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Assessing air quality across urban zones of Gopalganj, Bangladesh during the winter season

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Abstract

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 Gopalganj district town. This study was conducted in 59 locations of Gopalganj district town, by using portable Air Quality Monitor and portable CO Meter. The Department of Environment established the Bangladesh National Air Quality Standard (BNAAQS), which sets $PM_{2.5}$ and PM_{10} levels at 65 and 150 µg/m^3, respectively and for CO is 9 ppm. It is found that average concentrations of PM_1, $PM_{2.5}$ and PM_{10} of 59 places in Gopalganj district town were 44.88, 74.58 and 95.96 µg/m^3 respectively. It is estimated that the average $PM_{2.5}/PM_{10}$ was 77.60%, $PM_1/PM_{2.5}$ was 60.44%. The average concentration of CO found in the most polluted place was 1.29 times higher than NAAQS level. Average concentration of $PM_{2.5}$ which follows as industrial area > road intersection area > village area > sensitive area > commercial area > residential area> mixed area. Therefore, this study underscores the critical need for targeted air quality management strategies and regulatory measures to mitigate pollution in different land use settings, enhancing public health and environmental quality in Gopalganj district town.

Keywords: Particulate Matter; Gaseous Pollutant; Meteorology; Correlation; Gopalganj District Town

1. Introduction

Any chemical, physical, or biological substance that alters the atmosphere's inherent properties is considered to be an air pollutant when it contaminates the interior or outdoor environment (WHO, 2024). Particulate matter (PM) is a significant contributor to air pollution. According to U.S. Environmental Protection Agency (2024), PM are microscopic liquid and solid particles that are airborne and can be categorized according to size, with PM_{10} (particles smaller than 10 micrometers diameter) and $PM_{2.5}$ (particles smaller than 2.5 micrometers diameter), being the most health related. The sources of these particles include building sites, industrial activities, automobile emissions, and natural sources like dust storms and wildfires which can cause respiratory and cardiovascular problems by deeply penetrating the circulation and lungs (U.S. Environmental Protection Agency, 2024). In 2011, it was noted that over 80% of the world's population is exposed to $PM_{2.5}$ concentrations exceeding WHO air quality guidelines, with the health consequences of these exposures thought to contribute between 2 and 5% of the global disease burden (Ramanathan & Carmichael, 2011). However, According to IQAir (2023) report, the WHO's annual $PM_{2.5}$ guideline value of 5 µg/m^3 was achieved in 2023 by 10 of the 134 countries and regions that reported and much more work has to be done to address air pollution, since just 9% of cities worldwide report meeting the WHO annual $PM_{2.5}$ limit. According to WHO (2024) data, 99% of people on Earth breathe air that is polluted at levels higher than those recommended by the WHO, with low- and middle-income nations having the worst exposure. According to research, 716 million of the world's poorest people mostly in Sub-Saharan Africa are disproportionately affected by the 7.3 billion people who are exposed to dangerous levels of $PM_{2.5}$ worldwide, of them, 80% live in low- and middle-income nations (Mitra et al., 2023). This is due to the inefficient

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use of solid fuels like kerosene for lighting, heating, and cooking can emit harmful chemicals that have a negative effect on health, particularly in rural parts of sub-Saharan Africa, South and East Asia, and the Western Pacific (Breeze Technologies, 2024). Because of their obligations in the home, women, children, and the elderly are most vulnerable and lack of access to cleaner fuels and technology not only puts people's health at risk but also stunts economic growth by lowering prospects for employment, quality of life, and education (Breeze Technologies, 2024). Due to oxidative stress, inflammation, and decreased lung immune function, climate change and air pollution worsen respiratory illnesses, and these variables increase the likelihood of respiratory problems in vulnerable populations, such as children, the elderly, and those with underlying medical illnesses (Tran et al., 2023). The IQAir (2023) report highlights that Bangladesh, particularly Dhaka, experiences severe air pollution with high levels of particulate matter ($PM_{2.5}$ and PM_{10}), which poses significant health risks. According to the report Bangladesh ranked number one consisting of the average $PM_{2.5}$ concentration 16 times the WHO annual air quality guideline value. According to World Bank (2023) report, about 20% of all premature deaths in Bangladesh are caused by air pollution. Air pollution is a major cause of the growing incidence of respiratory diseases in Dhaka, where people who work outside and are exposed to air pollution do not exhibit other serious health problems, which suggests that air pollution is the direct cause of their problems (Dibya et al., 2023). However, the seasons affected the PM values significantly, which varied from higher in the winter to lower in the wet seasonal period. A study conducted by Majumder et al. (2020) found that there was a greater concentration of $PM_{2.5}$ and PM_{10} from December to February (winter), a decline from July to September (rainy season), and an increase starting in October.

Therefore, air quality is a critical factor influencing public health and environmental quality, particularly in urban areas where industrial activities, traffic congestion, and diverse land uses contribute to varying pollution levels. Understanding the distribution and concentration of particulate matter (PM_1, $PM_{2.5}$ and PM_{10}) and carbon monoxide (CO) is essential for effective air quality management and policymaking. The Gopalganj district town, like many rapidly developing regions, faces significant challenges related to air pollution. This study aims to address these challenges by monitoring the concentrations of PM_1, $PM_{2.5}$, PM_{10}, and CO across different land use areas in Gopalganj. By evaluating air quality at 59 locations throughout the district, this research seeks to provide a detailed assessment of pollutant levels and their variability according to land use patterns.

2. Research methodology

2.1. Study Area

Gopalganj District (Dhaka division) area 1489.92 sq km, located between 22°50' and 23°01' north latitudes and in between 89°40' and 90°02' east longitudes. However, 59 locations were selected on basis of 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 (Majumder et al., 2025).

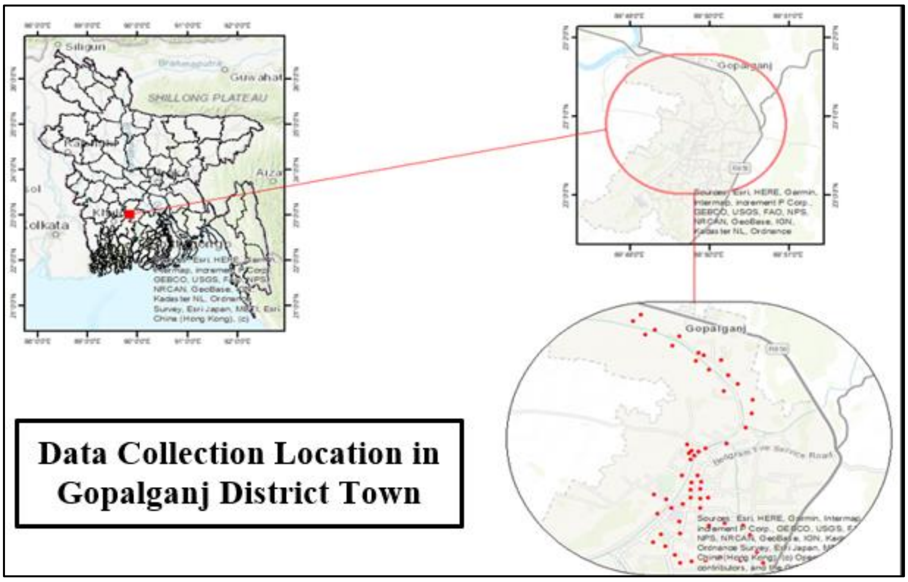

Figure 1 Study Area (Gopalganj District Town and Data Collection Location)

2.2. Flow Diagram of Research Methods

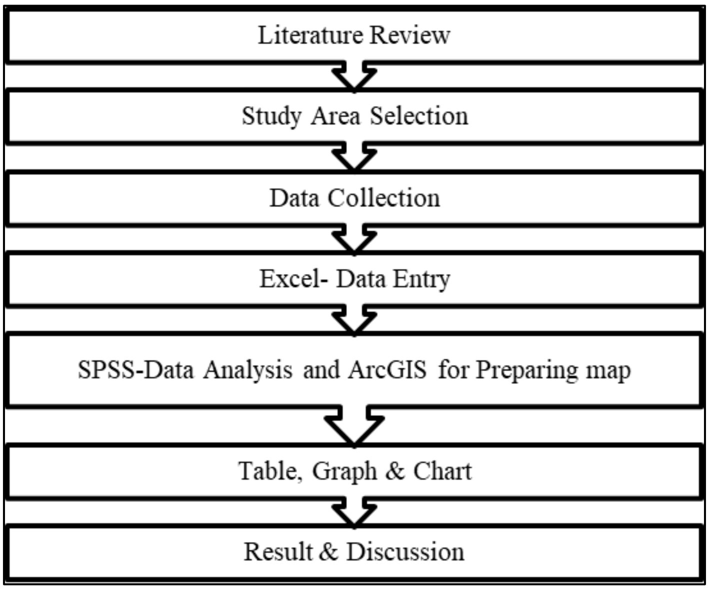

Figure 2 Flow Diagram of Research Methods

2.3. Data Collection

Over the course of two days, the Gopalganj district town's air quality was assessed at several locations. Along with GPS data, four separate sets of data: PM_1, $PM_{2.5}$, PM_{10}, and CO were gathered at each location. The tools used to determine the parameters for data collection are depicted in table 1.

Table 1 Tools used to determine the parameters

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)

2.4. Data Analysis

Analysis utilized MS Excel 2020 and IBM SPSS V20. Multiple graphs, tables, diagrams, and Box-Whisker plots were generated to understand the nature of the data. Descriptive statistics were conducted to assess the dispersion of each land use parameter, and ANOVA was performed for significance testing. The results were visualized using various graphs, charts, and maps. Specifically, ArcGIS 10.4.1 was employed to prepare concentration and Air Quality Index (AQI) maps for the Gopalganj district town area. The AQI for $PM_{2.5}$ and PM_{10} concentrations was calculated using the equation provided by USEPA, which determines the AQI based on pollutant concentrations. The highest AQI value calculated from the respective pollutant concentrations was used (U.S. Environmental Protection Agency, 2024).

$$I_P = \frac{(I_{HI} - I_{LO})}{(BP_{HI} - BP_{LO})}\,(C_P - BP_{LO}) + I_{LO}$$

If numerous contaminants are detected, the AQI is the maximum value determined by applying the above formula to each pollutant.

Were

- I = the (Air Quality) index
- C = the pollutant concentration
- C_{low} = the concentration breakpoint that is ≤ C

- C_{high} = the concentration breakpoint that is ≥ C
- I_{low} = the index breakpoint corresponding to C_{low}
- I_{high} = the index breakpoint corresponding to C_{high}

3. Results and Discussion

3.1. Status of Air Pollution Studies in Gopalganj District Town

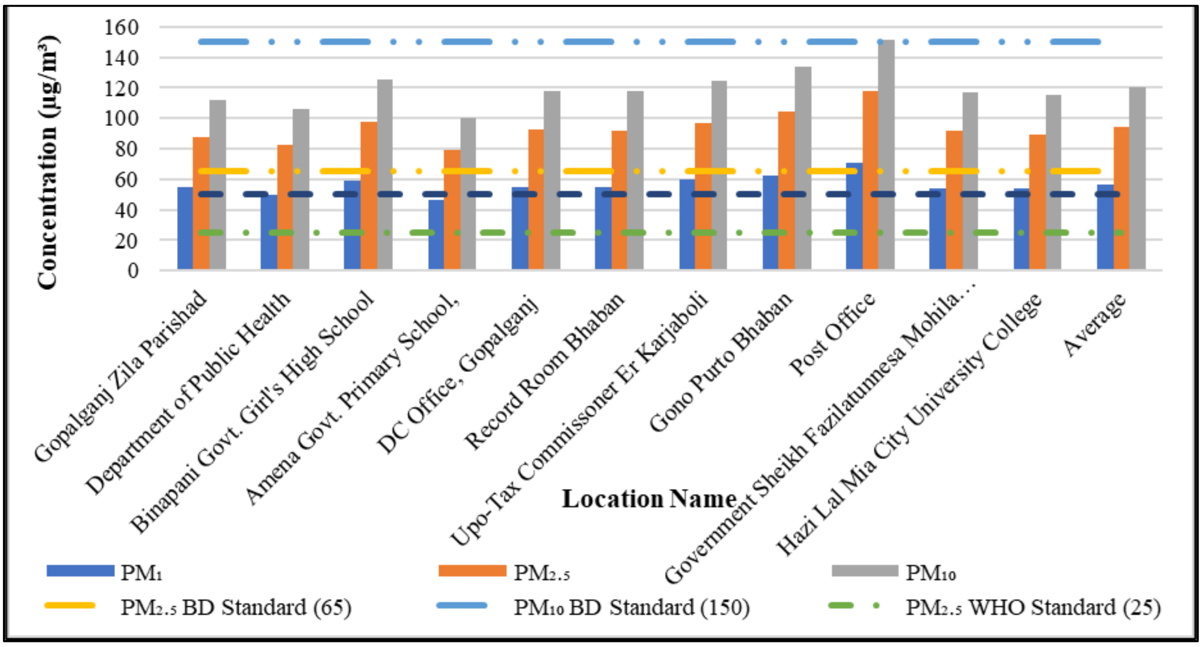

Figure 3 Comparison among Concentration of PM_1, $PM_{2.5}$ and PM_{10} in Sensitive Area

For comparison among concentration of PM_1, $PM_{2.5}$ and PM_{10} in different locations, the locations are categorized into 7 distinct areas, which are sensitive zone (figure 3), residential area (figure 4), mixed area (figure 5), commercial area (figure 6), road intersection area (figure 7), industrial area (figure 8) and village area (figure 9).

Administrative offices and educational institutions were among sensitive zones where $PM_{2.5}$ and PM_{10} concentrations were below the Bangladesh National Air Quality Standard (NAAQS) level. A comparison was made with the WHO criteria in this instance has established 25 and 50 g/m³ as the 24-hour air quality standards for $PM_{2.5}$ and PM_{10} respectively. Among these 11 sensitive places, three highly polluted places were Post office, Goncourt Bhaban and Bina Pani Govt. Girls' High School with $PM_{2.5}$ concentrations of 118.00, 104.75 and 97.75 µg/m³ respectively and comparatively less polluted places were Amena Rahman Govt. Primary School, Department of Public Health and Gopalganj Zila Parishad with $PM_{2.5}$ concentrations of 79.50, 82.75 and 88.00 µg/m³ respectively. It has been observed that concentration of PM_1, $PM_{2.5}$ and PM_{10} of Post office and Amena Govt. Primary School were 70.50, 118.00 and 151.75 µg/m³ and 46.25, 79.50 and 100.50 µg/m³ respectively. However, the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted location were 4.72 and 3.04 times higher than WHO standard level.

However, in case of residential areas (figure 4), out of 10 residential places, three polluted places were Bank para, Nichu para and 7 no Ward Aram bag with $PM_{2.5}$ concentrations of 94.50, 89.75 and 89.25 µg/m³ respectively and comparatively less polluted places were North Nichu para, Gohara and Aram bag with $PM_{2.5}$ concentrations of 83.00, 83.00 and 83.25 µg/m³ respectively. It has been observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of Bank para and North Nichu para were 59.25, 94.50 and 123.50 µg/m³ and 50.50, 83.00 and 107.00 µg/m³ respectively. It was also noted that the concentrations of $PM_{2.5}$ found in the most polluted place was 1.45 times higher than (NAAQS). However, the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted location were 3.78 and 2.47 times higher than (WHO) standard level respectively.

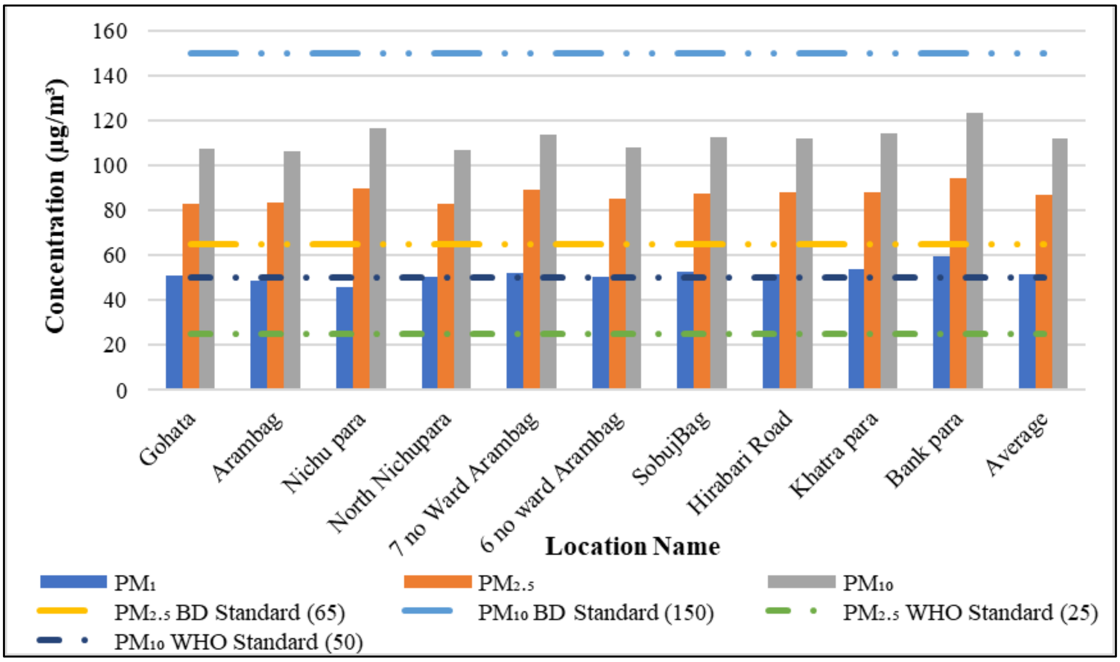

Figure 4 Comparison among Concentration of PM_1, $PM_{2.5}$ and PM_{10} in residential area

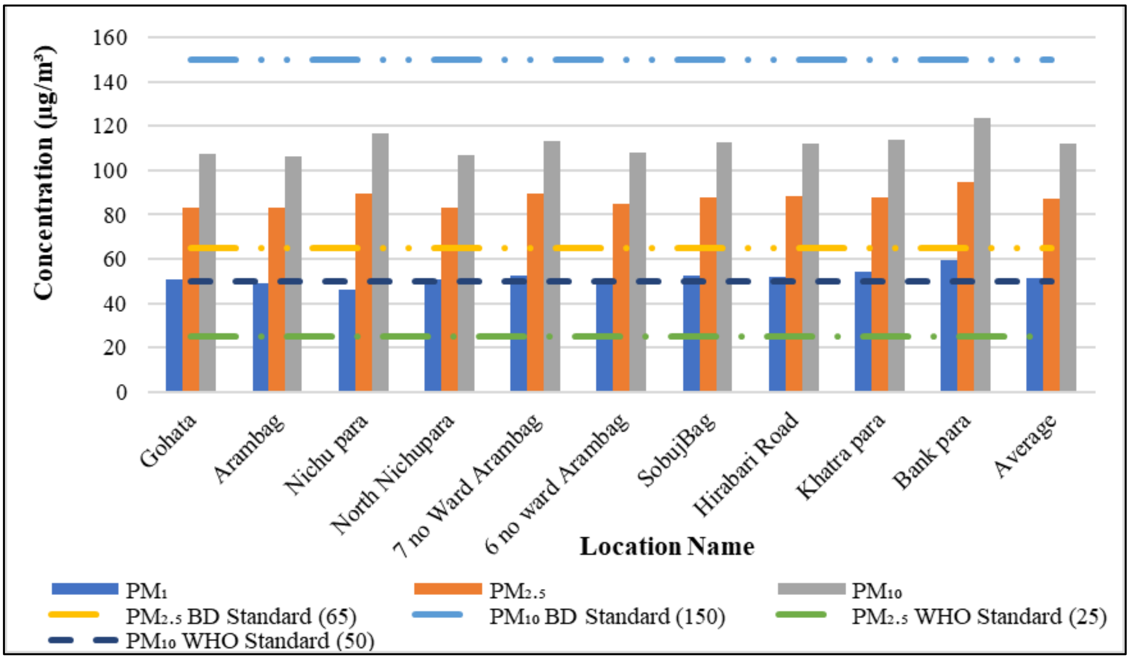

Figure 5 Comparison among Concentration of PM_1, $PM_{2.5}$ and PM_{10} in mixed area

Besides, it has been found that out of 6 mixed places (figure 5), three highly polluted places were AC Land office, Govt. Banga Bandhu College Jame Mosque and Chalehia Alia Madrasa with $PM_{2.5}$ concentrations of 109.00, 90.75 and 88.50 µg/m^3 respectively and comparatively less polluted places were Jugosikha Girls High School, Saral Bahan and BSCIC Bridge with $PM_{2.5}$ concentrations of 68.25, 69.75 and 80.00 µg/m^3 respectively. It has been observed that the concentrations of PM_1, $PM_{2.5}$ and PM_{10} of AC Land Office and Jugosikha Girls High School were found 67.75, 109 and 142.50 µg/m^3 and 41.75, 68.25 and 88.75 µg/m^3 respectively. It was noted that the concentrations of $PM_{2.5}$ found in the most polluted place was 1.68 times higher than NAAQS. It was also noted that the concentration of $PM_{2.5}$ and PM_{10} found in the most polluted was 4.36 and 2.85 times higher than WHO level.

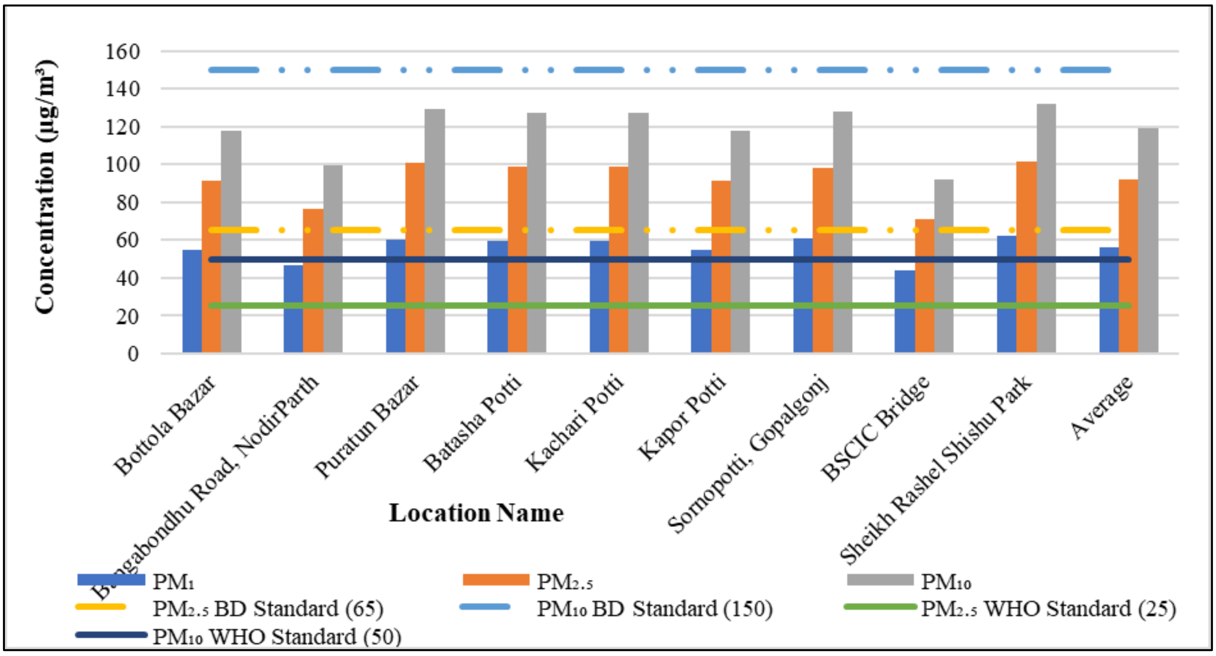

Figure 6 Comparison among Concentration of PM_1, $PM_{2.5}$ and PM_{10} in Commercial area

It has been found that out of 9 commercial places (figure 6), three highly polluted places were Sheikh Rashel Shishu Park, Puraton bazar and Batasa potti with $PM_{2.5}$ concentrations of 101.25, 100.75 and 99.00 µg/m^3 respectively and comparatively less polluted places were BSCIC Bridge, Bangabandhu road nodir par and Bottola bazar with $PM_{2.5}$ concentrations of 70.75, 76.50 and 91.50 µg/m^3 respectively. It has been observed that concentration of PM_1, $PM_{2.5}$ and PM_{10} of Sheikh Rashel Shishu Park and BSCIC Bridge were 62.50, 101.25 and 131.75 µg/m^3 and 43.75, 70.75 and 92.25 µg/m^3 respectively. It was also noted that the concentrations of $PM_{2.5}$ found in the most polluted place was 1.55 times higher than NAAQS. However, the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted location were 4.05 and 2.64 times higher than WHO standard level respectively.

Among the 4 road intersection places (figure 7), three highly polluted places were Kuwadanga bus stand, Chourongi and Launch ghat mor with $PM_{2.5}$ concentrations of 135.00, 100.00 and 92.75 µg/m^3 respectively and least polluted place was Gatepara mor with $PM_{2.5}$ concentrations of 73.00 µg/m^3 respectively. It also noted that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of Kuwadanga bus stand and Gatepara mor were 84.25, 135.00 and 176.50 µg/m^3 and 45.50, 73.00 and 95.75 µg/m^3 respectively. It was also noted that the concentration of $PM_{2.5}$ found polluted place was 2.08 times higher than NAAQS level. However, the concentrations of $PM_{2.5}$ and PM_{10} found in the WHO standard level respectively.

It has been found that out of 10 industrial places (figure 8), three highly polluted places were M/S Masud Enterprise, MS Rubel Chemical Bangladesh and M/S Nur Sanitary Factory with $PM_{2.5}$ concentrations of 178.50, 176.50 and 137.75 µg/m^3 respectively and relatively less polluted places were M/S Sohag Enterprise, Gopalganj Auto Flower Mill and M/S Khan Agro Daal Mill with $PM_{2.5}$ concentrations of 80.50, 80.50 and 81.50 µg/m^3 respectively. It has been observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of M/S Masud Enterprise and M/S Sohag Enterprise were 106.25, 178.50 and 229.00 µg/m^3 and 47.50, 80.50 and 102.50 µg/m^3 respectively. It was also noted that the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted location were 2.75- and 1.53-times higher NAAQS.

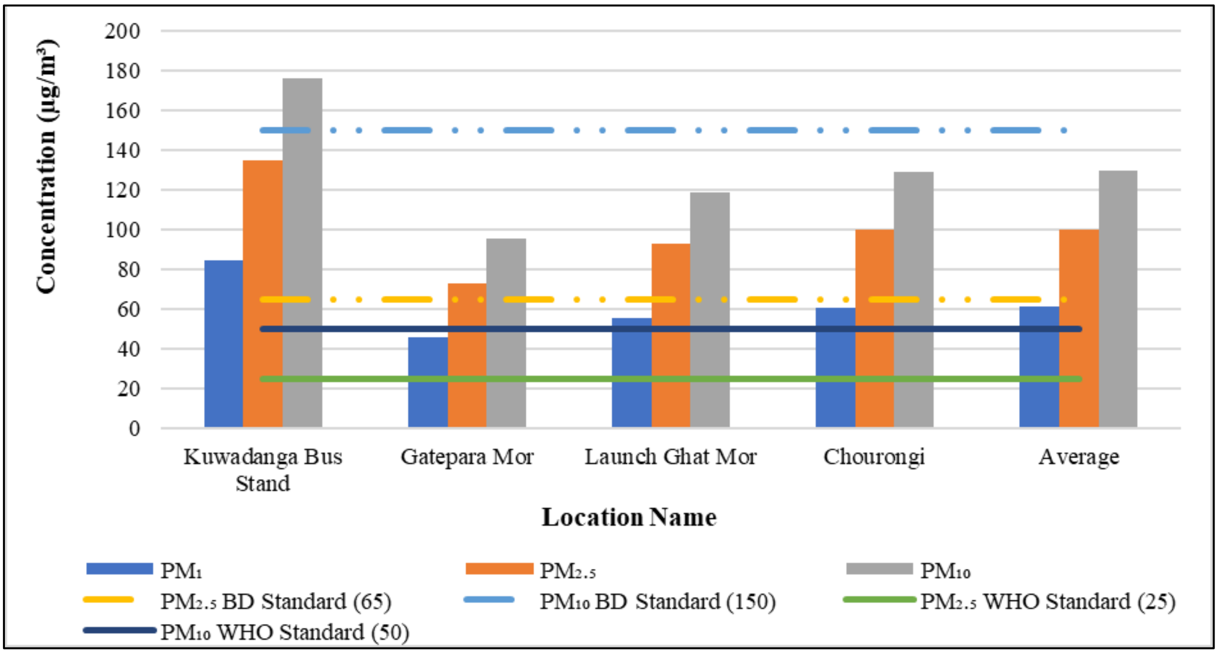

Figure 7 Comparison among Concentration of PM_1, $PM_{2.5}$ and PM_{10} in Road Intersection area

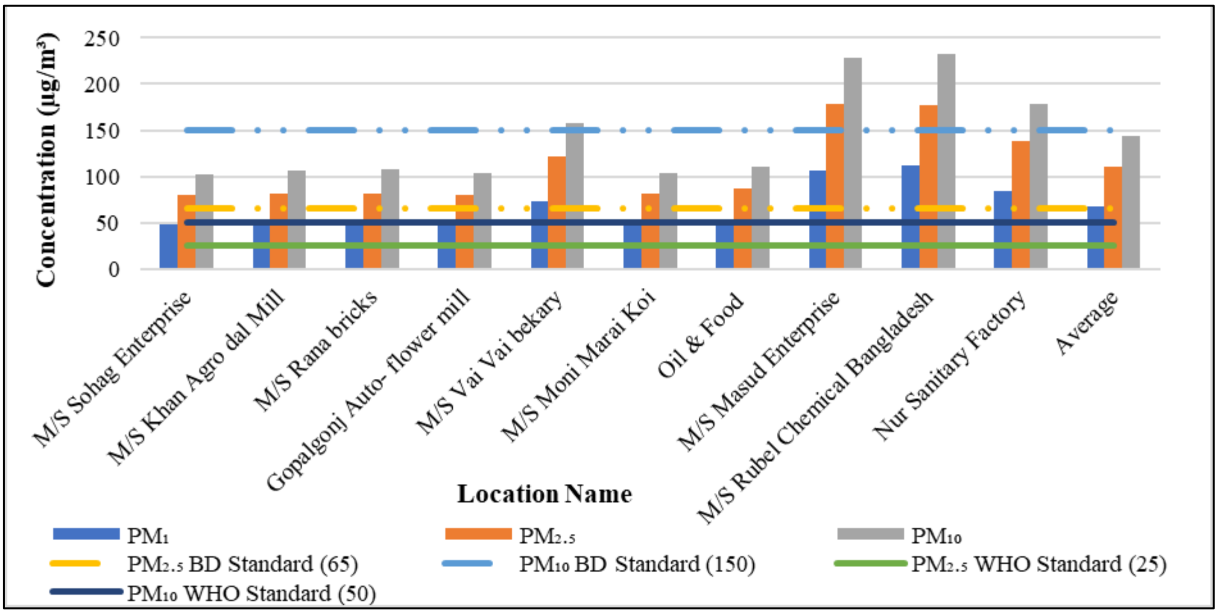

Figure 8 Comparison among Concentration of PM_1, $PM_{2.5}$ and PM_{10} in Industrial Area

However, it has been found that out of 9 village locations (figure 9), three highly polluted places were Kolabagan Jame Mosque, Mowlovi para and North Mowlovi para with $PM_{2.5}$ concentrations of 115.50, 99.75 and 93.75 µg/m^3 respectively and the less polluted places were Kolabagan, Haridaspur Jame Mosque and Kuwadanga gram with $PM_{2.5}$ concentrations of 80.00, 83.75 and 86.00 µg/m^3 respectively. It has been observed that concentrations of PM_1, $PM_{2.5}$ and PM_{10} of the Kolabagan Jame Mosque and Kolabagan places were 70.00, 115.50 and 149.50 µg/m^3 and 48.50, 80.00 and 103.25 µg/m^3 respectively. It was also noted that the concentrations of $PM_{2.5}$ found in the most polluted place was 1.78 times higher than and the concentrations of $PM_{2.5}$ and PM_{10} found in the most polluted location were 4.62 and 2.99 times higher than WHO standard level respectively.

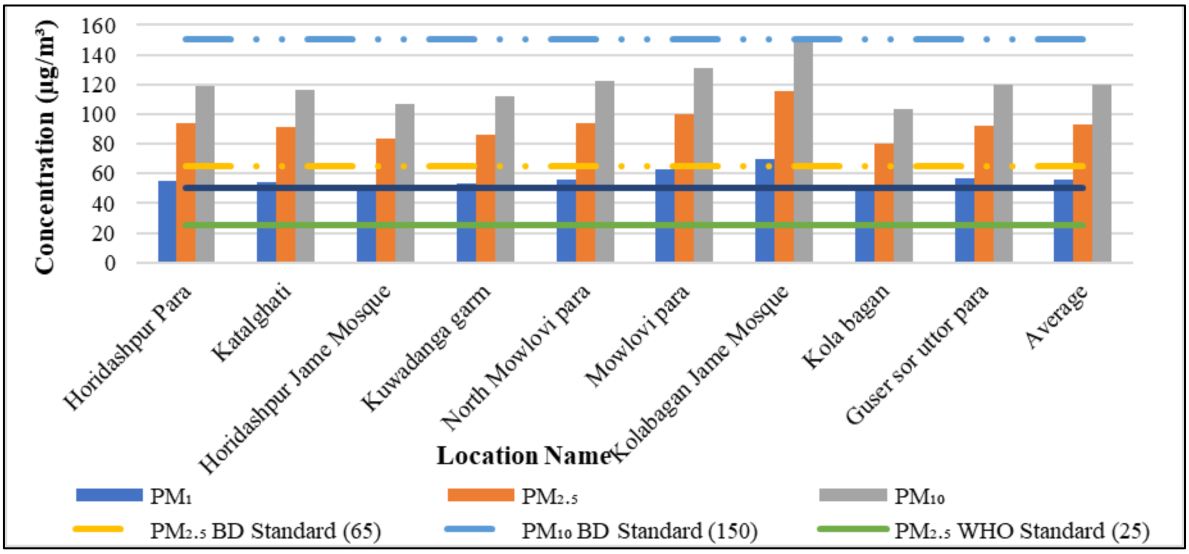

Figure 9 Comparison among Concentration of PM_1, $PM_{2.5}$ and PM_{10} in Village Area

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

Figure 10 shows the comparison among Average Concentration of CO of Different Land Use. It has been observed that the average CO was found to be higher in the commercial area (51.33 ppm), which is 5.70 times higher than the standard level. It is harmful for the living organism if anyone stays for long time in that concentration. According to a study, the excessive release of motor vehicle carbon monoxide (CO), which is harmful to human health, is caused by frequent stops and entry and exit in traffic flow (Aziz & Bazwa, 2007).

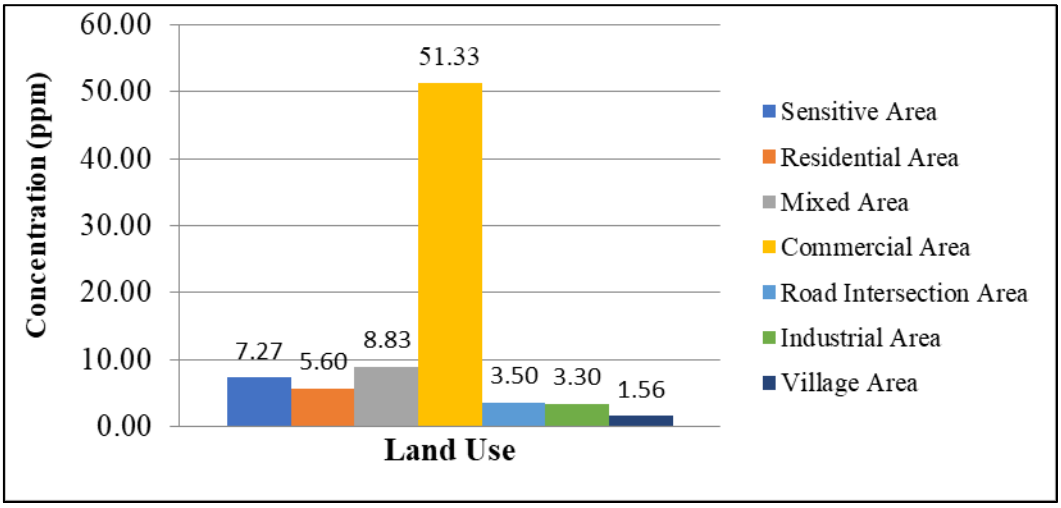

Figure 10 Average Concentration of CO in Different Land Use

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

The following table 2 shows the descriptive statistics for PM_1, $PM_{2.5}$, PM_{10}, CO of the studied seven land uses. The highest range was found in industrial areas in all the PM and lower ranges of PM and CO concentration were found in residential areas. The highest mean value of PM was found in the industrial area and the lowest mean value was found in the mixed area. The highest stander deviation was found in industrial area and lowest was found in residential area of PM. The coefficient of variation was found highest in industrial areas and lowest in residential areas for PM.

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

S. N.	Land use	Number	Range	Mean	Std. Deviation	Coefficient of Variation (%)	Range	Mean	Std. Deviation	Coefficient of Variation (%)
1	Sensitive Area	11	24.25	56.32	6.50	11.55	38.50	93.93	10.60	11.28
2	Mixed Area	6	26.00	50.96	9.95	19.52	40.75	84.38	15.21	18.03
3	Residential Area	10	13.24	51.60	3.48	6.73	11.50	87.15	3.67	4.22
4	Road Intersection Area	4	38.75	61.31	16.47	26.87	62.00	100.19	25.86	25.81
5	Commercial Area	9	18.75	55.97	6.59	11.77	30.50	92.03	11.11	12.08
6	Industrial Area	10	64.00	67.65	24.98	36.92	98.00	110.80	40.40	36.46
7	Village Area	9	21.50	56.25	6.59	11.71	35.50	92.81	10.37	11.18

S. N.	Land use	Number	Range	Mean	Std. Deviation	Coefficient of Variation (%)	Range	Mean	Std. Deviation	Coefficient of Variation (%)
1	Sensitive Area	11	51.25	120.32	13.88	11.54	18	7.27	6.25	85.89
2	Mixed Area	6	55.50	108.42	20.78	19.17	18	8.33	6.22	74.62
3	Residential Area	10	17.25	112.10	5.28	4.71	8	3.00	3.89	129.58
4	Road Intersection Area	4	80.75	129.88	34.01	26.18	14	3.50	7.00	200.00
5	Commercial Area	9	39.50	118.94	14.07	11.83	360	51.33	116.89	227.71
6	Industrial Area	10	130.00	143.15	53.06	37.06	13	3.30	4.64	140.73
7	Village Area	9	46.25	120.08	13.81	11.50	14	1.56	4.67	300.00

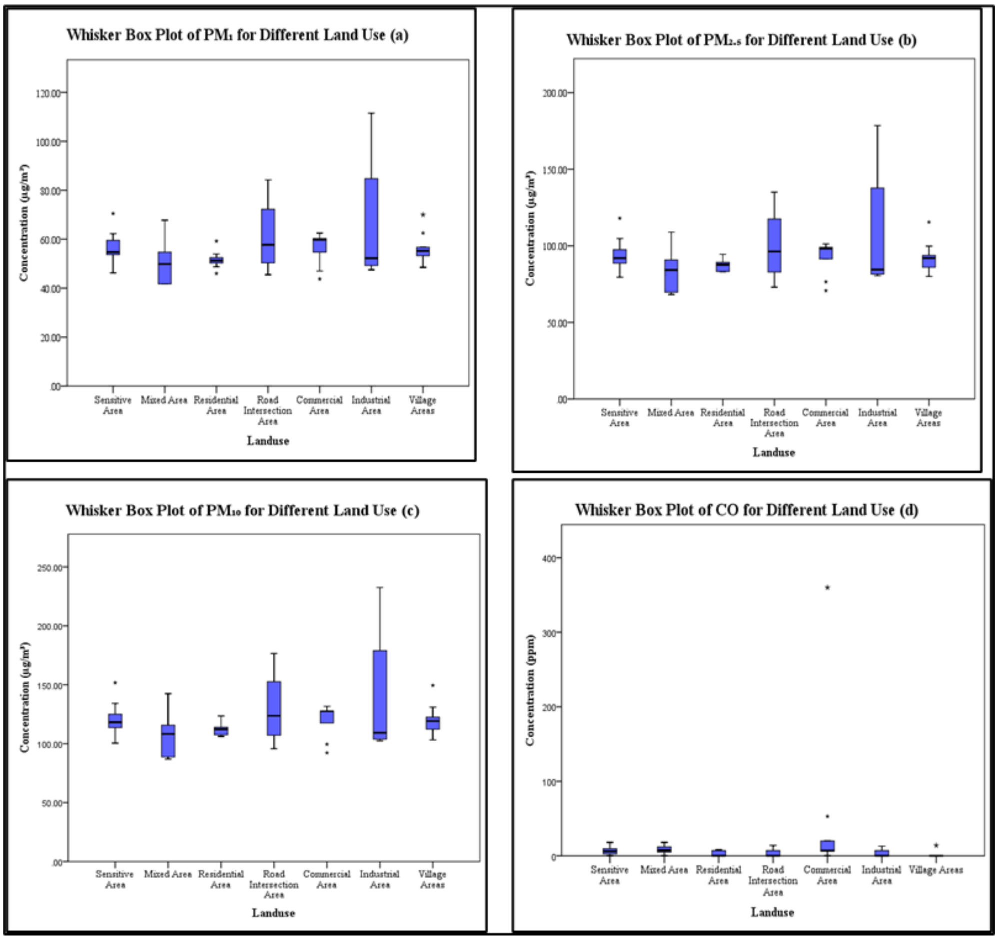

Figure 11 Whisker Box Plot of Concentration of PM_1, $PM_{2.5}$, PM_{10}, and CO in Different Land Use

The whisker box plot (figure 11) illustrates the average of PM_1, $PM_{2.5}$, PM_{10}, and CO concentrations in seven land uses. 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 revealed that industrial area had most dispersed concentration and values were positively skewed of PM; commercial area for CO along with two outliers. Commercial area content two closer outlier in Purton baser and Sheikh Rashel Shisha Park due to economic activities. Later dispersed concentration was found in road intersection area, mixed area and sensitive area for all the PM along with one outlier in sensitive area in Post Office area due to traffic. The concentrations of PM were tightly clustered in residential area and village area along with one outlier in PM_1 and two outliers in $PM_{2.5}$.

3.4. Significance Test

Table 3 shows 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 following table shows that the concentrations of PM, CO and do not change significantly as the p value are greater than 0.05. P values.

Table 3 Significance Test

ANOVA						
		Sum of Squares	**DF**	**Mean Square**	**F**	**Sig.**
PM_1	Between Groups	1737.136	6	289.523	1.847	0.108
	Within Groups	8149.638	52	156.724		
	Total	9886.774	58			

$PM_{2.5}$	Between Groups	4024.990	6	670.832	1.666	0.148
	Within Groups	20943.555	52	402.761		
	Total	24968.544	58			
PM_{10}	Between Groups	6956.624	6	1159.437	1.663	0.149
	Within Groups	36251.429	52	697.143		
	Total	43208.053	58			
CO	Between Groups	17077.569	6	2846.262	1.339	0.257
	Within Groups	110542.837	52	2125.824		
	Total	127620.407	58			

3.5. Land Use Based Cluster Analysis

For PM_1, $PM_{2.5}$, PM_{10}, CO dendrogram plot derived via cluster analysis with Z-score standardization has been shown in figure 12. From this analysis, the average linkage between groups has been considered.

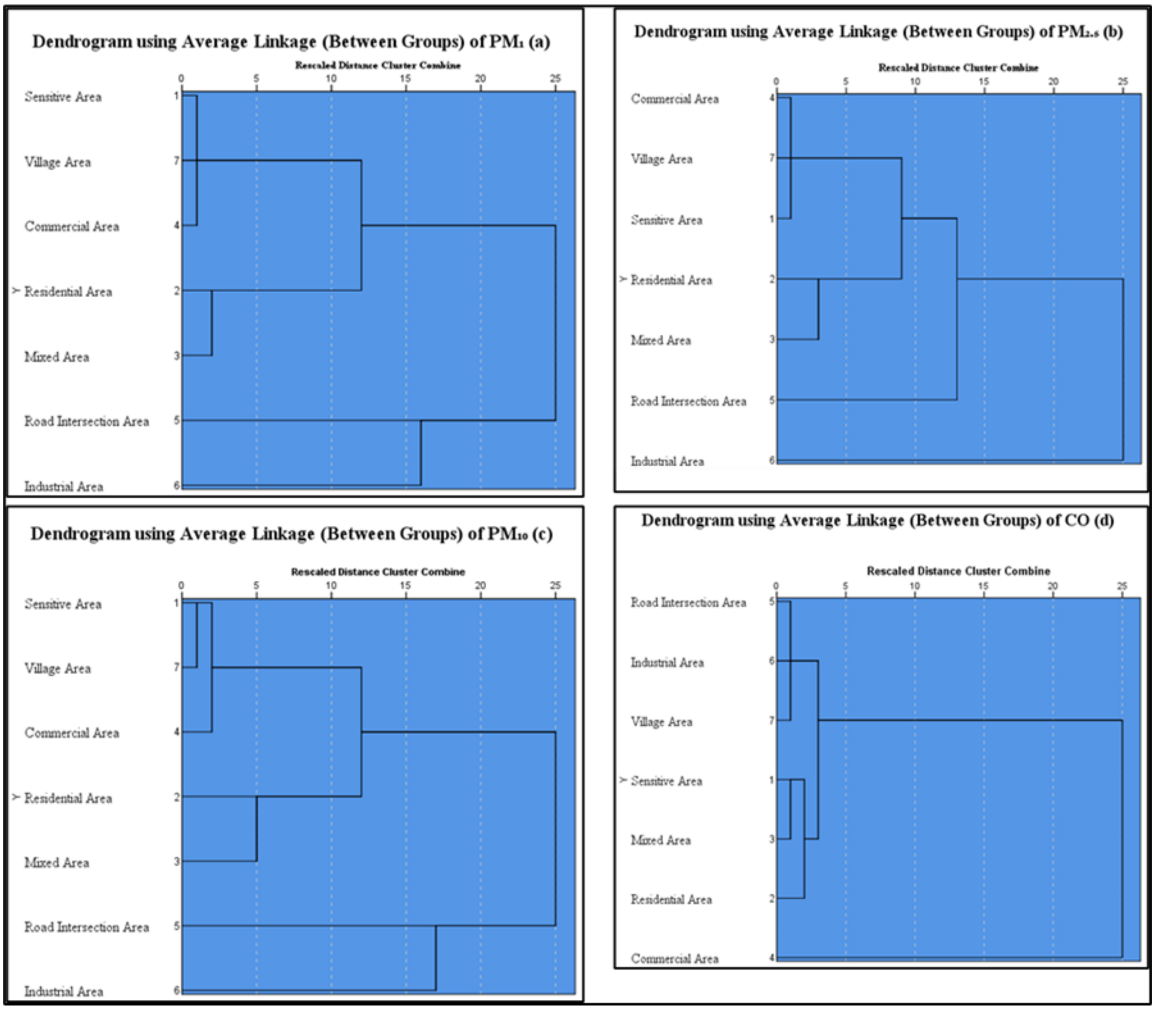

Figure 12 Rescaled Distance Cluster Combine for PM_1, $PM_{2.5}$, PM_{10} and CO

Four clusters have been found from the graph of PM. The first cluster consists of sensitive area, village areas and commercial areas; second cluster includes residential areas and mixed areas, third and fourth cluster includes road intersection area and industrial area respectively. First and second cluster join at the approximate distance of 12 and third and fourth cluster joins at the approximate distance of 16. These two broad clusters join at the approximate distance of 25. For $PM_{2.5}$; First cluster is consisted of commercial area, village area and sensitive area; second cluster is composed of residential area and mixed area, third cluster includes only road intersection area and forth cluster involves industrial area alone. First and second clusters join at the approximate distance of 9 which joins with third cluster at the approximate distance of 13 to finally joins with fourth cluster at the approximate distance of 25. For PM_{10}; First cluster is consisted of sensitive area, village area and commercial area; second cluster includes residential area and mixed area, third and fourth cluster is composed of road intersection area and industrial area respectively. First and second clusters join at the approximate distance of 12 and third and fourth cluster join at the approximate distance of 17. These two broad clusters join at the approximate distance of 25. For this analysis average linkage between groups has been considered. Three clusters have been found for CO; First cluster is consisted of road intersection area, industrial area, village area and sensitive area, second cluster includes sensitive area, mixed area and residential area and third cluster involves only commercial area. First and second clusters join at the approximate distance of 3 and this broad cluster joins with third cluster at the approximate distance of 25.

3.6. Comparison among Average Concentration of PM_1, $PM_{2.5}$ and PM_{10} of Different Land Use

The figure 13 shows the comparison of the average concentration of PM_1, $PM_{2.5}$ and PM_{10} of seven lands uses in Gopalganj district town. This study found that the average concentration of PM_1, $PM_{2.5}$ and PM_{10} was higher in industrial area, road intersection area and sensitive area with the values of 67.65, 110.80 and 143.15 μg/m^3 , 61.31, 100.19 and 129.88 μg/m^3 and 56.32, 93.93 and 120.32 μg/m^3 respectively with highest in industrial area. Similar results found from another study conducted Rajshahi during dry season which indicated the highest level of PM concentration found in industrial area (Majumder et al., 2024). Furthermore, the concentration of PM was found relatively lower in mixed area, residential areas and commercial areas. Moreover, the average concentration of PM_1 (50.96 μg/m^3), $PM_{2.5}$ (84.38μg/m^3) and PM_{10} (108.42 μg/m^3) were found to be least in mixed area. Another study conducted by Majumder et al. (2023), at Netrokona found the particulate matter concentrations (60.97, 99.63, 130.12 μg/m^3) respectively where averaged $PM_{2.5}$ was 1.53 times fold than Bangladesh's National Ambient Air Quality Standards (NAAQS) level and demonstrated that three of the most polluted places were located in commercial areas, whereas two of the least polluted places were in sensitive area on the basis of $PM_{2.5}$ concentration.

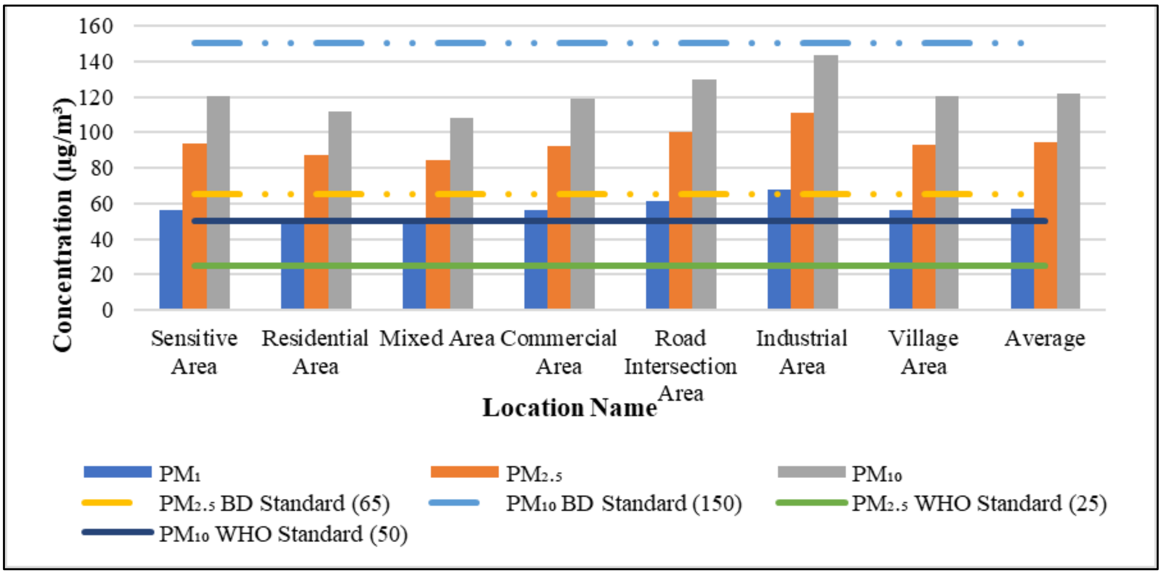

Figure 13 Comparison among Average Concentration of PM_1, $PM_{2.5}$ and PM_{10}

3.7. Correlation between Parameters

Pearson correlation analysis revealed weak but statistically significant positive relationships between all three particulate matters (PM_1, $PM_{2.5}$ and PM_{10}) and both humidity and temperature, with significance levels set at 0.05. The relationship between PM and temperature was negative, whereas it was positive with humidity. Carbon Monoxide (CO) was also significantly correlated with temperature and humidity at the 0.05 alpha level. The relationship between CO and temperature was weak and positive, while its relationship with humidity was weak and negative. Additionally, temperature and humidity showed a moderate negative correlation with a significance level of 0.01, indicating that changes in one of these environmental parameters are likely to result in opposite changes in the other.

Table 4 Correlation among PM, CO and Selected Meteorological Parameters

		PM_1	$PM_{2.5}$	PM_{10}	CO	Temperature	Humidity
PM_1	Pearson Correlation	1	0.991**	0.994**	-0.097	-0.297*	0.155
	Sig. (1-tailed)		0.000	0.000	.233	0.011	0.120
	N	59	59	59	59	59	59
$PM_{2.5}$	Pearson Correlation	0.991**	1	0.999**	-0.107	-0.273*	0.138
	Sig. (1-tailed)	0.000		0.000	0.210	0.018	0.148
	N	59	59	59	59	59	59
PM_{10}	Pearson Correlation	0.994**	0.999**	1	-0.102	-0.282*	0.146
	Sig. (1-tailed)	0.000	0.000		0.221	0.015	0.134
	N	59	59	59	59	59	59
CO	Pearson Correlation	-0.097	-0.107	-0.102	1	0.228*	-0.302*
	Sig. (1-tailed)	0.233	0.210	0.221		0.041	0.010
	N	59	59	59	59	59	59
Temperature	Pearson Correlation	-0.297*	-0.273*	-0.282*	0.228*	1	-0.730**
	Sig. (1-tailed)	0.011	0.018	0.015	0.041		0.000
	N	59	59	59	59	59	59
Humidity	Pearson Correlation	0.155	0.138	0.146	-0.302*	-0.730**	1
	Sig. (1-tailed)	0.120	0.148	0.134	0.010	0.000	
	N	59	59	59	59	59	59

*. Correlation is significant at the 0.05 level (1-tailed). ; **. Correlation is significant at the 0.01 level (1-tailed).

3.8. Three most Polluted Location and least polluted location in Different Land Use

Table 5 Top Three Most Polluted Locations and Least Polluted Location in Different Land Use

Rank	Land use Type	Land Use	PM_1	$PM_{2.5}$	PM_{10}
	Industrial Area	M/S Masud Enterprise	106.25	178.50	229.00
	Industrial Area	M/S Rubel Chemical Bangladesh	111.50	176.50	232.50
	Industrial Area	Nur Sanitary Factory	84.75	137.75	179.00
Rank	**Land use Type**	**Land Use**	**PM_1**	**$PM_{2.5}$**	**PM_{10}**
	Mixed Area	Zuk shikha Girls High School	41.75	68.25	88.75
	Mixed Area	Saral Bahan	41.75	69.75	87.00
	Commercial Area	BSCIC Bridge	43.75	70.75	92.25

In the following table 4 shows the top three most polluted locations regards to PM in Gopalganj district town. It was found out M/S Masud Enterprise was at the first place- followed by M/S Rubel Chemical Bangladesh and Nur Sanitary Factory was in the third position and comparatively 3 less polluted places were Zuk shikha Girls High School and Saral Bahan (mixed area) and BSCIC Bridge (commercial area) and three least polluted places were from two different land uses. In M/S Masud Enterprise the concentration of PM was 106.25, 178.50 and 229.00 μg/m^3 respectively which is 2.75- and 1.53-times higher NAAQS level. However, another study conducted at Lakshimipur, Bangladesh, found that the areas with the highest levels of pollution were the mixed and traffic intersection areas, whereas the areas with the lowest levels of pollution were the villages (Mazumder et al., 2023). Similar results found in another study conducted at Dhaka city which indicated the PM concentration was highest in mixed area during monsoon (Majumder et al., 2024).

3.9. Concentration Map of PM_1, $PM_{2.5}$, PM_{10} and CO

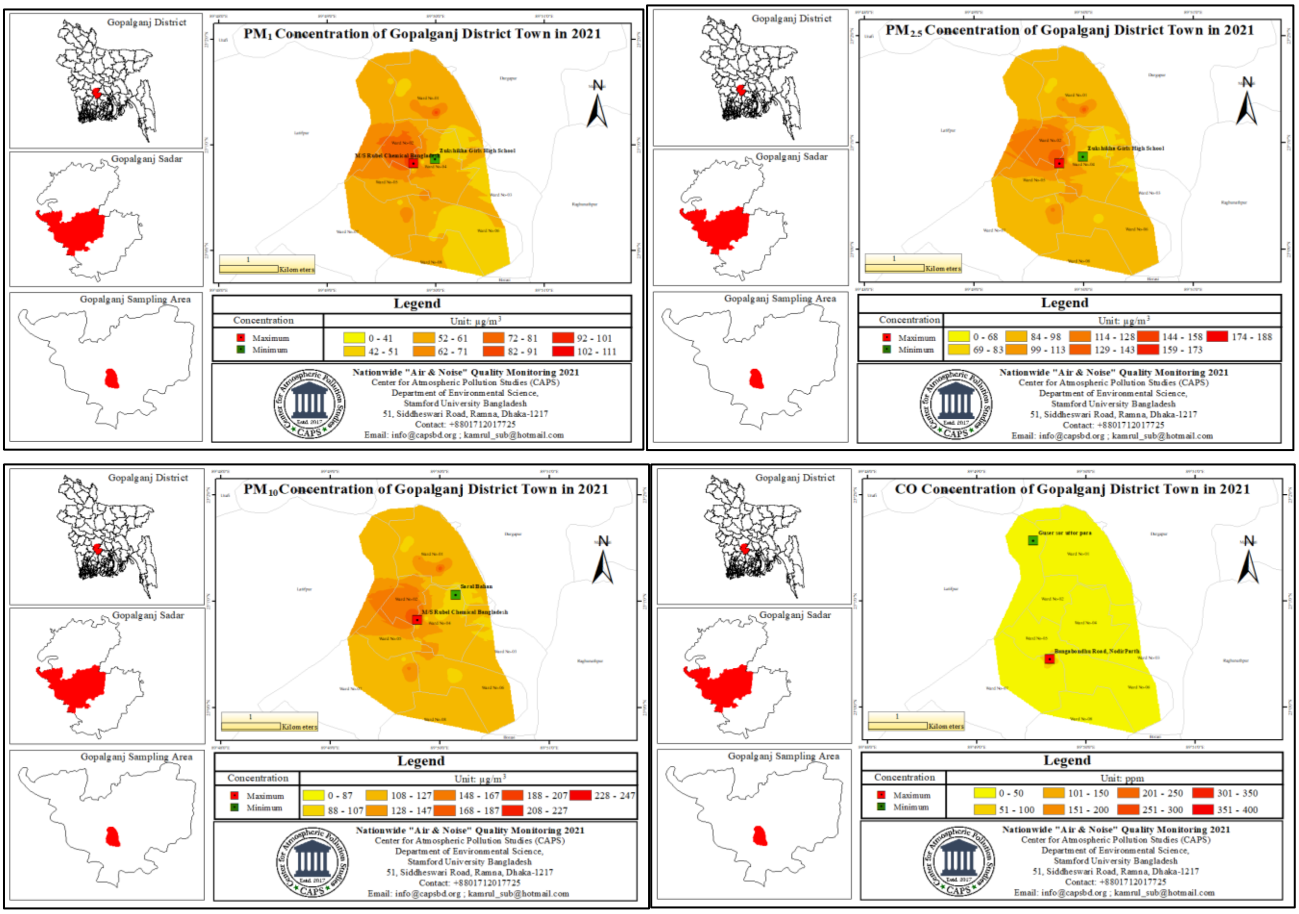

Figure 14 PM_1, $PM_{2.5}$, PM_{10} and CO Concentration in Gopalganj District Town in 2021

In figure 14 the PM concentration of Gopalganj district town in 2021 have shown in a spatial map and M/S Rubel Chemical Bangladesh found maximum polluted and Zuk shikha Girls High School and Saral Bahan found minimoon concentration of PM and comparatively heavy CO pollution was observed in Bangabandhu road.

3.10. AQI on $PM_{2.5}$ Concentration of Gopalganj District Town in 2021

Figure 15 Shows the AQI map Gopalganj district town based on $PM_{2.5}$. In this map different color represents the category of AQI according to NAAQS level. AQI of M/S Masud Enterprise, M/S Rubel Chemical Bangladesh, Nur Sanitary Factory area was the highest in the district. The AQI for the ward no-02 and ward no-04 area was found to be 201-300 which is considered as very unhealthy condition indicating by red colour. The AQI for the area of ward no-01, 04, 08, 06, and 03 was found to be 151-200 which is considered unhealthy condition indicating by orange color.

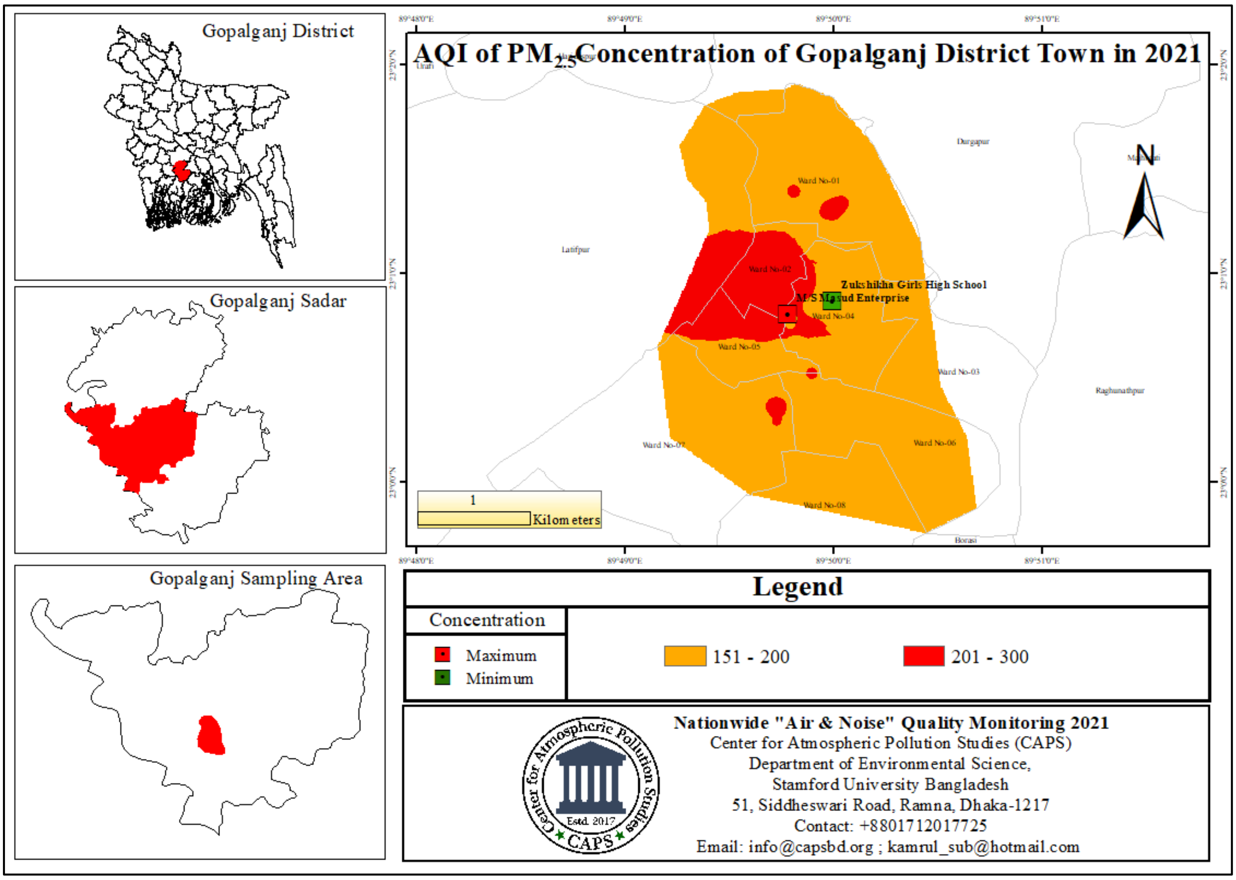

Figure 15 AQI map Gopalganj District Town based on $PM_{2.5}$

4. Conclusion

Study found that the average concentration of PM_1, $PM_{2.5}$ and PM_{10} of 59 places in Gopalganj district town were 57.15, 94.47 and 121.84 µg/m^3 respectively. From the outcome of this research the studied land uses are arranged in descending order based on average concentration PM which follows industrial area (67.65, 110.80 and 143.15µg/m^3) > road intersection area (61.31, 100.19 and 129.88 µg/m^3) > village area (56.25, 92.81 and 120.08 µg/m^3) > Sensitive area (56.32, 93.93 and 120.32 µg/m^3) > commercial area (55.97, 92.03 and 118.94 µg/m^3) > residential area (51.60, 87.15 and 112.10 µg/m^3) > mixed area (50.96, 84.38 and 108.42 µg/m^3). The Concentration of $PM_{2.5}$ (94.47 µg/m^3) of different land use was found to be very high which was nearly 1.40 times higher than the standard level. Moreover, it was estimated from the average ratio of $PM_{2.5}/PM_{10}$ that the $PM_{2.5}$ mass was 78.89% of the PM_{10} mass and the average ratio $PM_1/PM_{2.5}$ showed that the PM_1 mass was 59.37% of the $PM_{2.5}$ mass. On the basis of PM_1, $PM_{2.5}$ and PM_{10} dispersion among all those land uses the maximum range was found in commercial area and road intersection area while minimum was found in sensitive area, mixed area and village area. Std. deviation and coefficient of variation of PM_1, $PM_{2.5}$ and PM_{10} and CO among all those land uses was found higher in commercial area followed by least in sensitive area. Moreover, whisker box graph of PM_1, $PM_{2.5}$ and PM_{10} revealed that commercial area had the most dispersed concentration and the values were positively skewed. Also found the concentrations of PM and CO do not change significantly as the p values are greater than 0.05. From the dendrogram plot of PM_1, $PM_{2.5}$ and PM_{10} 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.

Recommendations

Air pollution is produced in the time when all types of vehicles run using diesel and petrol. The dynamic development of motor transport relates to the necessity to reduce its negative impact on the natural environment. There are some steps that can be taken to control air pollution in Bangladesh.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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