

Research Article

Spatial Variation of PM₁, PM_{2.5}, and PM₁₀ Linked to Urban Land Use in Lalmonirhat, Bangladesh

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Abstract

This study aims to assess the concentration of Particulate Matter (PM₁, PM_{2.5}, and PM₁₀) in relation to various land uses in Lalmonirhat district town. Study conducted this investigation in 32 sites within Lalmonirhat district town, using a portable Air Quality Monitor and an Indoor Outdoor Formaldehyde (HCHO) Detector (Model: DM106). The average concentrations of PM₁, PM_{2.5} and PM₁₀ are 51.92, 85.93, and 109.52 $\mu\text{g}/\text{m}^3$, respectively. The average concentration of PM_{2.5} (109.65 $\mu\text{g}/\text{m}^3$) in various land uses was observed to be elevated in industrial areas, exceeding the acceptable level by a factor of 2.19. The average PM_{2.5} / PM₁₀ ratio is assessed at 78.38%, whereas the PM₁/PM_{2.5} ratio is 60.3%. The alterations in the concentration of all investigated factors between land uses were negligible. The results of this research indicate that the examined land uses are ranked in descending order of average PM_{2.5} concentration as follows: industrial area, village area, road intersection area, sensitive region, residential area, mixed area, and commercial area.

Keywords

Particulate Matter, Land Use, Descriptive Statistics, Cluster, Lalmonirhat District Town

1. Introduction

Air pollution is one of the varieties of manmade environmental disasters currently taking place worldwide [1]. Air pollution may be an atmospheric condition in which various substances are present at concentrations high enough above their normal ambient levels to produce a measurable effect on people, animals, vegetation, or materials. ‘Substances’ refers to any natural or manmade chemical elements or compounds capable of being airborne [2]. These may exist in the atmosphere as gases, liquid drops, or solid particles. It includes any substance whether noxious or benign; however, the term ‘measurable effect’ generally restricts attention to those substances that cause undesirable effects.

Air Quality has deteriorated both due to human activities and natural phenomena such as windblown dust particles etc [3, 4]. Growing cities [5], increasing traffic [6], rapid economic development [7], and higher levels of energy consumption [8] lead to air pollution very seriously. However, these are mainly concentrated in the cities. Recently, air pollution has received priority among environmental issues in Asia as well as in other parts of the world. Exposure to air pollution is the main environmental threat to human health in many towns and cities. Bangladesh is in the top position in the Air Quality Report of 2019 and 2020 in terms of air pollution, where Dhaka city is in the second position among the capital cities of

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the world [9, 10]. Apart from this, the latest report released by IQAir states that in 2020 the average of $PM_{2.5}$ in the air of Bangladesh was found $77.1 \mu g/m^3$. It is 5.5 times higher than the standard level which is 15 micrograms per cubic meter set by the Department of Environment (DoE). According to the Report, about 7 million people die every year in the world due to air pollution. In 2018, about 1 lakh 58 thousand people died of air pollution in Bangladesh [11]. For many decades, like Dhaka air pollutants have increased continuously in the different cities in Bangladesh. Cities surrounding Dhaka are also polluting day by day. Cities like Tangail, Narsingdi, Barisal, Chattogram, Gazipur, Narayanganj and Sylhet any other division are being polluted because of developing work [3, 12, 13]. Air pollution seriously affects the respiratory tract and can cause high respiratory disease, headache, asthma, high blood pressure, and even cancer [14-16]. One of the most difficult problems is irritation of the eyes or throat, coughing, sneezing; high fever [15]. The mental faculty of children will be adversely affected by PM pollution, which can also affect the central nervous system and cause renal damage and hypertension [17].

Air pollution is one of the major problems in the Lalmonirhat District town area in the last few years due to a lot of ongoing development work. There are various sources of air pollution in Lalmonirhat city, among them, unfit vehicles and industries are notable, with the under-construction work done by the Lalmonirhat city Corporation. The number of mostly reconditioned vehicles is increasing every year. One-third of these vehicles do not have a fitness certificate. Due to the port facility, this city is attractive for investors to build an industry. Most industries do not follow environmental rules and regulations. Along with the air pollution, it is increasing in Lalmonirhat city due to the construction of various road repairs. Nowadays, the whole of Lalmonirhat has become a city of dust. For local transportation, rickshaws and autos (battery-operated) are the most commonly used vehicles. Since the area of the main city is not very large, buses are not required for public transportation. However, private cars are increasing significantly nowadays within the city area, which is contributing to air pollution. For connecting with other districts, the City has a Railway station (Junction) and several bus stops. To meet the rising population of the city, local people are building high-rise residential and commercial projects. In contrast, the city infrastructure, i.e., roads, parks, and open spaces, is the same as before. These development activities are directly or indirectly contributing to the air pollution of Lalmonirhat District town. For development work, construction masteries were carried out without any cover at that time; the air became polluted. Thus, over the past decade, the city has become a crowded place. Moreover, construction without following proper guidelines (for example, not covering the project site to prevent dust pollution) leads to harm to the environment, particularly the Air. These five pollutants have primary sources such as brickfields, cement industry, rock crusher, motor vehicles, and open burning and secondary sources such as road dust, airborne soil from

agricultural fields, transboundary, etc. [6, 8]. Emissions from the brick kiln are the major contributors to air pollution in different cities; Dhaka especially in the dry seasons and $PM_{2.5}$ concentrations in mixed and motorized areas were on average higher than the non-motorized and vehicle-free areas [6, 18]. Particulate Matters originate from a variety of sources, such as power plants, industrial processes, transports, brick kilns, biomass burning, wind-blown dust, sea spray, and also, they are formed in the atmosphere by the transformation of gaseous emissions. Their chemical and physical compositions depend on the characteristics of the emission sources, location area, time of year, and prevailing weather conditions [12, 19]. Particle conversions through chemical processes in the atmosphere by burning of biomass, gas, and fossil fuel is the main sources of the $PM_{2.5}$ [12] and while coarse particles ($PM_{2.5-10}$) are the result of mechanical activities such as wind-blown dust, grindings, re-suspended road dust, etc [13]. In the urban area, CO is mostly emitted from anthropogenic emissions such as the incomplete combustion of hydrocarbon fuels and biomass burning [20, 21].

Air Pollution has tremendous and various effects on the human body [14, 17]. Air pollution alone is responsible for one-third of the deaths from stroke, heart disease, and lung cancer [22]. Pollutants, especially $PM_{2.5}$, are considered more harmful due to their characteristics and it is capable of traveling deeper into the respiratory system and also passing through the alveoli into the bloodstream, which causes premature mortality, lung cancer, and increases the risk of respiratory and heart disease. Developing countries like Bangladesh suffer $PM_{2.5}$ exposures that are four to five times more than developed countries, and worldwide, air pollution is the fifth risk factor for mortality [17, 23]. Exposure to CO can be detrimental to human health in that it binds to hemoglobin to form carboxy-hemoglobin, thus reducing the oxygen-carrying capacity of the blood, it reduces the ability of organ tissues to extract oxygen from the hemoglobin, negatively affecting organs such as the brain, heart, and lungs [24, 25]. Acute exposure to high concentrations of CO may result in CO poisoning with an onset of symptoms including nausea, vomiting, headaches, shortness of breath, confusion, and can quickly lead to death [17]. The effects of long-term exposure to elevated ambient concentrations of CO are often associated with cardiovascular problems amongst exposed individuals. $PM_{2.5}$ affect the respiratory, cardiovascular, nervous and renal system that cause persistent cough, asthma, nasal blockage, respiratory infections, hypertension, eye irritation, drowsiness, headaches and renal damage [8, 14] and eventually in increasing number of premature deaths [20]. Apart from this, air pollution is also responsible for some fatal diseases such as cancer and heart attack [13].

2. Objectives of the Study

- 1) To identify the status of air pollution in Lalmonirhat

District Town.

- 2) To assess the relationship between land use and all parameters (PM_1 , $PM_{2.5}$, and PM_{10}).
- 3) To identify AQI of Lalmonirhat based on $PM_{2.5}$ and do the spatial map.
- 4) Geospatial mapping on the concentration of PM_1 , $PM_{2.5}$, and PM_{10} .

3. Study Area and Methodology

3.1. Study Area

Lalmonirhat District town is an upazila of Lalmonirhat

District in the Division of Rangpur, Bangladesh. Lalmonirhat District town is located at 25.9153°N 89.4500°E. It has 79,147 units of household and its total area is 259.54 km². The River Dharla, Tista, Swarnamati crosses the section of Lalmonirhat. According to the 2011 Bangladesh census, Lalmonirhat District town had a population of 333,166. Males constituted 51.4% of the population. Lalmonirhat Municipality is subdivided into nine wards and 64 mahallas. Lalmonirhat District town Upazila is divided into nine union parishads: Barobari, Gokunda, Harati, Khuniagachh, Kulaghat, Mogolhat, Mohendranagar, Panchagram, and Rajpur. The union parishads are subdivided into 117 mauzas and 173 villages [26].

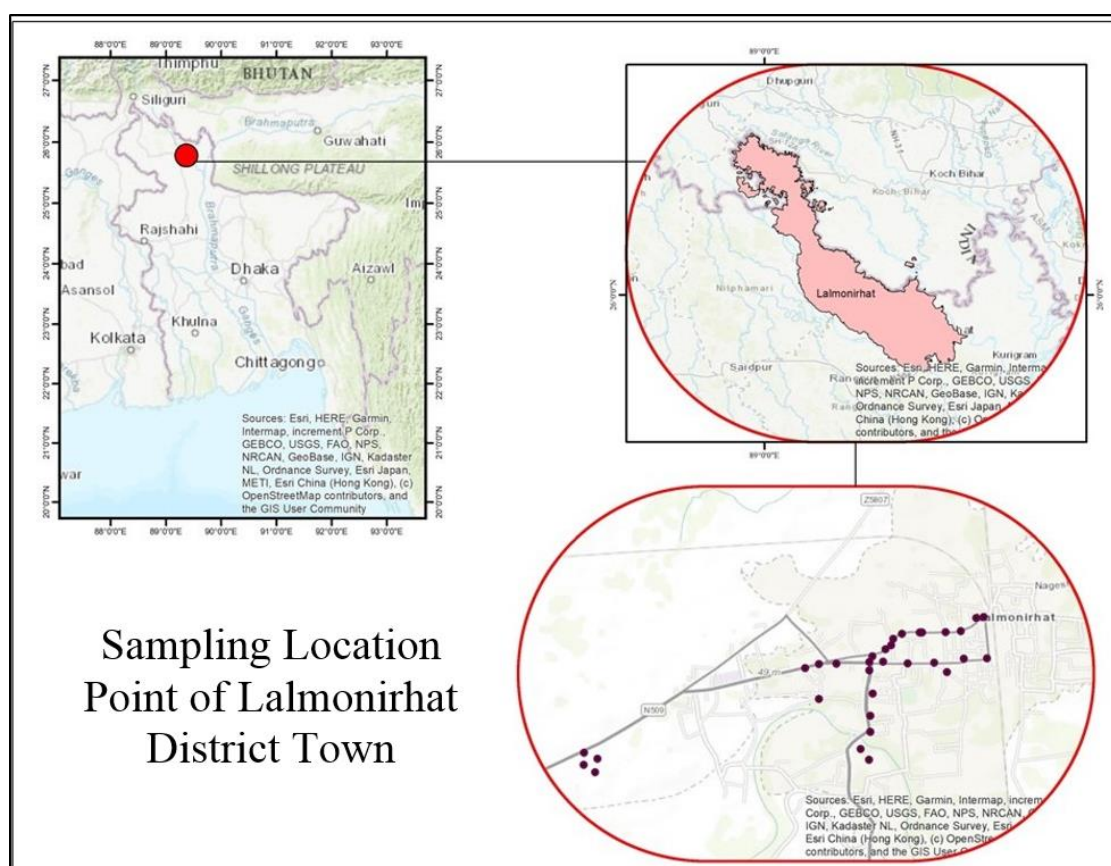


Figure 1. Study Area (Lalmonirhat District Town and Data Collection Locations Point).

3.2. Area Selection

32 locations were selected on the 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 [27]. There are a total of 5 sensitive areas that were selected, including hospitals and clinics, schools, colleges, mosques,

madrasas, temples, churches, and administrative dhaban. On the other side, mixed areas contain bazars, buildings, main roads, etc. The remaining 27 locations were categorized as residential areas; 3 locations, mixed areas; 3 locations, commercial areas; 9 locations, road intersection or busiest road junctions and bends; 5 locations, industrial area; 4 locations, village area; 3 locations. The list of these 38 locations is shown in Table 1.

Table 1. List of 32 Selected Areas of Lalmonirhat District Town Area.

S.N.	Location Type	Location Name	Latitude	Longitude
1.	Sensitive Area	Felloship Church	25.9112016	89.4338037
2.		BGB Lalmonirhat	25.9114173	89.4280183
3.		Church of God Convention Center	25.9119982	89.4350751
4.		Govt. Library	25.9118463	89.4373011
5.		Land Office	25.9134736	89.4357898
S.N.	Location Type	Location Name	Latitude	Longitude
1.	Residential Area	Staf Quarter	25.9122735	89.4423694
2.		Rahaman Monjil Complex	25.9146541	89.438591
3.		East Harivanga	25.9030958	89.4337804
S.N.	Location Type	Location Name	Latitude	Longitude
1.	Mixed Area	Bashundhara Dhara Mosque	25.9146826	89.4407373
2.		Gias Uddin High School	25.9146377	89.4384048
3.		Taluk Kutamara	25.9118099	89.4308433
S.N.	Location Type	Location Name	Latitude	Longitude
1.	Commercial Area	Shena Moitry Hawakers Market	25.9090931	89.434136
2.		Circuit House	25.90709044	89.43392897
3.		Fakol Bus Stand	25.9056394	89.43392639
4.		Railway Station	25.9122997	89.4444797
5.		Mosque Market	25.9159516	89.44350907
6.		BDR Bazar	25.9160335	89.4441874
7.		Rajshahi Agriculture Development Bank	25.9145358	89.4367994
8.		Occupation Bank	25.9140506	89.4359922
9.		Appolo Dayagonestic Center	25.9131115	89.4352696
S.N.	Location Type	Location Name	Latitude	Longitude
1.	Road Intersection Area	TNT More	25.9124799	89.4340799
2.		CP More	25.9118932	89.4397034
3.		Alorupa More	25.9147773	89.4421312
4.		Mission More Lalmonirhat	25.9119544	89.4338259
5.		Main Road Lalmonirhat	25.9117807	89.4292516
S.N.	Location Type	Location Name	Latitude	Longitude
1.	Industrial Area	Store Bicic	25.9031959	89.4091777
2.		Jaman Poltry Fids Product and Industry	25.9019638	89.4089987
3.		West Bicic	25.9026462	89.4079169
4.		Fatema Cuton Cutting Mill	25.9037343	89.407952
S.N.	Location Type	Location Name	Latitude	Longitude
1.	Village Area	Station Para	25.9110576	89.4408799
2.		Harivanga	25.9040594	89.4330466

S.N.	Location Type	Location Name	Latitude	Longitude
3.		Balatari	25.9086148	89.4292618

3.3. Data Collection

As part of the survey, Air Quality was measured in different locations of the Lalmonirhat District town area for two days with the help of various automated portable instruments, namely the Air Quality Monitor and the Handheld Carbon Monoxide Meter. GPS data was also collected by Garmin

ETrex 10. Four individual data of PM₁, PM_{2.5}, PM₁₀ and CO was collected from each location. Data was collected from 32 different locations by the CAPS team. Data was collected in different times in a day from morning to late evening. Sharing the instrument details below.

Table 2. Instrument Description for Air Quality Monitor (Particulate Matter).

S. N.	Instrument Name	Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector
1.	Instrument Name	Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector
2.	Brand	Saiko
3.	Model	Model: DM106 B07SCM4YN3
4.	Measuring Parameter	PM ₁ , PM _{2.5} , PM ₁₀ , HCHO, TVOC, AQI, Temperature, Humidity
5.	PM _{2.5} /PM ₁ / PM ₁₀ Technology	Laser Scattering
6.	HCHO Technology	Electrochemistry sensor
7.	TVOC Technology	Semiconductor sensor
8.	Processor	ARM, High-speed complex calculations
9.	Detection Range	AQI 0-500
10.	HCHO	0.001-1.999 mg/m ³
11.	TVOC	0.001-9.999 mg/m ³
12.	Temperature	0-50°C
13.	Relative Humidity	0-90%



Figure 2. Air Quality Monitor, Indoor Outdoor Formaldehyde (HCHO) Detector.

3.4. Data Processing

Collected data was input into an IBM SPSS V20 and MS Excel 2020. The study used a formula for the conversion of the concentration of PM_{2.5} and PM₁₀ to AQI. Formula for Conversion- To convert from concentration to AQI, this equation was used:

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

If multiple pollutants are measured, the calculated AQI is the highest value calculated from the above equation for each pollutant.

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, IBM SPSS V20, and MS Excel 2020 were used for data analysis in this study. Various visual tools—including graphs, tables, diagrams, and box-whisker plots were generated to interpret the nature and distribution of the data. Descriptive statistics were applied to assess the dispersion of each parameter across different land use types, and ANOVA was conducted to test statistical significance. The results are presented through a combination of charts, graphs, and maps. For spatial analysis, ArcGIS 10.4.1 was used to develop both concentration and AQI maps for the Lalmonirhat District town area. Multiple projected locations were used in GIS to create detailed maps, with varying color schemes applied to indicate different concentration levels for enhanced interpretability.

4. Result and Discussion

4.1. Comparison among Concentration of PM₁, PM_{2.5}, and PM₁₀ at Different Landuse in Lalmonirhat District Area

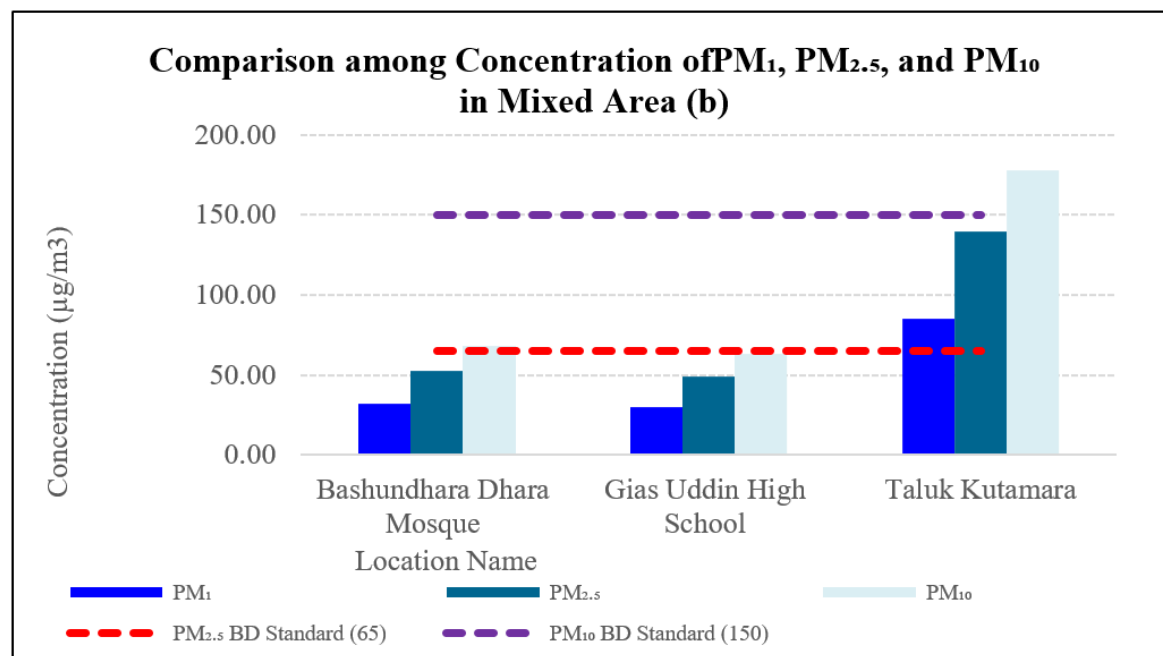
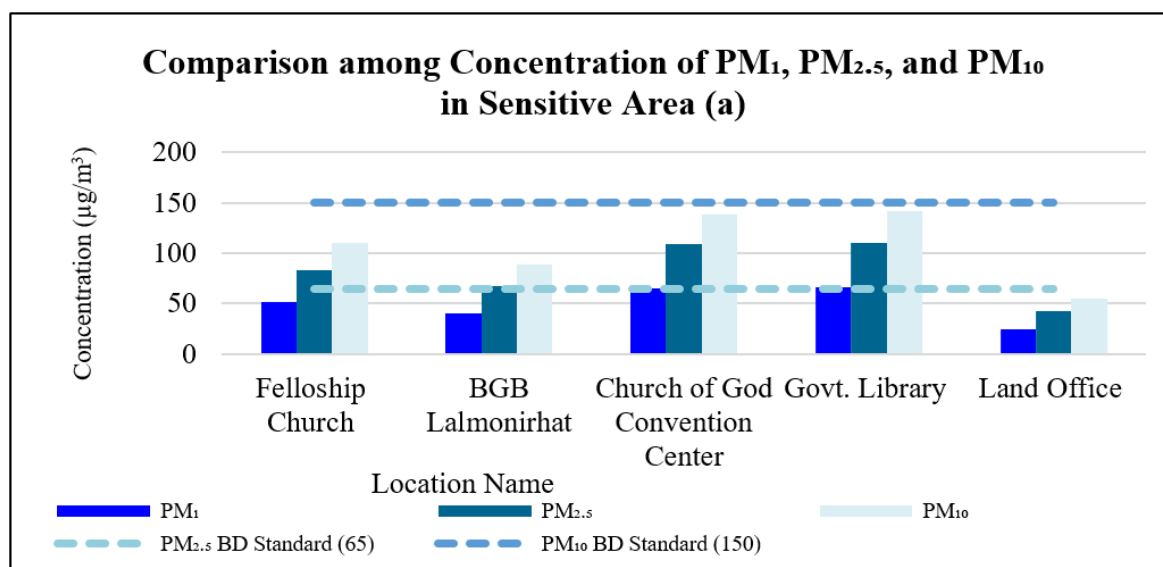
Figure 3 (a) shows the concentration (µg/m³) of PM₁, PM_{2.5}, and PM₁₀ of some locations in sensitive areas in Lalmonirhat district town. These particular locations included administrative offices, educational institutes, and mosques. As we could see, the government was among the three polluted places among these five sensitive places. Library, Church of God Convention Center, and Fellowship Church with PM_{2.5} concentration of 110.25, 109.00, and 82.75 µg/m³ respectively, and one contaminated place was the Land Office. A comparatively less

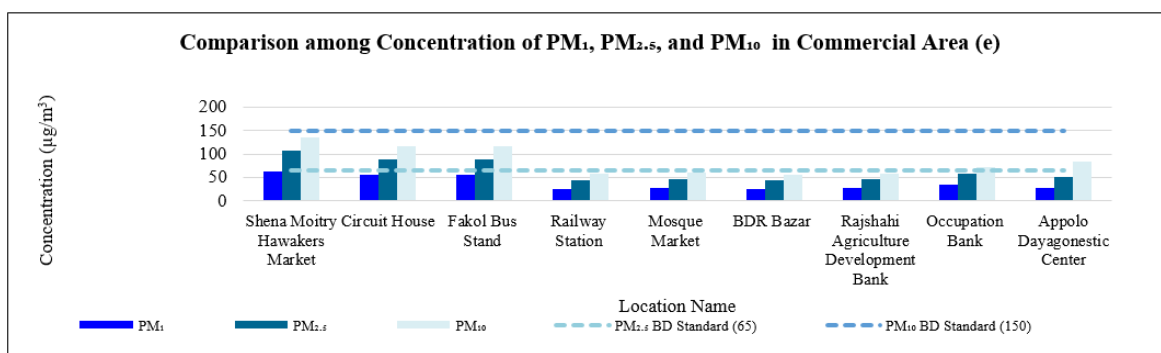
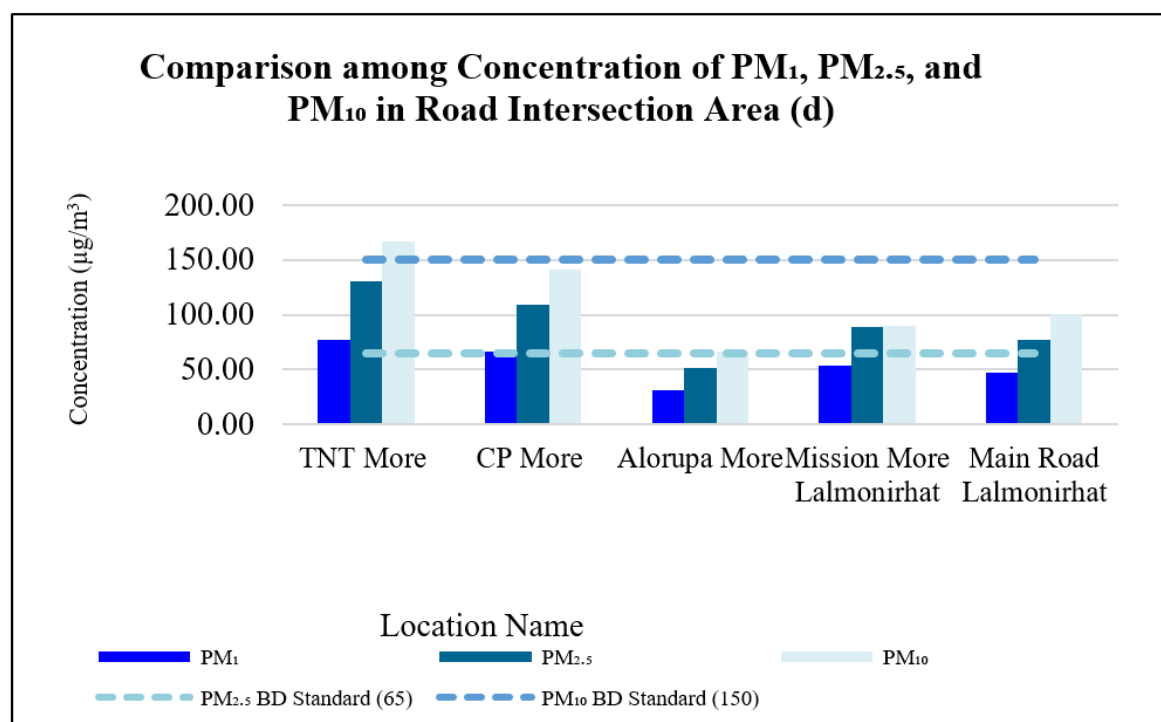
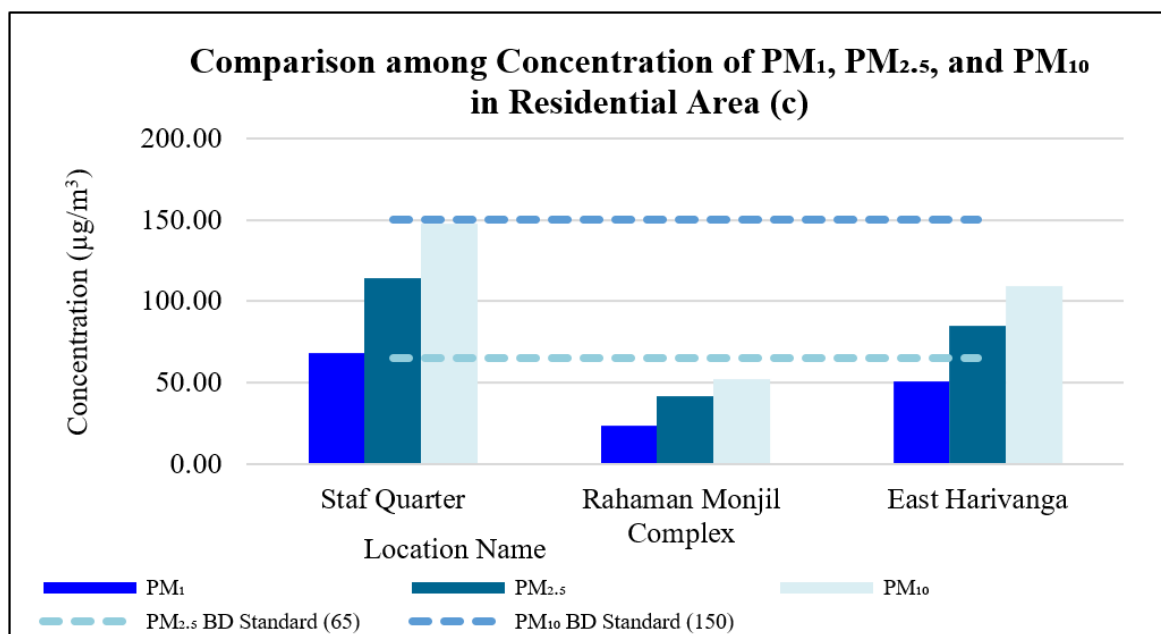
polluted place was BGB Lalmonirhat. It has been observed that the concentration of PM₁, PM_{2.5}, and PM₁₀ of the Govt. Library and Land Office were 66.00, 110.25, and 141.25 µg/m³ and 25.00, 43.00, and 54.67 µg/m³, respectively. It was also noted that the concentrations of PM_{2.5} found in the most polluted location were 1.70 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS), which is 65 µg/m³ set by the Department of Environment (DoE). The concentrations of PM_{2.5} and PM₁₀ found in that location were 4.41 and 2.83 times higher than World Health Organization (WHO) standard level respectively. The Air Quality Standard (24-hour) set by the WHO for PM_{2.5} and PM₁₀ are 25 and 50 µg/m³ respectively. The study estimated that in all sensitive areas, 77.29% of PM_{2.5} was present in PM₁₀ and 59.92% of the PM₁ was present in PM_{2.5}. Figure 3 (b) shows the concentration (µg/m³) of PM₁, PM_{2.5}, and PM₁₀ of some locations in mixed areas in Lalmonirhat district town. It has been found that out of 3 mixed places, one most polluted place was Taluk Kutamara with PM_{2.5} concentration 139.75 µg/m³ and comparatively less contaminated places were Gias Uddin High School and Bashundhara Dhara Mosque respectively. It has been observed that concentrations of PM₁, PM_{2.5}, and PM₁₀ of Taluk Kutamara and Gias Uddin High School were 85.00, 139.75 and 177.67 µg/m³ and 29.50, 48.75 and 63.25 µg/m³ respectively. It was also noted that the concentrations of PM_{2.5} and PM₁₀ found in the most polluted location were 2.15 and 1.18 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which is 65 and 150 µg/m³ set by the Department of Environment (DoE). The study estimated that the ratio of PM_{2.5}/PM₁₀ was 77.67%. It was also found that 60.82% of PM₁ mass was present in PM_{2.5}.

Figure 3 (c) shows the concentration (µg/m³) of PM₁, PM_{2.5}, and PM₁₀ of some locations in residential areas in Lalmonirhat district town. It has been found that out of 3 residential places, two highly polluted places were Staf Quarter and East Harivanga and comparatively less contaminated place was Rahaman Monjil Complex. It has been observed that concentrations of PM₁, PM_{2.5}, and PM₁₀ of Staf Quarter and Rahaman Monjil Complex were 68.00, 114.25 and 147.50 µg/m³ and 23.75, 41.75 and 52.25 µg/m³ respectively. It was also noted that the concentrations of PM_{2.5} found in the most polluted location was 2.29 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which is 65 µg/m³ set by the Department of Environment (DoE). However, the concentrations of PM_{2.5} and PM₁₀ found in the most polluted location were 4.57 and 2.95 times higher than World Health Organization (WHO) standard level respectively. The Air Quality Standard (24-hour) set by the WHO for PM_{2.5} and PM₁₀ are 25 and 50 µg/m³ respectively. The concentrations of PM_{2.5} of Staf Quarter and East Harivanga were found 114.25 and 85.25 µg/m³. The study estimated that in all residential areas, 78.52% of PM_{2.5} was present in PM₁₀ and 58.55% of the PM₁ was present in PM_{2.5}. Figure 3 (d) shows the concentration (µg/m³) of PM₁, PM_{2.5}, and PM₁₀ of some locations in road intersection areas in Lalmonirhat district town. It has been found

that out of 5 road intersection places, three highly polluted places were TNT More, CP More and Mission More Lalmonirhat and comparatively least contaminated places were Alorupa More and Main Road, Lalmonirhat respectively. It has been observed that concentrations of PM_{10} , $PM_{2.5}$, and PM_{10} of TNT More and Alorupa More were found 77.50, 130.25 and 167.00 $\mu g/m^3$ and 31.75, 51.50 and 67.00 $\mu g/m^3$ respectively. It

was also noted that the concentration of $PM_{2.5}$ and PM_{10} found in the most polluted area were 2.61 and 1.11 times higher than Bangladesh National Ambient Air Quality Standards (NAAQS) which are 65 and 150 $\mu g/m^3$ set by the Department of Environment (DoE). The study estimated that in all road intersection areas, 81.52% of $PM_{2.5}$ was present in PM_{10} and 60.82% of the PM_{10} was present in $PM_{2.5}$.





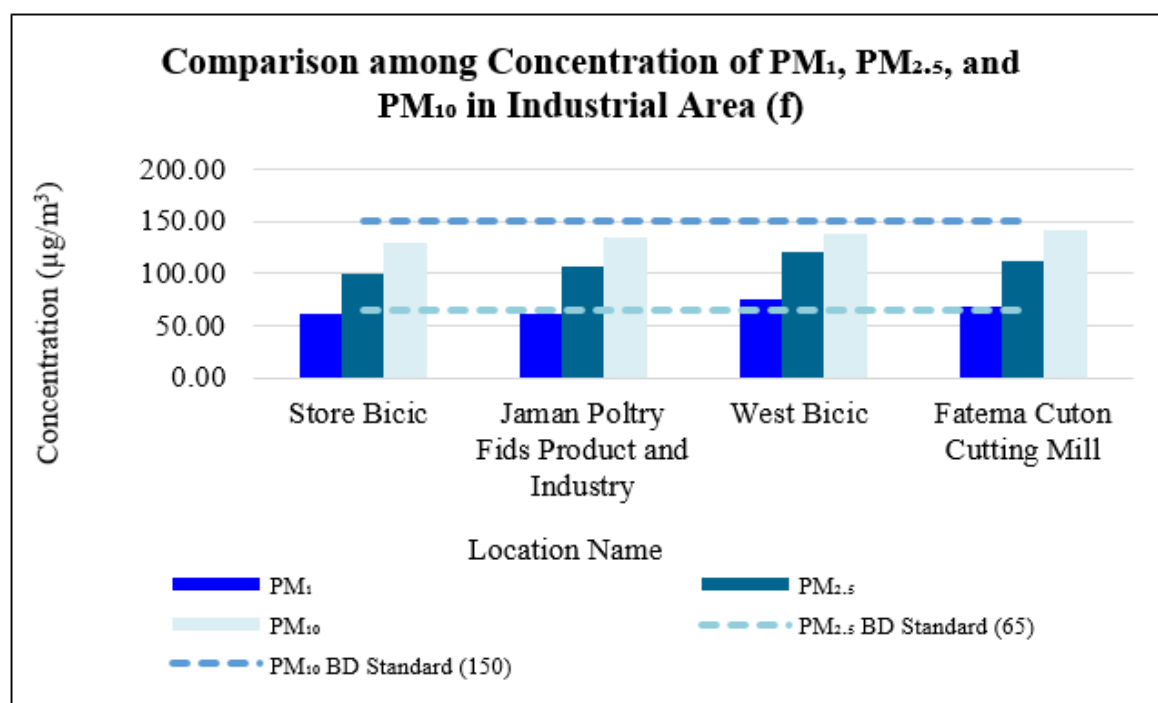


Figure 3. Comparison among Concentration of PM₁, PM_{2.5}, and PM₁₀ at Different Landuse in Lalmonirhat District Area.

Figure 3 (e) shows the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5}, and PM₁₀ of some locations in commercial areas in Lalmonirhat district town. It has been found that out of 9 commercial places, three polluted places were Shena Moitry Hawakers Market, Circuit House and Fakol Bus Stand and comparatively least contaminated places were BDR Bazar, Railway Station and Rajshahi Agriculture Development Bank. It has been observed that concentrations of PM₁, PM_{2.5}, and PM₁₀ of Shena Moitry Hawakers Market and BDR Bazar were 63, 108 and 136 $\mu\text{g}/\text{m}^3$ and 26, 44 and 56 $\mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentration of PM_{2.5} found in the most polluted area was 2.16 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). However, the concentrations of PM_{2.5} and PM₁₀ found in the most polluted location were 4.32 and 2.72 times higher than World Health Organization (WHO) standard level respectively. The Air Quality Standard (24-hour) set by the WHO for PM_{2.5} and PM₁₀ are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively. The study estimated that in all commercial areas, 75.73% of PM_{2.5} was present in PM₁₀ and 59.56% of the PM₁ was present in PM_{2.5}.

Figure 3 (f) shows the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5}, and PM₁₀ of some locations in industrial locations in Lalmonirhat district town. It has been found that out of 4 industrial places, three highly polluted places were West BSCIC, Fatema Cuton Cutting Mill and Jaman Poltry Fids Product and Industry with PM_{2.5} concentration of 121.25, 111.33 and 106.75 $\mu\text{g}/\text{m}^3$ respectively and relatively less polluted place was Store BSCIC with PM_{2.5} concentration 99.25 $\mu\text{g}/\text{m}^3$ respectively. It has been observed that

concentration of PM₁, PM_{2.5}, and PM₁₀ of West BSCIC and Store BSCIC were 75.75, 121.25 and 139.00 $\mu\text{g}/\text{m}^3$ and 61.75, 99.25 and 129.50 $\mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentrations of PM_{2.5} found in the most polluted area was 2.43 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). However, the concentrations of PM_{2.5} and PM₁₀ found in the most polluted location were 4.85 and 2.78 times higher than World Health Organization (WHO) standard level respectively. The Air Quality Standard (24-hour) set by the WHO for PM_{2.5} and PM₁₀ are 25 and 50 $\mu\text{g}/\text{m}^3$ respectively. The study estimated that in Industrial areas, 80.31% of PM_{2.5} was present in PM₁₀ and 60.98% of the PM₁ was present in PM_{2.5}.

Figure 3(g) shows the concentration ($\mu\text{g}/\text{m}^3$) of PM₁, PM_{2.5}, and PM₁₀ of polluted locations in village areas in Lalmonirhat district town. It has been found that out of 3 village places, two most polluted places were the Station para and Harivanga and the less polluted place was Balatari respectively. It has been observed that concentrations of PM₁, PM_{2.5}, and PM₁₀ of the Station para and Balatari were 72.75, 121.50 and 156 $\mu\text{g}/\text{m}^3$ and 40.50, 67.75 and 86.50 $\mu\text{g}/\text{m}^3$ respectively. It was also noted that the concentrations of PM_{2.5} and PM₁₀ were 2.43 and 1.04 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 village areas, 77.61% of PM_{2.5} was present in PM₁₀ and 61.45% of the PM₁ was present in PM_{2.5}. However, the average concentration of PM₁, PM_{2.5}, and PM₁₀ was found

highest in industrial area followed by village and road intersection area with the values of 66.90, 109.65 and 136.42 $\mu\text{g}/\text{m}^3$, 57.08, 93.25 and 120.17 $\mu\text{g}/\text{m}^3$ and 55.40, 91.40 and 113.15 $\mu\text{g}/\text{m}^3$ respectively. Moreover, the concentration was found relatively lower in commercial area, residential area and mixed area. Furthermore, the average concentration of PM_{10} (38.17 $\mu\text{g}/\text{m}^3$), $\text{PM}_{2.5}$ (63.92 $\mu\text{g}/\text{m}^3$) and PM_{10} (84.31 $\mu\text{g}/\text{m}^3$) were found to be least in commercial area.

4.2. Descriptive Statistics of PM_{10} , $\text{PM}_{2.5}$, and PM_{10}

The following Table 3 shows the descriptive statistics for PM_{10} of the studied seven land uses. The higher ranges were found in mixed area (55.50 $\mu\text{g}/\text{m}^3$) and road intersection area (45.75 $\mu\text{g}/\text{m}^3$) and lower ranges were found in industrial area

(14.00 $\mu\text{g}/\text{m}^3$) and village area (28.25 $\mu\text{g}/\text{m}^3$). Among all those land uses the minimum concentration was seen in residential area (23.75 $\mu\text{g}/\text{m}^3$) and the maximum concentration was seen in mixed area (85.00 $\mu\text{g}/\text{m}^3$). The highest mean value of PM_{10} was found in industrial area (66.90 $\mu\text{g}/\text{m}^3$) followed by village area (57.08 $\mu\text{g}/\text{m}^3$) and the lowest mean was found in commercial area (38.17 $\mu\text{g}/\text{m}^3$). The highest standard deviation was seen in mixed area (31.28 $\mu\text{g}/\text{m}^3$) and the lowest was seen in industrial area (6.67 $\mu\text{g}/\text{m}^3$). Table also shows that, the highest coefficient of variation was seen in mixed area which was 63.94% and lowest was seen in industrial area which was 9.97%. It was observed that the highest variation in the concentration of the PM_{10} prevailed in mixed area followed by residential area. The less variation was found in industrial area prior to village area.

Table 3. Descriptive Statistics for PM_{10} .

S. N.	Land Use	NoL	Range ($\mu\text{g}/\text{m}^3$)	Min. ($\mu\text{g}/\text{m}^3$)	Max. ($\mu\text{g}/\text{m}^3$)	Mean ($\mu\text{g}/\text{m}^3$)	Std. Deviation ($\mu\text{g}/\text{m}^3$)	Coefficient of Variation (%)
1.	Sensitive Area	5	41.00	25.00	66.00	49.55	17.43	35.17
2.	Mixed Area	3	55.50	29.50	85.00	48.92	31.28	63.94
3.	Residential Area	3	44.25	23.75	68.00	47.42	22.29	47.00
4.	Road Intersection Area	5	45.75	31.75	77.50	55.40	17.60	31.78
5.	Commercial Area	9	36.75	25.75	62.50	38.17	14.90	39.05
6.	Industrial Area	4	14.00	61.75	75.75	66.90	6.67	9.97
7.	Village Area	3	28.25	44.50	72.75	57.08	14.38	25.18

The whisker box plot shows the average of PM_{10} concentrations in seven land uses illustrate in 4 (a). 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. Whisker box plot revealed that commercial area, mixed area, sensitive area and residential area had more dispersed concentration with highest in commercial area and mixed area and the spreading of area had positively skewed distribution. Moderate dispersion was found in road intersection area and village area where both of them were positively skewed. Another point was to be noted that the values of mixed area were comparatively higher than any other land uses of this district town. The concentration of PM_{10} had less distribution in industrial area and positively skewed distribution. The episode was found in Taluk Kutamara due to the ongoing

development work (road reconstruction).

The following Table 4 shows the descriptive statistics for $\text{PM}_{2.5}$ of the studied seven land uses. The higher ranges were found in The higher ranges were found in mixed area (91.00 $\mu\text{g}/\text{m}^3$) and road intersection area (78.75 $\mu\text{g}/\text{m}^3$) and lower ranges were found in industrial area (22.00 $\mu\text{g}/\text{m}^3$) and village area (50.00 $\mu\text{g}/\text{m}^3$). Among all those land uses the minimum concentration was seen in residential area (41.75 $\mu\text{g}/\text{m}^3$) and the maximum concentration was seen in mixed area (139.75 $\mu\text{g}/\text{m}^3$). The highest mean value of $\text{PM}_{2.5}$ was found in industrial area (109.65 $\mu\text{g}/\text{m}^3$) followed by village area (93.25 $\mu\text{g}/\text{m}^3$) and the lowest mean was found in commercial area (63.92 $\mu\text{g}/\text{m}^3$). The highest standard deviation was seen in mixed area (51.42 $\mu\text{g}/\text{m}^3$) and the lowest was seen in industrial area (9.20 $\mu\text{g}/\text{m}^3$). Table also shows that, the highest coefficient of variation was seen in mixed area which was 63.95% and lowest was seen in industrial area which was 8.39%. It was observed that the highest variation in the

concentration of the PM_{2.5} prevailed in mixed area followed by residential area. The reasons behind the higher dispersion in concentration in mixed area and residential were different

types of vehicular movement and burning of fossil, fuel and biomass for cooking purpose. The less variation was found in industrial area and village area.

Table 4. Descriptive Statistics for PM_{2.5}.

S. N.	Land Use	NoL	Range (µg/m ³)	Min. (µg/m ³)	Max. (µg/m ³)	Mean (µg/m ³)	Std. Deviation (µg/m ³)	Coefficient of Variation (%)
1.	Sensitive Area	5	67.25	43.00	110.25	82.45	28.57	34.65
2.	Mixed Area	3	91.00	48.75	139.75	80.42	51.42	63.95
3.	Residential Area	3	72.50	41.75	114.25	80.42	36.49	45.38
4.	Road Intersection Area	5	78.75	51.50	130.25	91.40	30.18	33.02
5.	Commercial Area	9	63.75	43.75	107.50	63.92	24.51	38.34
6.	Industrial Area	4	22.00	99.25	121.25	109.65	9.20	8.39
7.	Village Area	3	50.00	71.50	121.50	93.25	25.63	27.48

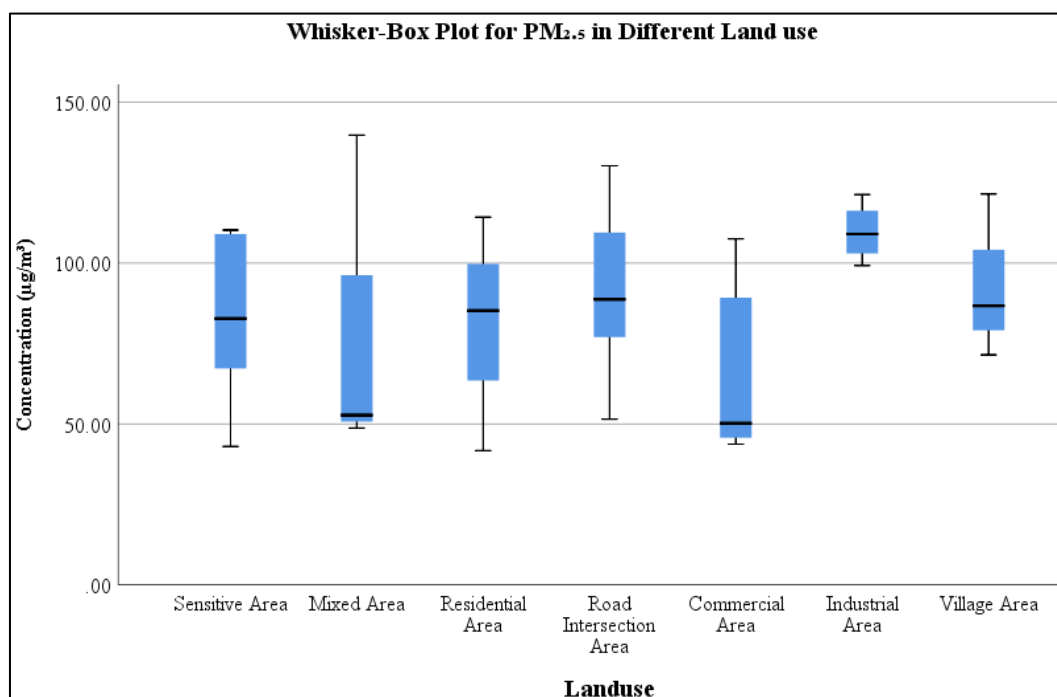
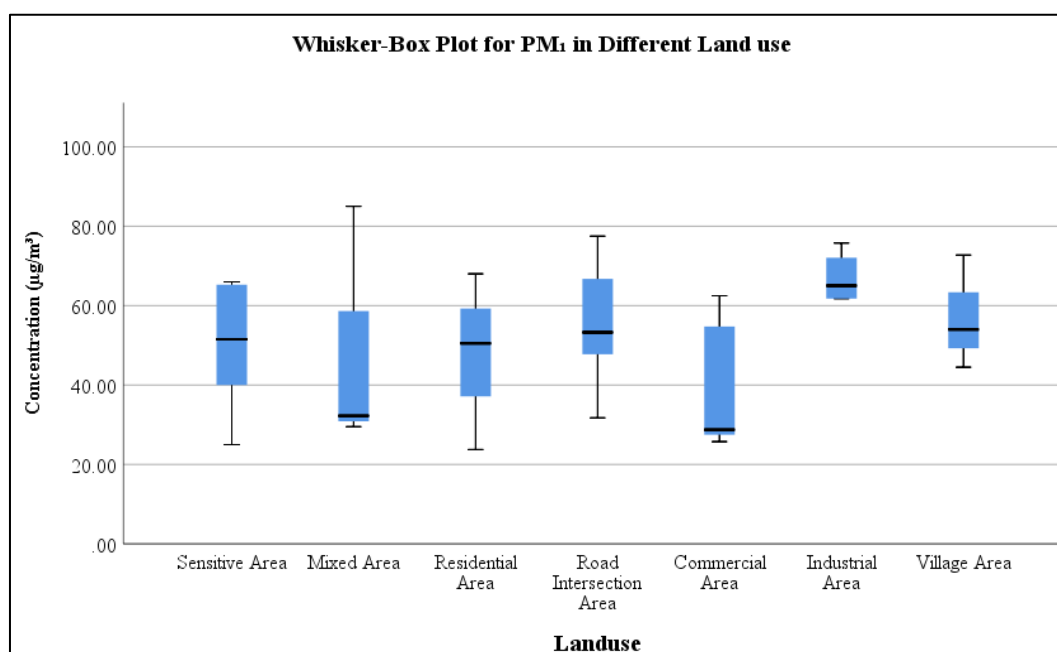
The whisker box plot demonstrates the average of PM_{2.5} concentrations in seven land uses illustrate in 4 (b). A horizontal black line within the box marks the median; the lower boundary of the box indicates the 25th percentile, the upper boundary of the box indicates the 75th percentile. The whisker represents the maximum (upper whisker) and minimum value (lower whisker) for each land use. Whisker box plot revealed that commercial area, mixed area, sensitive area and residential area had more dispersed concentration with highest in commercial area and mixed area and the spreading of area had positively skewed distribution. Moderate dispersion was found in road intersection area and village area where both of them were positively skewed. Another point was to be noted that the values of mixed area were comparatively higher than any other land uses of this district town. The concentration of PM₁ had less distribution in industrial area and positively skewed distribution. This area was occupied with different types of vehicle in the survey time which might be reasons of relatively higher values of PM_{2.5} though the surveyed locations were only two.

The following table 5 shows the descriptive statistics for PM₁₀ of the studied seven land uses. The higher ranges were found in mixed area (114.42 µg/m³) and road intersection area (100.00 µg/m³) and lower ranges were found in industrial area (12.17 µg/m³) and village area (64.75 µg/m³). Among all those land uses the minimum concentration was seen in residential area (52.25 µg/m³) and the maximum concentration was seen in mixed area (177.67 µg/m³). The highest mean value of PM₁₀ was found in industrial area (136.42 µg/m³) followed by village area (120.17 µg/m³) and the lowest mean was found in commercial area (84.31 µg/m³). The highest standard deviation was seen in mixed area (64.66 µg/m³) and the lowest was seen in industrial area (5.26 µg/m³). Table also shows that, the highest coefficient of variation was seen in mixed area which was 62.75% and lowest was seen in industrial area which was 3.85%. It was observed that the highest variation in the concentration of the PM₁₀ prevailed in mixed area followed by residential area where the concentration varies a lot. The less variation was found in industrial area followed by village area.

Table 5. Descriptive Statistics for PM₁₀.

S. N.	Land Use	NoL	Range (µg/m ³)	Min. (µg/m ³)	Max. (µg/m ³)	Mean (µg/m ³)	Std. Deviation (µg/m ³)	Coefficient of Variation (%)
1.	Sensitive Area	5	86.58	54.67	141.25	106.65	36.34	34.07
2.	Mixed Area	3	114.42	63.25	177.67	103.06	64.66	62.75

S. N.	Land Use	NoL	Range ($\mu\text{g}/\text{m}^3$)	Min. ($\mu\text{g}/\text{m}^3$)	Max. ($\mu\text{g}/\text{m}^3$)	Mean ($\mu\text{g}/\text{m}^3$)	Std. Deviation ($\mu\text{g}/\text{m}^3$)	Coefficient of Variation (%)
3.	Residential Area	3	95.25	52.25	147.50	102.92	47.92	46.56
4.	Road Intersection Area	5	100.00	67.00	167.00	113.15	40.36	35.67
5.	Commercial Area	9	80.00	56.00	136.00	84.31	30.49	36.16
6.	Industrial Area	4	12.17	129.50	141.67	136.42	5.26	3.85
7.	Village Area	3	64.75	91.25	156.00	120.17	32.92	27.40



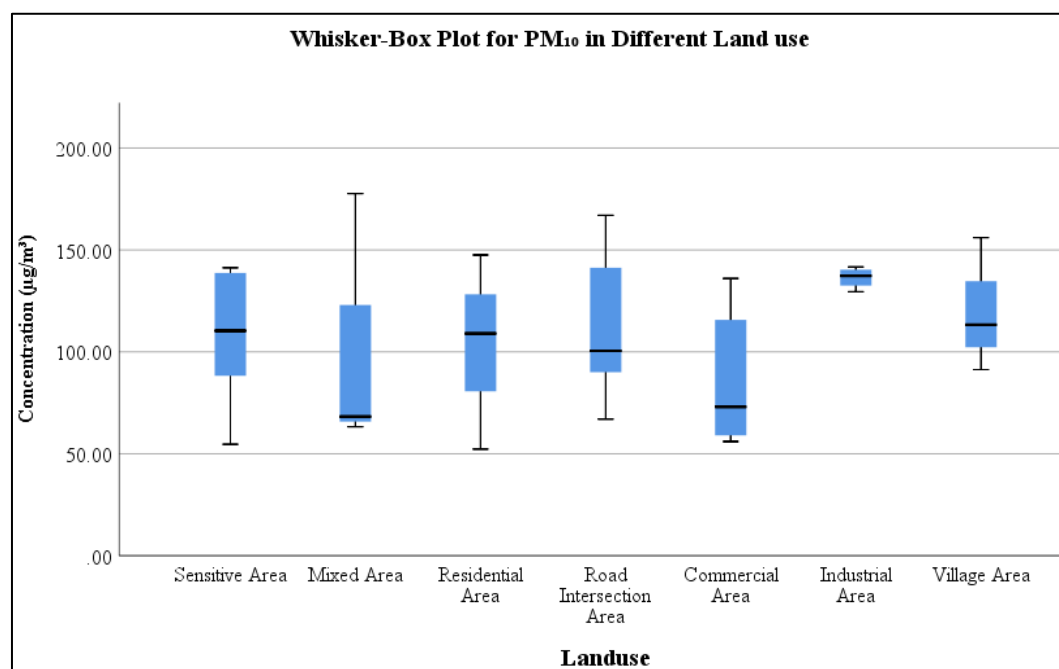


Figure 4. Whisker Box Plot showing the Concentration of PM_{10} , $PM_{2.5}$, and PM_{10} in Different Land use.

The whisker box plot shows the average of PM_{10} concentrations in seven land uses illustrate in 4 (b). 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. Whisker box plot revealed that commercial area, mixed area, sensitive area and residential area had more dispersed concentration with highest in commercial area and mixed area and the spreading of area had positively skewed distribution. Moderate dispersion was found in road intersection area and village area where both of them were positively skewed. Another point was to be noted that the values of mixed area were comparatively higher than any other land uses of this district town. The concentration of PM_{10} was tightly clustered in industrial area and negatively skewed distribution. The

episode was found in Taluk Kutamara due to the ongoing development work (road reconstruction).

4.3. Significance Test

Table 6 shows ANOVA for the significant test. ANOVA has been performed to find whether the changes in the concentration of all the parameters between and within land uses are significant. Here the F value of found to be 1.468 for PM_{10} , 1.339 for $PM_{2.5}$ and 1.070 for PM_{10} respectively. P values found for PM_{10} , $PM_{2.5}$, and PM_{10} are 0.230, 0.277 and 0.406 respectively. The following tables revealed that the concentrations of none of the parameters change significantly as the p values are greater than 0.05. Therefore, the concentration of PM might not be changed significantly between and within in the land uses.

Table 6. Significance Test.

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
PM_{10}	Between Groups	2722.522	6	453.754	1.468	0.230
	Within Groups	7728.297	25	309.132		
	Total	10450.819	31			
$PM_{2.5}$	Between Groups	6823.550	6	1137.258	1.339	0.277
	Within Groups	21231.672	25	849.267		

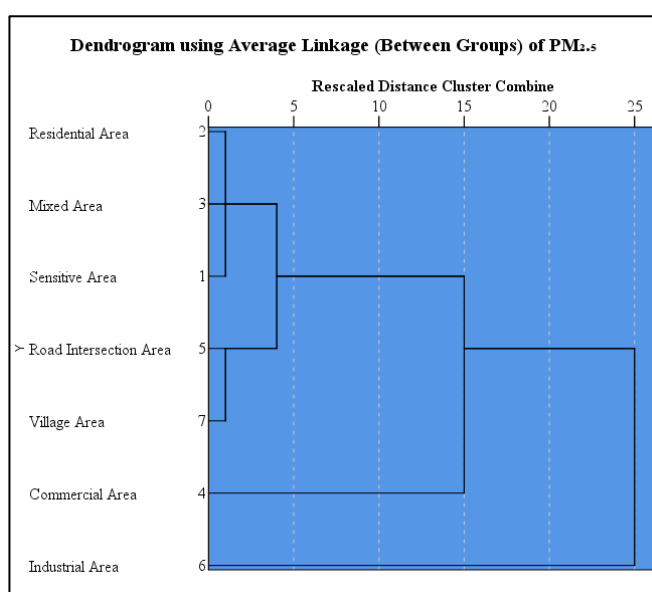
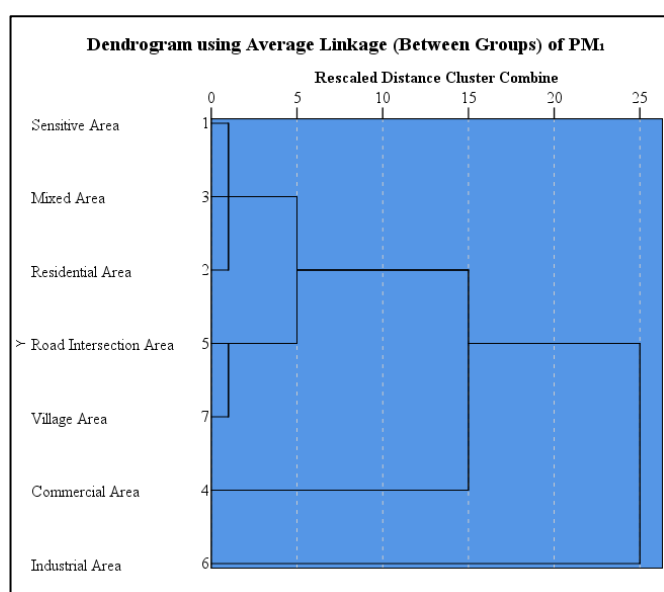
ANOVA		Sum of Squares	df	Mean Square	F	Sig.
PM ₁₀	Total	28055.222	31			
	Between Groups	8847.643	6	1474.607	1.070	0.406
	Within Groups	34439.169	25	1377.567		
	Total	43286.812	31			

4.4. Land Use Based Cluster Analysis

Figure 5 shows the dendrogram plot obtained from cluster analysis in terms of PM_{1.0} with Z-score normalization. For this analysis, group linkage and Euclidean distance have been considered. Four clusters have been found from the below graph. The first cluster consists of sensitive area, mixed area and residential area; the second cluster includes road intersection area and village area; the third cluster is consisted of commercial area; and the fourth cluster includes industrial area alone. First and second clusters join at the approximate distance of 5 which joins with third cluster at the approximate distance of 15. This broad cluster joins with fourth cluster at the approximate distance of 25. Figure 5 shows the dendrogram plot obtained from cluster analysis in terms of PM_{2.5} with Z-score normalization. For this analysis, between-group linkage and Euclidean distance have been

considered. Three clusters have been found from the below graph. The first cluster consists of residential area, mixed area, sensitive area, road intersection area and village area; the second cluster includes commercial area and the third cluster is consisted of industrial area alone. First and second clusters join at the approximate distance of 15 which joins with third cluster at the approximate distance of 25.

Figure 5 shows the dendrogram plot obtained from cluster analysis in terms of PM₁₀ with Z-score normalization. For this analysis, between-group linkage and Euclidean distance have been considered. Three clusters have been found from the below graph. The first cluster consists of residential area, mixed area, sensitive area, road intersection area and village area; the second cluster includes commercial area and the third cluster is consisted of industrial area alone. First and second clusters join at the approximate distance of 15 which joins with third cluster at the approximate distance of 25.



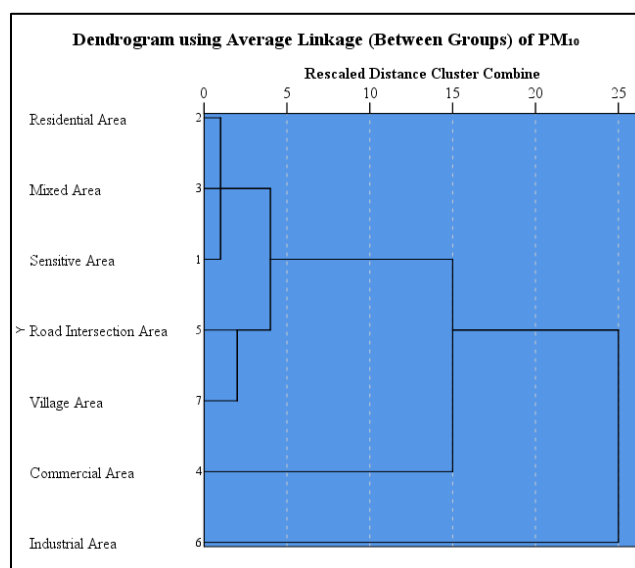


Figure 5. Rescaled Distance Cluster Combine for PM_{10} , $PM_{2.5}$, and PM_{10} in Different Land use.

4.5. Concentration Map of PM_{10} , $PM_{2.5}$, and PM_{10} Lalmonirhat District Town in 2021

Figure 6 show the concentration of Particulate Matter (PM_{10}) at various location of Lalmonirhat District town area in the year of 2021. Concentrations of Particulate Matter (PM_{10}) are expressed in $\mu g/m^3$. The concentration of $\mu g/m^3$ means one-millionth of a gram of PM_{10} per cubic meter of air. Yellow areas have less, while progressively higher concentrations are shown in orange and red. The concentration of PM_{10} was found

to higher (75-84 $\mu g/m^3$) in the Taluk Kutamara, TNT More and West BSCIC area. It also shows that PM_{10} concentration was found (22-30 $\mu g/m^3$) in Rahaman Monjil Complex, Land Office, BDR Bazar, Railway Station, Rajshahi Agriculture Development Bank, Appolo Dayagonestic Center, Mosque Market and Gias Uddin High School. The maximum concentration shows with red flag and minimum concentration with green flag. The maximum concentration was found in Taluk Kutamara and the minimum concentration was found in Rahaman Monjil Complex.

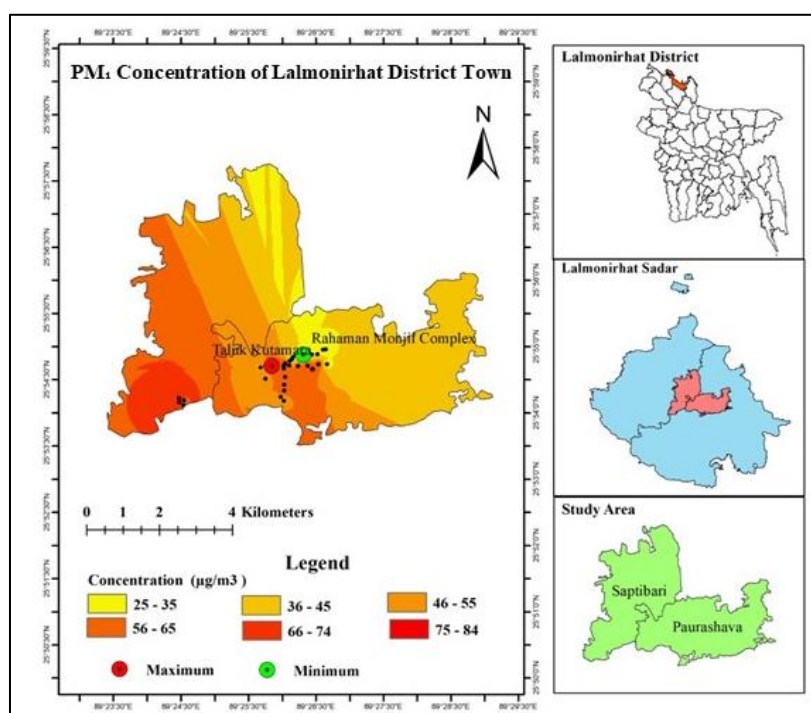


Figure 6. PM_{10} , $PM_{2.5}$, and PM_{10} Concentration Map of Lalmonirhat District Town in 2021..

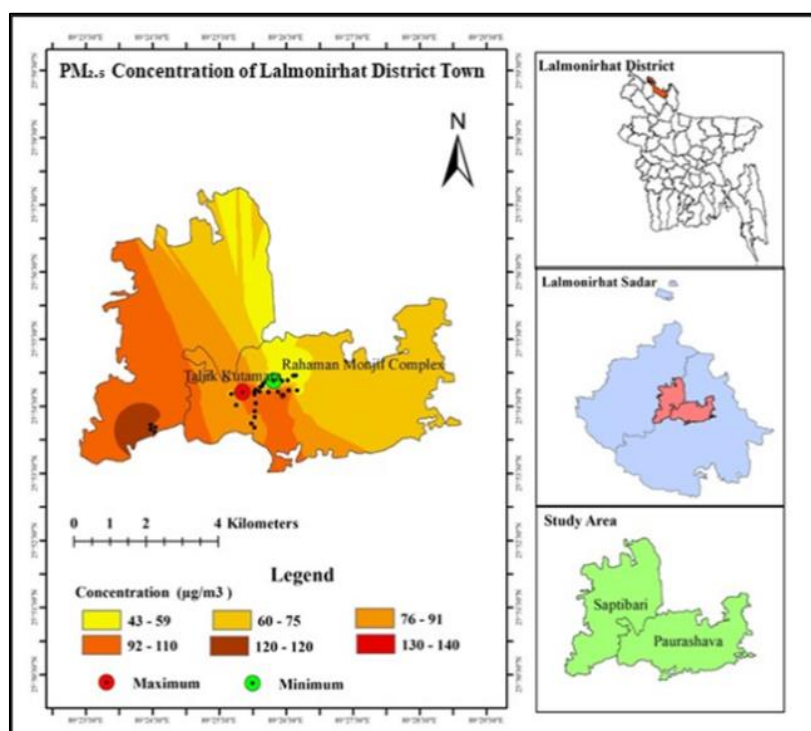


Figure 7. PM₁, PM_{2.5}, and PM₁₀ Concentration Map of Lalmonirhat District Town in 2021.

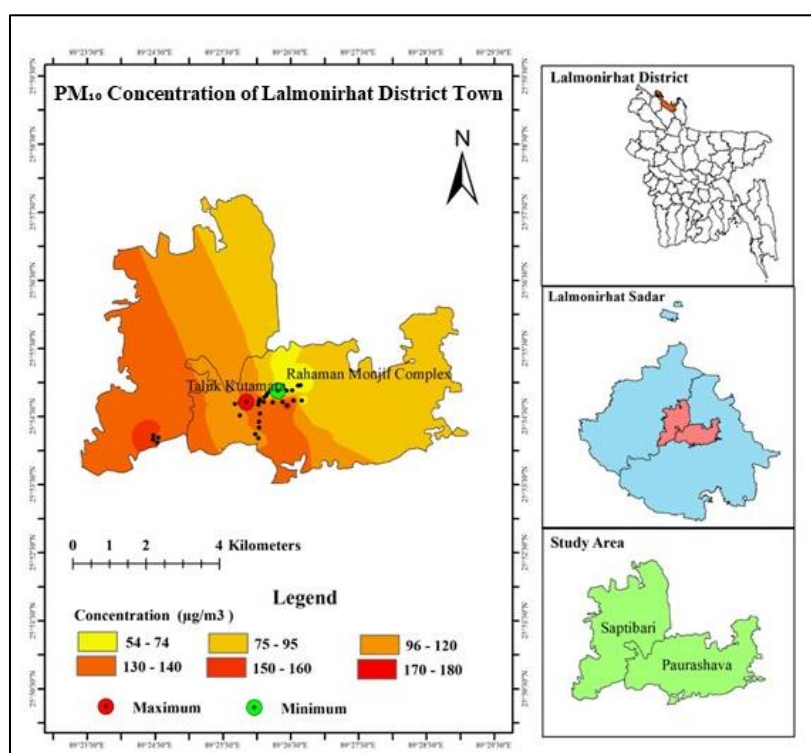


Figure 8. PM₁, PM_{2.5}, and PM₁₀ Concentration Map of Lalmonirhat District Town in 2021.

Figure 7 show the concentration of Particulate Matter (PM_{2.5}) at various location of Lalmonirhat District town area in the year of 2021. Concentrations of Particulate Matter (PM_{2.5}) are expressed in µg/m³. The concentration of µg/m³ means one-millionth of a gram of PM_{2.5} per cubic meter of air.

Yellow areas have little, while progressively higher concentrations are shown in orange and red. The concentration of PM_{2.5} was found to higher (110-140 µg/m³) in the Taluk Kutamara, TNT More, Station Para, West BSCIC, Staf Quarter, Fatema Cuton Cutting Mill and Govt.

Library area. It also shows that $PM_{2.5}$ concentration was found ($41-59 \mu g/m^3$) in Rahaman Monjil Complex, Land Office, BDR Bazar, Railway Station, Rajshahi Agriculture Development Bank, Mosque Market, Gias Uddin High School, Appolo Dayagonestic Center, Alorupa More and Occupation Bank. The maximum concentration shows with red flag and minimum concentration with green flag. The maximum concentration was found in Taluk Kutamara and the minimum concentration was found in Rahaman Monjil Complex.

Figure 8 shows the concentration of Particulate Matter (PM_{10}) at various locations of Lalmonirhat District town area in the year 2021. Concentrations of Particulate Matter (PM_{10}) are expressed in $\mu g/m^3$. The concentration of $\mu g/m^3$ means one-millionth of a gram of PM_{10} per cubic meter of air. Yellow areas have little, while progressively higher concentrations are shown in orange and red. The concentration of PM_{10} was found to higher ($141-180 \mu g/m^3$) Taluk Kutamara, TNT More, Station Para, Staf Quarter, Fatema Cuton Cutting Mill, CP More and Govt. Library area. It also shows that PM_{10} concentration was found ($52-67 \mu g/m^3$) in Rahaman Monjil Complex, Land Office, BDR Bazar, Railway Station, Rajshahi Agriculture Development Bank, Mosque Market, Gias Uddin High School and Alorupa More. The maximum

concentration shows with red flag and minimum concentration with green flag. The maximum concentration was found in Taluk Kutamara and the minimum concentration was found in Rahaman Monjil Complex.

4.6. AQI on $PM_{2.5}$ Concentration of Lalmonirhat District Town in 2021

Figure 9 Shows the Lalmonirhat District town area 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 shows that AQI (151-200) was unhealthy condition in the Taluk Kutamara, West BSCIC, Staf Quarter, TNT More, Station Para, Fatema Cuton Cutting Mill and the central part of the city which is indicating in red color. Also shows that, Rahaman Monjil Complex, Land Office, BDR Bazar, Railway Station, Rajshahi Agriculture Development Bank and the north side of the city were found in a cuation condition where the AQI was (101-150) which indicate by orange color. The maximum concentration was found in Taluk Kutamara which shows with red flag and the minimum concentration was found in Rahaman Monjil Complex that indicates with green flag.

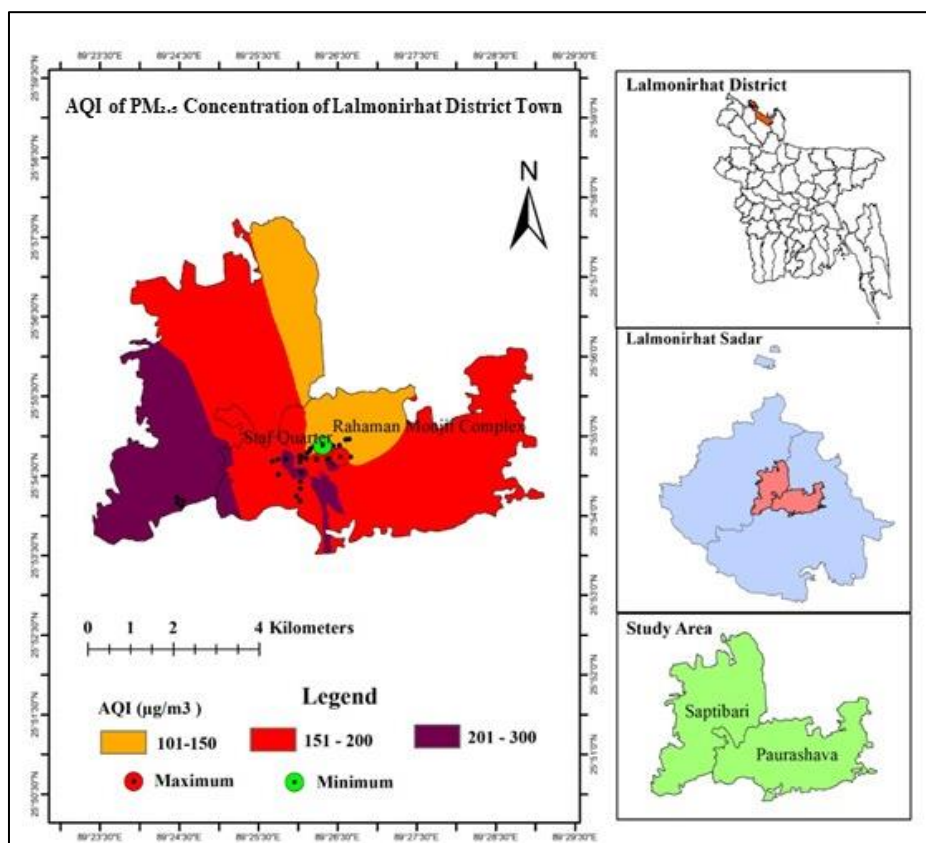


Figure 9. AQI on $PM_{2.5}$ Concentration Map of Lalmonirhat District Town in 2021.

5. Conclusion

The study found that the average concentration of PM₁, PM_{2.5}, and PM₁₀ of 32 places in Lalmonirhat district town area found to be 51.92, 85.93 and 109.52 µg/m³ respectively. 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 industrial area (109.65 µg/m³) > village area (93.25 µg/m³) > road intersection area (91.40 µg/m³) > sensitive area (82.45 µg/m³) > residential area (80.42 µg/m³) > mixed area (80.42 µg/m³) > commercial area (63.92 µg/m³). Along with that, the average concentration of PM_{2.5} (109.65 µg/m³) of different land use was found higher in industrial area which 2.19 times higher than the standard value of PM_{2.5}. 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 that the average ratio of PM_{2.5} /PM₁₀ showed that the PM_{2.5} mass was 78.38% of the PM₁₀ mass and the average ratio of PM₁/PM_{2.5} showed that the PM₁ mass was 60.3% of the PM_{2.5} mass. Based on PM_{1.0}, PM_{2.5} and PM₁₀ dispersion, among all those land use the maximum range was found in mixed and road intersection areas where the minimum range was found in the area and industrial area. Further found that in PM_{1.0}, PM_{2.5} and PM₁₀ dispersion Std. deviation and coefficient of variation higher in the mixed area and residential area. Moreover, whisker box graph of PM_{1.0}, PM_{2.5} and PM₁₀ show that values commercial area, mixed area, sensitive area and residential area had more dispersed concentration with highest in commercial area and and the industrial area had concentrated value. It also revealed that that the concentrations of none of the parameters change significantly as the p values are greater than 0.05. From the dendrogram plot of PM₁, PM_{2.5}, PM₁₀ it has been found out that each of the analyses included at least three clusters at the first phase and these were consecutive to make a single cluster at the approximate distance of 25.

Abbreviations

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

Conflicts of Interest

The authors declare no conflicts of interest.

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