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Investigating Variability of Roadside Air Pollution and Its Association with Traffic Volume in Urban Areas, Bangladesh

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ABSTRACT

Globally, air pollution has now become one of the most serious threats to human health. This situation is very dire at roadside areas and poses adverse health outcomes, especially in developing countries experiencing rapid urbanization and industrialization, such as Bangladesh. This study aims to investigate seasonal variation at roadside environments air pollution and its association with traffic volume in an urban area (Gazipur City), Bangladesh. Measurements of air pollutant ($PM_{2.5}$) and traffic volume were estimated from seven different locations in Gazipur by using Aeroqual sensor and digital devices, respectively, during two distinct seasons (winter and summer) in 2024. Simple linear regression was used to estimate the association between roadside air pollution and traffic volume. Results indicated that the average $PM_{2.5}$ concentration varied from 192 to 324 µg/m3 during winter and 27 to 72 µg/m3 during summer. Concentrations were highest in the morning, particularly during winter (311 µg/m³), approximately 36% higher than in the afternoon. Results also revealed that there is significant seasonal variation of roadside air pollution. During winter, the average $PM_{2.5}$ concentration was 4.84 times higher than in the summer season. Additionally, air pollution showed significant association with traffic, explaining up to 92% and 77% of the variance in the winter and summer season, respectively. These findings highlight the importance of tighter control policies (such as proper maintenance of the vehicles, stricter fuel quality standards, phasing out unfit vehicles, proper traffic management etc.) aimed at lowering long-term average roadside air pollution levels and reducing traffic's contribution to air pollution.

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INTRODUCTION

Air pollution is one of the most significant risk factors for human health around the world, and it is responsible for more than 6.7 million premature deaths annually (WHO, 2022). Exposure to air pollutants has a wide range of negative health impacts including increased mortality and morbidity (Manisalidis et al., 2020). Among these pollutants, particulate matter (PM) is one of the most critical indicators of urban air quality, as it represents a complex mixture of solid and liquid particles suspended in the air (Mukhopadhyay et al., 2021). Urban roadside environments in developing countries experience particularly high $PM_{2.5}$ (fine particulate matter with an aerodynamic diameter of ≤ 2.5 μm) concentrations due to dense and poorly regulated vehicular movement (Huang et al., 2021). Vehicle exhaust, resuspended road dust, and fuel combustion collectively contribute to elevated fine particulate levels, making traffic one of the dominant sources of $PM_{2.5}$ pollution (Anenberg et al., 2017; Huang et al., 2020). The variability of PM concentrations is strongly influenced by different factors including traffic volume, vehicle type, fuel quality, and meteorological conditions (Rahman, 2024; Simeunović et al., 2023). Besides air pollution, road traffic also contributes to other environmental externalities, including noise pollution, which imposes significant health and social costs (Amini et al., 2024).

Air pollution, particularly on roadsides, shows seasonal variation over the year (Vandeninden et al., 2025). Multiple studies have analyzed and explained both long-term and short-term trends, seasonal variations, and patterns occurring within a year for air pollution. It exhibits a strong seasonal pattern, with higher levels in winter and lower levels in spring and summer (Alam et al., 2025). Additionally, pollutants associated with traffic were also greater in winter compared to the other seasons. Particle number concentrations peaked in the winter, followed by the spring, and reached their lowest levels in the summer and fall (Padró-Martínez et al., 2012). The primary factors that exert influence are the moist oceanic summer monsoon and the arid continental winter monsoon (Cheng et al., 2006). Besides this, traffic volume is one of the significant factors that determine fluctuation at roadside locations air pollution over time (Hung-Lung & Yao-Sheng, 2009).

Bangladesh has been grappling with air pollution for many years. Between 2018 and 2021, Bangladesh became the most polluted country in the world, with an average $PM_{2.5}$ concentration 15.4 times higher than the standard level (Akter et al., 2026; IQAir, 2022). The degradation of air quality is mostly due to widespread urbanization, increased vehicular traffic, and lack of regulation of vehicle emissions (Rahaman & Kalam, 2023). In major cities like Dhaka, roadside and highway traffic frequently surpass national air-quality standards (Begum & Hopke, 2018). In addition, air quality trends in Bangladesh over the previous decade exhibit significant seasonal fluctuations, surpassing the national criteria during the dry season but maintaining slightly below the standards during the rainy season due to stagnant meteorological conditions and reduced rainfall (M. M. Islam et al., 2015). Additionally, the air quality of roadsides in several cities in Bangladesh is extremely poor (Kudrat-E-Khuda, 2020). Vehicular exhaust, re-suspended road dust, and non-exhaust sources contribute substantially to the degradation of air quality (IQAir, 2024).

The present study reveals some novel aspects. Existing literature mainly focused on the overall air pollution scenario through inter-seasonal measurement in Bangladesh. So far, there has been found very limited study conducted on roadside air pollution and its traffic contributions in Bangladesh. Besides this, most of the existing literature regarding the air pollution domain in Bangladesh is Dhaka- or divisional-city-based; other parts of Bangladesh are hardly concentrated. Very limited evidence exists examining seasonal variation and traffic associations simultaneously in Bangladesh. To our knowledge, no previous study has investigated roadside air pollution variability and its association with traffic volume across different seasons. Furthermore, urban areas are the major air pollution hubs in Bangladesh that seeks further investigation due to high population density, industrial activity, and vehicular emissions. This study addresses these critical gaps by investigating the variability of roadside air pollution and its association with traffic volume in Urban areas of Bangladesh. The goal is to reveal crucial connections between traffic volumes with air pollution and seasonal variation that can be used for a better understanding of air pollution mechanisms. The findings from this study might be used as a background indicator for similar contexts in many developing countries. However, the present study will equip policymakers with precise guidelines to design effective initiatives for lowering roadside air pollution in Bangladesh.

MATERIALS & METHODS

Study setting

This study includes seven different locations from Gazipur City, Bangladesh. These are Tongi, Konabari, Gazipur Bypass, Masterbari, Zirani, Mirerbazar, and Kashimpur. The data was collected from roadside points in these areas conveniently. Gazipur City has serious air pollution issues owing to rising urbanization, high industrial activity, vehicle emissions, and biomass burning (M. S. Islam, 2014). The study area exhibits a significant volume of vehicles, leading to elevated levels of vehicular emissions and consequent air pollution.

Study period

The data collection was carried out during two distinct seasons, namely summer and winter, to capture possible seasonal variations at roadside locations air pollution levels. The study's sampling period for the winter period was from January 23rd, 2024, to January 31st, 2024, encompassing a total of seven days, excluding weekends. The summer sampling period was designated as May 21st to June 1st, 2024, with a total of 7 days excluding weekends. The monitoring period began in the morning (8am) and lasted until late afternoon (6pm).

Air pollution data collection

Air pollution data was measured by using a portable handheld air quality sensor named Aeroqual (Series 500). The sensors were factory-calibrated to ensure accuracy and reliability for both indoor and outdoor settings (Kiurski et al., 2022); this instrument has been used in existing literature (Indu & Shiva Nagendra, 2023; Kiurski et al., 2022; Kranrod et al., 2024). The accuracy of the sensor was further validated by deploying the Aeroqual sensor adjacent to reference equipment at a government-run Continuous Air Monitoring Station (CAMS) on the Department of Environment (DoE) campus in Dhaka, Bangladesh. The coefficient of determination (R^2) for this co-location was 0.83. For this study, the sensor was placed conveniently on the nearest side of the road for measuring $PM_{2.5}$ in terms of air pollution. Measurements were conducted over a seven-day period in each season. After the measurement, the air pollution data were averaged hourly (e.g., 8am to 9am, 9am to 10am). Then, the mean air pollution concentration at each location was classified with time as morning (8am to 10am), late morning (10am to 12pm), afternoon (12pm to 3pm), late afternoon (3pm to 6pm) to observe finer-scale peak activity patterns and more effectively resolve diurnal fluctuations (Chen et al., 2015).

Traffic data collection

To measure the association between roadside air pollution and traffic volume, this study obtained traffic data for individual road segments and corresponding locations by using a digital device (Samsung Galaxy Tab A). The present study recorded a total number of vehicles that emit air pollutants and passed by the road from 8am to 6pm (such as buses, mini-buses, micro-buses, private cars, trucks, motorbikes, pick-up/cargo/covered vans, taxicabs, auto-rickshaws/ CNG [Compressed Natural Gas], human haulers) (Kawsar et al., 2022). Then, the traffic data was averaged per hour (e.g., 8am to 9am, 9am to 10am).

Data analysis

The Statistical Package for Social Sciences (SPSS version 25.0) and Microsoft Excel (version 2021) were applied for analyzing the data. Microsoft Excel has been used for the purposes of cleaning, coding, and sorting. The descriptive statistics (i.e., frequencies, percentages, means, medians, and standard deviations) were subsequently determined, and the Excel file was loaded into the SPSS program. Then, to determine whether there were statistically significant differences in mean $PM_{2.5}$ concentrations between winter and summer seasons at the same roadside locations, a paired-samples t-test was performed. To further evaluate the impact of traffic on air pollution, this study applied simple linear regression to estimate the average concentration of pollutant per hour at each location based upon the number of total vehicles at the location per hour from the traffic statistics. This relationship is expressed by the following equation:

$$y = \beta_0 + \beta_1 x_1$$

where y is the dependent variable (i.e., average air quality concentration per hour), β represents the regression coefficients, and x represents the independent variable (i.e., the volume of traffic per hour). A p-value less than 0.05 was regarded as significant for all sorts of analyses.

RESULTS

Average roadside air pollutant concentration in Gazipur City during winter: The average roadside $PM_{2.5}$ concentrations in different locations of Gazipur City during winter are presented in Table 1. Results highlighted that air pollution levels varied significantly depending on location and time. However, air pollution was consistently above acceptable ambient levels at all locations and at all times. The highest $PM_{2.5}$ concentration was found in Zirani [(382 µg/m^3), in the morning], and the lowest $PM_{2.5}$ concentration was found in Kashimpur [(135 µg/m^3), in the late afternoon]. Additionally, the morning average $PM_{2.5}$ concentration in all locations of Gazipur (311 µg/m^3) was at its peak in winter compared to other times, almost 36% higher than afternoon time.

Table 1. Average roadside $PM_{2.5}$ concentration in different locations of Gazipur City during winter

Location	Air pollutant $PM_{2.5}$ concentration (µg/m^3)			
	Morning (8 am – 10 am)	**Late morning (10 am – 12 pm)**	**Afternoon (12 pm – 3 pm)**	**Late afternoon (3 pm – 6 pm)**
Tongi	354 (280-606)	311 (183-519)	226 (157-375)	229 (152-416)
Konabari	315 (272-445)	299 (269-398)	320 (267-478)	352 (306-434)
Gazipur Bypass	218 (166-315)	297 (235-411)	253 (197-330)	254 (209-360)
Masterbari	320 (253-393)	327 (292-376)	283 (245-340)	292 (244-354)
Zirani	382 (348-416)	313 (230-388)	186 (122-271)	181 (141-237)
Mirerbazar	309 (218-555)	204 (117-569)	161 (77-688)	185 (76-574)
Kashimpur	282 (234-322)	214 (181-269)	174 (122-312)	135(80-249)
Average	311 (166-606)	281 (117-569)	229 (77-688)	233 (76-574)

Average roadside air pollutant concentration in Gazipur City during summer

Table 2 shows the average roadside $PM_{2.5}$ concentration in different locations of Gazipur City during summer. Results indicated that the air pollution varied broadly depending upon the location and time period, but air pollution levels in all locations were above acceptable ambient levels at all times. The highest $PM_{2.5}$ concentration was found in Mirerbazar (90 µg/m^3; in the afternoon). Additionally, the lowest $PM_{2.5}$ concentration was found in Gazipur Bypass (24 µg/m^3; in the late morning). The average $PM_{2.5}$ concentration in all locations of Gazipur city during summer were relatively similar across different times of the day.

Average daytime air pollutant concentration across roadside locations in Gazipur City

Average daytime (from 8 am to 6 pm) $PM_{2.5}$ concentrations across roadside locations in Gazipur City are shown in Figure 1. During winter, the highest $PM_{2.5}$ concentrations were found in Konabari (324 µg/m^3), and the lowest $PM_{2.5}$ concentrations were found in Kashimpur (192 µg/m^3). During summer, the highest and lowest $PM_{2.5}$ concentrations were found in Mirerbazar (72 µg/m^3), and Gazipur bypass (27 µg/m^3), respectively. The average $PM_{2.5}$ concentration of

Table 2. Average roadside $PM_{2.5}$ concentration in different locations of Gazipur City during summer

Location	Air pollutant $PM_{2.5}$ concentration (µg/m^3)			
	Morning (8 am – 10 am)	**Late morning (10 am – 12 pm)**	**Afternoon (12 pm – 3 pm)**	**Late afternoon (3 pm – 6 pm)**
Tongi	56 (27-132)	57 (21-253)	62 (24-321)	76 (34-208)
Konabari	87 (37-194)	56 (35-194)	63 (37-105)	69 (38-166)
Gazipur Bypass	25 (14-62)	24 (5-63)	24 (11-84)	33 (14-75)
Masterbari	42 (38-48)	42 (29-75)	44 (28-84)	44 (15-117)
Zirani	60 (32-162)	33 (22-75)	35 (23-59)	50 (24-112)
Mirerbazar	60 (31-112)	65 (30-168)	93 (41-235)	62 (29-236)
Kashimpur	44 (24-137)	48 (36-125)	53 (30-105)	60 (30-256)
Average	53 (14-194)	46 (5-253)	53 (11-321)	56 (14-256)

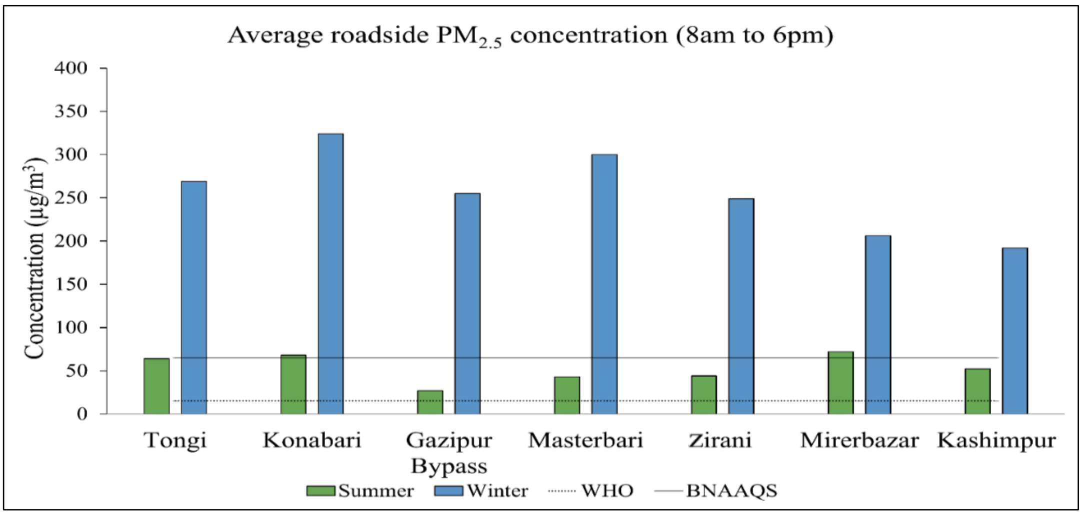

Fig. 1. Average daytime $PM_{2.5}$ concentration across roadside locations in Gazipur City. [WHO- World Health Organization; BNAAQS- Bangladesh National Ambient Air Quality Standards]

all the locations in Gazipur exceeded national and international air quality standards levels during winter. During summer, the $PM_{2.5}$ concentration of all the locations in Gazipur exceeded the WHO (World Health Organization) air quality standards, but in most places, the $PM_{2.5}$ concentration remained normal according to the Bangladesh National Ambient Air Quality Standards (BNAAQS).

Seasonal variation of air pollutant concentration across roadside locations in Gazipur City

Seasonal variations of average daytime $PM_{2.5}$ concentration across roadside locations in Gazipur City are presented in Figure 2. It showed that $PM_{2.5}$ concentration during winter was much higher than during summer and revealed a significant difference ($p < 0.05$). Gazipur bypass, Zirani, and Masterbari showed the highest seasonal variation compared to others; the $PM_{2.5}$ concentration of that area was 9.44 times, 5.66 times, and 6.98 times higher, respectively, during winter than summer. Other locations in Gazipur showed considerable variation too. The $PM_{2.5}$ concentrations in Tongi, Konabari, and Kashimpur were 4.2 times, 4.77 times, and 3.69 times higher during the winter than the summer season. However, Mirerbazar showed the lowest seasonal variation (2.86 times more in winter).

Differences in the distribution of air pollutant concentration in Gazipur City

The mean air pollutant ($PM_{2.5}$) concentration in all locations of Gazipur significantly increased during winter compared to summer ($p < 0.05$). This finding is represented by Figure 3, which illustrates the distribution of the mean air pollutant concentrations during winter and summer across all seven locations. The average $PM_{2.5}$ concentration were 4.84 times higher during winter compared to summer, respectively. It showed a statistically significant difference ($p < 0.05$).

Assessment of traffic volume during different seasons in Gazipur City

Traffic volume per hour during winter in Gazipur City is presented in Table 3. Results indicated that the number of vehicles varied from 523 to 875 and showed fluctuation throughout the time. The traffic volume was found to be high in the morning time; gradually it started

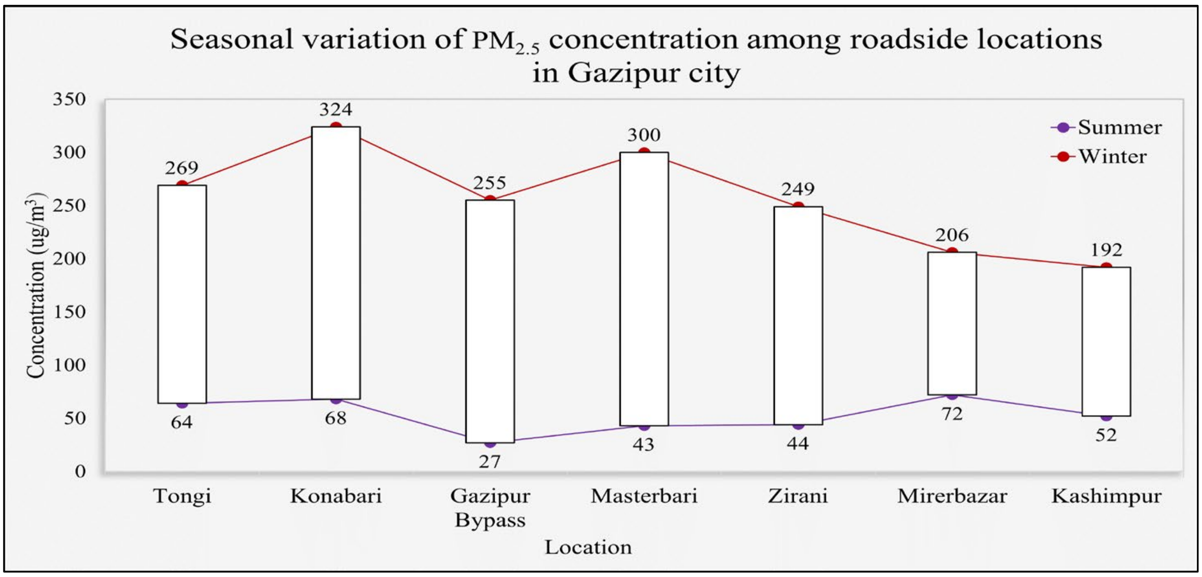

Fig. 2. Seasonal variation of $PM_{2.5}$ concentration across roadside locations in Gazipur City

to decrease slightly, and it started to increase again in the afternoon. Additionally, the higher number of traffic volume was found in the place of Tongi and Konabari, comparatively.

Traffic volume per hour during summer in Gazipur City is presented in Table 4. Results showed that the number of vehicles fluctuated between 513 and 874. The higher number of vehicle volumes were found in the locations of Konabari and Masterbari, compared to other locations. Furthermore, the morning and afternoon times indicated a higher number of vehicles in almost all the locations. However, trends in traffic in different locations of Gazipur in two distinct seasons are presented in Figure 4. The average traffic volume was almost the same quantity in both in the summer and winter seasons.

Association between roadside air pollutant and traffic volume in Gazipur City

Linear regression was utilized to forecast the mean level of pollutant for each hour at each location based on the quantity of traffic per hour during the measurement time frame (8am-6pm) in both winter and summer. The results demonstrated that the association fluctuated

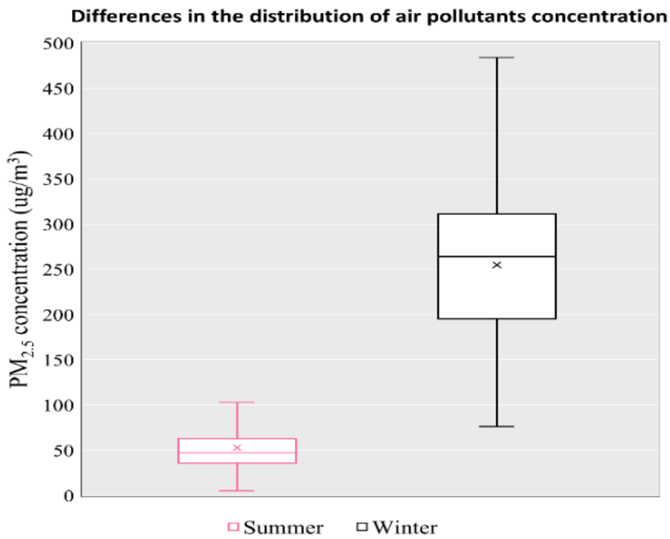

Fig. 3. Differences in the distribution of air pollutant concentration in Gazipur City

Table 3. Traffic volume per hour during winter in Gazipur City

Time duration (per hour)	Total number of pollutant-emitting vehicles by location						
	Tongi	**Konabari**	**Gazipur bypass**	**Masterbari**	**Zirani**	**Mirerbazar**	**Kashimpur**
8 am to 9 am	841	811	601	746	796	795	734
9 am to 10 am	829	823	723	816	832	711	672
10 am to 11 am	875	800	765	795	790	623	634
11 am to 12 pm	807	755	752	801	689	652	628
12 pm to 1 pm	764	773	706	713	680	678	588
1 pm to 2 pm	787	780	730	722	610	598	586
2 pm to 3 pm	711	850	687	730	598	624	523
3 pm to 4 pm	755	830	731	632	651	710	676
4 pm to 5 pm	867	815	702	701	602	596	567
5 pm to 6 pm	844	851	796	781	671	759	721

significantly based on the location and pollutant (Figure 5). During winter, the $PM_{2.5}$ pollutant showed a strong linear association with traffic, explaining up to 92% of the variance as indicated by the R^2 (coefficient of determination) value. Zirani showed a very strong linear association ($R^2 = 0.92$). Additionally, very strong associations were found in Konabari ($R^2 = 0.72$), Gazipur Bypass ($R^2 = 0.67$), and Masterbari ($R^2 = 0.78$); strong relationships were found in Mirerbazar ($R^2 = 0.49$); and moderate associations were found in Kashimpur ($R^2 = 0.24$) and Tongi ($R^2 = 0.33$). All the locations showed statistically significant association except Kashimpur and Tongi ($p < 0.05$). During summer, PM2.5 pollutant showed a strong linear association with traffic, explaining up to 77% of the variance as indicated by the R^2 value. Gazipur Bypass and Tongi showed the very strong association ($R^2 = 0.77$ and $R^2 = 0.72$, respectively). Additionally, strong associations were found in Mirerbazar ($R^2 = 0.68$), Zirani ($R^2 = 0.61$), and Masterbari ($R^2 = 0.60$); and moderate associations were found in Konabari ($R^2 = 0.39$) and Kashimpur ($R^2 = 0.33$). All the locations showed statistically significant association except Konabari and Kashimpur ($p < 0.05$).

Table 4. Traffic volume per hour during summer in Gazipur City

Time duration (per hour)	Total number of pollutant-emitting vehicles by location						
	Tongi	**Konabari**	**Gazipur bypass**	**Masterbari**	**Zirani**	**Mirerbazar**	**Kashimpur**
8 am to 9 am	677	855	766	801	808	789	513
9 am to 10 am	701	799	752	798	801	726	645
10 am to 11 am	719	771	804	750	756	798	574
11 am to 12 pm	691	788	699	767	673	675	654
12 pm to 1 pm	661	830	735	826	755	756	590
1 pm to 2 pm	710	726	739	744	765	876	578
2 pm to 3 pm	678	722	723	765	698	845	684
3 pm to 4 pm	736	844	766	856	782	708	777
4 pm to 5 pm	768	874	795	809	813	688	756
5 pm to 6 pm	699	815	809	734	836	604	701

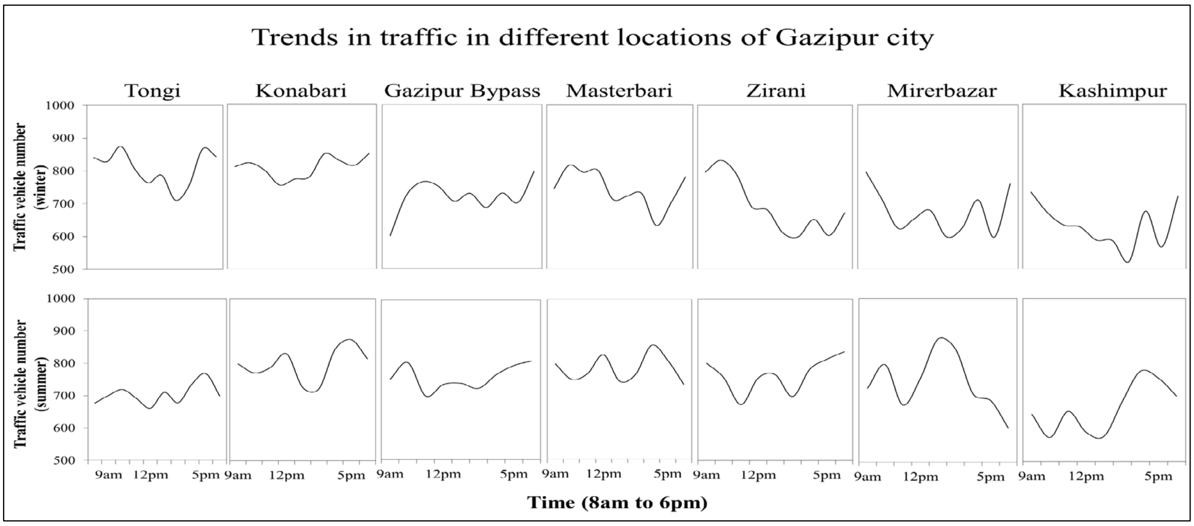

Fig. 4. Trends in traffic in different locations of Gazipur City

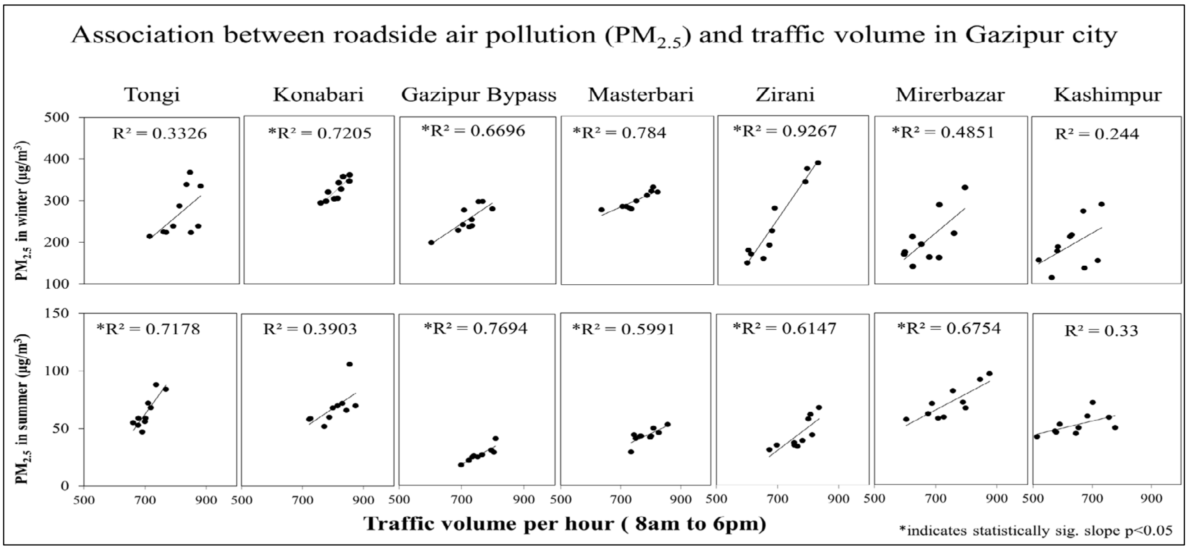

Fig. 5. Association between roadside air pollutant PM2.5 and traffic volume in Gazipur City

DISCUSSION

This study captured the roadside air pollution scenario with seasonal variation and the association between traffic volume and roadside air pollution in Gazipur City. Results demonstrated that the roadside air pollution level in different locations of Gazipur was critically high. Almost all the time it exceeded normal national ambient air quality standards, consistent with similar findings in a study conducted in Gazipur, Bangladesh (Hasan et al., 2020). Another study conducted in Bangladesh found a similar observation and reported that seventy percent of the roadsides in several cities in Bangladesh are extremely dirty (Kudrat-E-Khuda, 2020). Another study from India also showed that the average concentration of the total suspended particulate matter measured at roadside locations air over the entire duration of the investigation was extremely high (Prakash et al., 2012). Diverse factors are involved in this increased level of pollution. A recent study on source apportionment has determined that approximately 58% of the fine particle concentration is caused by the brick kiln industry, 10.4% is attributed to vehicles, and 15.3% is due to dust (Environment, 2019). From 2010 to 2018, there was a 68% rise in the total number of vehicles on the roads in urban areas (IQAir, 2021). However, the factors such as poor quality of fuels, lack of fitness of the vehicle, lack of proper maintenance of the vehicles, proper traffic management are the probable influencing reasons for the higher level of roadside air pollution (Pathak et al., 2011). However, morning $PM_{2.5}$ concentrations were higher than at other times of the day, likely due to increased traffic volume during that period (Zhang & Batterman, 2013).

The present study showed that roadside air pollution concentration in different locations of Gazipur shows higher seasonal variation, mentioning the dry/winter season has a much higher air pollution level than the summer season. Similar findings were also reported in a study in Gazipur, Bangladesh (Mukta et al., 2020). Another study revealed that from October to March, which is the dry season, the air quality in cities of Bangladesh deteriorated significantly (Momen et al., 2021). Different studies that are conducted in China (Padró-Martínez et al., 2012), Pakistan (Colbeck, 2008), and India (Prakash et al., 2012) also follow similar observations by showing higher levels of pollution in the winter season. There are a lot of influencing factors behind this finding. Both fine particles and coarse particles are released and generated in city areas as a result of human action. Consequently, fine particles can travel greater distances than coarse particles before being eliminated from the environment. This leads to higher $PM_{2.5}$ in suburban areas (Zhou et al., 2015). The increase in human activities, such as burning wood for residential use, industrial heating, and fuel consumption, along with a low mixing height that allows the accumulation of substances that contribute to the creation of secondary organic aerosols, has led to their intensified production, leading to a rise in the release of small particles (Han et al., 2010; Klejnowski et al., 2012). Nevertheless, the presence of moist weather conditions may suppress larger particles, and the absence of precipitation results in a higher proportion of smaller particles during colder seasons (Speranza et al., 2016).

The present study also revealed a significant association between roadside air pollution and traffic volume, reporting that traffic volume explained up to 92% of the temporal variability in hourly $PM_{2.5}$ concentration at specific locations. If the traffic volume increased, the air pollution level also increased significantly. Although existing literature is not rich regarding this, a study conducted in Bangladesh found a similar observation as traffic number is the significant air pollution contributor (Tabassum et al., 2023). The study conducted in other parts of the world also showed that traffic and roadside air pollution have a strong association (Hay et al., 2023; Singh et al., 2022). Vehicle exhaust is one of the main sources of air pollutants in a street environment (Huang et al., 2021). A higher volume of traffic typically leads to increased emissions, resulting in elevated pollution levels within a street. Additionally, road traffic can have a substantial impact on air pollution levels, with the extent of contribution varying between 5% and 80% depending on factors such as the size and location of the area (Bui et al., 2023). Particles are emitted from various sources, including engine exhaust, tire wear, highway damage, and brake elements. They can also be resuspended from the highway surface, which helps to show a strong relationship (Mukherjee & Agrawal, 2018). The lower quality of vehicle fitness and type of vehicle fuel use together lead to incomplete combustion, which poses a higher air pollution danger (Kar et al., 2024).

Policy implications

The findings of this study provide practical guidance for reducing traffic-related $PM_{2.5}$ exposure and improving urban air quality management in rapidly urbanizing cities of Bangladesh. The strong linear association between traffic volume and roadside $PM_{2.5}$ concentrations, highlights the need for targeted traffic emission control measures. Regulatory authorities should prioritize stricter vehicle fitness inspections, enforcement of emission standards, improved fuel quality, and gradual removal of highly polluting vehicles, particularly in high-traffic areas. The observed morning and winter peaks in $PM_{2.5}$ concentrations further support the implementation of time- and season-specific interventions, including improved traffic management during peak periods and increased public awareness regarding pollution exposure during high-risk periods. Furthermore, expanding routine roadside air quality monitoring beyond major cities and integrating traffic-related exposure considerations into urban planning can support evidence-based decisions for pollution reduction in industrial and rapidly developing urban areas.

Limitations of the study

The present study acknowledges certain uncertainties and limitations. This study includes only particulate matter measurement, as these kinds of air pollutants dominate in Asian cities. In addition, monitoring was conducted over limited seven-day periods in winter and summer which may not fully capture intra-seasonal variability. Moreover, the study's focus on certain areas and coverage of two seasons restrict the generalizability of findings to other regions and whole seasons. Furthermore, although traffic volume explained a substantial proportion of $PM_{2.5}$ variability, other influential factors- such as meteorological parameters, nearby industrial emissions, brick kiln activity, construction dust may result in residual confounding. Despite these constraints, the study provides robust, location-specific evidence on seasonal roadside pollution dynamics and traffic associations, offering a valuable empirical foundation for future multi-pollutant, longer-term, and source-resolved investigations.

CONCLUSION

The present study identified that the roadside air pollution scenario is found to be substantially higher in urban areas like Gazipur City, Bangladesh. The pollution level was substantially higher during the winter season compared to summer. Additionally, this study indicated that heavy traffic congestion in peak hours is strongly associated with roadside air pollution. A substantial proportion of the people are regularly exposed to the high air pollutant concentration in roadside environments that may create adverse health outcomes for them. Nevertheless, individual-level interventions (such as using fuel-standard vehicles, wearing protective face masks, and avoiding roadsides in the morning, especially in winter) help to reduce air pollution exposure. These findings highlight the importance of tighter traffic-centered emission control strategies (such as proper maintenance of the vehicles, stricter fuel quality standards, phasing out unfit vehicles, proper traffic management etc.) aimed at lowering long-term average roadside air pollution levels and reducing traffic's contribution to air pollution.

ABBREVIATIONS

BNAAQS- Bangladesh National Ambient Air Quality Standards; CNG- Compressed Natural Gas; PM- Particulate Matter; WHO- World Health Organization; R^2- Coefficient of Determination.

STATEMENTS AND DECLARATIONS

Conflict of interest

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Life science reporting

No life science threat was practiced in this research.

Author's contribution

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