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The Concentration of $PM_{2.5}$ and PM_{10} on a Busy Highway in Bangladesh and their Spatial Variation: A Case Study of the Mymensingh - Gazipur Highway

Research Article

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ABSTRACT

Air pollution is a threat to the environment in developing countries. Air pollution from particulate matter ($PM_{2.5}$ and PM_{10}) is a critical environmental and public health issue in Bangladesh. This study evaluates the spatial and temporal variation of PM concentrations along the Mymensingh-Gazipur Highway, a high-traffic corridor, using air quality data collected at 14 locations during morning, noon, and evening hours in the winter season. Measurements were taken with Airveda air quality monitors, and spatial distribution was analysed using Geographic Information System (GIS) mapping. The maximum average concentrations were recorded at 450+ µg/m3 for $PM_{2.5}$ and 605+ µg/m3 for PM_{10}. These values are several times higher than the World Health Organization air quality standard and the Bangladesh National Ambient Air Quality Standard. According to the size and fractional distribution of PM, most of the monitoring locations were dominated by fine particles. Comparison of the PM_{10} and $PM_{2.5}$ concentrations at 14 different sites with the standard value (BNAAQS) and (WHO), where all the PM concentrations exceeded the BNAAQS and WHO limits. The spatial variation analysis showed unhealthy atmospheric conditions throughout the study area. The study recommended spraying water on roads every two to three hours in the dry season, protecting water bodies, plying suction trucks on roads to collect dust, and introducing environmental cadre's service and effective environmental courts. Therefore, air pollution reduction plans and risk mitigation strategies should be developed and implemented by the government authorities.

Keywords: Air pollution, GIS, Highway, Particulate matter, Spatial distribution.

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Index; **BNAAQS** - Bangladesh National Ambient Air Quality Standard; **WHO** - World Health Organization; **USEPA**-United States Environmental Protection Agency; **EPA** - Environmental Protection Agency.

1. Introduction

Air pollution has emerged as a major global health concern, with particulate matter (PM) being a significant contributor to respiratory and cardiovascular diseases (WHO,2021).In developing countries like Bangladesh, rapid urbanization and industrialization have led to a significant increase in air pollution levels, particularly in urban areas (Hasan *et al.,* 2020). Air pollution is a serious problem in Bangladesh, which ranks 178th (out of 180 nations) on the Environmental Performance Index for Air Quality (Block *et al.,* 2024). Various sources contribute to air pollution including vehicular emissions are a major source of pollutants, emitting gases such as carbon monoxide (CO), nitrogen oxides (NO_x), Sulfuric dioxide (SO_2), and volatile organic compounds (VOCs), along with particulate matter (PM) (Khan *et al.,* 2019). Some of the pollutants, in particular particulate matter like PM 2.5 and PM10 pose an alarming concern due to its capacity to infiltrate deep into respiratory system leading toward different health concerns (Islam *et al.,* 2020). The harmful impact of air pollution arises from its complex mixture of gases and particles (Hamanaka & Mutlu, 2018). Highways are a major source of air pollution, especially in densely settled horizonal cities like Bangladesh. Vehicles are a source of various pollutants, such as nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs) and particulate matter (PM). Common at sites adjacent to a roadway, these chemical compounds stream out of tailpipes and build up during stop-and-go traffic tie-ups (Zhang *et al.,* 2018). Diesel vehicles are the largest source of on-road transportation-generated air pollution and release greater nitrogen oxides (NOx) as well as a high level of particulate matter into our atmosphere compared to gasoline engines (EPA, 2023; Khan *et al.*, 2024). With high vehicle density on highways, the air pollution index is worsening exponentially causing serious health hazards to commuters and residents located around that area. This high traffic density leads to an increase in air pollutants, which carries health risks for passengers, residents near the station and vulnerable groups such as children and elders (Cheng & Li, 2010; Zhu *et al.,* 2021). Previous studies have investigated air pollution levels in different parts of Bangladesh, including Dhaka, Gazipur and Mymensingh (Alam *et al.,* 2018; Hossain *et al.,* 2023). However, there is a lack of comprehensive studies on the spatial variation of $PM_{2.5}$ and PM_{10} concentrations along the Mymensingh-Gazipur Highway. Understanding the spatial distribution of these pollutants is crucial for implementing effective air quality management strategies and mitigating the associated health risks.

This study aims to investigate the concentration of $PM_{2.5}$ and PM_{10} along the Mymensingh-Gazipur Highway and analyse their spatial variation. By conducting a comprehensive assessment of air quality along this major roadway, this research will contribute to a better understanding of the air pollution problem in Bangladesh and provide valuable insights for policymakers and environmental scientists.

2. Materials and Method

2.1 Study Area

The study was conducted at various bus shelters along the Mymensingh to Gazipur highway routes. Sampling locations were selected randomly from Trishal, Signbord, Bhaluka, Seedstore, Square Masterbari, Joina bazar, Noyonpur, MC, Mawna, Hotapara, Rajandrapur, Porabari, Salna, Gazipur Chowrasta areas where high traffic volume occurs that can lead to significant vehicle emissions and dust generation, which are the major sources of $PM_{2.5}$ and PM_{10} emissions, especially during peak hours. The geographical coordinates of each sampling site were recorded using GPS and later used to create spatial distribution maps with GIS software, providing a detailed visual representation of air quality patterns along the highway.

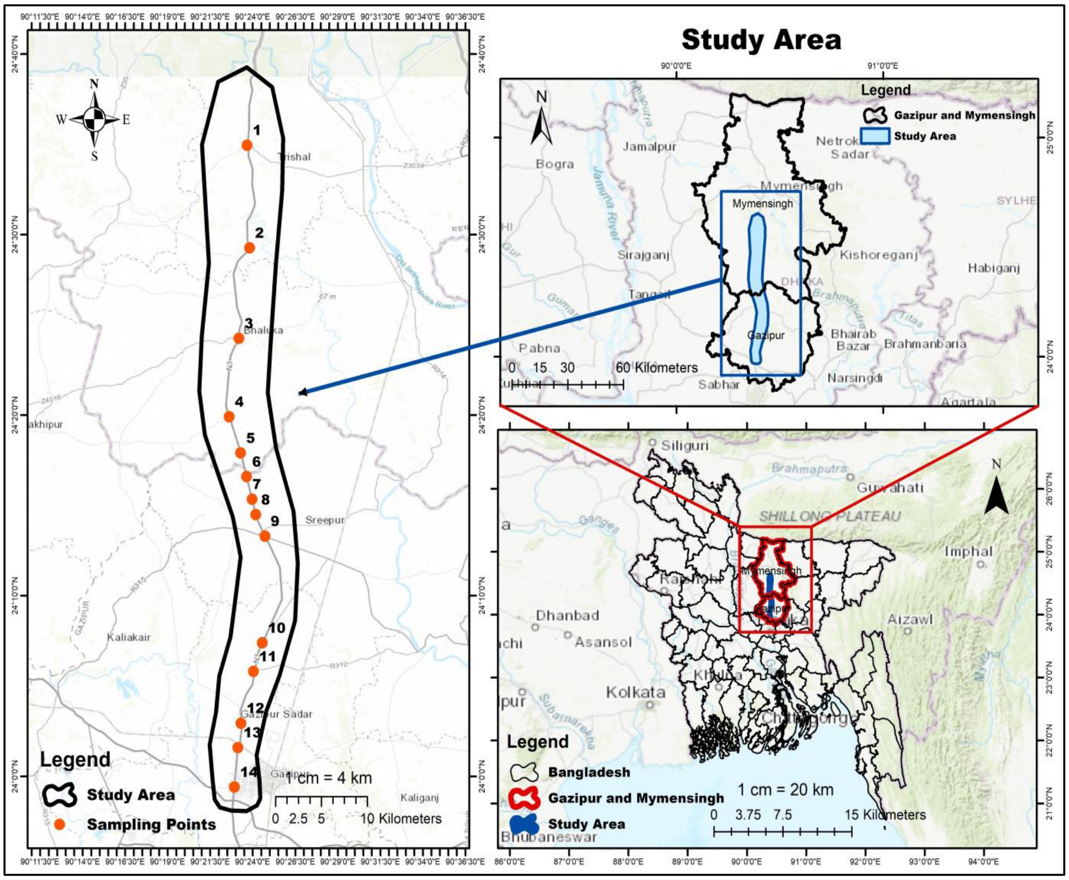

Figure 1: The map showing study area along the highway.

2.2 Data Collection

During the sampling period, the air quality data were collected from the study area by using an instrument air quality tester offered by Indian "Airveda". It was calibrated against laboratory-grade reference instruments prior to field deployment. The monitor uses high quality laser sensor to measure $PM_{2.5}$ and PM_{10}, calibrated against BAM (Beta Attenuation Monitor) which is the most advanced system for measuring ambient air quality. Data comparison with BAM reveals a correlation of more than 90%. The instrument has a special LED indicator that displays the condition of the air quality using an easy-to-read "traffic signal" color-coded, with green denoting "good" and red denoting “severe”. This study was conducted during the winter season. PMs levels were measured at three discrete time points throughout the day: morning (7:00-10:00 AM), noon (12:00-3:00 PM), and evening (5:00-7:00 PM). Future research should investigate potential seasonal variations in PMs levels. After selecting the sampling point, a map was created by using the ArcGIS 10.8 version. While collecting samples, the geographic coordinates were noted down using a GPS meter. The coordinates were first converted into decimal and then the points were calculated by the software and the points were displayed in the map.

Figure 2: Air quality measurement instrument (AIRVEDA).

2.3 Methodology framework & data processing analysis

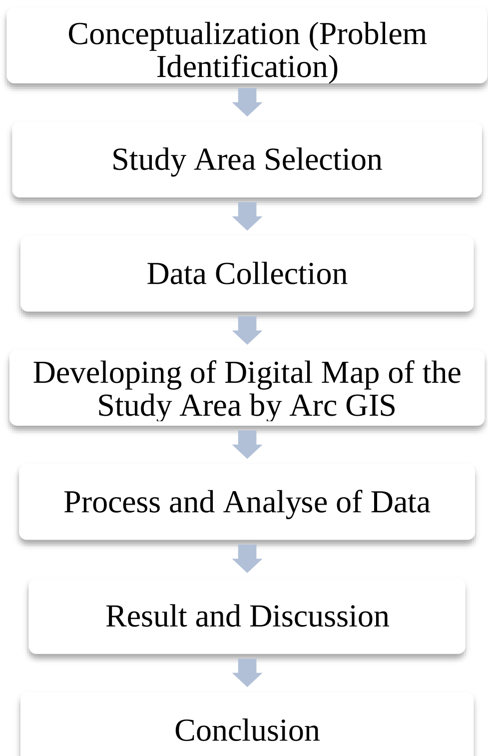

Figure 3: Schematic flow diagram of the methodology process.

The collected data was processed first and then the data was analysed using Microsoft Excel of Office 2019 version. The study area map was used and made by ArcGIS 10.8. Methodology is very important to determine a conceptual framework that helps to guide scientific investigation. It helps to understand how it is oriented to the study by organizing the research approach and linking it to the goal of the research.

3. RESULT AND DISCUSSION

Throughout the study period, data were collected from various locations between the Trishal to Gazipur highway routes. Sampling locations were selected randomly from Trishal, Sainbord, Bhaluka, Seed store, Square Masterbari, Joina bazar, Noyonpur, MC, Mawna, otapara, Rajandrapur, Porabari, Salna, Gazipur highway, in Gazipur district. The following table mentions PM 2.5 value and PM 10 value in this chapter.

3.1 Analysis the present concentration of $PM_{2.5}$ and PM_{10}

Table 1: Average PM Concentration values in 14 study areas (Morning, Noon, Evening) time.

Location Name	$PM_{2.5}$ (Morning)	$PM_{2.5}$ (Noon)	$PM_{2.5}$ (Evening)	PM_{10} (Morning)	PM_{10} (Noon)	PM_{10} (Evening)
Trishal	221	73	293	244	81	408
Signboard	220	151	323	240	167	351
Bhaluka	242	123	226	281	149	288
Seedstore	215	344	221	246	420	331
Square Masterbari	222	362	131	342	476	231
Joina	246	346	216	314	419	308
Noyonpur	242	382	423	381	518	507
MC Bazar	279	290	450	341	367	502
Mawna	232	363	421	297	569	608
Hotapara	308	209	337	336	231	410
Rajandrapur	256	245	405	343	382	490
Porabari	356	208	400	387	316	460
Salna	335	214	332	366	408	390
Gazipur Chowrasta	331	248	336	380	391	425

Table 1 lists the $PM_{2.5}$ and PM_{10} concentrations during collection period and from this table, below graphs are generated.

3.2 Comparison of $PM_{2.5}$ and PM_{10} concentration in study areas with BNAAQS and WHO Standard

The figures present a detailed comparison of $PM_{2.5}$ and PM_{10} concentrations measured at 14 locations along the Mymensingh-Gazipur Highway during morning, noon, and evening against the BNAAQS and WHO air quality standards. The results indicate that both pollutants consistently exceed permissible limits in all locations, with concentrations peaking at hotspots such as Gazipur Chowrasta, Mawna, and Hotapara. The top chart demonstrates that the observed levels frequently surpass the BNAAQS thresholds, especially during the noon and evening periods, highlighting the impact of increased vehicular emissions and industrial activities during these hours. Even in the morning, when traffic is relatively lower, pollution levels remain significantly above national standards, revealing the persistence of air quality issues throughout the day.

The bottom chart further emphasizes the severity of pollution when compared to the stricter WHO air quality guidelines. All measured concentrations far exceed WHO-recommended limits, with PM_{10} levels in certain locations peaking above 500 µg/m³, particularly during noon and evening. The stark exceedances underscore the dire state of air pollution along this highway and its potential health risks for nearby communities and commuters

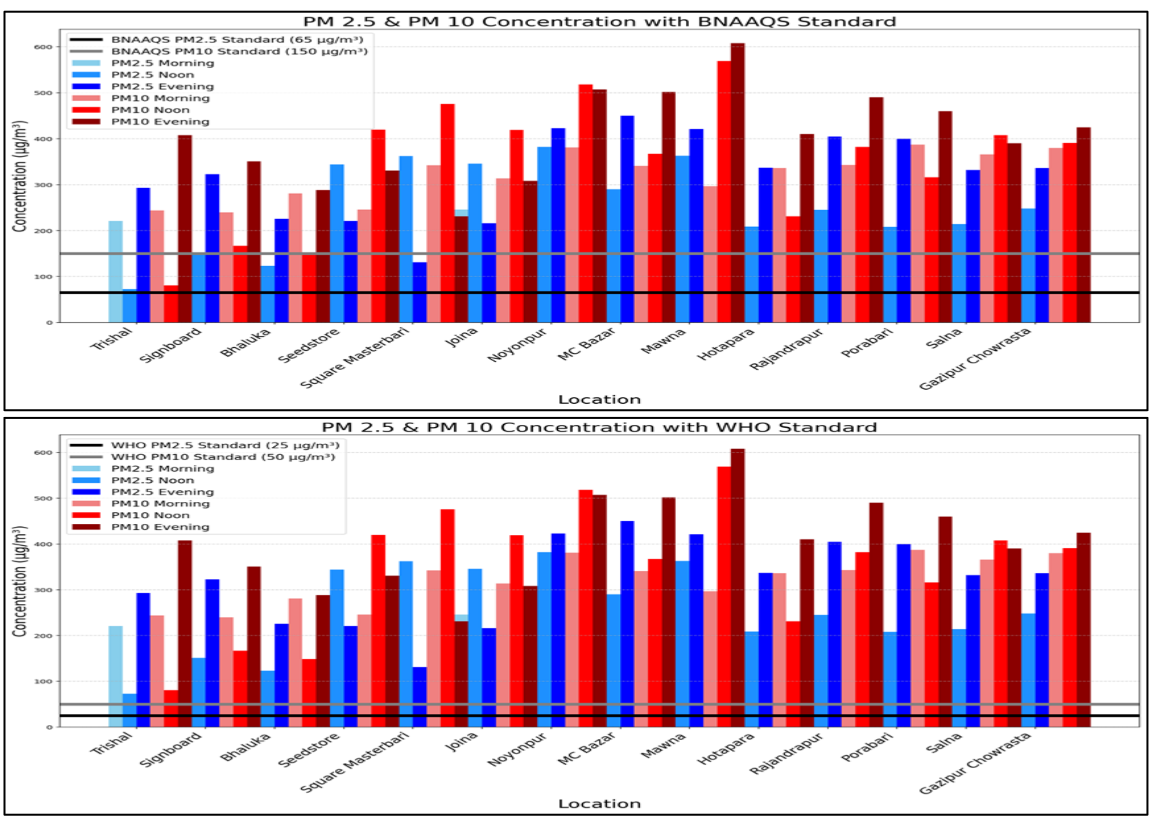

Figure 4: Comparison of $PM_{2.5}$ and PM_{10} concentrations at 14 locations along the Mymensingh-Gazipur Highway with BNAAQS (top) and WHO standards (bottom).

3.3 Understanding AQI colour indicators of $PM_{2.5}$ and PM_{10} concentration in study areas

Table 2: Classes of AQI values with identifying colour with range of PM concentration.

AQI (US EPA 2018)		
Air Category (Range)	PM2.5 (µg/m3) 24 hr	PM10 (µg/m3) 24 hr
Good (0-50)	0-30	0-50
Satisfactory (51-100)	30-60	50-100
Moderately Polluted (101-200)	60-90	100-250
Poor (201-300)	90-120	250-350
Very Poor (301-400)	120-250	350-430
Severe (401-500)	250+	430+

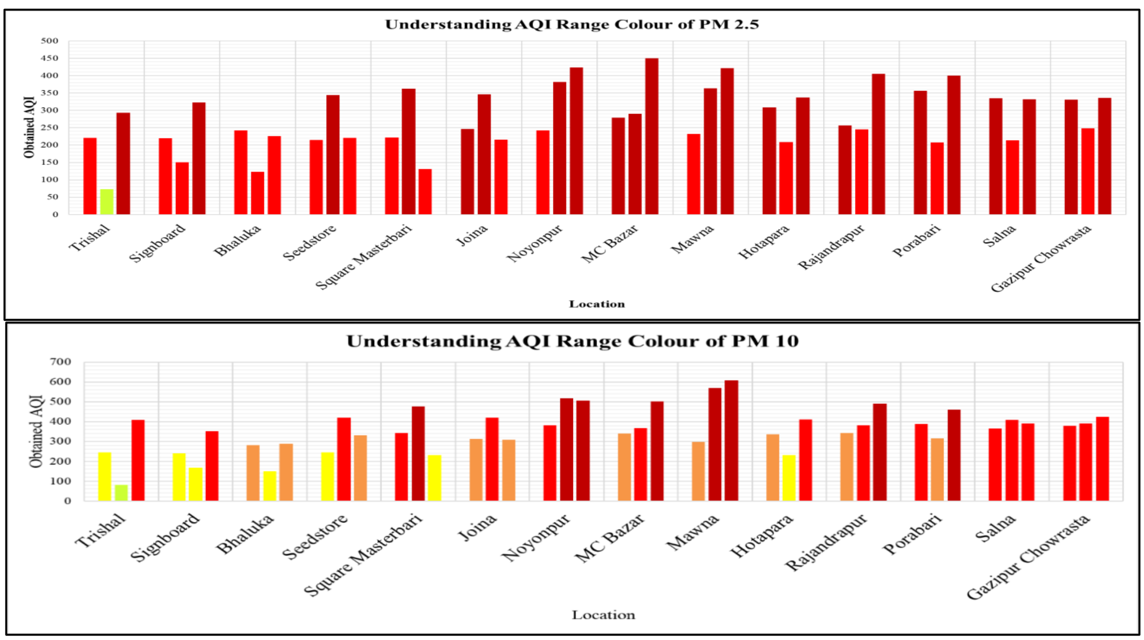

Figure 5: Understanding AQI range color for $PM_{2.5}$(top) and PM_{10}(bottom) across locations along the Mymensingh-Gazipur Highway.

The figure 5 (top) clearly shows the present situation of 14 sampling $PM_{2.5}$ concentration data with the AQI color range indicator, which was approved by USEPA in 2018. Here, it showed a fully severe situation at Mawna, and Noyonpur in the noon and evening. The recorded maximum average highest value is 450 µg/m3 in the evening at MC bazar and the recorded maximum average lowest value is 73 µg/m3 at the Trishal bus stand. For Mawna, a very poor situation was recorded at noon and in the morning. Porabari, Rajandropur showed a fully severe situation in the morning and evening while a very poor situation at noon. Gazipur, Highway shows a very poor situation, respectively, in the morning and evening. The first location is Trishal, which shows a very poor situation in the morning, a severe situation in the evening, and a satisfactory situation at noon, respectively. MC Bazar shows fully severe situation in all three-specific time during data collection.

The figure 5 (bottom) clearly shows the present situation of 14 sampling PM_{10} concentration data with the AQI colour range, which was approved by USEPA in 2018. Here, it showed a fully severe situation at Mawna and Noyonpur for noon and evening. Recorded maximum average highest value is 608 µg/m3 in the evening at Mawna. And recorded maximum average lowest value is 81 µg/m3 at the Trishal bus stand. For Mawna, fully severe situation was recorded at noon and evening, and a poor situation in the morning. The location of Noyonpur shows a fully severe situation at noon and evening and a very poor situation in the morning. MC Bazar shows severe pollution in the evening, a very poor situation at noon, and a poor situation in the morning. The Gazipur Highway shows a very poor situation, respectively, in the morning, evening, and noon. Signboard and Seedstore showed a moderately polluted situation in the morning. Bhaluka shows a poor situation in the morning and evening, while the situation is moderate at noon.

3.4 Spatial Variation of PM Concentration in Sampling Points through Arc GIS map

Spatial Variation gives a better visualization to mark the higher concentration in generating grids. This Section presents the spatial distribution of PM concentration in GIS maps. Every figure shows PM concentration in different grids by various shades of colour, where dark red means severe, red means very poor, orange means poor, yellow means moderately polluted, light green is satisfactory, and dark green indicates good for each 14 locations.

Figure 6 shows the $PM_{2.5}$ concentration, where it is easy to notice that the $PM_{2.5}$ concentration is much higher in the evening than morning & noon, which is visualized by the red color that indicates a very poor situation & the range is (396-450µg/m3), & those ares shows it is found at Noyonpur, MC Bazar, Mawna and Rajandrapur.

Figure 7 show the PM_{10} concentrations where it is easy to notice that the PM_{10} concentration is much higher in the evening and after in the noon than morning, which is visualized by red colour that indicates a very poor situation & the range is (600+ µg/m3) l.

Different amounts of particle pollution are indicated by distinct colours or shadings for each zone on this each map. A colour scale for evaluating pollution levels is provided in the map's legend.

3.4.1 Spatial Variation of $PM_{2.5}$

Top Left Map: Spatial Variation of $PM_{2.5}$ in the Morning

This map depicts the spatial distribution of $PM_{2.5}$ concentrations during the morning hours (7:00–10:00 am). The map clearly shows a concentration gradient, with higher $PM_{2.5}$ levels observed in the southern part of the study area, particularly around Gazipur Chowrasta (location 14). This suggests potential sources of $PM_{2.5}$ emissions or accumulation in this region during the morning. The northern areas, around Trishal (location 1), exhibit relatively lower concentrations.

Top Right Map: Spatial Variation of $PM_{2.5}$ in the Noon

This map presents the $PM_{2.5}$ concentration levels during noon (12:00–3:00 pm). A pronounced increase in $PM_{2.5}$ levels is evident across many parts of the highway, especially in the central and southern sections. This can be attributed to higher traffic volumes and lower dispersion of pollutants during this time. The red and orange zones dominate, indicating unhealthy air quality conditions for sensitive groups in these areas. The results of this data analysis showed that $PM_{2.5}$ values varied within 73 – 382 µg/m3. "Trishal bus stand" has the least $PM_{2.5}$ concentration of 73 µg/m³. On the other end, 'Noyonpur' has the highest $PM_{2.5}$ concentration of 382 µg/m³.

Bottom Map: Spatial Variation of $PM_{2.5}$ in the Evening

The map displays $PM_{2.5}$ concentration levels during evening (5:00–7:00 pm). Pollution levels remain elevated, with southern and central regions showing the highest concentrations (orange and red zones). The persistence of elevated $PM_{2.5}$ levels in these areas can be linked to peak traffic congestion during this period and limited atmospheric ventilation. The data analysis's findings show that $PM_{2.5}$ levels in the investigated locations varied from 131 to 450 µg/m3. "MC Bazaar" has the highest $PM_{2.5}$ concentration of 450 µg/m³, while "Square Masterbari" has the lowest concentration of 131 µg/m³.

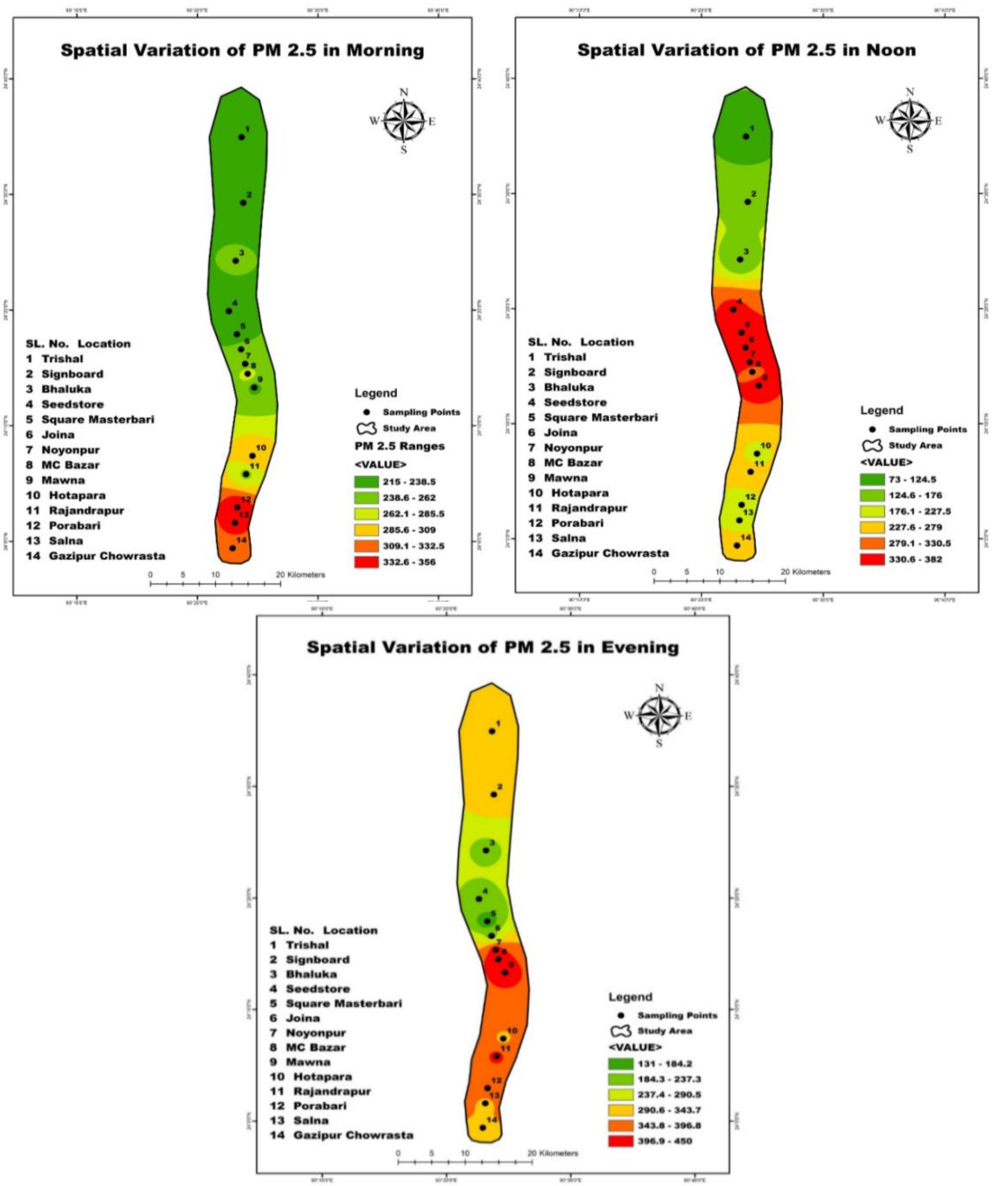

Figure 6: Spatial variation of $PM_{2.5}$ concentrations along the Mymensingh-Gazipur Highway during morning (7:00–10:00 am), noon (12:00–3:00 pm), and evening (5:00–7:00 pm).

3.4.2 Spatial Variation of PM_{10}

Top Left Map: Spatial Variation of PM_{10} in the Morning

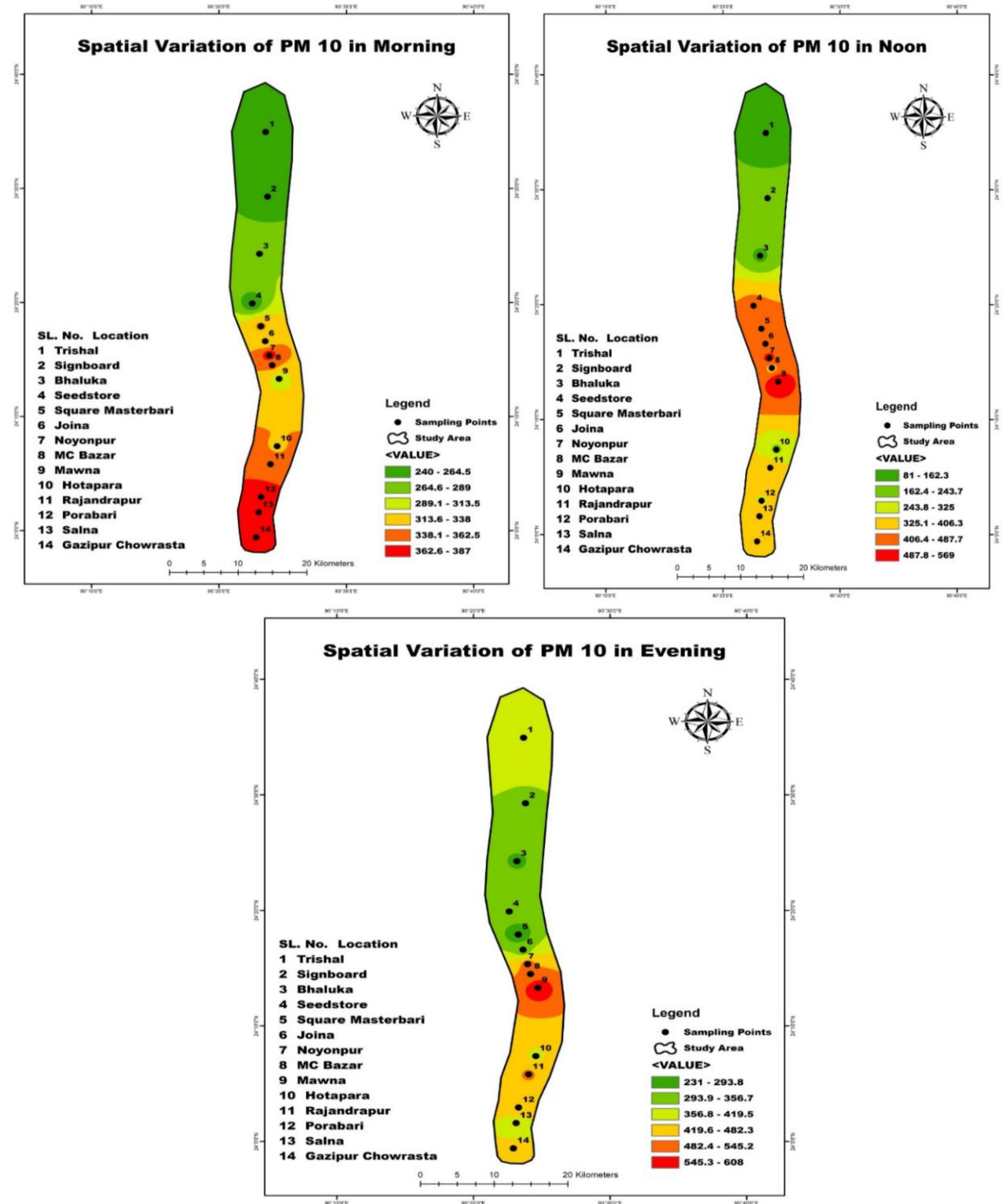

Figure 7: Spatial variation of PM_{10} concentrations along the Mymensingh-Gazipur Highway during morning (7:00–10:00 am), noon (12:00–3:00 pm), and evening (5:00–7:00 pm).

This map illustrates the spatial distribution of PM_{10} concentrations during the morning period within the study area. Higher concentrations are observed in the southern region, particularly towards Gazipur Chowrasta (location 14), suggesting potential sources or factors contributing to elevated pollution levels in this area during the morning hours. The northern part of the study area, around Trishal (location 1), exhibits relatively lower PM_{10} concentrations.

3.5 Correlation between particulate matter with temperature and humidity

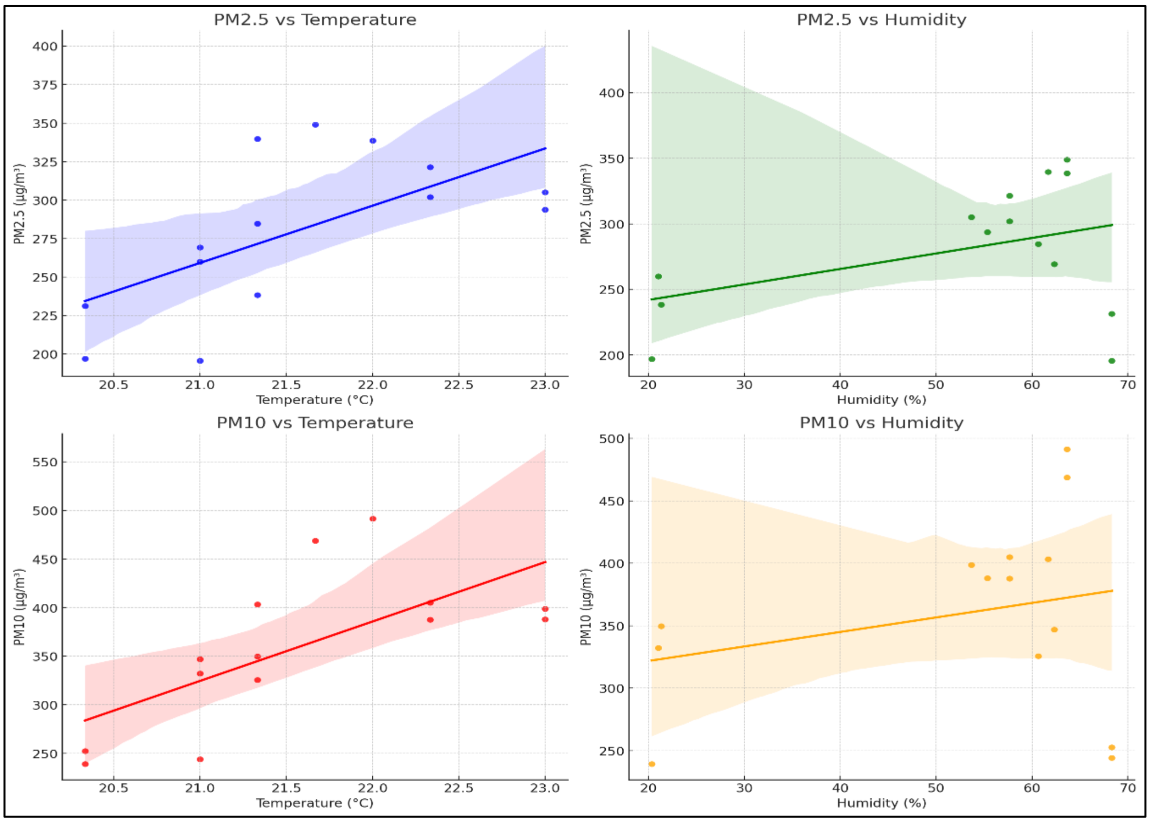

Figure 8: Correlation between particulate matter with temperature and humidity.

Top Right Map: Spatial Variation of PM_{10} in the Noon

The midday PM10 distribution, as depicted in this map, reveals a similar trend to the morning pattern. The southern region, especially around Gazipur Chowrasta, continues to experience high PM_{10} concentrations. Additionally, the area near Square Masterbari (location 5) also shows elevated levels, indicating a possible localized source or accumulation of pollutants. The persistence of high concentrations in these areas suggests consistent contributing factors throughout the morning and noon periods.

Bottom Map: Spatial Variation of PM_{10} in the Evening

This map presents the spatial variation of PM_{10} concentrations during the evening. While the southern region near Gazipur Chowrasta remains a hotspot, the overall distribution pattern shows some variations compared to the morning and noon periods. The area around Hotapara (location 10) also exhibits relatively higher concentrations in the evening. This shift in the distribution pattern may be attributed to changes in emission sources, meteorological conditions, or other influencing factors during the evening.

Numerous researches have mostly focused on the function of temperature, humidity, and other climatic factors for the change of PM levels since atmospheric dispersion is primarily responsible for the accumulation of PM particles in the air. Due to increased photochemical activity at higher temperatures, several studies found a positive relationship between temperature and particle matter (Kavouras & Chalbot, 2017; Gu *et al.,* 2022; Zhang *et al.,* 2010). A positive correlation was observed between $PM_{2.5}$ levels and temperature, particularly in the morning and evening. Higher $PM_{2.5}$ concentrations were recorded in locations with average temperatures above 22°C. This relationship may be attributed to reduced atmospheric mixing at higher temperatures, which traps pollutants closer to the surface. PM 10 levels exhibited a strong positive correlation with temperature, particularly in the morning. Higher PM_{10} concentrations were consistently recorded at locations with temperatures exceeding 21°C, suggesting limited pollutant dispersion under stable atmospheric conditions.

Most of the studies have examined that, relative humidity remains positively correlated with PM concentration (Lou *et al.,* 2017). $PM_{2.5}$ levels showed a strong positive relationship with humidity during the evening. Higher humidity (above 60%) appeared to enhance particulate matter concentrations, likely due to the hygroscopic growth of particles and the formation of secondary aerosols. A moderate positive relationship was found between PM_{10} levels and humidity, particularly during the evening. Elevated humidity likely promotes particle growth, which increases PM 10 concentrations.

3.6 Potential PM Pollution Sources in the observed study Area

Identifying the specific sources of $PM_{2.5}$ and PM_{10} is critical for understanding the factors driving air quality degradation within the highway. This research investigates the sources of particulate matter (PM) pollution in the study area, focusing on $PM_{2.5}$ and PM_{10}. The subsequent section delves into potential and observes PM sources, such as:

1. Vehicle emissions: Vehicle emission are a significant contributor to $PM_{2.5}$ and PM_{10} pollution along highways. The high volume of traffic in specific locations, such as Trishal bus stand, Noyonpur, MC Bazar, Mawna, Salna, Gazipur Chowrasta leads to the combustion of fossil fuels, resulting in the release of particulate matter into the atmosphere.

2 Road dust: Road dust is a significant contributor to particle pollution, especially in areas with heavy traffic. The sources of road dust form are vehicle tires, road wear, wind erosion, etc. Higher traffic volume and speeds lead to more intense tire-road contact, generating more dust Construction activities are known to generate significant amounts of dust, thereby contributing to PM pollution.

3. Ongoing construction projects and demolition activities: Ongoing construction projects and areas with demolition activities, such as Bhaluka, Seedstore, Square Masterbari, Joina MC Bazar, Mawna, Hotapara, and Gazipur Chowrast are likely to exhibit higher levels of particulate matter. These areas serve as hotspots for PM pollution, as the dust particles released during construction and demolition activities become suspended in the air and can be easily transported by currents.

Moreover, during data collection near the highway many industries and factories were observed where numerous processes with several facilities were found to be responsible for PM pollution.

4.CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This study provides a comprehensive analysis of $PM_{2.5}$ and PM_{10} concentrations along the Mymensingh-Gazipur Highway, highlighting the alarming levels of air pollution caused primarily by vehicular emissions and associated activities. The findings reveal that the recorded PM concentrations at all sampling points significantly exceed the World Health Organization (WHO) and Bangladesh National Ambient Air Quality Standards (BNAAQS), indicating severe air quality degradation throughout the region. Spatial variation analysis identified hotspots, particularly around bus shelters and high-traffic zones, emphasizing the need for targeted intervention. The results showed severe pollution at sampling locations, clearly depicted in the spatial variation maps. The maximum PM_{10} value recorded was 608 µg/m³, and the lowest $PM_{2.5}$ concentration was 83 µg/m³, both of which are very high. This underscores the urgent need for measures to mitigate PM pollution and protect public health. Dealing with particulate matter requires finding its sources, among other measures. They pose significant hazards to any environment and to health. There is an urgent need for action by policymakers, town planners, and environmental organisations in regard to improving air quality, limiting health risks, and fostering development that does not degrade the environment. Over the long term, addressing PM pollution will require working collaboratively across sectors, engaging stakeholders, and raising awareness among the public. Minimizing concentrations of particulate pollution is necessary to manage particulate emissions more effectively.

4.2 Recommendations

To tackle PM pollution and improve air quality, we need a well-rounded approach. This means improving traffic management by encouraging public transportation and cycling, which can help cut down on vehicle emissions. We also need to strengthen air monitoring networks to get a clearer picture of air quality trends. Investing in green transportation, like electric vehicles and hydrogen fuel cells, is key to reducing pollution from vehicles. In construction and demolition, we should promote water spraying and eco-friendly practices to limit dust and debris. Finally, setting up emissions testing for vehicles will ensure that they comply with environmental standards, helping to keep our air cleaner.

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APPENDIX

Figure A. 1: Picture of Data Collection at Gazipur Chowrasta.

Figure A. 2: Picture of Data Collection at Nayonpur.

Figure A. 3: Picture of Data Collection by airveda