

Research Article

Spatial Distribution of Air Quality in Rangpur Metropolitan, Bangladesh

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Abstract

This study investigates the spatial distribution of air quality in Rangpur metropolitan city, Bangladesh, by analyzing particulate matter (PM) concentrations across various land use categories. Using a portable Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector (Model: DM106), and Garmin ETrex 10, data was collected from 40 locations categorized into sensitive, residential, mixed, commercial, road intersection, industrial, and village areas. Furthermore, ArcGIS software (version 10.4.1) was applied for spatial analysis, and a dendrogram plot was developed to classify and interpret pollutant clusters. Descriptive statistics and whisker box plots were employed to analyze and visualize variations in pollutant concentrations across different locations. The average concentrations of PM₁, PM_{2.5}, and PM₁₀ were found to be 42.22 µg/m³, 70.13 µg/m³, and 89.66 µg/m³, respectively. The Department of Environment (DoE) established the Bangladesh National Ambient Air Quality Standards (NAAQS) for PM_{2.5} and PM₁₀, which were 65 µg/m³ and 150 µg/m³, respectively. Notably, the PM_{2.5} concentration (70.13 µg/m³) across different land uses exceeded the NAAQS by 1.07 times. Furthermore, the average PM_{2.5} and PM₁₀ concentrations were 2.80 and 1.79 times higher than the World Health Organization's (WHO) 24-hour standard levels of 25 µg/m³ and 50 µg/m³, respectively. Commercial areas exhibited the highest pollution levels, attributed to high traffic volumes, ongoing construction, and limited green spaces. In contrast, the industrial area recorded the lowest PM levels, likely due to stringent regulatory measures and lower population density. The study also highlighted that fine particulate matter constitutes a significant proportion of total particulate pollution. Statistical analysis revealed no significant variation in PM concentrations across different locations, while cluster analysis indicated interconnected pollution sources. These findings emphasize the need for targeted pollution control measures and increased awareness to address air quality concerns in Rangpur metropolitan and similar urban settings.

Keywords

Particulate Matter, Descriptive Statistics, Cluster, Spatial Distribution, Rangpur Metropolitan Area

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Air pollution is the presence of hazardous substances in the air from both human-made sources, such as vehicle emissions, fuel combustion, industrial by-products chemical fumes and natural sources [1]. According to WHO [2], air pollution is defined as any chemical, physical or biological material that contaminates the interior or outer surroundings of the atmosphere and alters its fundamental properties. Particulate matter (PM), carbon monoxide (CO), ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), sulfur trioxide (SO₃) and chlorofluorocarbons (CFCs) and hydro fluorocarbons (HFCs) used as refrigerants are the pollutants that have the most evidence to support concerns for public health. Particulate matter (PM) consists of inhalable particles with common sizes categorized as PM_{2.5} and PM₁₀ based on their aerodynamic diameter [3]. The sources of particulate matter vary by size, coarse particles (PM₁₀) primarily come from natural sources like pollen and dust, while finer particles (PM_{2.5}) originate from both primary sources such as fuel combustion and secondary sources like chemical reactions in the atmosphere [3]. Health risks associated with PM_{2.5} and PM₁₀ include severe cardiovascular and respiratory conditions, with long-term exposure linked to lung cancer and adverse perinatal outcomes [3].

Air pollution is the biggest environmental threat to public health globally and is connected to climate change because many major pollutants come from the same sources as greenhouse gases and harm the climate [4]. World Bank report [5] stated that industrialization, the use of pesticides and nitrogen-based fertilizers, crop residues in agriculture, urbanization, forest fires, desert dust and poor waste management have exacerbated environmental health risks and pollution, particularly in lower and middle-income countries. Natural Resources Defense Council (NRDC) report [6] also indicated

1. Introduction

that Air pollution leads to about seven million deaths each year worldwide, with the majority occurring in lower and middle-income countries. Besides, nine out of ten people are exposed to air pollution levels that exceed the recommendations set by the World Health Organization [6]. Evidence shows that lower-income communities face higher exposure to unsafe air pollution levels and greater health risks due to reliance on outdoor jobs and limited access to affordable healthcare, which exacerbates mortality rates and highlights their increased vulnerability [7]. Bangladesh has been categorized as a lower-middle-income country by the World Bank since 2015 [8]. According to the IQAir report [9], Bangladesh is the most polluted country, with an annual average PM_{2.5} level of 79.9 $\mu\text{g}/\text{m}^3$ over 15 times the WHO guideline. Air pollution is responsible for about 20% of premature deaths in Bangladesh [10]. In the Global Livability Index for 2024, Bangladesh is ranked 168 out of 173 countries [11]. Research shows that in 2023, Dhaka's average PM_{2.5} concentration was 103.67 $\mu\text{g}/\text{m}^3$ nearly three times above the national air quality threshold [12]. Major sources of air pollution include brick kilns, vehicles, unfit vehicles, industrial and construction activities and unplanned urbanization, with meteorological factors like reduced rainfall exacerbating PM_{2.5} levels, especially in winter [13].

Therefore, this research seeks to provide the air pollution scenario in Rangpur by determining PM (PM₁, PM_{2.5} and PM₁₀) concentration. This study is significant as it addresses the gap in existing data for Rangpur, an area with limited or no prior air pollution information. Additionally, it will provide valuable insights that can inform localized interventions, help policy makers and enhance public health protection in Rangpur.

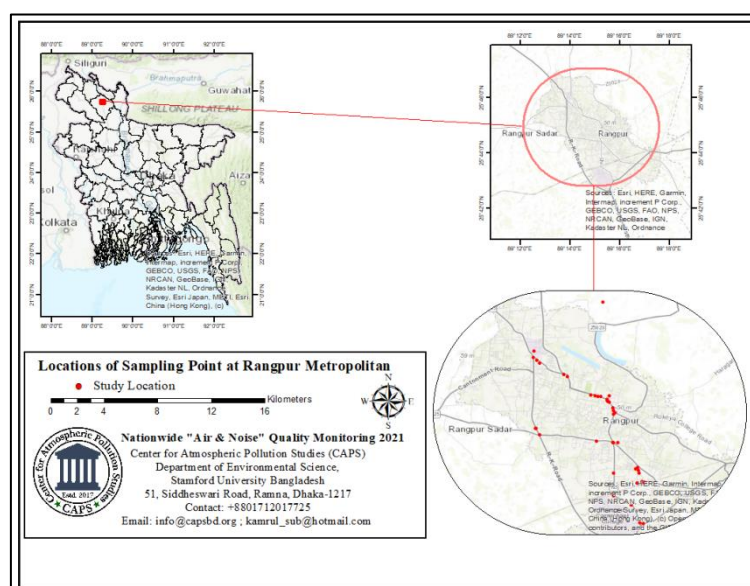


Figure 1. Rangpur Metropolitan Area and Data Collection Locations Point.

2. Materials and Methods

2.1. Study Area

Rangpur metropolitan is a marked area of Rangpur City Corporation which was under Sadar upazilla of Rangpur district in the Division of Rangpur, Bangladesh, located at 25 ° N and 89 ° E. However, 40 locations were selected and categorized into seven types: sensitive (7 locations), residential (4

locations), mixed (6 locations), commercial (11 locations), road intersection (6 locations), industrial (3 locations) and village areas (3 locations) shown on figure 1 [17]. The sensitive areas, totaling seven, include hospitals, clinics, schools, colleges, mosques, madrasas, temples, churches and administrative buildings. Mixed areas consist of bazars, buildings and main roads.

2.2. Research Methods

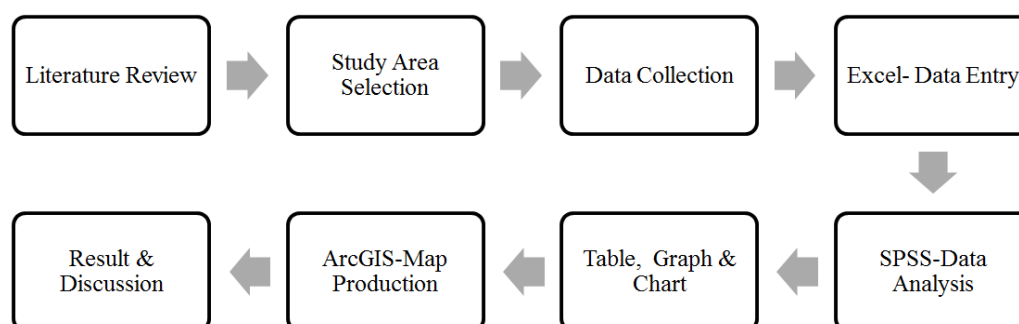


Figure 2. Flow Diagram of Research Methods.

2.3. Data Collection

Air quality was measured at 40 locations within the Rangpur metropolitan area over two days using automated portable instruments known as portable Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector (Model: DM106). GPS data was recorded using an Android application called Garmin ETrex 10. For each location, four individual measurements of PM₁, PM_{2.5}, and PM₁₀ were collected. Data was gathered at various times throughout the day, from morning until late evening.

2.4. Data Analysis

The data obtained was analyzed using Microsoft Excel 2020 and IBM SPSS V20. A conversion formula was employed to translate PM_{2.5} concentrations into the Air Quality Index (AQI). The formula for calculating the AQI is as follows:

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} and I_{high} = the index breakpoint corresponding to C_{high}.

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

In addition, multiple graphs, tables, diagrams and Box-Whisker plots were created to analyze the data. Descriptive statistics were conducted to examine the dispersion of each parameter related to land use and an ANOVA test was performed to determine the statistical significance of the results. The findings are presented through various graphs and charts, offering a comprehensive overview of the data.

3. Results and Discussion

3.1. Concentration of PM₁, PM_{2.5} and PM₁₀ in Different Land Use

The concentration of PM₁, PM_{2.5} and PM₁₀ in 7 different land use are shown in figure 3 (a), (b), (c), (d), (e), (f) and (g). Among the sensitive areas, maximum concentration was found at Upazila Freedom Fighter Complex (65.75, 110.25 and 141.50 µg/m³) followed by Zilla parishad community center (49.50, 83.50 and 106.75 µg/m³) and Rangpur medical (38, 63.25 and 73.75 µg/m³) followed by divisional Govt. public Library (40.25, 67.75 and 81.5 µg/m³). The concentration of PM₁, PM_{2.5} and PM₁₀ at Rangpur high school (44.25, 73.75 and 94.5 µg/m³), Rangpur technical school and college (45.75, 75.25 and 88.67 µg/m³) and Rangpur Govt. Girls' High School (41, 67.75 and 87.25 µg/m³) were significant. Additionally, it was observed that the only lower concentration of PM_{2.5} belonged to Rangpur medical with 63.25 µg/m³.

The concentration of $PM_{2.5}$ concentration of most polluted was 1.69 times higher than NAAQS level. However, the concentration of $PM_{2.5}$ and PM_{10} found in the most polluted location were 4.41 and 2.83 times higher than WHO standard. Nevertheless, the study estimated that in all sensitive areas, 80.35% of $PM_{2.5}$ was present in PM_{10} and 59.92% of the PM_1 was present in $PM_{2.5}$.

In case of mixed area, it was found that out of six different areas, neighboring areas of Anowara building in Rangpur has the highest concentration of PM_1 , $PM_{2.5}$ and PM_{10} . Which were 50.5, 87.25 and 110.25 $\mu g/m^3$ respectively. Conversely, the Baptist church sangha had the lowest concentration of PM (36.25, 59.5 and 76.5 $\mu g/m^3$ respectively for PM_1 , $PM_{2.5}$ and PM_{10}) followed by Begum Rokeya University, Rangpur (36.25, 60.75 and 77.75 $\mu g/m^3$) with reasonably lowermost PM_1 , $PM_{2.5}$ and PM_{10} concentrations, as well as lower than the NAAQS. After that, others 3 places named Alamnar primary school (37, 62.5 and 79.75 $\mu g/m^3$), Zila parishad rangpur (42, 69.75 and 89.75 $\mu g/m^3$) and Police line training center (42.50, 71 and 91.25 $\mu g/m^3$) had pretty moderate PM_1 , $PM_{2.5}$ and PM_{10} concentrations in the atmosphere though $PM_{2.5}$ concentrations at Zila parishad and Police line training center were higher than NAAQS. Notably among all the selected areas, three areas are respectively less polluted and other three areas had visible identical PM concentrations particularly $PM_{2.5}$. However, it was noticeable that the concentrations of PM near religious places, educational places were underneath only at the aforementioned six places. But then again at every place in the study area, atmosphere has very less PM_{10} concentration about half times lower than NAAQS. It was also noted that, the concentration $PM_{2.5}$ concentration of most polluted was 1.34 times higher than NAAQS level. However, the concentration of $PM_{2.5}$ and PM_{10} found in the most polluted location were 3.49 and 2.20 times higher than WHO standard. Besides, the study estimated that the concentration ratio of $PM_{2.5}/PM_{10}$ was 78.20% and 59.52% of PM_1 mass was in $PM_{2.5}$.

However, concentration of PM_1 , $PM_{2.5}$ and PM_{10} concentration of Dhap residential area was found as lowermost with 34.75, 57.25 and 73.67 $\mu g/m^3$ respectively followed by Nurpur with 39.5, 66.5 and 85.25 $\mu g/m^3$ concentration that was also under the NAAQS level. Whereas, Golden tower had the maximum PM_1 , $PM_{2.5}$ and PM_{10} concentration with 44.75, 70.50 and 93 $\mu g/m^3$ respectively and particularly $PM_{2.5}$ was higher than NAAQS. Besides, Chartala mor had also surpassed $PM_{2.5}$ concentration (70.75 $\mu g/m^3$) though PM_1 and PM_{10} (41.75 and 83.67 $\mu g/m^3$) were below NAAQS level. It was also noted that, the concentration $PM_{2.5}$ concentration of most polluted was 1.08 times higher than NAAQS level. However, the concentration of $PM_{2.5}$ and PM_{10} found in the most polluted location were 2.83 and 1.86 times higher than WHO standard. Moreover, the study estimated 78.96% of $PM_{2.5}$ was present in PM_{10} and 60.66% of PM_1 was present in $PM_{2.5}$ at residential areas in atmosphere.

Among the road intersection area, it was found that, Jahaj

company mor was the most polluted area with 59.5, 93.75 and 123.5 $\mu g/m^3$ PM_1 , $PM_{2.5}$ and PM_{10} concentration correspondingly where $PM_{2.5}$ exceeded NAAQS. Whereas Medical mor showed the lowest (36.25 $\mu g/m^3$) PM_1 , (57.75 $\mu g/m^3$) $PM_{2.5}$ and (75.75 $\mu g/m^3$) PM_{10} concentration consisting of all the PM value below NAAQS. However, concentration of PM_1 , $PM_{2.5}$ and PM_{10} at Park more (39, 65 and 83.5 $\mu g/m^3$) followed by Shapla chattar (39.75, 63.5 and 83.5 $\mu g/m^3$) were near the lowest PM value as well. Although Paira chattar (54.5, 89 and 115.5 $\mu g/m^3$) and Terminal mor (45.75, 76.25 and 98 $\mu g/m^3$) road intersections showed higher $PM_{2.5}$ concentrated area. It was also noted that the concentration $PM_{2.5}$ concentration of most polluted was 1.44 times higher than NAAQS level. However, the concentration of $PM_{2.5}$ and PM_{10} found in the most polluted location were 3.56 and 2.47 times higher than WHO standard. Furthermore, it was estimated that 76.80% of $PM_{2.5}$ was present in PM_{10} and 61.70% of the PM_1 was present in $PM_{2.5}$.

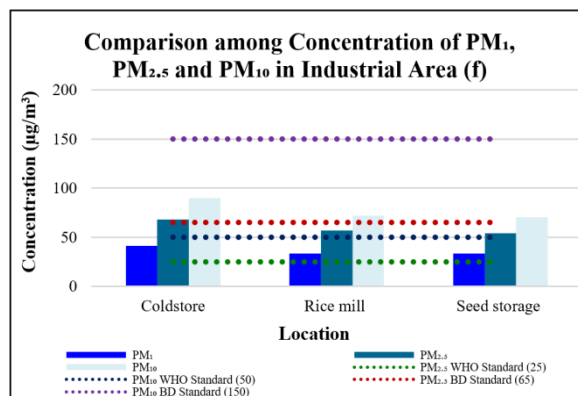
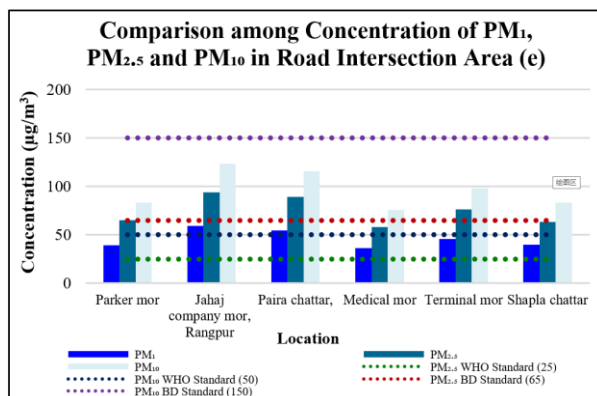
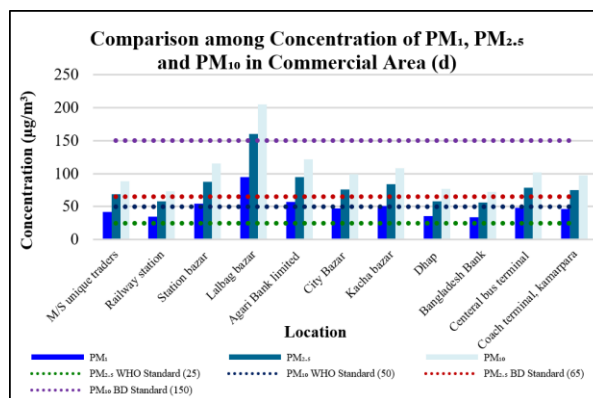
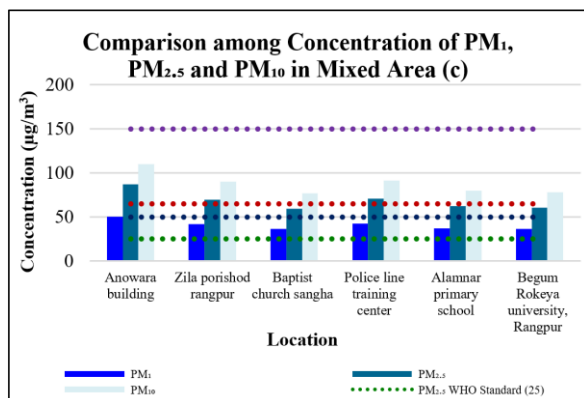
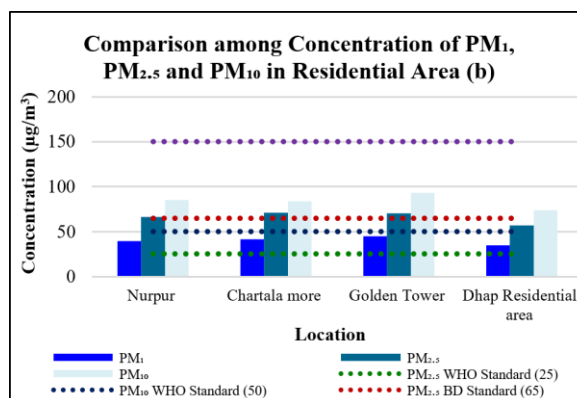
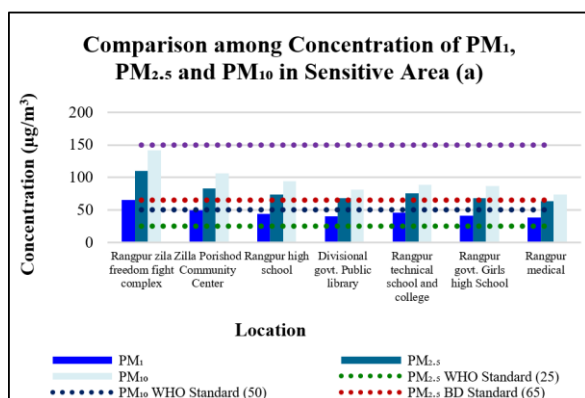
However, among the commercial locations, it was found that PM_{10} concentration ($\mu g/m^3$) is higher than NAAQS at one commercial place, Lalbag bazar, showed highest PM_1 , $PM_{2.5}$ and PM_{10} concentration with 95, 160 and 205 $\mu g/m^3$ where $PM_{2.5}$ and PM_{10} were 2.46 and 1.37 times higher than NAAQS level. After that, high concentration of PM_1 , $PM_{2.5}$ and PM_{10} at Agrani bank limited (57, 94.25 and 121.5 $\mu g/m^3$) was followed by Station bazar (54.75, 87.75 and 115 $\mu g/m^3$) and Kacha bazar (51, 83.75 and 108.5 $\mu g/m^3$). Besides, Bangladesh bank revealed the lowermost concentration of PM_1 (33.5 $\mu g/m^3$), $PM_{2.5}$ (56 $\mu g/m^3$) and PM_{10} (72 $\mu g/m^3$) followed by railway station and Dhap with the second and third lowermost concentration of PM_1 (34.75, 35.5 $\mu g/m^3$), $PM_{2.5}$ (58.25, 58 $\mu g/m^3$) and PM_{10} (73, 76.67 $\mu g/m^3$). It was also noted that, at M/S unique traders, City bazar, Central bus terminal and Coach terminal Kamarpara Dhaka Bus Stand areas PM concentrations were (41.75, 69 and 88.75 $\mu g/m^3$), (47, 75.75 and 98.75 $\mu g/m^3$), (47.75, 78.75 and 101.75 $\mu g/m^3$) and (46.25, 75 and 97.75 $\mu g/m^3$) respectively. Besides, the study indicated that 77.36% of $PM_{2.5}$ was present in PM_{10} and 60.72% of PM_1 was present in $PM_{2.5}$.

Among three industrial places, Cold storage was highly PM_1 , $PM_{2.5}$ and PM_{10} concentrated area with 41.5, 68.25 and 90 $\mu g/m^3$ concentration, respectively. Whereas seed storage place demonstrated the least PM_1 33.25 $\mu g/m^3$, $PM_{2.5}$ 54.25 and PM_{10} with 70.5 $\mu g/m^3$ concentration, respectively. At Rice mill PM concentrations were 33.50, 56.75, 72.25 $\mu g/m^3$ respectively, which considered not enormously high and desirably not ample sensitive for people. It was also noted that, the concentration $PM_{2.5}$ concentration of most polluted was 1.05 times higher than NAAQS level. However, the concentration of $PM_{2.5}$ and PM_{10} found in the most polluted location were 2.73 and 1.80 times higher than WHO standard. However, a study estimated total 77.01% of $PM_{2.5}$ was present in PM_{10} and 60.38% of the PM_1 was present in $PM_{2.5}$.

It was found that out of three village areas all were moderately less polluted with PM. Alamnagar demonstrated high

PM (39.25, 65.25 and 83.75 $\mu\text{g}/\text{m}^3$ respectively), followed by South station para (38.75, 67 and 84.75 $\mu\text{g}/\text{m}^3$) and Station para (32.75, 58 and 72.5 $\mu\text{g}/\text{m}^3$). Besides, concentrations of $\text{PM}_{2.5}$ at all sites were below the NAAQS, except only South station para. While PM_{10} concentrations were also lower than the standards, PM_{10} contamination was comparatively less than $\text{PM}_{2.5}$. It was also noted that the concentration $\text{PM}_{2.5}$ concentration of most polluted was 1.03 times higher than NAAQS. However, the concentration of $\text{PM}_{2.5}$ and PM_{10} found in the most polluted location were 2.68 and 1.69 times higher than WHO standard. Study estimated that, 78.94% $\text{PM}_{2.5}$ was present in PM_{10} and 58.21% PM_{10} was present in $\text{PM}_{2.5}$. The commercial area recorded the highest concentra-

tions of PM_{10} , $\text{PM}_{2.5}$ and PM_{10} , with values of 49.48 $\mu\text{g}/\text{m}^3$, 81.48 $\mu\text{g}/\text{m}^3$ and 105.33 $\mu\text{g}/\text{m}^3$ respectively. Additionally, the sensitive area (46.36 $\mu\text{g}/\text{m}^3$, 77.37 $\mu\text{g}/\text{m}^3$ and 96.27 $\mu\text{g}/\text{m}^3$), road intersections (45.79 $\mu\text{g}/\text{m}^3$, 74.21 $\mu\text{g}/\text{m}^3$ and 96.62 $\mu\text{g}/\text{m}^3$), mixed area (40.75 $\mu\text{g}/\text{m}^3$, 68.46 $\mu\text{g}/\text{m}^3$ and 87.54 $\mu\text{g}/\text{m}^3$) and residential area (40.19 $\mu\text{g}/\text{m}^3$, 66.25 $\mu\text{g}/\text{m}^3$ and 83.9 $\mu\text{g}/\text{m}^3$) also displayed relatively high $\text{PM}_{2.5}$ concentrations, though the PM_{10} concentrations remained below the NAAQS, across all locations. However, the comparative analysis of average concentrations revealed that only the village and industrial areas had $\text{PM}_{2.5}$ concentrations below the NAAQS limits.



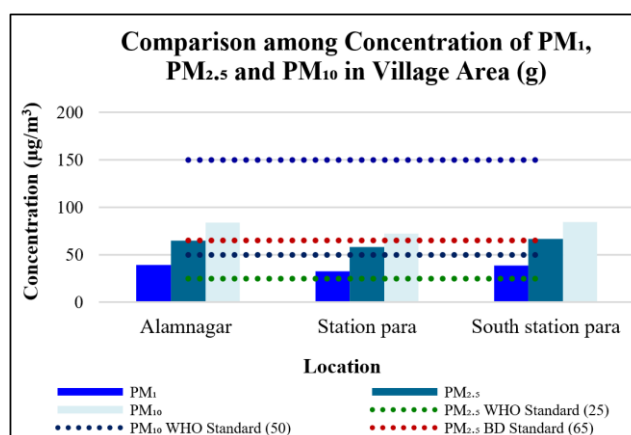


Figure 3. Comparison among Concentration of PM_1 , $PM_{2.5}$ and PM_{10} in Sensitive, Mixed Area, Residential area, Commercial area and Industrial area.

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

The following table 1 shows the descriptive statistics for PM_1 , $PM_{2.5}$ and PM_{10} of the studied land uses. There are notable differences in the descriptive statistics for PM concentrations across the seven land uses. The commercial area had the greatest mean (49.48 $\mu\text{g}/\text{m}^3$), standard deviation (17.05 $\mu\text{g}/\text{m}^3$), and coefficient of variation (34.45%) for PM_1 , as well as the highest range (61.50 $\mu\text{g}/\text{m}^3$) and maximum concentration (95.00 $\mu\text{g}/\text{m}^3$). On the other hand, the village area had the lowest mean (32.92 $\mu\text{g}/\text{m}^3$), coefficient of variation (9.80%), and range (6.50 $\mu\text{g}/\text{m}^3$). In terms of $PM_{2.5}$, the commercial area had the highest concentration (160.00

$\mu\text{g}/\text{m}^3$), mean (81.48 $\mu\text{g}/\text{m}^3$), standard deviation (28.90 $\mu\text{g}/\text{m}^3$), coefficient of variation (35.46%), and range (104.00 $\mu\text{g}/\text{m}^3$). The village area had the lowest coefficient of variation (7.52%), standard deviation (3.67 $\mu\text{g}/\text{m}^3$), and range (9.00 $\mu\text{g}/\text{m}^3$). The commercial sector also had the greatest concentration (205.00 $\mu\text{g}/\text{m}^3$), mean (105.33 $\mu\text{g}/\text{m}^3$), standard deviation (36.97 $\mu\text{g}/\text{m}^3$), coefficient of variation (35.09%), and range (133.00 $\mu\text{g}/\text{m}^3$) for PM_{10} . The range (12.25 $\mu\text{g}/\text{m}^3$), standard deviation (6.80 $\mu\text{g}/\text{m}^3$), and coefficient of variance (8.47%) were all lowest in the village area. Overall, the village area demonstrated the lowest values across all parameters, whereas the commercial region continuously displayed the highest levels of pollution and fluctuation.

Table 1. Descriptive statistics of PM_1 , $PM_{2.5}$ and PM_{10} .

SL. No.	Land Use	PM_1				
		No. 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 (%)
1	Sensitive Area	7	27.75	46.36	9.37	20.21
2	Mixed Area	6	14.25	40.75	5.55	13.63
3	Residential Area	4	10.00	40.19	4.21	10.49
4	Road Intersection Area	6	23.25	45.79	9.35	20.43
5	Commercial Area	11	61.50	49.48	17.05	34.45
6	Industrial Area	3	8.25	36.08	4.69	13.00
7	Village Area	3	6.50	36.92	3.62	9.80

Table 1. Continued.

SL. No.	Land Use	PM _{2.5}			
		Range (µg/m ³)	Mean (µg/m ³)	Std. Deviation (µg/m ³)	Coefficient of Variation (%)
1	Sensitive Area	47.00	77.37	15.92	20.58
2	Mixed Area	27.75	68.46	10.36	15.13
3	Residential Area	13.50	66.25	6.31	9.52
4	Road Intersection Area	36.00	74.21	14.66	19.76
5	Commercial Area	104.00	81.48	28.90	35.46
6	Industrial Area	14.00	59.75	7.47	12.50
7	Village Area	9.00	63.42	4.77	7.52

Table 1. Continued.

SL. No.	Land Use	PM ₁₀			
		Range (µg/m ³)	Mean (µg/m ³)	Std. Deviation (µg/m ³)	Coefficient of Variation (%)
1	Sensitive Area	67.75	96.27	22.45	23.32
2	Mixed Area	33.75	87.54	12.75	14.56
3	Residential Area	19.33	83.90	7.95	9.47
4	Road Intersection Area	47.75	96.62	19.29	19.96
5	Commercial Area	133.00	105.33	36.97	35.09
6	Industrial Area	19.50	77.58	10.79	13.91
7	Village Area	12.25	80.33	6.80	8.47

However, the Whisker Box Plot of the Concentration of PM₁, PM_{2.5}, and PM₁₀ in Different Land uses is presented in Figure 4 (a), (b), (c). With the largest concentrations in road intersections, PM₁ was most widely distributed in commercial and road intersection areas. Road intersections had positive skewness, whereas commercial areas had negative skewness, driven by vehicle movements and Lalbag Bazar's economic activity. Outliers in the commercial area also contradicted the descriptive statistics. Sensitive, residential and mixed regions showed moderate dispersion, with one outlier in the sensitive area (Rangpur Zilla Freedom Fighter Complex) as a result of vehicle traffic. Concentrated values were seen in both industrial and village zones, with extreme negative skewness in the latter and extreme positive skewness in the former. Activities involving storing and processing seeds were identified as dust sources in villages. For PM_{2.5}, similar patterns emerged. The most widely distributed concentrations were seen in commercial and road intersections, regions where there was neg-

ative skewness and positive skewness. In addition, outliers contradict descriptive findings, particularly in the commercial sector. Residential regions showed significant negative skewness, but sensitive and mixed areas showed moderate dispersion with normal distributions. Due to localized dust sources, there was extreme positive skewness in industrial regions and extreme negative skewness in villages, which were the most concentrated places. Road intersections and commercial areas once more demonstrated notable dispersion for PM₁₀, with positive skewness in the first area and negative skewness in the other. Sensitive, residential, and mixed regions have normal distributions and moderate dispersion, with a vehicle movement-induced outlier in the sensitive area. Due to seed preparation and storage dust, values were most concentrated in industrial and village locations, with extreme positive skewness in the former area and extreme negative skewness in the latter.

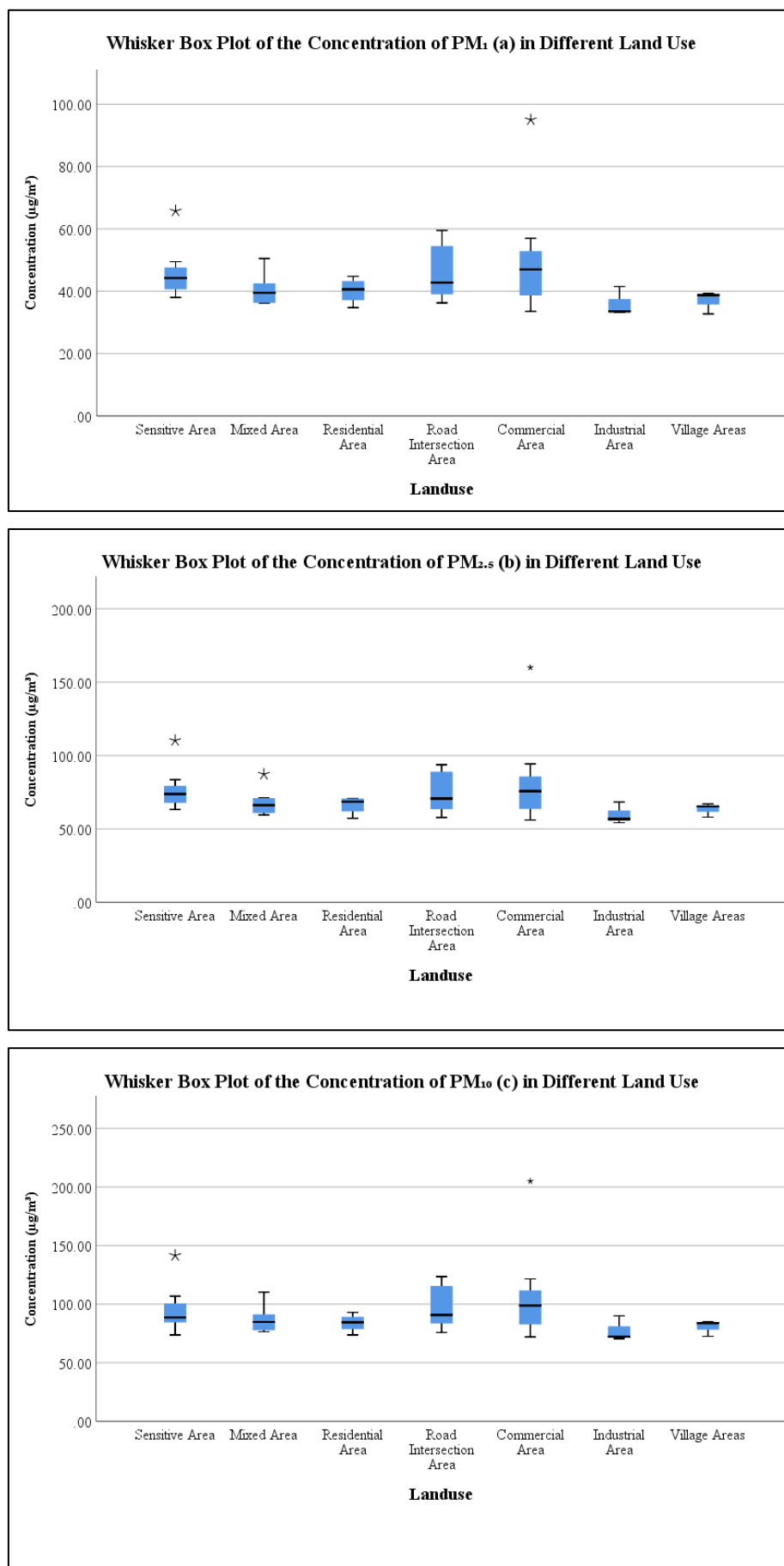


Figure 4. Whisker Box Plot of the Concentration of PM_{10} , $PM_{2.5}$, and PM_{10} in Different Land Use.

3.3. Significance Test by Using Analysis of Variance (ANOVA)

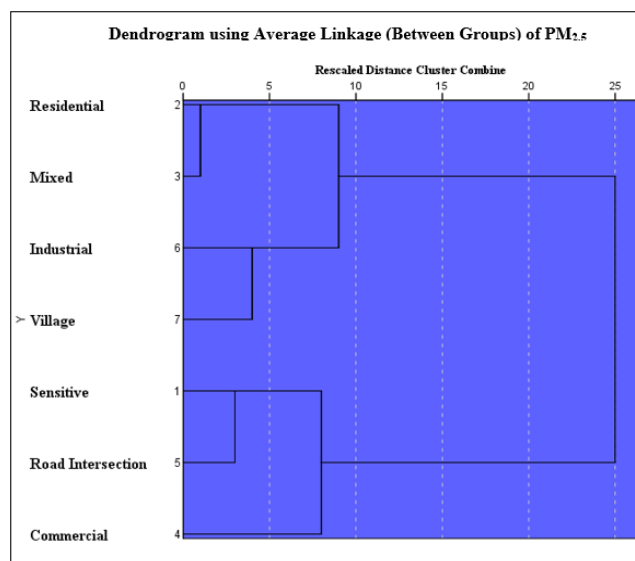
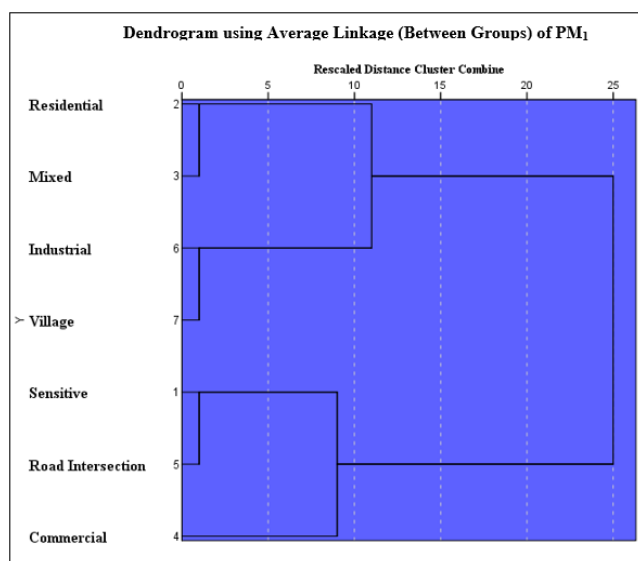
ANOVA test finds out if results are significant or not, as well as to determine the hypothesis's acceptance or rejection. ANOVA is performed to find whether the changes in the concentration of all the parameters between and within land uses are significant. The following table 2 shows that, the

change of PM_{10} , $PM_{2.5}$ and PM_{10} , of value are different and somewhat significant as the P value (Probability value) is different than the Significance level (a pre-specified threshold). Therefore, concentration for PM_{10} , $PM_{2.5}$ and PM_{10} are insignificant as the 'Significance values' on ANOVA test are 0.371, 0.470 and 0.459 respectively much greater than 0.05. Table 2 shows that the PM concentration did not change significantly since the p value is greater than 0.05.

Table 2. Significance Test.

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
PM_{10}	Between Groups	846.715	6	141.119	1.123	0.371
	Within Groups	4147.596	33	125.685		
	Total	4994.311	39			
$PM_{2.5}$	Between Groups	2042.816	6	340.469	0.955	0.470
	Within Groups	11759.878	33	356.360		
	Total	13802.694	39			
PM_{10}	Between Groups	3513.636	6	585.606	0.972	0.459
	Within Groups	19876.758	33	602.326		
	Total	23390.394	39			

3.4. Land Use-Based Cluster Analysis



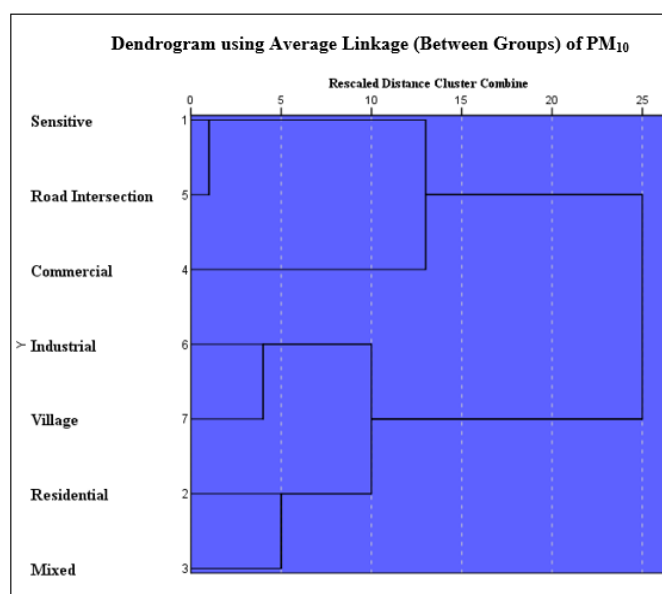


Figure 5. Rescaled Distance Cluster Combine for PM_1 , $PM_{2.5}$, and PM_{10} .

The dendrogram plots in Figure 5 display cluster analyses based on PM_1 , $PM_{2.5}$, and PM_{10} concentrations, respectively, using Z-score normalization, group linkage, and Euclidean distance. In all three cases, four clusters were identified, though the specific groupings varied slightly. For PM_1 , residential and mixed areas, as well as industrial and village areas, formed the first two clusters, followed by sensitive and road intersection areas in the third cluster, and commercial areas in the fourth. The clusters merged at linkage distances of approximately 9, 11, and finally 25. For $PM_{2.5}$, the clustering pattern was similar, with residential, mixed, industrial, and village areas forming the first two clusters, followed by sensitive and road intersection areas, and lastly, the commercial area. These clusters also merged at similar distances of 8, 9, and finally 25. In the case of PM_{10} , the first cluster combined residential and road intersection areas, the second consisted of the commercial area, the third included industrial and village areas, and the fourth featured residential and mixed areas. These clusters joined at linkage distances of 10, 13, and ultimately 25.

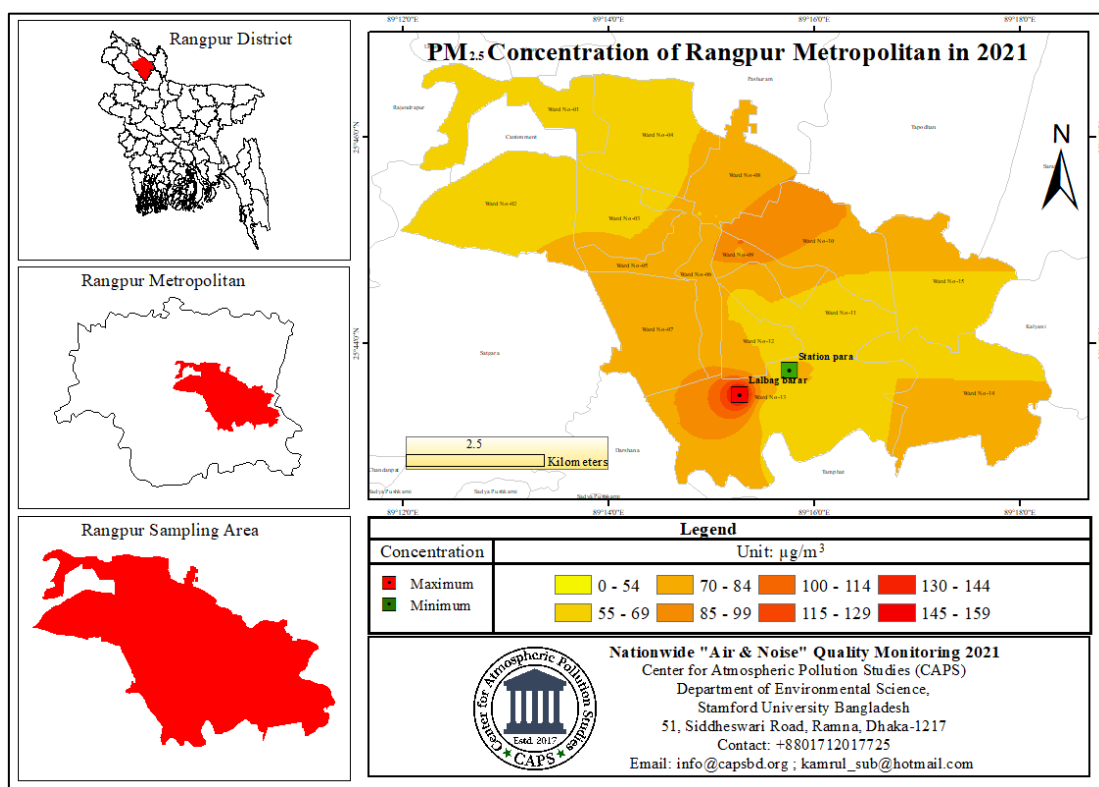
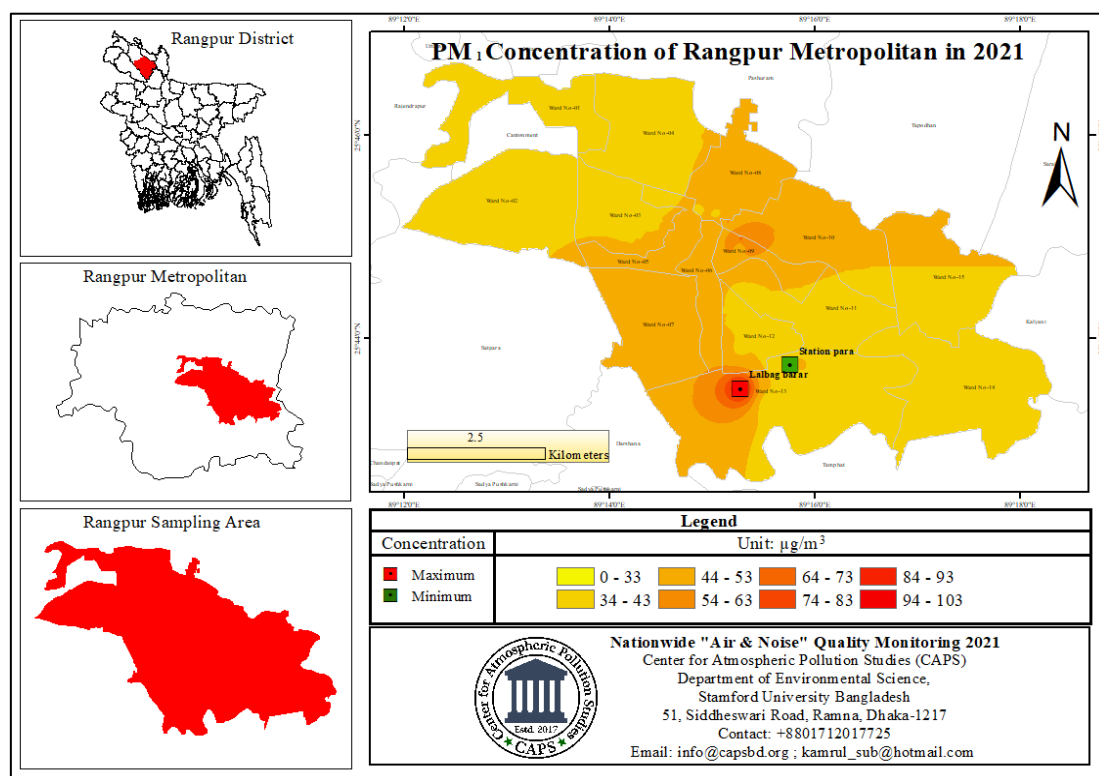
3.5. PM_1 , $PM_{2.5}$, and PM_{10} Concentration Map of Rangpur Metropolitan in 2021

The highest concentrations of PM_1 (74–103 $\mu\text{g}/\text{m}^3$) were identified in areas of Lalbag Bazar, whereas moderate values (44–73 $\mu\text{g}/\text{m}^3$) were found outside Rangpur Technical School and College, Station Bazar, and close to Zilla Parishad Community Center. Most of the northwest and southeast sample sites, Shapla Chattar, and the Bangladesh Bank area had the lowest amounts (less than 43 $\mu\text{g}/\text{m}^3$). Station Para had the lowest concentration, while Lalbag Bazar had the most. In terms of $PM_{2.5}$, the Rangpur Zilla Freedom Fighter Complex and Lalbag Bazar had the greatest amounts (100–159 $\mu\text{g}/\text{m}^3$).

Zilla Parishad Community Center, Anwara Building, Station Bazar, Agrani Bank Limited, Central Bus Terminal, and Zahaj Company Mor were among the central locations where moderate values (70–99 $\mu\text{g}/\text{m}^3$) were noted. Wards 01 through 04 and portions of the southeast sample region had lower values (less than 69 $\mu\text{g}/\text{m}^3$). The areas around the Rangpur Zilla Freedom Fighter Complex, Zilla Parishad Community Center, Lalbag Bazar, and Agrani Bank Limited reported the greatest concentrations of PM_{10} (147–206 $\mu\text{g}/\text{m}^3$). Central areas such as Terminal Mor, City Bazar, and Police Line Training Center had a moderate level (87–146 $\mu\text{g}/\text{m}^3$). The Divisional Government Public Library, Rangpur Medical College, Bangladesh Bank area, and the majority of the northwest sampling region had the lowest amounts (less than 86 $\mu\text{g}/\text{m}^3$). However, this time, Lalbag Bazar had the highest concentration, while Station Para had the lowest concentration. Among all the locations, Lalbag Bazar, identified as a commercial area, recorded the highest particulate matter (PM) concentrations, with measurements of 95 $\mu\text{g}/\text{m}^3$ for PM_1 , 160 $\mu\text{g}/\text{m}^3$ for $PM_{2.5}$, and 205 $\mu\text{g}/\text{m}^3$ for PM_{10} . This was followed by the Rangpur Zilla Freedom Fighter Complex, categorized as a sensitive area, and Agrani Bank Limited, another commercial area, with corresponding PM concentrations of 65.75 $\mu\text{g}/\text{m}^3$, 110.25 $\mu\text{g}/\text{m}^3$, and 141.50 $\mu\text{g}/\text{m}^3$, and 57 $\mu\text{g}/\text{m}^3$, 94.25 $\mu\text{g}/\text{m}^3$, and 121.50 $\mu\text{g}/\text{m}^3$, respectively. In contrast, the seed storage facility in the industrial area displayed the lowest PM concentrations, at 33.25 $\mu\text{g}/\text{m}^3$, 54.25 $\mu\text{g}/\text{m}^3$, and 70.50 $\mu\text{g}/\text{m}^3$ for PM_1 , $PM_{2.5}$ and PM_{10} , respectively. Similarly, both the commercial area near Bangladesh Bank and the village area of Alamnagar showed relatively low PM concentrations, with values of 33.5 $\mu\text{g}/\text{m}^3$, 56 $\mu\text{g}/\text{m}^3$, and 72 $\mu\text{g}/\text{m}^3$, and 39.25 $\mu\text{g}/\text{m}^3$, 65.25 $\mu\text{g}/\text{m}^3$, and 83.75 $\mu\text{g}/\text{m}^3$, respectively. Notably, the concentrations of $PM_{2.5}$ and PM_{10} in the most polluted area were found to be 2.46 and 1.36 times higher than the NAAQS. Therefore, three most polluted and three least pol-

luted locations along with their respective PM concentrations. To facilitate a clearer understanding, concentration maps based on PM₁, PM_{2.5}, and PM₁₀ are provided in figure 6,

where the most polluted locations are marked with red flags, while the least polluted locations are marked with green flags.



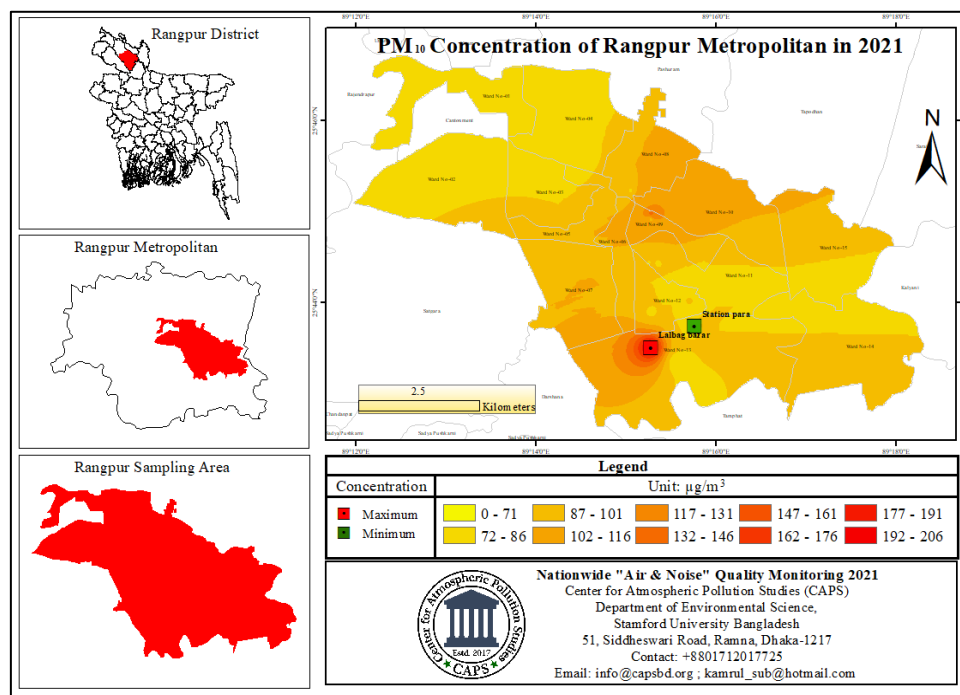


Figure 6. PM₁, PM_{2.5} and PM₁₀ Concentration Map of Rangpur Metropolitan in 2021.

3.6. AQI on PM_{2.5} Concentration of Rangpur Metropolitan in 2021

Figure 7 illustrates the air quality in Rangpur Metropolitan based on PM_{2.5} concentrations. The map uses different colors to represent various Air Quality Index (AQI) categories according to the NAAQS. The Lalbag Bazar area is depicted in

red, indicating a "very unhealthy" AQI (201-300). The central part of the Rangpur metropolitan sampling area is shown in orange, representing an "unhealthy" AQI (151-200). Additionally, the highest PM_{2.5} concentration is marked with a red flag, and the lowest concentration with a green flag. The highest concentration was recorded in Lalbag Bazar, while the lowest was found in Station Para.

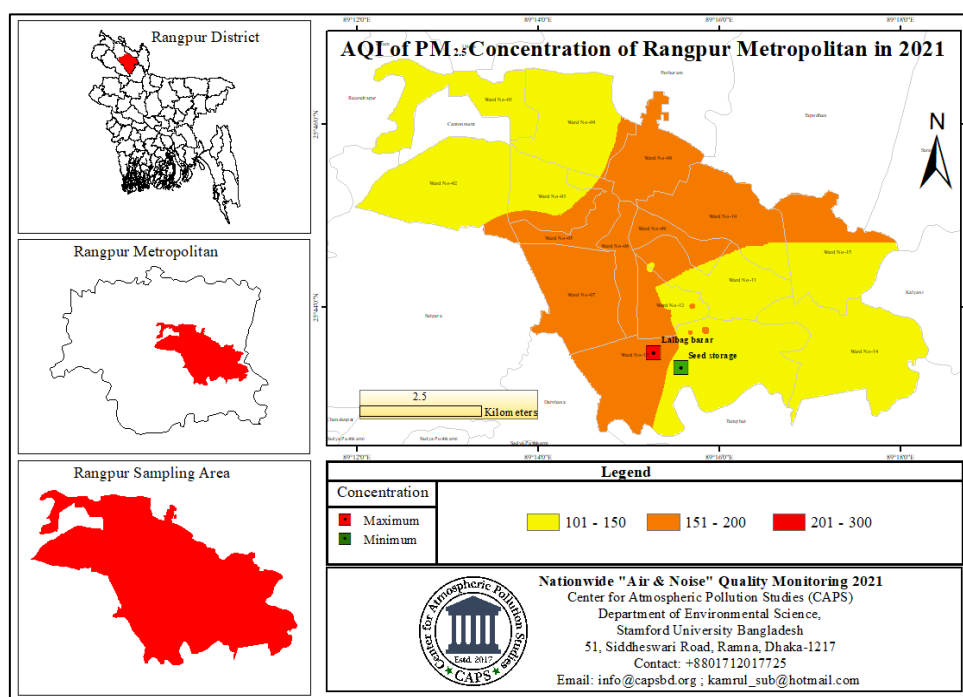


Figure 7. AQI on PM_{2.5} Concentration Map of Rangpur Metropolitan in 2021.

4. Discussion

This study highlights the critical issue of air pollution in the Rangpur metropolitan area, contributing to the growing body of research on air quality in Bangladesh's urban and peripheral regions. The findings indicate that air pollution is not confined to major cities but is also a serious concern in smaller urban centers and rural areas. The average concentrations of PM_1 ($42.22 \mu\text{g}/\text{m}^3$), $PM_{2.5}$ ($70.13 \mu\text{g}/\text{m}^3$), and PM_{10} ($89.66 \mu\text{g}/\text{m}^3$) across 40 sampled locations reflect the concerning levels of particulate matter in the region. Commercial areas were identified as the most polluted. The possible reasons behind commercial areas include several key factors that might influence the most polluted. High traffic volume is a significant contributor, as these areas typically experience dense vehicular activity, including trucks, delivery vans, and customer vehicles, which emit substantial amounts of exhaust pollutants. Additionally, construction and renovation projects in commercial zones generate dust and emissions from construction equipment, further elevating particulate matter levels. Besides, high energy consumption, including the use of generators, heating, ventilation and air conditioning systems, also contributes to increase air pollution. Furthermore, the limited presence of green spaces in these areas reduces natural filtration of pollutants, exacerbating the problem. Collectively, these factors contribute to the elevated levels of air pollution observed in commercial areas. This finding aligns with a study conducted by Majumder et al. 2023 [14], which also reported the highest amounts of PM_1 , $PM_{2.5}$, and PM_{10} in commercial zones at Lakshmipur district.

However, the least polluted location was Seed storage, which was identified as an industrial area, with PM concentrations of $33.25 \mu\text{g}/\text{m}^3$, $54.25 \mu\text{g}/\text{m}^3$, and $70.50 \mu\text{g}/\text{m}^3$ respectively. The lower pollution levels observed in the industrial area can be attributed to several factors. Regulatory measures in industrial zones may be more stringent, with enforced pollution control practices such as dust suppression and emission controls, leading to reduced particulate matter levels. Additionally, industrial areas are often situated away from dense urban traffic, which minimizes the impact of vehicle emissions. Furthermore, industrial zones typically experience fewer construction activities compared to commercial areas, reducing the amount of dust and particulate emissions associated with such projects. Lower population density in industrial areas than commercial zones, results in less vehicular activity and waste production, which further diminishes pollution levels. Lastly, the specific types of industries present may be less polluting in terms of particulate matter. These factors combined help explain why the industrial area, despite its potential for pollution, exhibits relatively lower levels of particulate matter compared to other areas. Nevertheless, this cannot be claimed for every industrial location, as it varies according to the industry's type and practice. A study conducted at Chittagong showed the average $PM_{2.5}$ concen-

trations was highest in industrial area ($175.36 \mu\text{g}/\text{m}^3$) [15]. Similar results observed from another study conducted at Rajshahi where highest pollution level observed at industrial zone [16].

However, the analysis of the $PM_{2.5}/PM_{10}$ and $PM_1/PM_{2.5}$ ratios revealed that fine particulate matter constitutes a substantial proportion of total particulate pollution. Specifically, $PM_{2.5}$ made up 78.32% of PM_{10} , and PM_1 accounted for 60.18% of $PM_{2.5}$. This suggests that finer particles, which pose greater health risks, dominate the particulate matter composition in the study area. Besides, statistical analysis showed no significant variations in PM concentrations across the study area, with p-values exceeding 0.05, indicating consistent pollution levels across different locations. The dendrogram analyses for PM_1 , $PM_{2.5}$, and PM_{10} further confirmed that the pollution sources were interconnected, as the clustering process revealed at least four clusters in the initial phase, eventually merging into a single cluster at a linkage distance of 25. Therefore, these findings underscore the urgent need for increased awareness and action to mitigate the short- and long-term effects of air pollution across Bangladesh.

5. Conclusion

Air pollution remains a significant issue not only in the major cities of Bangladesh but also in peripheral areas. This study found that the average concentrations of PM_1 , $PM_{2.5}$, and PM_{10} in 40 locations within the Rangpur metropolitan area were $42.22 \mu\text{g}/\text{m}^3$, $70.13 \mu\text{g}/\text{m}^3$, and $89.66 \mu\text{g}/\text{m}^3$ respectively. The three most polluted locations were Lalbag Bazar (commercial area), Rangpur Zila Freedom Fighter Complex (sensitive area), and Agrani Bank Limited (commercial area), while the three least polluted locations were the seed storage facility (industrial area), Bangladesh Bank (commercial area), and Alamnagar (village area). Land use types were ranked in descending order of PM concentration as follows: commercial areas > road intersections > sensitive areas > residential areas > village areas > industrial areas. The study also revealed that, on average, $PM_{2.5}$ constituted 78.32% of PM_{10} , and PM_1 made up 60.18% of $PM_{2.5}$. Statistical analysis showed no significant variation in PM concentrations, with p-values exceeding 0.05. Finally, the dendrogram analysis for PM_1 , $PM_{2.5}$, and PM_{10} demonstrated that the clustering process initially identified at least four clusters, eventually merging into a single cluster at a linkage distance of approximately 25. However, these findings underscored the urgent need for comprehensive air quality management strategies, including stricter regulations enforcement, cleaner technologies promotion, and widespread public awareness campaigns. Addressing air pollution in Rangpur and similar regions is critical to protecting public health, preserving the environment, and ensuring sustainable development across Bangladesh.

Abbreviations

AQI	Air Quality Index
NAAQS	National Ambient Air Quality Standard
PM	Particulate Matter
WHO	World Health Organization
CAPS	Center for Atmosphere Pollution Studies, Bangladesh
DoE	Department of Environment
NRDC	Natural Resources Defense Council
ANOVA	Analysis of Variations

Author Contributions

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

Md Abrar Hossain: Formal Analysis, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing

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

Md Nasir Ahmmad Patoary: Data curation, Formal Analysis, Methodology, Software, Validation, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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