

Research Article

Geospatial Analysis of Particulate Matter and CO Concentrations in Relation to Urban Land Use: A Case Study of Sunamganj District Town

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Abstract

Air pollution is a major environmental issue in Bangladesh, particularly in industrial districts such as Sunamganj, where growing urbanization and industrialization worsen already severe air quality difficulties. The objective of the study is to identify the status of air pollution in Sunamganj District Town area, assessing the relationship among land use and some parameters: Particulate Matters (PM₁, PM_{2.5} & PM₁₀) and Carbon Monoxide (CO) concentration, to show the distribution of PM and CO concentration and PM_{2.5} based AQI. Descriptive statistics, whisker box plots, ArcGIS and cluster analysis carried out to draw a spatial distribution pattern of pollutants. In this study, 60 locations were selected based on the use of land in Sunamganj District Town area, and air quality parameters was measured in those locations with the help of various automated portable Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector (Model: DM106) and CO Meter (Model: AS8700A). After that, IBM SPSS V20 and MS Excel 2020 were used for analysis. It was found that, the average concentrations of PM₁, PM_{2.5} & PM₁₀ of 60 places in Sunamganj district town were 53.36, 88.86 and 113.90 µg/m³ respectively. The average concentration of PM_{2.5} was found 1.75 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) level. It is estimated that the average PM_{2.5}/PM₁₀ was 77.83%, PM₁/PM_{2.5} was 60.13%. From the outcome of this research the studied land uses are arranged in descending order based on average concentration PM_{2.5} which follows as sensitive area (113.10 µg/m³) > road intersection area (108.30 µg/m³) > mixed area (91.85 µg/m³) > commercial area (87.21 µg/m³) > industrial area (81.56 µg/m³) > residential area (81.33 µg/m³) > village area (58.65 µg/m³). The findings exhibit the absolute need for effective air quality management and policy actions to alleviate the negative impacts of air pollution on public health and the environment.

Keywords

Particulate Matter, Gaseous Pollutants, Land Use, Meteorological Correlation, Sunamganj District Town

1. Introduction

WHO [2] defined air pollution as any chemical, physical, or biological substance that can able to alter the fundamental features of the atmosphere and pollutes its internal or external

surroundings. Air pollution is predicted to cause seven million premature deaths per year, making it the most serious environmental threat to public health worldwide, and it is strongly

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linked to climate change [3]. PM refers to microscopic airborne particles, with PM_{10} smaller than 10 and $PM_{2.5}$ smaller than 2.5 micrometers [6]. Although both may be breathed in, $PM_{2.5}$ is more likely to reach deeper sections of the lung, whereas PM_{10} settles in the upper lung's bigger airways [4, 5]. According to a research by Moniruzzaman et al. [11], $PM_{2.5}$ accumulates more metals in the alveolar sections due to its deeper penetration compared to PM_{10} . A study reported 80% of early fatalities linked to air pollution are caused by $PM_{2.5}$, with a significant correlation with cardiovascular health [9]. An investigation conducted by Supasri et al. [10] found that $PM_{2.5}$ and PM_{10} are responsible for 0.04% to 0.08% of lung cancer and heart disease fatalities in northern Thailand. Dhaka has witnessed a significant increase in respiratory diseases, with many instances attributed to air pollution, making it a serious public health problem [25, 26]. The 2023 IQAir study identified Dhaka as the most polluting city and Bangladesh as the most polluted nation, with an annual $PM_{2.5}$ average of 79.9, which is more than 15 times higher than the WHO guidelines. According to a World Bank research [12], Dhaka's areas with high growth and traffic have $PM_{2.5}$ levels that are 150% higher than WHO limits [12]. Additionally, neighborhoods near brick kilns have 136% higher levels [12]. A number of studies has been identified Gazipur as a highly polluted city, with increasing $PM_{2.5}$ and PM_{10} concentrations influenced by the

factors like increase of urbanization, industrial emissions, and traffic pollution [20, 24]. Brick kilns are the most extensive source of air pollution in cities, contributing considerably to fine particulate matter, although automobiles, particularly older ones, industries, and development activities also play important roles [1, 19, 21]. According to research from 2010 to 2019, brick kilns account for 58% of fine particles, followed by automobiles at 10.4% and dust at 15.3% [1]. Unplanned urbanization, industry, high traffic, and biomass burning, along with less rainfall, have increased $PM_{2.5}$ levels, especially during winter [18, 22]. $PM_{2.5}$ and PM_{10} have a strong positive correlation, suggesting that the origins of both types of particulate matter are identical [23]. Furthermore, air pollution is not limited by international borders since pollutants may travel across huge distances, influencing air quality far away from their sources [7, 8]. The purpose of this study is to analyze particulate matter concentrations (PM_1 , $PM_{2.5}$ and PM_{10}) in 59 locations of Sunamganj, by categorized them into seven distinct land use types, to estimate the degree of air quality there. However, understanding air pollution levels is critical for raising awareness, directing policy choices, and executing successful air quality improvements. Thus, the study will help highlighting the critical need for action to combat air pollution and safeguard the community's well-being.

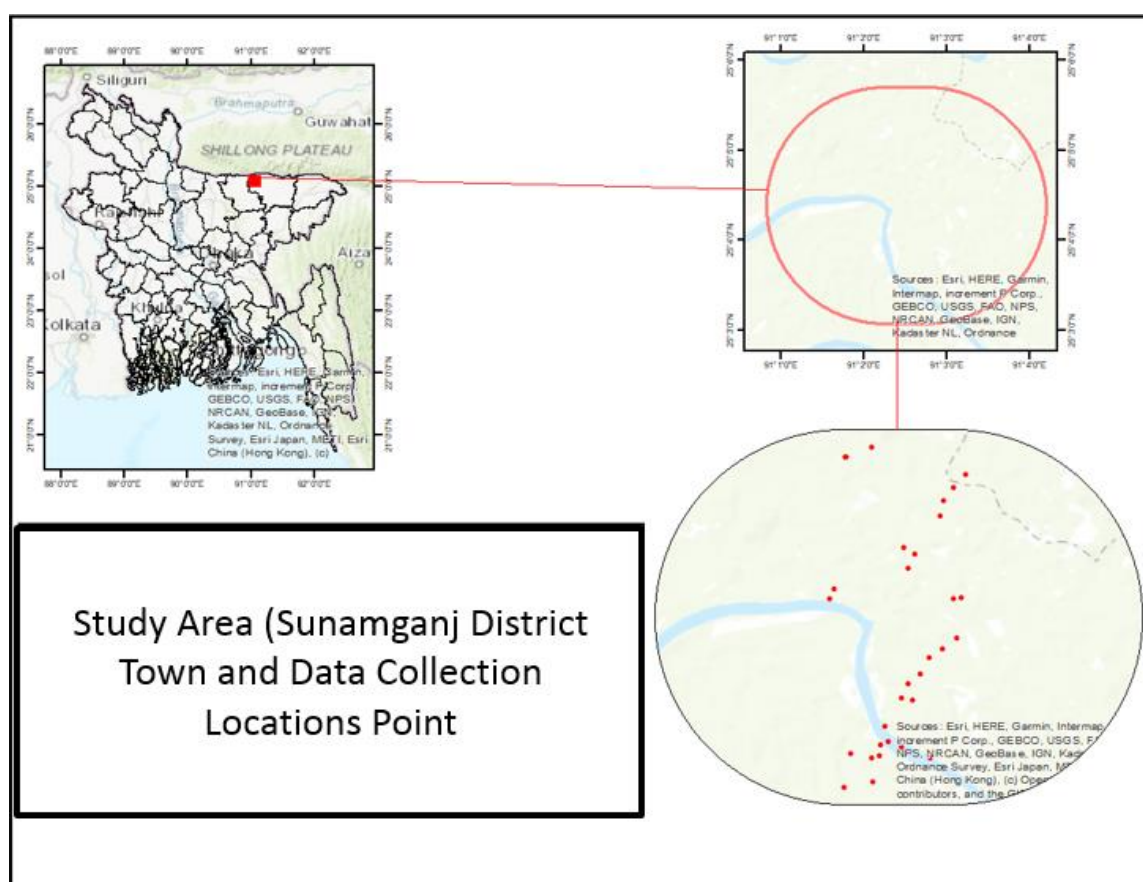


Figure 1. Study Area (Sunamganj District Town Area and Data Collection Locations Point).

2. Objectives of the Study

The objectives of this study are:

- 1) To identify the status of air pollution in Sunamganj District Town.
- 2) To assess the relationship between land use and all parameters (PM₁, PM_{2.5}, PM₁₀, and CO).
- 3) To identify AQI of Haiganj based on PM_{2.5} and do the spatial map.
- 4) Geospatial mapping on the concentration of PM₁, PM_{2.5}, PM₁₀, and CO.

3. Methodology

3.1. Study Area

Sunamganj district town locates 25.030869 N, 91.403761 E in Sylhet Division, Bangladesh [13]. There were 318,099 people living in Sunamganj District Town as per the 2022 Bangladesh Census. Its total area is 290.71 km², and it contains 49,557 households. Of them, 70,126 (25.13%) were urban dwellers [14].

3.2. Area Selection

60 locations were select on basis of the use of land use [17].

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. There is total 10 sensitive area were select that includes hospitals and clinics, schools, colleges, mosques, madrasas, temples, churches, and administrative dhaban. On the other side, mixed areas contain bazars, buildings, main roads etc. Rest 50 locations were categorized as residential areas; 10 locations, mixed areas; 5 locations, commercial areas; 11 locations, road intersection or busiest road junctions and bends; 10 locations, industrial area; 4 locations and village area; 10 locations.

3.3. Data Collection

As part of the survey, Air Quality was measured in different location of Sunamganj District Town area for one day with the help of various automated portable instruments Name Air Quality Monitor and Handheld Carbon Monoxide Meter. GPS data was also collected by an android software name as “GPS Location Camera”. Four individual data of PM₁, PM_{2.5} & PM₁₀ and CO was collected from each location. Data was collected from 60 different locations by CAPS team. Data was collected in different times in a day from morning to late evening. Sharing the instrument detail in the below.

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)

3.4. Data Processing

Collected data was input in an IBM SPSS V20 and MS Excel 2020. We used a formula for conversion of concentration of PM_{2.5} to AQI. Formula for Conversion- To convert from concentration to AQI this equation was used: If multiple pollutants are measured, the calculated AQI is the highest value calculated from the above equation applied for each pollutant.

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low}$$

where:

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}

3.5. Map Preparation and Result Interpretation

MS Excel table, IBM SPSS V20 and MS Excel 2020 were used for analysis. Multiple graphs, table, diagram, box-whisker was generated for understating the data nature. We also did descriptive statistics to know the dispersion of every parameter of land use and ANOVA for significance Test. The results are displayed with various graphs, charts and maps. In the study used ArcGIS 10.4.1. version for preparing our concentration map and AQI map of Sunamganj District Town

area. We used different projection locations for making concentration and AQI map in the GIS. Used different color for understanding the concentration of Map.

4. Result & Discussion

4.1. Status of Air Quality in Sunamganj District Town

Figure 2 shows the concentration ($\mu\text{g}/\text{m}^3$) of PM_{10} , $\text{PM}_{2.5}$ & PM_1 of some locations in sensitive areas in Sunamganj District Town. These particular locations included administrative offices, educational institutes and mosques. As we could see, among these 10 sensitive places, three highly polluted places were Jamiy Circuit House, Jela Dayra Jaj Court and Islamia

Darul Ulum Madrasa with PM_1 , $\text{PM}_{2.5}$ & PM_{10} concentration of 119.50, 203.00 and $258.50 \mu\text{g}/\text{m}^3$; 141.25, 233.75 and $276.50 \mu\text{g}/\text{m}^3$ and 71.75, 121.00 and $154.50 \mu\text{g}/\text{m}^3$ respectively and comparatively less polluted places were in front of Chan Miya Town Masjid, DC Office and besides Sunamganj Govt. Girls High School with PM_1 , $\text{PM}_{2.5}$ & PM_{10} concentration of 115.67, 197.50 and $251.25 \mu\text{g}/\text{m}^3$; 122.75, 197.25 and $258 \mu\text{g}/\text{m}^3$ and 123.25, 204.75 and $26.00 \mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentrations of $\text{PM}_{2.5}$ and PM_{10} found in the most polluted place were 4.37 and 2.47 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which are 65 and $150 \mu\text{g}/\text{m}^3$ set by the Department of Environment (DoE). The study estimated that in all sensitive areas, 78.13% of $\text{PM}_{2.5}$ was present in PM_{10} and 60.34% of the PM_1 was present in $\text{PM}_{2.5}$.

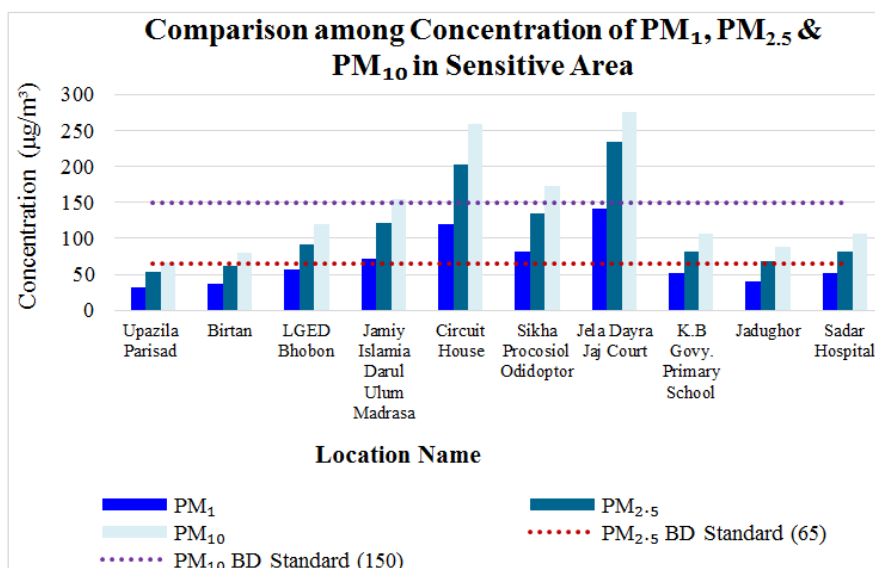


Figure 2. Comparison among Concentration of PM_1 , $\text{PM}_{2.5}$ & PM_{10} in Sensitive Area.

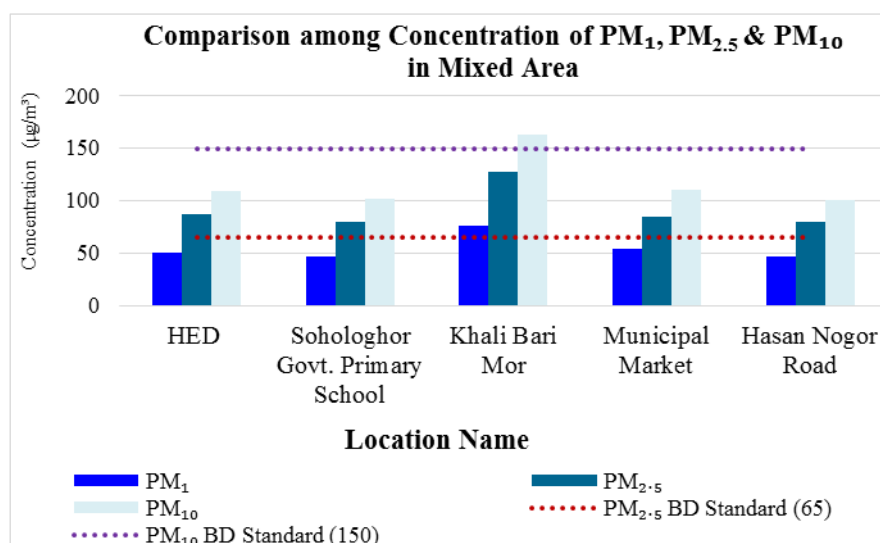


Figure 3. Comparison among Concentration of PM_1 , $\text{PM}_{2.5}$ & PM_{10} in Mixed Area.

Figure 3 illustrates the concentration ($\mu\text{g}/\text{m}^3$) of PM_{10} , $\text{PM}_{2.5}$ & PM_1 of some locations in mixed areas in Sunamganj District Town. It has been found that out of 5 mixed places, three highly polluted places were Ashraf Jahan Complex, RK Misson Road and Post Office with PM_1 , $\text{PM}_{2.5}$ & PM_{10} concentration of 155.5, 257 and $331.5 \mu\text{g}/\text{m}^3$; 135.5, 224.75 and $289.5 \mu\text{g}/\text{m}^3$ and 136.25, 216.25 and $284.75 \mu\text{g}/\text{m}^3$ respectively and comparatively less polluted place were Tinkona Pukur par and Puran Munshefi Road with PM_1 , $\text{PM}_{2.5}$ & PM_{10} concen-

tration of 129.75, 208.75 and $27.25 \mu\text{g}/\text{m}^3$ and 129.25, 216.25 and $278 \mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentrations of $\text{PM}_{2.5}$ and PM_{10} found in the most polluted places were 3.95 and 2.21 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which are 65 and $150 \mu\text{g}/\text{m}^3$ set by the Department of Environment (DoE). The study estimated that in all mixed areas, 78.40% of $\text{PM}_{2.5}$ was present in PM_{10} and 59.35% of the PM_1 was present in $\text{PM}_{2.5}$.

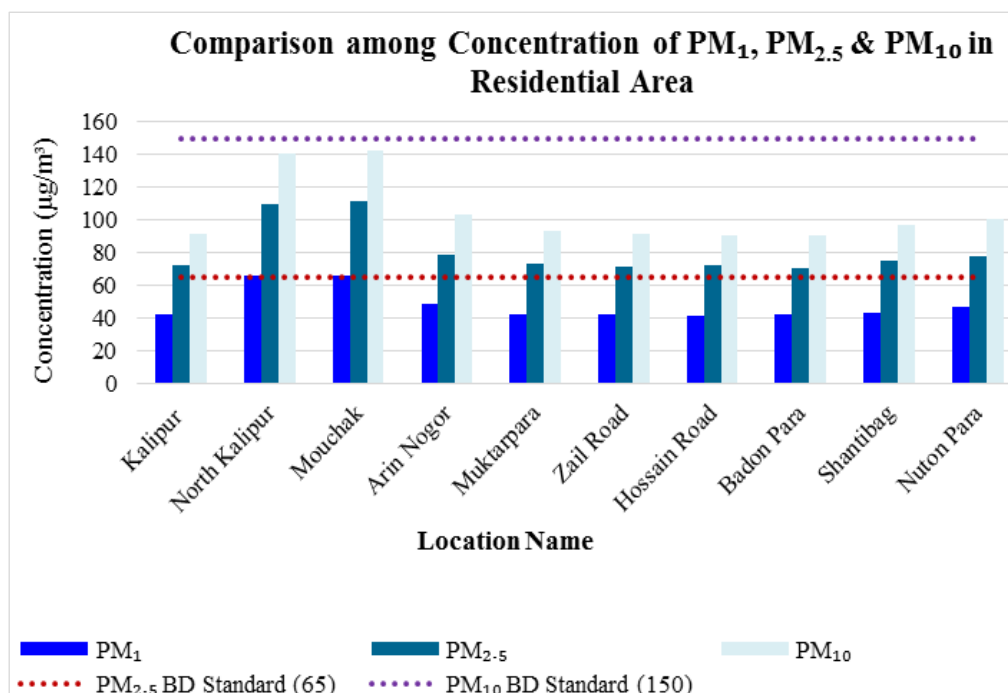


Figure 4. Comparison among Concentration of PM_1 , $\text{PM}_{2.5}$ & PM_{10} in Residential Area.

Figure 4 demonstrates the concentration ($\mu\text{g}/\text{m}^3$) of PM_1 , $\text{PM}_{2.5}$ & PM_{10} of some locations in residential areas in Sunamganj District Town. It has been found that out of 10 residential places, among three highly polluted places were Mouchak, North kalipur mor and Notun para mor with PM_1 , $\text{PM}_{2.5}$ & PM_{10} concentration of 111.25, 110 and $77.50 \mu\text{g}/\text{m}^3$ respectively. Comparatively less polluted places were badhon para, Zail road and kalipur with $\text{PM}_{2.5}$ concentration of 70.25, 71.50 and $7.25 \mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentrations of $\text{PM}_{2.5}$ found in the most polluted places was 1.69 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which is $65 \mu\text{g}/\text{m}^3$ set by the Department of Environment (DoE). The study estimated that the ratio of $\text{PM}_{2.5}/\text{PM}_{10}$ was 78.08%. It was also found that 59.24% of PM_1 mass was present in $\text{PM}_{2.5}$.

Figure 5 shows 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 Sunamganj District Town. It has been found that out of 10 road intersection places, three highly polluted places were Traffic mor, DS road mor and jela porishad with PM_1 , $\text{PM}_{2.5}$ & PM_{10} concentration of 136.75, 231.25 and $295.00 \mu\text{g}/\text{m}^3$; 106.25, 174.75 and $226.00 \mu\text{g}/\text{m}^3$ and 108.25, 171.25 and $225.75 \mu\text{g}/\text{m}^3$ respectively and relatively least contaminated places were Abduj Jahur Setu, sunamgonj with $\text{PM}_{2.5}$ concentration of $59.50 \mu\text{g}/\text{m}^3$ respectively. It was also observed that the concentrations of $\text{PM}_{2.5}$ and PM_{10} found in the most polluted places were 3.55 and 1.97 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which are 65 and $150 \mu\text{g}/\text{m}^3$ set by the Department of Environment (DoE). The study estimated that the ratio of $\text{PM}_{2.5}/\text{PM}_{10}$ was 77.28%. It was also found that 60.78% of PM_1 mass was present in $\text{PM}_{2.5}$.

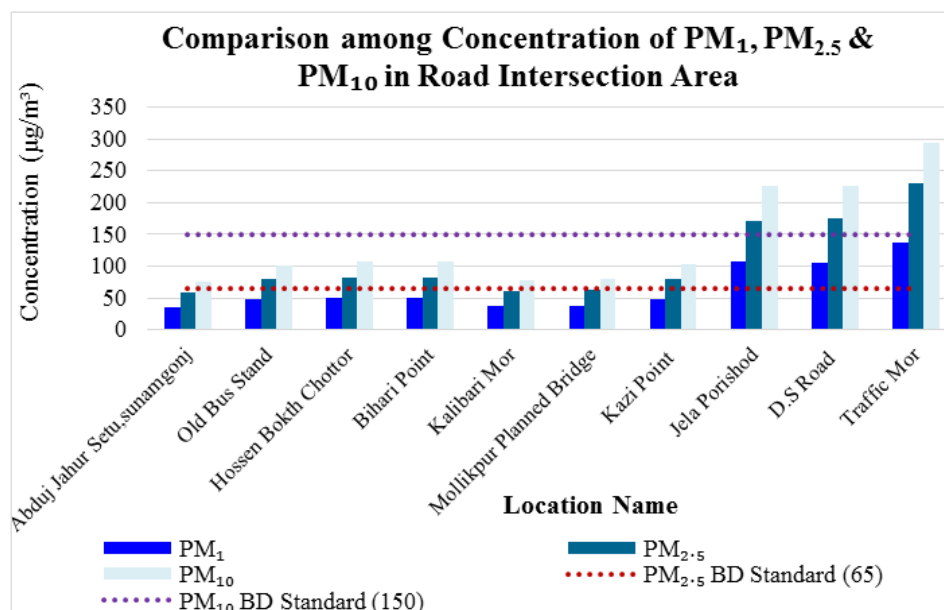


Figure 5. Comparison among Concentration of PM₁, PM_{2.5} & PM₁₀ in Road Intersection Area.

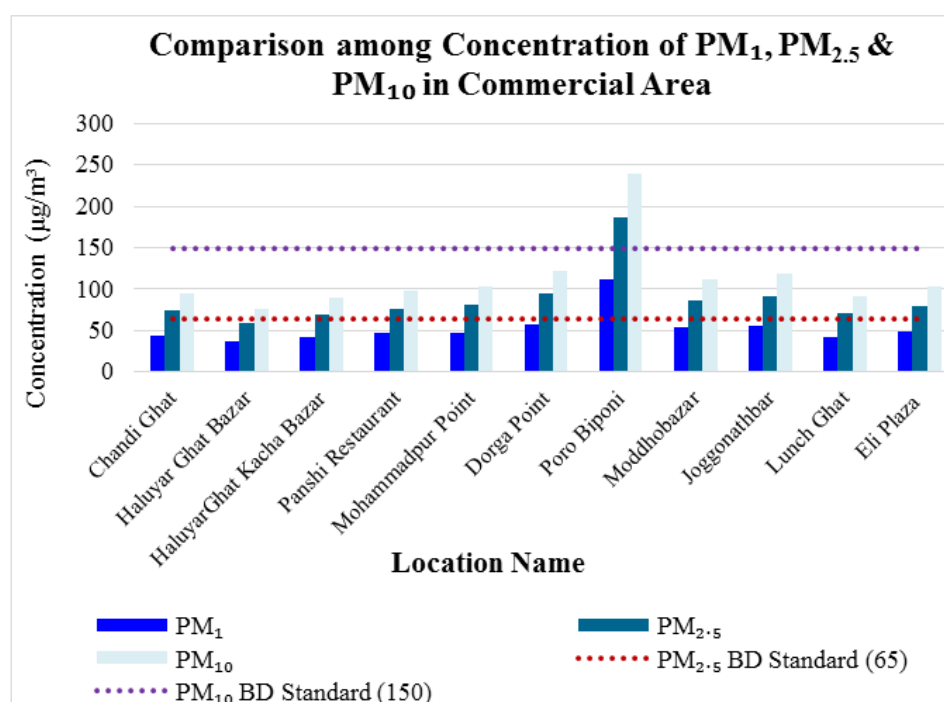


Figure 6. Comparison among Concentration of PM₁, PM_{2.5} & PM₁₀ in Commercial Area.

Figure 6 illustrates the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5} & PM₁₀ of some locations in commercial areas in Sunamganj District Town. It has been found that out of 10 commercial places, three highly polluted places were Poro Biponi, Dorga point and Joggonathbar with PM₁, PM_{2.5} & PM₁₀ concentration of 111.75, 186.5 and 239.75 $\mu\text{g}/\text{m}^3$, 57, 94.75 and 122 $\mu\text{g}/\text{m}^3$ and 56.5, 91.5 and 119 $\mu\text{g}/\text{m}^3$ respectively. One contaminated places was Haluyar Ghat Bazar with PM_{2.5}

concentration of 58.75 $\mu\text{g}/\text{m}^3$ respectively. It was also observed that the concentrations of PM_{2.5} and PM₁₀ found in the most polluted places were 2.86 and 1.50 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which are 65 and 150 $\mu\text{g}/\text{m}^3$ set by the Department of Environment (DoE). The study estimated that the ratio of PM_{2.5}/PM₁₀ was 77.45%. It was also found that 60.60% of PM₁ mass was present in PM_{2.5}.

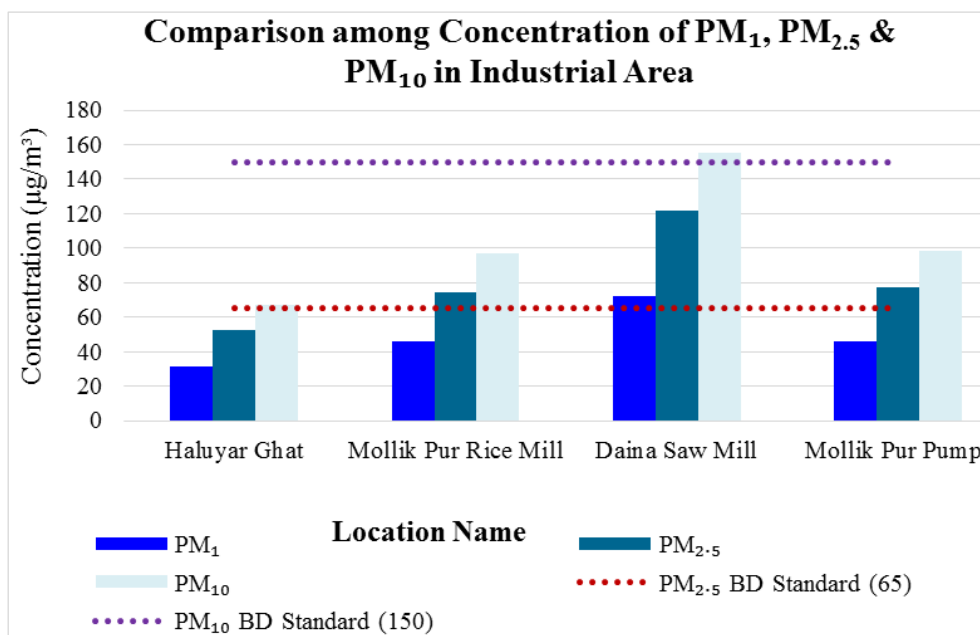


Figure 7. Comparison among Concentration of PM_1 , $PM_{2.5}$ & PM_{10} in Industrial Area.

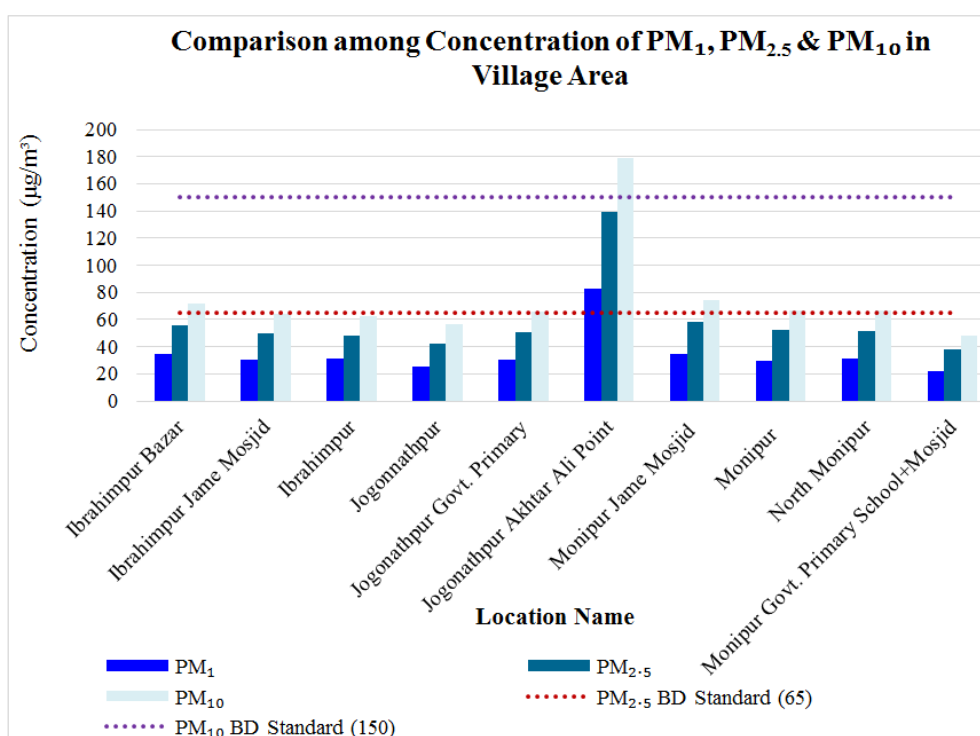


Figure 8. Comparison among Concentration of PM_1 , $PM_{2.5}$ & PM_{10} in Village Area.

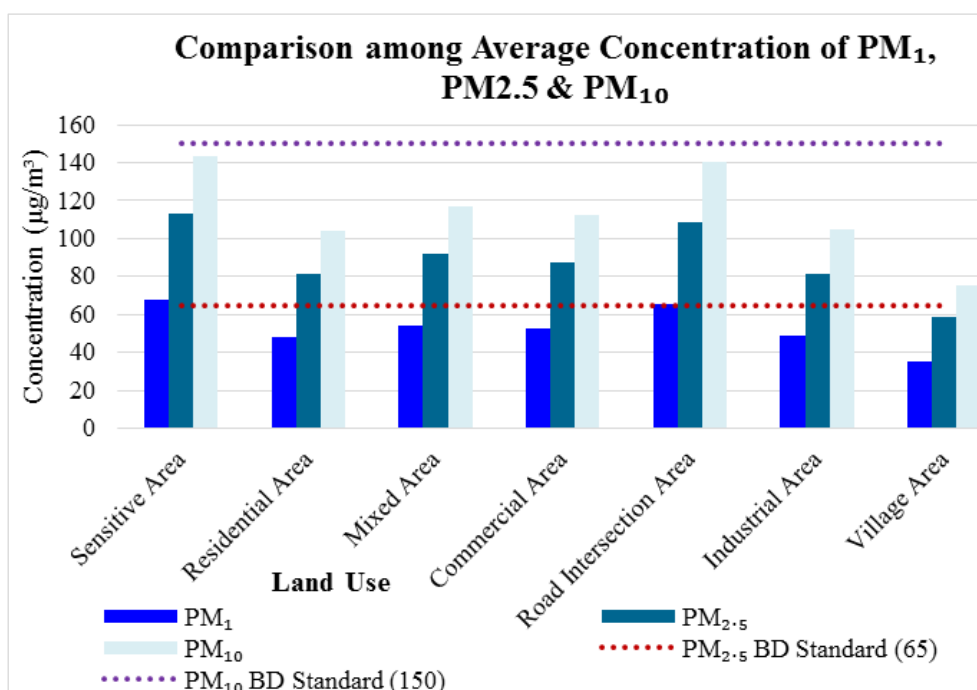


Figure 9. Comparison among Average Concentration of PM₁, PM_{2.5} and PM₁₀.

Figure 7 shows the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5} & PM₁₀ of some locations in industrial locations in Sunamganj District Town. It has been found that out of 4 industrial places, most polluted places Daina Saw Mill with PM₁, PM_{2.5} & PM₁₀ concentration of 72.00, 121.50 and 155.50 $\mu\text{g}/\text{m}^3$ respectively and comparatively less polluted places were Mollik Pur Pump, Mollik Pur Rice Mill with PM_{2.5} concentration of 77.50 and 74.75 $\mu\text{g}/\text{m}^3$ respectively. It was also observed that the concentrations of PM_{2.5} and PM₁₀ found in the most polluted places were 1.87 and 1.03 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which are 65 and 150 $\mu\text{g}/\text{m}^3$ set by the Department of Environment (DoE). The study estimated that the ratio of PM_{2.5}/PM₁₀ was 78.06%. It was also found that 59.99% of PM₁ mass was present in PM_{2.5}.

Figure 8 shows the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5} & PM₁₀ of polluted locations in village areas in Sunamganj District Town. It has been found that out of 10 village areas, It has been found that out of 10 commercial places, most polluted places were Jogonathpur Akhtar Ali Point with PM₁, PM_{2.5} & PM₁₀ concentration of 82.75, 139.75 and 178.75 $\mu\text{g}/\text{m}^3$ respectively and comparatively less contaminated places were Monipur Govt. Primary School+Mosjid, Ibrahimpur and Ibrahimpur Jame Mosjid with PM_{2.5} concentration of 38, 42.50 and 48.50 $\mu\text{g}/\text{m}^3$ respectively. It was also observed that the concentrations of PM_{2.5} and PM₁₀ found in the most polluted places were 2.15 and 1.19 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which are 65 and 150 $\mu\text{g}/\text{m}^3$ set by the Department of Environment (DoE). The study estimated that the ratio of

PM_{2.5}/PM₁₀ was 77.47%. It was also found that 60.40% of PM₁ mass was present in PM_{2.5}.

The Figure 9 illustrates the comparison of the average concentration of PM₁, PM_{2.5} and PM₁₀ of seven lands uses in Sunamganj District Town. The average concentration of PM₁, PM_{2.5} and PM₁₀ was higher in the sensitive area, road intersection area and mixed area with the values of 68.10, 113.10 and 143.28 $\mu\text{g}/\text{m}^3$; 65.83, 108.30 and 140.10 $\mu\text{g}/\text{m}^3$ and 54.55, 91.85 and 117.20 $\mu\text{g}/\text{m}^3$ respectively with highest in the sensitive area. It was also observed that the concentrations of PM_{2.5} found in the most polluted land use was 1.74 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which is 65 $\mu\text{g}/\text{m}^3$ set by the Department of Environment (DoE). The concentration of PMs were found relatively lower in residential area, commercial area, industrial area and village area.

Figure 10 illustrates a comparison of average concentration of CO among seven land use in Sunamganj District Town. The graph shows that the average of CO was found to be highest in the industrial area (27 ppm). 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 3 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) level which is 9 ppm (8-hour) set by the Department of Environment (DoE). The average concentration of CO was found relatively lower in the other areas where the concentration did not exceed the standard level. The average concentrations of CO found least in commercial area (3.25 ppm).

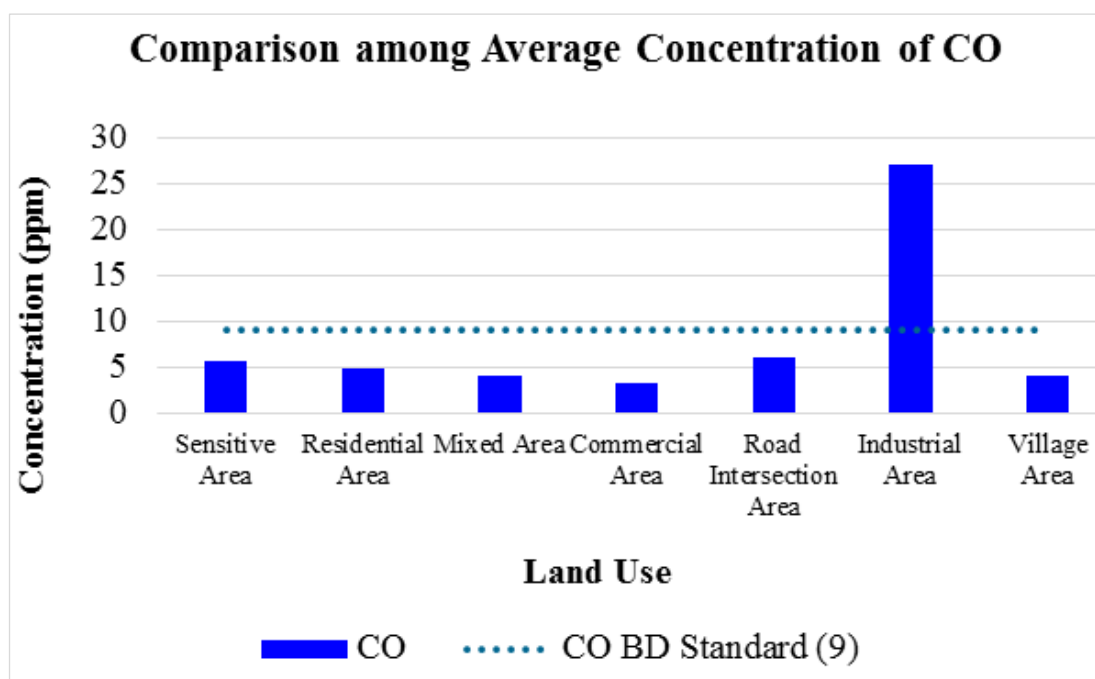


Figure 10. Comparison among average Concentration of CO in Different Land Use.

4.2. Descriptive Statistics of PM₁, PM_{2.5}, PM₁₀ and CO

The following Table 2 shows the descriptive statistics for Particulate Matters (PM₁, PM_{2.5} & PM₁₀) and Carbon Monoxide (CO) of the seven land uses studied. For PM₁, the highest range was found in sensitive area (110.25 µg/m³) followed by road intersection area (101.75 µg/m³) and lower ranges were found in residential area (24.75 µg/m³) and mixed area (29.75 µg/m³). Among all those land uses the minimum

concentration (31 µg/m³) was found in road intersection area and the maximum (141.25 µg/m³) value found in sensitive area. The highest mean value of PM₁ was found in sensitive area (68.10 µg/m³) followed by road intersection area (65.83 µg/m³) and the lowest mean was found in village area (35.35 µg/m³). The highest standard deviation was seen in sensitive area (36.48 µg/m³) and the lowest was seen in residential area (9.67 µg/m³). Table also shows that; the highest coefficient of variation was seen in road intersection area which was 55.78% and the lowest was seen in residential area which was 20.05%.

Table 2. Descriptive Statistics for PM₁, PM_{2.5}, PM₁₀ and CO.

Sl. No.	Land Use	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	10	110.25	68.10	36.48	53.56	181.25	113.10	61.33	54.23
2	Mixed Area	5	29.75	54.55	12.34	22.60	47.75	91.85	20.19	21.98
3	Residential Area	10	24.75	48.23	9.67	20.05	41.00	81.33	15.66	19.25
4	Road Intersection Area	10	101.75	65.83	36.72	55.78	171.75	108.30	60.86	56.19
5	Commercial Area	11	75.50	53.32	20.39	38.24	127.75	88.09	34.22	38.85
6	Industrial Area	4	40.25	48.81	16.81	34.43	69.00	81.56	28.88	35.41
7	Village Area	10	60.75	35.35	17.11	48.39	101.75	58.65	29.08	49.59

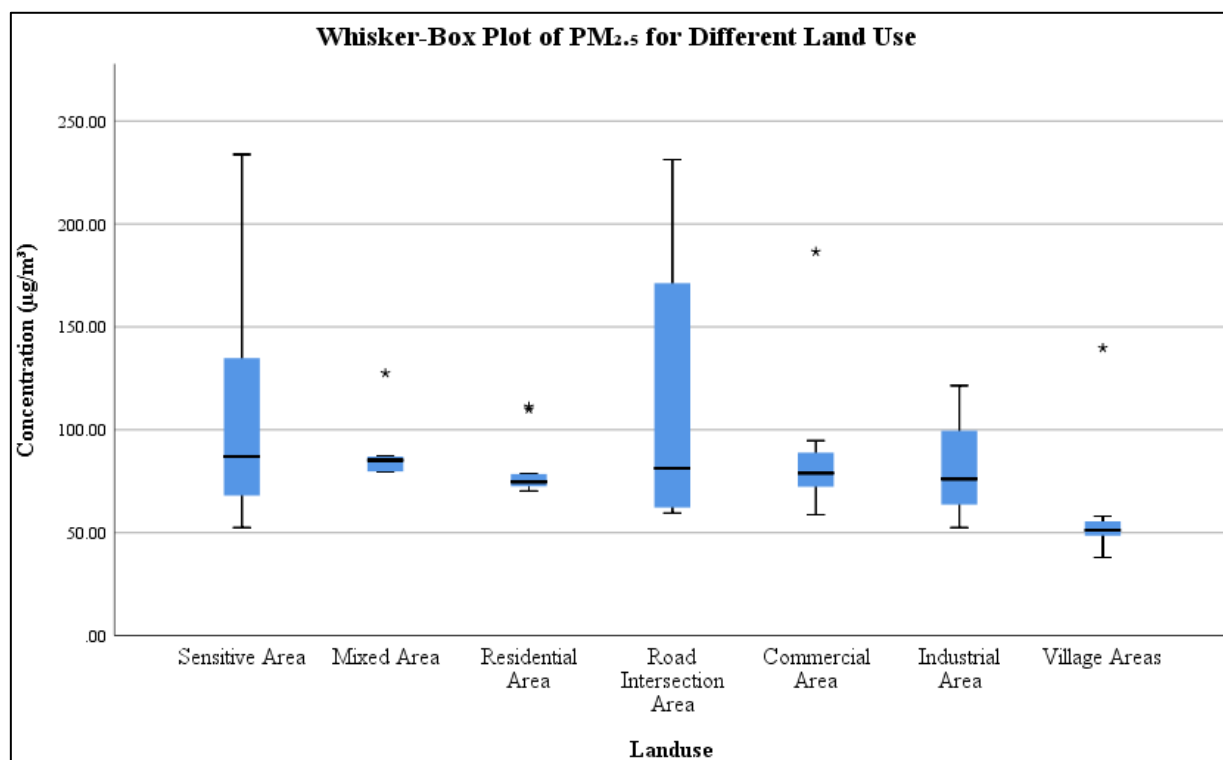
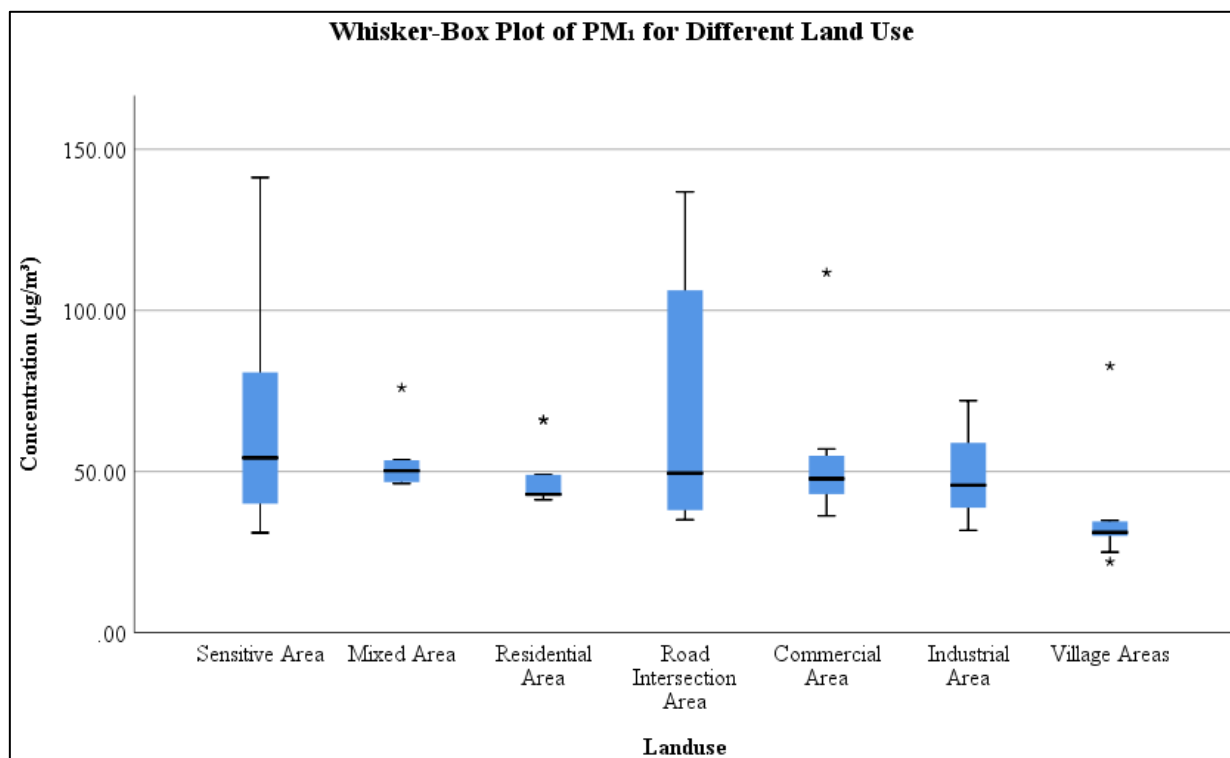
Table 2. Continued.

Sl. No.	Land Use	Number of locations	Range ($\mu\text{g}/\text{m}^3$)	Mean ($\mu\text{g}/\text{m}^3$)	Std. Deviation ($\mu\text{g}/\text{m}^3$)	Coefficient of Variation (%)	Range (ppm)	Mean (ppm)	Std. Deviation (ppm)	Coefficient of Variation (%)
1	Sensitive Area	10	209.50	143.28	72.99	50.94	14	5.60	5.23	93.44
2	Mixed Area	5	62.00	117.20	25.98	22.16	12	4.00	5.66	141.42
3	Residential Area	10	52.00	104.20	20.23	19.41	15	4.80	6.43	133.87
4	Road Intersection Area	10	219.25	140.10	78.31	55.90	14	6.10	5.70	93.52
5	Commercial Area	11	163.25	113.68	43.89	38.61	11	3.00	3.79	126.49
6	Industrial Area	4	88.50	104.50	36.97	35.38	76	21.75	36.26	166.72
7	Village Area	10	130.50	75.60	36.99	48.92	10	4.10	3.814	93.02

For $\text{PM}_{2.5}$ the highest range was found in sensitive area ($181.25\mu\text{g}/\text{m}^3$) followed by road intersection area ($171.75\mu\text{g}/\text{m}^3$) and lower ranges were found in residential area ($41\mu\text{g}/\text{m}^3$) and mixed area ($47.75\mu\text{g}/\text{m}^3$). Among all those land uses the minimum concentration ($38\mu\text{g}/\text{m}^3$) was found in village area and the maximum ($233.75\mu\text{g}/\text{m}^3$) value found in sensitive area. The highest mean value of $\text{PM}_{2.5}$ was found in sensitive area ($113.10\mu\text{g}/\text{m}^3$) followed by road intersection area ($231.25\mu\text{g}/\text{m}^3$) and the lowest mean was found in village area ($58.65\mu\text{g}/\text{m}^3$). The highest standard deviation was seen in sensitive area ($61.33\mu\text{g}/\text{m}^3$) and the lowest was seen in residential area ($29.08\mu\text{g}/\text{m}^3$). Table also shows that; the highest coefficient of variation was seen in road intersection area which was 56.19% and the lowest was seen in residential area which was 19.25%. For PM_{10} the highest range was found in road intersection area ($219.25\mu\text{g}/\text{m}^3$) followed by sensitive area ($209.50\mu\text{g}/\text{m}^3$) and lower ranges were found in residential area ($52\mu\text{g}/\text{m}^3$) and mixed area ($62\mu\text{g}/\text{m}^3$). Among all those land uses the minimum concentration ($48.25\mu\text{g}/\text{m}^3$) was found in village area and the maximum ($276.50\mu\text{g}/\text{m}^3$) value found in sensitive area. The highest mean value of PM_{10} was found in sensitive area ($143.28\mu\text{g}/\text{m}^3$) followed by road intersection area ($140.10\mu\text{g}/\text{m}^3$) and the lowest mean was found in village area ($75.60\mu\text{g}/\text{m}^3$). The highest standard deviation was seen in road intersection area ($78.31\mu\text{g}/\text{m}^3$) and the lowest was seen in residential area ($20.23\mu\text{g}/\text{m}^3$). Table also shows that; the highest coefficient of variation was seen in road intersection area which was 55.90% and the lowest was seen in residential area which was 19.41%.

For CO the highest ranges were found in industrial area (76 ppm) and lowest ranges was found in mixed and village area (10 ppm). Among all those land uses the minimum concentration (0 ppm) was seen in all of zones and maximum concentration was seen in industrial area (76 ppm). The highest mean value of CO was found in industrial area (21.75 ppm) and lowest mean found in commercial area (3.00 ppm). It was observed that the highest coefficient of Variation was found in industrial area (166.72%) followed by residential area and the least variation was found in village area which was 93.02%.

The whisker box plot shows in figure 11 the average of Particulate Matters (PM_1 , $\text{PM}_{2.5}$ & PM_{10}) and Carbon Monoxide (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 [15, 16]. Following whisker revealed that road intersection area and sensitive area had similar dispersed concentration where road intersection area had shown the highest dispersion with positively skewed values. Industrial area had moderate dispersion were found positive skewness with one outlier. However, the commercial area, mixed area and residential area had less concentration with normal distribution though having one outlier in mixed area and residential area had extremely positive skewness with one close outlier. Village area had compact concentration had extremely positive skewness with one very close outlier and one distance outlier.



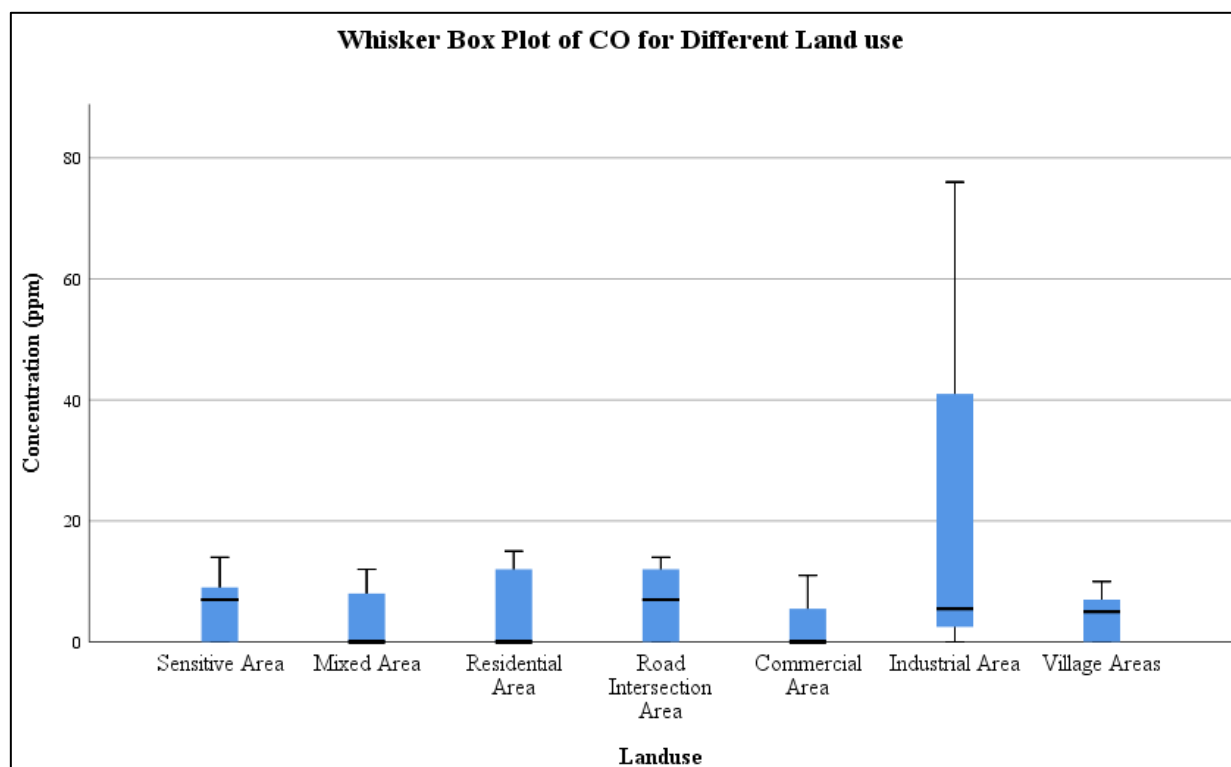
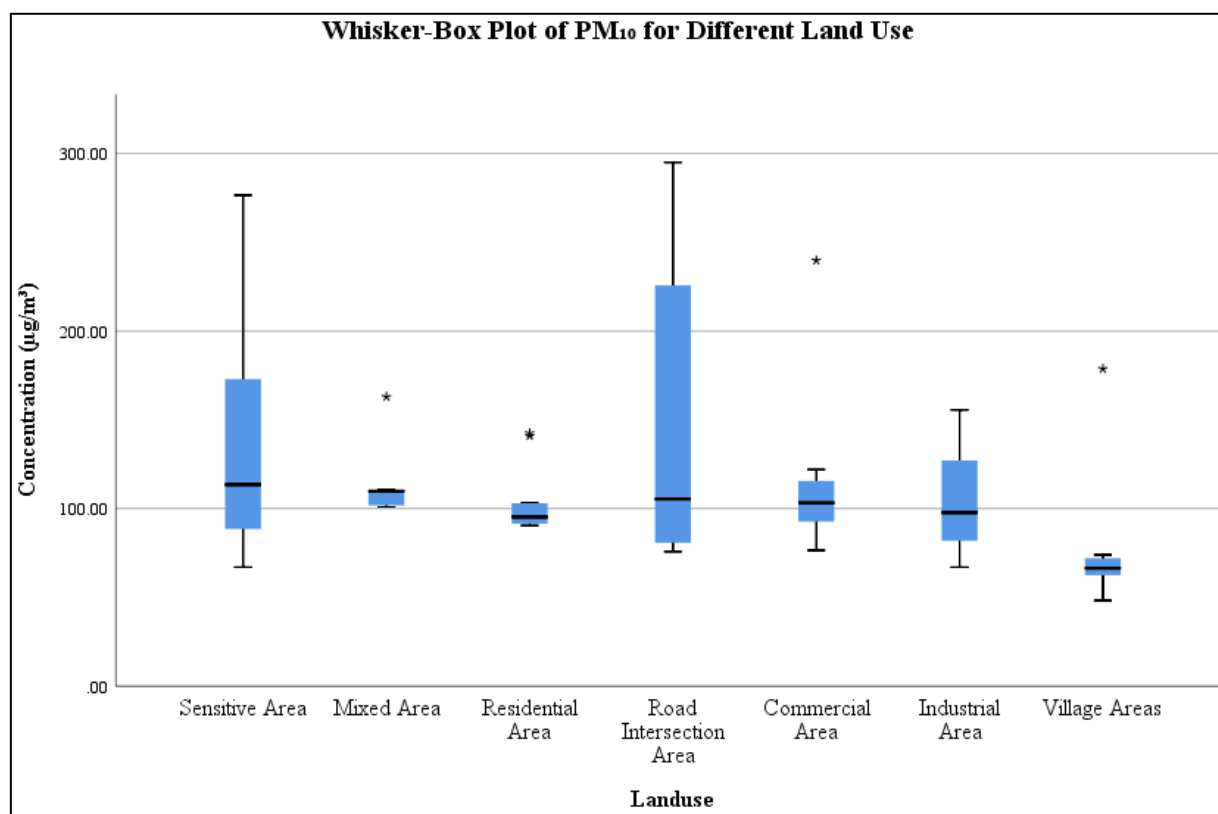


Figure 11. Whisker Box Plot of the Concentration of PM₁, PM_{2.5}, PM₁₀ and CO in Different Land use.

Following whisker box plot of PM_{2.5} revealed that road intersection area and sensitive area had similar dispersed concentration where road intersection area had shown the highest disper-

sion with positively skewed values. Industrial area had moderate dispersion where found positive skewness. However, the mixed area, residential and village area had compact concentra-

tion had extremely positive skewness with one close outlier in village area. Residential area had extremely positive skewness with one close outlier and negatively skewness in mixed area.

Following whisker box plot of PM_{10} revealed that road intersection area and sensitive area had similar dispersed concentration where road intersection area had shown the highest dispersion with positively skewed values. Industrial area had moderate dispersion where found positive skewness. However, the mixed area, residential and village area had compact concentration had extremely positive skewness with one close outlier in village area. Residential area had extremely positive skewness with one close outlier and negatively skewness in mixed area.

Following whisker box plot of CO revealed that industrial area had highest dispersed concentration with positively skewed value. Sensitive area, mixed area, residential area and road intersection area had similar type of dispersion where positive values shown in mixed area and residential area and negative values

shown in sensitive area and road intersection area. However, commercial area and village area had compact dispersion where positive skewness found in commercial and negative skewness found in village area.

4.3. 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 1.945 for PM_1 , 1.864 for $PM_{2.5}$, 1.914 for PM_{10} , 1.949 for CO. The P value calculated for PM_1 , $PM_{2.5}$, PM_{10} and CO was 0.090, 0.104, 0.096 and 0.090. The following table reveals that the concentration of $PM_{2.5}$ do not change significantly as the p value is greater than 0.05. But the concentration of PM_1 , PM_{10} and CO change 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	7310.567	6	1218.428	1.945	0.090
	Within Groups	33199.346	53	626.403		
	Total	40509.912	59			
$PM_{2.5}$	Between Groups	19590.949	6	3265.158	1.864	0.104
	Within Groups	92847.437	53	1751.838		
	Total	112438.386	59			
PM_{10}	Between Groups	31466.019	6	5244.336	1.914	0.096
	Within Groups	145194.143	53	2739.512		
	Total	176660.161	59			
CO	Between Groups	1160.183	6	193.364	1.949	0.090
	Within Groups	5258.550	53	99.218		
	Total	6418.733	59			

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

Figure 12 illustrates the concentration of Particulate Matter (PM_1) at various location of Sunamganj 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 $\mu\text{g}/\text{m}^3$ mean one millionth of gram of PM_1 per cubic meter air. Yellow areas have less, while progressively higher concentrations are shown in orange and red. Concentration of PM_1 was found to

be higher ($76\text{--}109\mu\text{g}/\text{m}^3$) in Khali Bari Mor, Sikha Procosiol Odidoptor, Jogonathpur Akhtar Ali Point, D. S Road, Jela Porishod, Poro Biponi, Circuit House, Traffic Mor and Jela Dayra Jaj Court. It also shows that PM_1 concentration was lower than $40\mu\text{g}/\text{m}^3$ in Monipur Govt. Primary School+Mosjid, Jogonathpur, Monipur, Ibrahimpur Jame Mosjid, Jogonathpur Govt. Primary, Upozila Parisod, Ibrahimpur, North Monipur, Haluyar Ghat, Monipur Jame Mosjid, Ibrahimpur Bazar, Abduj Jahur Setu, sunamgonj, Haluyar Ghat Bazar, Kalibari Mor, Birtan and Mollikpur Planned Bridge. The maximum concentration shows with blue flag

and minimum concentration with green flag. The maximum concentration was found in District & Sessions Judge Court,

Sunamjong and the minimum concentration was found in Monipur Govt. Primary School.

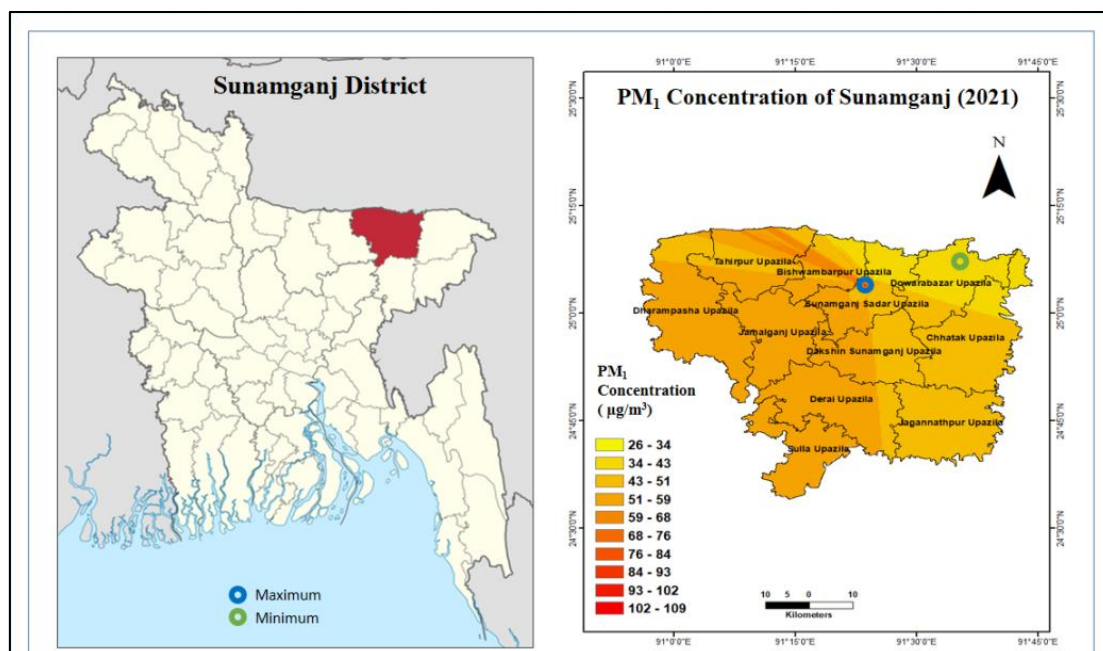


Figure 12. PM_{10} Concentration of Sunamganj District Town in 2021.

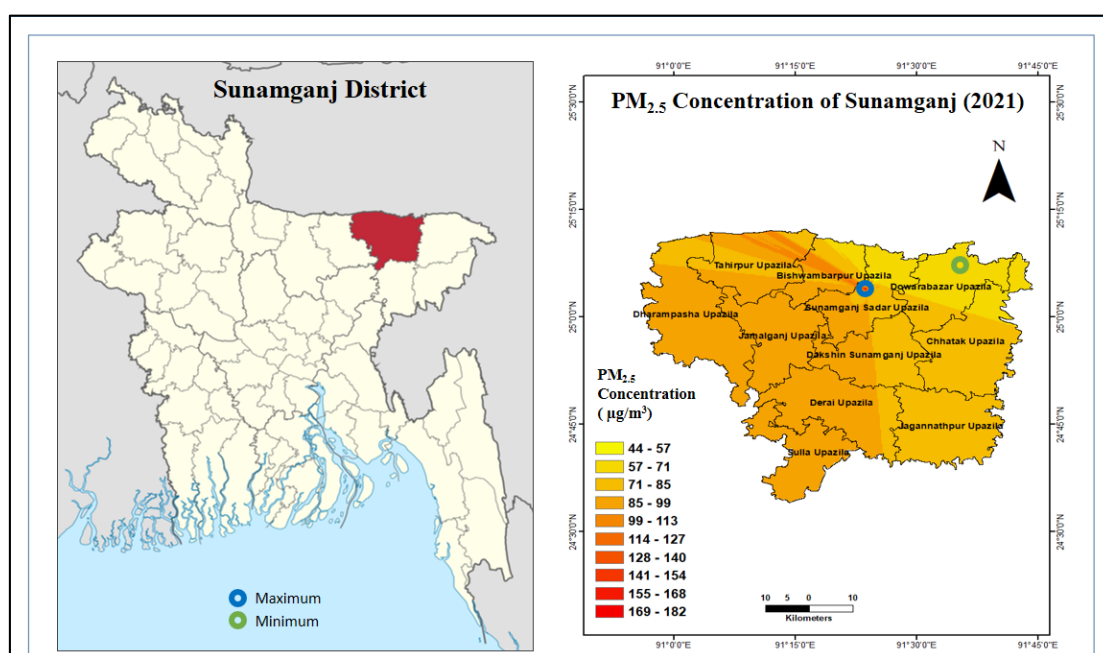


Figure 13. $PM_{2.5}$ Concentration Map of Sunamganj District Town in 2021.

Figure 13 demonstrates the concentration of Particulate Matter ($PM_{2.5}$) at various location of Sunamganj district town in the year of 2021. Concentration of $PM_{2.5}$ was found to be higher ($114-182\mu g/m^3$) in Jamiy Islamia Darul Ulum Madrasa, Daina Saw Mill, Khali Bari Mor, Sikha Procosiol Odi-doptor, Jogonathpur Akhtar Ali Point, Jela Porishod, D. S

Road, Poro Biponi, Circuit House, Traffic Mor and Jela Dayra Jaj Court. It also shows that $PM_{2.5}$ concentration was lower than $65\mu g/m^3$ in Monipur Govt. Primary School, Jogonnathpur, Ibrahimpur, Ibrahimpur Jame Masjid, Jogonathpur Govt. Primary, North Monipur, Monipur, Upazila Parisad, Haluyar Ghat, Ibrahimpur Bazar, Monipur Jame

Mosjid, Haluyar Ghat Bazar, Abduj Jahur Setu, sunamgonj, Kalibari Mor and Mollikpur Planned Bridge. The maximum concentration shows with blue flag and minimum concentration with green flag. The maximum concentration was found

in District & Sessions Judge Court, Sunamjong and the minimum concentration was found in Monipur Govt. Primary School.

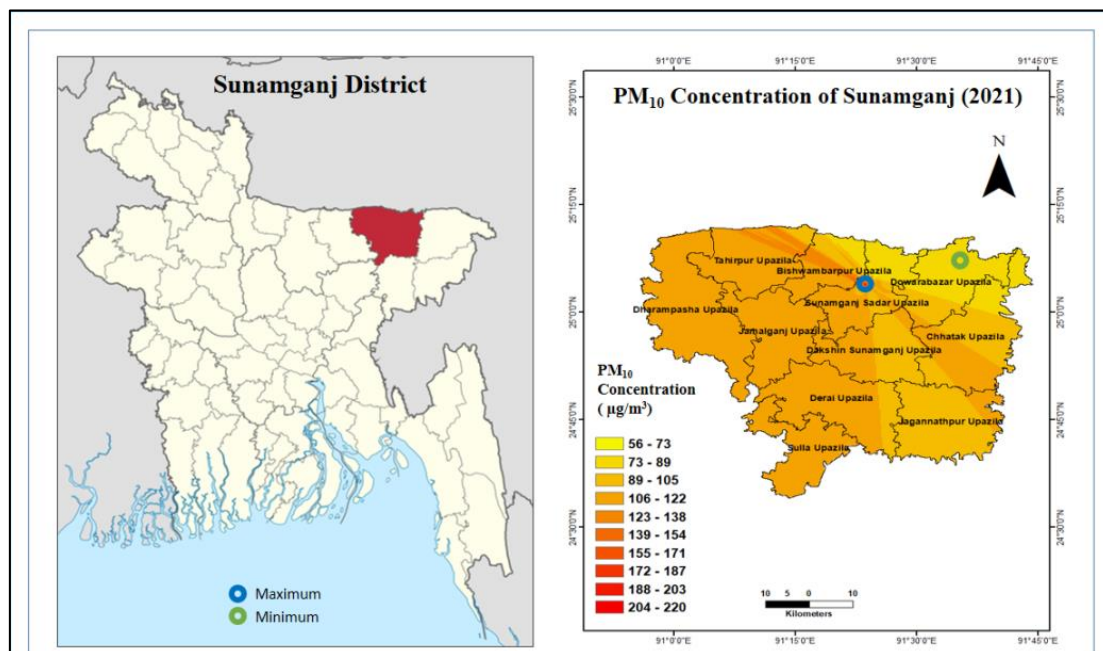


Figure 14. PM_{10} Concentration Map of Sunamganj District Town in 2021.

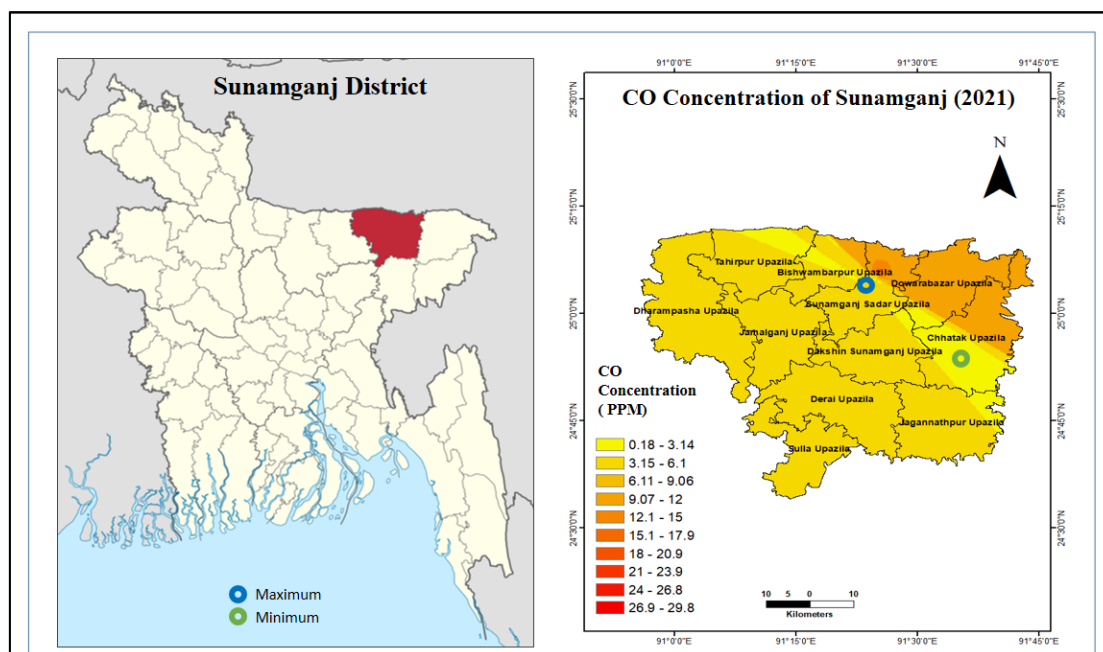


Figure 15. CO Concentration Map of Sunamganj District Town in 2021.

Figure 14 demonstrates the concentration of Particulate Matter (PM_{10}) at various locations of Sunamganj District Town in the year 2021. The concentration of PM_{10} was found to be higher ($150-220 \mu\text{g}/\text{m}^3$) in Daina Saw Mill, Khali Bari

Mor, Sikha Procosiol Odidoptor, Jagonathpur Akhtar Ali Point, Jela Parishod, D. S Road, Poro Biponi, Circuit House, Jela Dayra Jaj Court and Traffic Mor. It also shows that PM_{10} concentration was lower than $150 \mu\text{g}/\text{m}^3$ in Monipur Govt.

Primary School, Jogonathpur, Ibrahimpur, Ibrahimpur Jame Masjid, Jogonathpur Govt. Primary, North Monipur, Monipur, Upazila Parisad, Haluyar Ghat, Ibrahimpur Bazar, Monipur Jame Masjid, Haluyar Ghat Bazar, Abduj Jahur Setu, sunamgonj, Kalibari Mor and Mollikpur Planned Bridge. The maximum concentration shows with blue flag and minimum concentration with green flag. The maximum concentration was found in Traffic Mor and the minimum concentration was found in Monipur Govt. Primary School.

Figure 15 illustrates the concentration of carbon monoxide at various location of Sunamganj district town in the year of 2021. Concentrations of carbon monoxide are expressed in parts per million by volume (ppm). 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 (10-76 ppm) in Jogonathpur Akhtar Ali Point, Poro Biponi, Mouchak, Municipal Market, Jela Porishod, D. S Road, Kalipur, Sadar Hospital, Kalibari Mor, Hossain Road and Haluyar Ghat. It also shows that CO concentrations was lower than 9 ppm in almost all the area. The maximum concentration shows with blue flag and minimum concentration with green flag. The maximum concentration was found in Haluyar Ghat the minimum concentration was found in LGED bhaban.

4.5. AQI on $PM_{2.5}$ Concentration of Sunamganj District Town in 2021

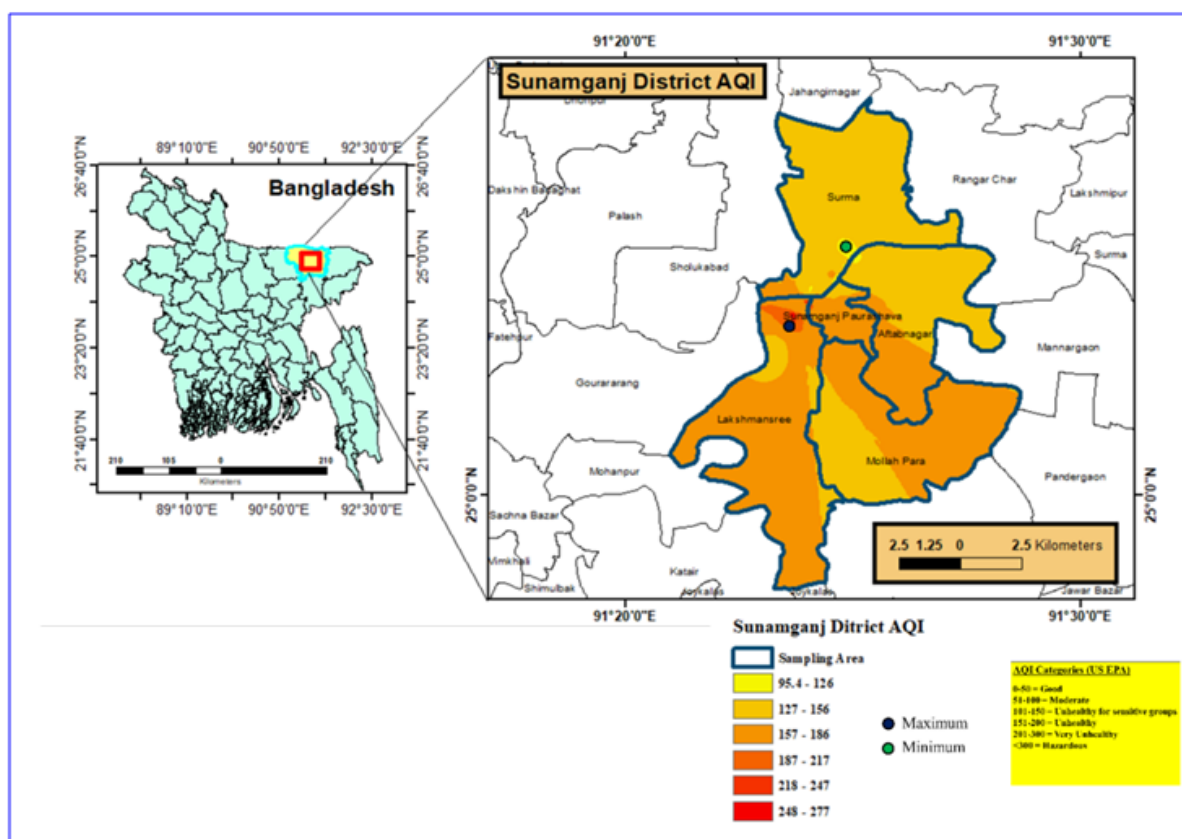


Figure 16. AQI on $PM_{2.5}$ Concentration Map of Sunamganj District Town in 2021.

Figure 16 Shows the Sunamganj District Town based on $PM_{2.5}$. In this map, different colors represent the category of AQI according to Bangladesh National Ambient Air Pollution Standard. The map also shows that AQI (201-300) was in very unhealthy condition in the Jela Porishod, D. S Road, Poro Biponi, Circuit House, Traffic Mor and Jela Dayra Jaj Court which is indicated in red color. The map also shows that AQI (150-200) was in unhealthy condition in Jadughor, Haluyar-Ghat Kacha Bazar, Badon Para, Lunch Ghat, Zail Road, Kalipur, Hossain Road, Muktarpara, Chandi Ghat, Mollik Pur

Rice Mill, Shantibag, Panshi Restaurant, Nuton Para, Mollik Pur Pump, Arin Nogar, Eli Plaza, Old Bus Stand, Sohologhor Govt. Primary School, Hasan Nogar Road, Kazi Point, Mohammadpur Point, K. B Govy. Primary School, Sadar Hospital, Bihari Point, Hossen Bokth Chottor, Municipal Market, Moddhobazar, HED, Joggonathbar, LGED Bhobon, Dorga Point, North Kalipur, Mouchak, Jamiy Islamia Darul Ulum Madrasa, Daina Sawmill, Khali Bari Mor, Sikha Procosiol Odidoptor, Jogonathpur Akhtar Ali Point which is indicating in orange color.

5. Conclusion

The study found that the average concentration of PM₁, PM_{2.5} & PM₁₀ of 60 places in Sunamganj District Town were 53.36, 88.86 and 113.90 µg/m³ respectively. From the outcome of this research the studied land uses are arranged in descending order based on average concentration PM₁, PM_{2.5} & PM₁₀ which follows sensitive area (113.10 µg/m³) > road intersection area (108.30 µg/m³) > mixed area (91.85 µg/m³) > commercial area (87.21 µg/m³) > industrial area (81.56 µg/m³) > residential area (81.33 µg/m³) > village area (58.65 µg/m³). The Concentration of PM_{2.5} was found 1.75 times higher than the standard level. The National Air Quality Standard (Daily) set by the Department of Environment (DoE) for PM_{2.5} is 65 µg/m³. Moreover, it was estimated from the average ratio of PM_{2.5} /PM₁₀ showed that the PM_{2.5} mass was 77.83% of the PM₁₀ mass and the average ratio PM₁/PM_{2.5} showed that the PM₁ mass was 60.13% of the PM_{2.5} mass. It also reveals that the concentration of PM_{2.5} do not change significantly as 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 three clusters at the first phase and these were consecutively to make a single cluster at the approximate distance of 25.

Abbreviations

AQI	Air Quality Index
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

Md Rifatul Islam: 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.

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