; and third cluster includes road intersection area alone. First and second cluster joins at the approximate distance of 8 which joins with third cluster the approximate distance of 25. Figure 5(d) shows the dendrogram plot obtained from cluster analysis in terms of CO with Z-score normalization. For this analysis, group linkage and Euclidean distance have been considered. Four clusters have been found from the graph below. First cluster consists of residential area and mixed area; second cluster includes sensitive area only; third cluster includes commercial area and industrial area; and forth cluster includes the road intersection area alone. First and second cluster joins with third cluster at the distance of 7 which joins with forth cluster the approximate distance of 25.

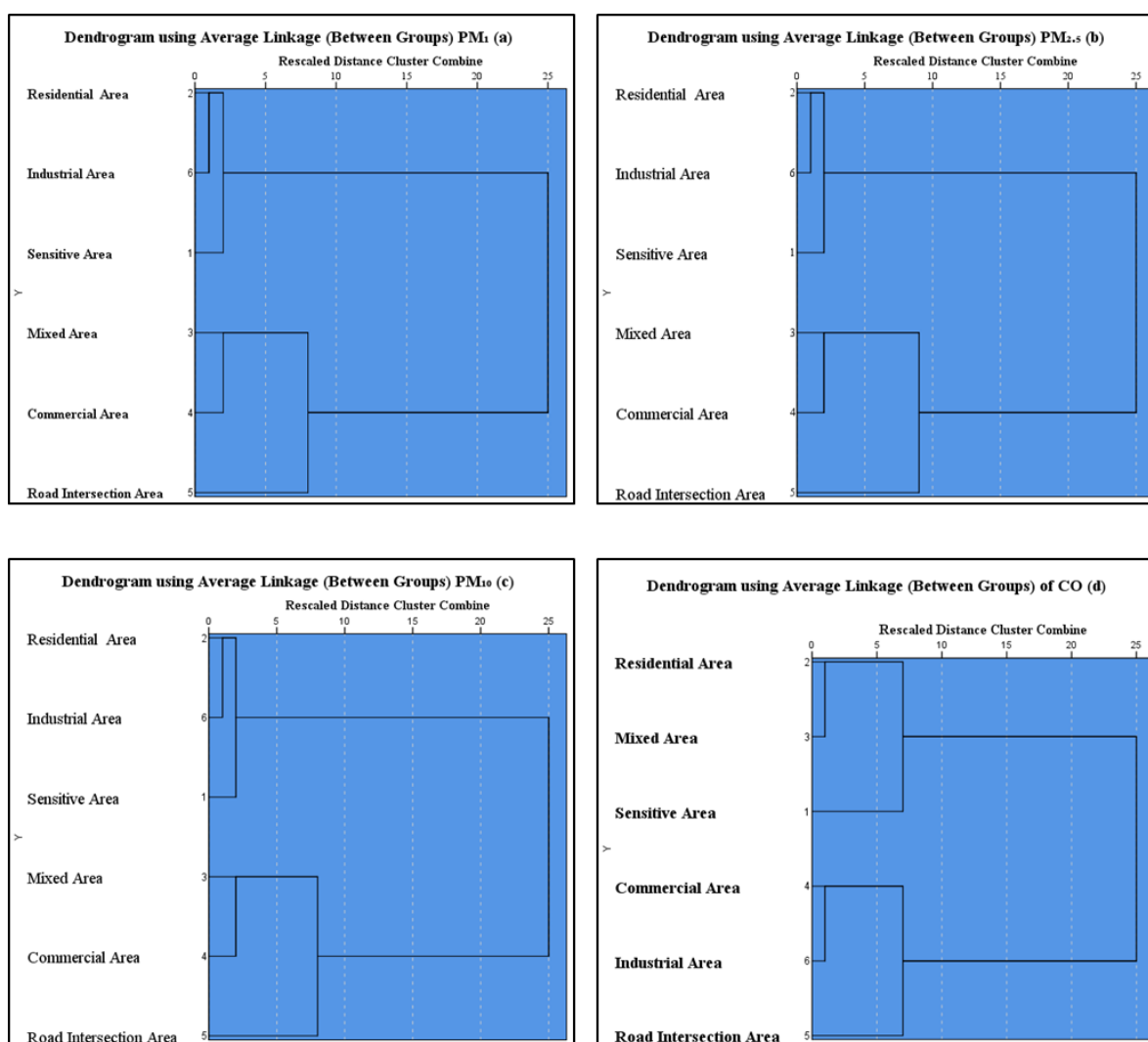


Figure 5. Land Use Based Cluster Analysis of PM_1 , $PM_{2.5}$, PM_{10} and CO.

3.6. Comparison Among Average Concentration of PM₁, PM_{2.5} & PM₁₀ of Different Land Use

The Figure 6 illustrates the comparison of the average concentration of PM₁, PM_{2.5} & PM₁₀ of seven lands uses in Pabna district town. The average concentration of PM₁, PM_{2.5} & PM₁₀ was higher in the road intersection area, commercial area and mixed area with the values of 45.85, 76.60 and 98.10 $\mu\text{g}/\text{m}^3$; 40.63, 65.88 and 85.71 $\mu\text{g}/\text{m}^3$ and 36.83, 60.75 and

78.29 $\mu\text{g}/\text{m}^3$ respectively with highest in the road intersection area. It was also observed that the concentrations of PM_{2.5} and PM₁₀ found in the most polluted land use were 3.06 and 1.95 times higher than World Health Organization (WHO) which are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively. The concentration of PM was found relatively lower in sensitive area, residential area and industrial area. Moreover, the average concentration of PM₁ (25.64 $\mu\text{g}/\text{m}^3$), PM_{2.5} (42.61 $\mu\text{g}/\text{m}^3$) and PM₁₀ (54.58 $\mu\text{g}/\text{m}^3$) were found to be least in sensitive area.

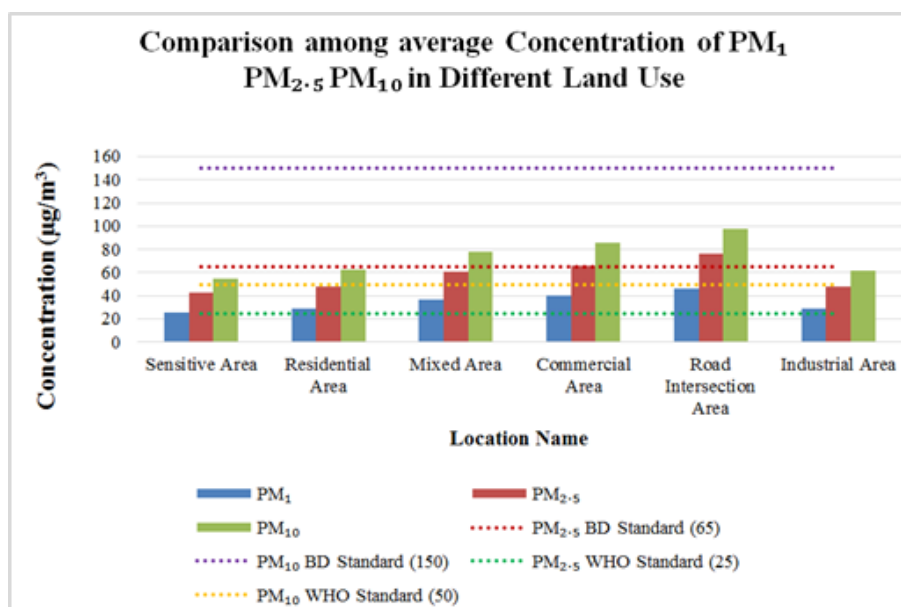


Figure 6. Comparison among Average Concentration of PM₁, PM_{2.5} & PM₁₀.

3.7. Three (3) Most and Least Polluted Locations in 40 Locations of Pabna District Town

Table 5. Three (3) Most and Least Polluted Locations.

Rank	Land use Type	Land Use	PM ₁	PM _{2.5}	PM ₁₀
	Road Intersection Area	Chadmari Moor	78.25	132.25	169
	Commercial Area	Tula Potti	54	85.5	112.25
	Mixed Area	Pabna Medical College	51.25	85	108.75
	Sensitive Area	Chief Judicial Magistrate Court	14.75	25	32
	Mixed Area	Public Library Pabna	18.75	33	41.75
	Sensitive Area	Onukul Chandra Shotshonggo	22.75	36.75	47.75

According to the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5} & PM₁₀ among 40 locations, 3 most polluted places were Chadmari Moor (Road Intersection Area), Tula Potti (Commercial Area) and Pabna Medical College (Mixed Area) and 3 least contaminated places were Chief Judicial

Magistrate Court, Public Library Pabna and Onukul Chandra Shotshonggo (Table 5). It has been observed that concentrations of PM₁, PM_{2.5} & PM₁₀ of Chadmari Moor and Chief Judicial Magistrate Court were 78.25, 132.25 and 169 $\mu\text{g}/\text{m}^3$ and 14.75, 25 and 32 $\mu\text{g}/\text{m}^3$ respectively. It was

also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted location were 5.29 and 3.38 times higher than World Health Organization (WHO) which are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively.

3.8. Concentration Map on PM_1 , $PM_{2.5}$, PM_{10} and CO

Figure 7 show the concentration of Particulate Matter (PM_1 , $PM_{2.5}$, PM_{10}) and CO at various location of Pabna district town in the year of 2021. Concentrations of Particulate Matter (PM_1) are expressed in $\mu\text{g}/\text{m}^3$. The concentration of $\mu\text{g}/\text{m}^3$ means one-millionth of a gram of PM_1 per cubic meter of air. Yellow areas have less, while progressively higher concentrations are shown in orange and red. The concentration of PM_1 was found to higher (50-40.2 $\mu\text{g}/\text{m}^3$) in some part of Pabna Sadar Upazila, Sujanagar Upazila, Bera Upazila. The maximum concentration shows with blue point and minimum concentration with green point. The top maximum concentration was found in Chadmari Moor and the least concentration was found in Chief Judicial Magistrate Court. Concentrations of Particulate Matter ($PM_{2.5}$) are expressed in $\mu\text{g}/\text{m}^3$. The concentration of $\mu\text{g}/\text{m}^3$ means one-millionth of a gram of $PM_{2.5}$ per cubic meter of air. Yellow areas have little, while progressively higher concentrations are shown in orange and red. The concentration of $PM_{2.5}$ was found to higher (83.8-67.5 $\mu\text{g}/\text{m}^3$) in some part of Pabna Sadar Upazila, Atgaria Upazial and Chatmohar Upazila. The maximum concen-

tration shows with red flag and minimum concentration with green flag. The top maximum concentration was found in Chadmari Moor and the least concentration was found in Chief Judicial Magistrate Court. Concentrations of Particulate Matter (PM_{10}) are expressed in $\mu\text{g}/\text{m}^3$. The concentration of $\mu\text{g}/\text{m}^3$ means one-millionth of a gram of PM_{10} per cubic meter of air. Yellow areas have little, while progressively higher concentrations are shown in orange and red. The concentration of $PM_{2.5}$ was found to higher (107-79.3 $\mu\text{g}/\text{m}^3$) in the part of Sujanagar Upazila, Atgaria Upazila, Pabna Sadar Upazila. The maximum concentration shows with blue point and minimum concentration with green point. The top maximum concentration was found in Chadmari Moor and the least concentration was found in Chief Judicial Magistrate Court. Concentrations of carbon monoxide are expressed in parts per million by volume (ppm). A concentration of 1 ppm means that for every million molecules of gas in the measured volume, one of them is a carbon monoxide molecule. Yellow areas have little or no carbon monoxide, while progressively higher concentrations are shown in orange and red. The concentration of CO was found to higher (22.8-16.2 $\mu\text{g}/\text{m}^3$) in the Bera Upazila, Sujanagar Upazila, Faridpur Upazila, Santhia Upazila. The maximum concentration shows with blue point and minimum concentration with green point. The top maximum concentration was found in Chadmari Moor and the least concentration was found in Chief Judicial Magistrate Court.

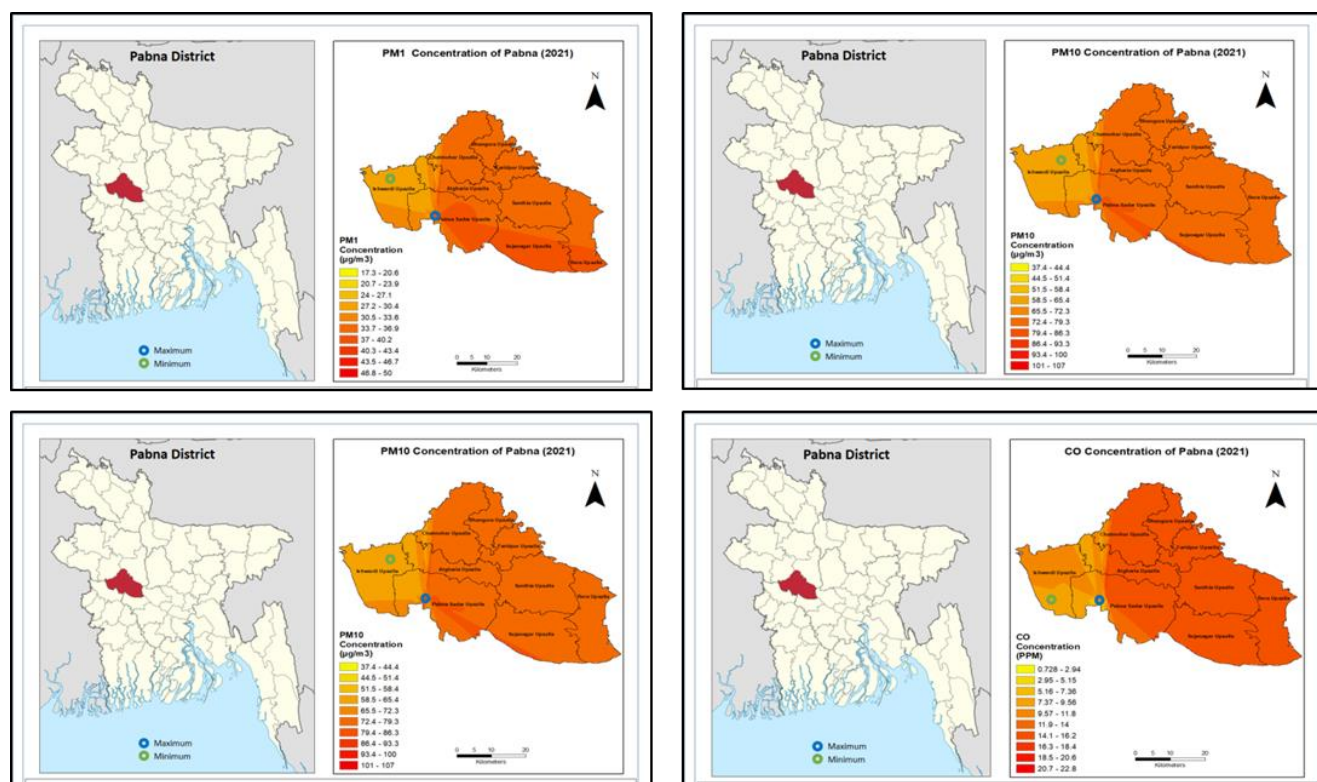


Figure 7. PM_1 , $PM_{2.5}$, PM_{10} and CO Concentration of Pabna District Town.

4. Conclusion

Study found that the average concentration of PM₁, PM_{2.5} & PM₁₀ of 41 places in Pabna district town were 34.50, 57.02 and 73.43 µg/m³ respectively. From the outcome of this research the studied land uses are arranged in descending order based on average concentration PM which follows road intersection area > commercial area > mixed area > village area > industrial area > residential area > sensitive area. The Concentration of PM_{2.5} and PM₁₀ were found 2.28 and 1.49 times higher than the standard level. Moreover, it was estimated from the average ratio of PM_{2.5} /PM₁₀ showed that the PM_{2.5} mass was 77.63% of the PM₁₀ mass and the average ratio PM₁ /PM_{2.5} showed that the PM₁ mass was 60.46% of the PM_{2.5} mass. It is further found that, the changes in the concentration of PM and CO do not change significantly since the p value is greater than 0.05. From the dendrogram plot of PM₁, PM_{2.5}, PM₁₀ it has been found out that each of the analysis included at least four clusters at the first phase and these were consecutively to make a single cluster at the approximate distance of 25.

5. Limitation of the Study

To improve analysis and achieve more accurate results, we need data from more locations, with greater spatial distribution within each area. Regular weekly or monthly data collection is essential for tracking trends over time. Additionally, selecting locations based on specific land use types will allow for more detailed and targeted research.

Abbreviations

ECA	Energy and Clean Air
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, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing

Mohammad Tariq Ali: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Funding, Resources, Software, Validation, Writing - original draft, Writing - review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] WHO- World Health Organization (2024). Air pollution. Retrieved August 25, 2024, from https://www.who.int/health-topics/air-pollution#tab=tab_1
- [2] NRDC - Natural Resources Defense Council (2024). Clean air. Natural Resources Defense Council. Retrieved August 27, 2024, from <https://www.nrdc.org/issues/clean-air#overview>
- [3] UNEP - United Nations Environment Programme (2023). Air Pollution Note: Data You Need to Know. UNEP. Retrieved August 27, 2024, from <https://www.unep.org/interactives/air-pollution-note/>
- [4] World Bank (2022^a). Fighting air pollution: A deadly killer and core development challenge. World Bank. Retrieved August 27, 2024, from <https://blogs.worldbank.org/en/health/fighting-air-pollution-deadly-killer-and-core-development-challenge>
- [5] AQLI - Air Quality Life Index. (2023). AQLI top charts 2023. The University of Chicago, Energy Policy Institute. Retrieved from <https://aqli.epic.uchicago.edu/news/aqli-top-charts-2023/>
- [6] UNICEF (2024). *Disease burden of air pollution on children continues to rise in Bangladesh, according to latest report.* UNICEF. Retrieved from <https://www.unicef.org/bangladesh/en/press-releases/disease-bur-den-air-pollution-children-continues-rise-bangladesh-according-latest>
- [7] World Bank. (2022^b). Bangladesh clean air and sustainable environment project implementation completion and results report (Report No. P168901). World Bank. Retrieved from <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099440011162223258/p16890102a72ac03b0bcb00ad18c4acbb10>
- [8] U. S. EPA - U. S. Environmental Protection Agency (2024^a). Particulate matter (PM) basics. Retrieved August 25, 2024, from <https://www.epa.gov/pm-pollution/particulate-matter-pm-basics>
- [9] IQAir (2023). World Air Quality Report 2023. IQAir. Retrieved from <https://www.iqair.com/newsroom/waqr-2023-pr>
- [10] Thangavel, P., Park, D. and Lee, Y. (2022). Recent Insights into Particulate Matter (PM_{2.5})-Mediated Toxicity in Humans: An Overview. *Int J Environ Res Public Health*, 19(12), 7511. <http://dx.doi.org/10.3390/ijerph19127511>
- [11] HEI - Health Effects Institute (2024). State of global air report 2024. Health Effects Institute. Retrieved August 27, 2024, from <https://www.stateofglobalair.org/resources/report/state-global-air-report-2024>

- [12] EIU - Economist Intelligence Unit (2024). The global liveability index 2024: Summary report. Economist Intelligence Unit. Retrieved August 27, 2024, from <https://livewirecalgary.com/wp-content/uploads/2024/06/The-Global-Liveability-Index-Summary-Report-final.pdf>
- [13] Majumder, A. K., Hossain, S. M. A., Patoary, M. N. A., & Rahman, M. (2023). Spatial distribution of air quality in Netrokona district town, Bangladesh. *Open Access Research Journal of Engineering and Technology*, 5(1), 1-11.
- [14] Majumder, A. K., Mahmud, K. K., Rahman, M., Patoary, M. N. A., Gautam, S., and Tanima, K. R. (2025). Spatial distribution and health implications of particulate matter concentrations across diverse land use types in Dinajpur District, Bangladesh. *Geosystems and Geoenvironment*, 4(3), 100397, ISSN 2772-8838. <https://doi.org/10.1016/j.geogeo.2025.100397>
- [15] Majumder, A. K., Rahman, M., Patoary, M. N. A., Kamruzzaman, A. M. and Majumder, R. (2024^a). Time Series Analysis PM_{2.5} Concentration for Capital City Dhaka from 2016 to 2023. *Science Frontiers*, 5(1): 35-42.
- [16] Majumder, A. K., Akbar, A. T. M. M., Rahman, M., Patoary, M. N. A., Islam, M. R., and Majumder, R. (2024^b). Monsoon Season Spatial Distribution of Particulates Concentration in the Road Intersection Area of Different Land Use in Major City in South Asian Countries. *Journal of Health and Environmental Research*, 10(1): 15-28.
- [17] Dibya, T. B., Proma, A. Y. and Dewan, S. M. R. (2023). Poor Respiratory Health is a Consequence of Dhaka's Polluted Air: A Bangladeshi Perspective. *Environ Health Insights*, 17: 11786302231206126. <http://dx.doi.org/10.1177/11786302231206126>.
- [18] *Pabna District - Banglapedia*. (2025). https://en.banglapedia.org/index.php/Pabna_District