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Airborne Particulate Matter Concentrations at Key Transportation Stations in Freetown, Sierra Leone: Compliance with WHO Guidelines

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ABSTRACT: Air pollution, particularly from particulate matter (PM), is a significant public health risk, especially in urban environments where transportation plays a critical role. This study quantifies airborne particulate matter (PM1.0, PM2.5, and PM10) concentrations at key transportation stations (Central and Shell Bus Stations) in Freetown, Sierra Leone. Multifunctional digital air quality monitors (DM502) were used to record measurements during the rainy season in August and at peak traffic hours, spanning three daily intervals: 7:00–11:00 AM, 12:00–4:00 PM, and 5:00–9:00 PM.

Our findings reveal elevated levels of particulate matter throughout the study. The average concentrations at the Central Bus Station of 15.40 µg/m³, 27.60 µg/m³, and 31.38 µg/m³ for $PM_{1.0}$, $PM_{2.5}$, and PM_{10}, respectively. At Shell Bus Station, these values were notably higher, with averages of 17.71 µg/m³ for $PM_{1.0}$, 30.33 µg/m³ for $PM_{2.5}$, and 37.24 µg/m³ for PM_{10}. These average concentrations notably exceed the World Health Organization (WHO) 24-hour guidelines of 15 µg/m³ for $PM_{2.5}$ and 45 µg/m³ for PM_{10}, indicating deteriorating air quality in these densely populated transit areas. Also, the mean Air Quality Indices (AQI) of $PM_{2.5}$, and PM_{10} at Central Bus Station are 95.16 and 26.81 respectively while mean AQI of $PM_{2.5}$, and PM_{10} at Shell Bus Station are 90.05 and 32.08 respectively.

Significant variations were observed throughout the week, primarily influenced by daily traffic patterns and local activities. Peak $PM_{2.5}$ levels reached 62.33 µg/m³ at Central Bus Station and 74.67 µg/m³ at Shell Bus Station on Tuesdays. Our analysis underscores the urgent need for improved air quality management strategies in Freetown to mitigate health risks associated with elevated airborne particulate levels.

In conclusion, this study serves as a pivotal contribution to understanding air quality dynamics in Freetown's urban transit environment, providing essential data for stakeholders to address public health concerns linked to air pollution. Recommendations include implementing stricter vehicle emissions regulations, enhancing public transportation options, and promoting community awareness initiatives surrounding air quality. These measures are critical in fostering a healthier urban environment for residents and commuters alike.

KEYWORDS: Air pollution, Particulate Matter, Air quality, WHO compliance.

1. INTRODUCTION

According to the World Health Organization (2008), air pollution causes approximately 1.3 million deaths worldwide each year, with 82,000 of those occurring in sub-Saharan Africa. Among the numerous air pollutants, particulate matter (PM) is recognized as a critical concern due to its adverse effects on human health. Also, the World Health Organization PM was responsible for 3 million premature deaths worldwide in 2016 (Chalvatzaki, et al., 2019). PM is a widespread air pollutant, consisting of a mixture of solid and liquid particles suspended in the air. PM is categorized based on its aerodynamic diameter: $PM_{1.0}$, $PM_{2.5}$, and PM_{10}. Smaller particles, such as $PM_{2.5}$ and $PM_{1.0}$, pose greater health risks as they can penetrate deep into the respiratory system and even enter the bloodstream (Pope & Dockery, 2006). Chronic exposure to PM has been linked to cardiovascular and respiratory, leading to hospital admission, cancer and premature mortality (WHO, 2013; Loomis, et al., 2013; Hoek, et al., 2013). In fact, the International Agency for Research on Cancer (IARC) designated PM in outdoor air pollution as a Group I carcinogen (Hamra, et al., 2014). In urban centers such as Freetown, Sierra Leone, where urban growth outpaces infrastructure development and environmental regulation, key transportation hubs often become hotspots for elevated PM concentrations.

Urban environments are particularly susceptible to elevated PM levels due to emissions from vehicular traffic, industrial activities, domestic fuel burning, and natural sources like dust and sea salt. A growing body of literature has highlighted the contribution of

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transportation to PM levels in urban environments, a situation worsened by the prevalence of aged vehicle fleets and the use of substandard fuels (Naidja, Ali-Khodja, & Khardi., 2017). The study identifies significant sources of particulate matter (PM) in urban West Africa, particularly in Bamako and Dakar, with major contributors being motor vehicles, dust, and combustion activities, leading to PM concentrations exceeding WHO standards and posing health risks.

In West Africa, a study by Etyemezian et al. (2005) in Accra, Ghana, reported that PM_{10} levels in major roadways were routinely above safe thresholds, particularly during morning and evening commuting hours. This study emphasized the direct impact of vehicular density, fuel type, and road conditions on PM emissions, conditions that are also mirrored in Freetown's transport sector. Similarly, Apeagyei et al. (2011) highlighted the disproportionate exposure of individuals who spend extended time near traffic-dense areas, such as transport workers and commuters, a demographic that is sizable in Freetown. Closer to Sierra Leone, Brauer et al. (2012) developed a global model of ambient $PM_{2.5}$ exposure and found that West African cities ranked among the regions with the highest exposures. Despite these findings, there is a critical data gap regarding air pollution in Sierra Leone, particularly in Freetown. Recent policy efforts, such as those led by Sierra Leone's Environment Protection Agency (EPA-SL), aim to draft and implement national air quality regulations; however, the absence of localized, real-time PM data continues to hinder effective enforcement and planning (Independent Observer, 2024).

Against this backdrop, this study aims to quantify and analyze the concentration levels of airborne $PM_{1.0}$ $PM_{2.5}$ and PM_{10} in key transportation stations in Freetown, Sierra Leone. The study further evaluates the compliance of these concentrations with WHO's updated Air Quality Guidelines (WHO, Air quality guidelines: Global update 2021). By situating these findings within the broader literature and local policy context, the research contributes to filling the empirical gap necessary for informed public health and urban planning interventions in Freetown.

2. MATERIALS AND METHODS

2.1 STUDY AREA

Freetown, situated on the Atlantic coast, is characterized by a tropical climate and topography that influences air pollution dispersion. The city's transportation network includes major bus terminals, ferry docks, and busy intersections, which are focal points for vehicular emissions. This study focuses on two major transportation hubs: Central Bus Station, serving the city's core, and Shell Bus Station, located in a busier commercial district.

Figure 1: Map of the study area

2.2 DATA COLLECTION

Airborne particulate matter concentrations were measured using DM502 multifunctional air quality monitors (Fig. 2), which can detect the formaldehyde (HCHO), Total Volatile Organic Compounds (TVOC), particulate matter ($PM_{2.5}/PM_{1.0}/PM_{10}$) in the air as well as temperature and humidity, and also show you air quality index (AQI) on the LCD display.

The monitors were fully charged and calibrated prior to data collection and were positioned approximately 2 meters above ground level during measurements. Sampling occurred in three weeks, with data collected and average concentrations of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} were determined and recorded in micrograms per cubic meter (µg/m³) at three-time intervals (7.00 AM – 11.00 AM, 12.00 PM – 4.00 PM, and 5.00 PM – 9.00 PM) spanning from 6th August 2024 to 26th August, 2024.

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Figure 2: Digital DM502 Air Quality Monitor

2.3 DATA ANALYSIS

After cleaning and quality assurance of the raw data, descriptive statistics were conducted for each location's dataset to identify patterns and distributions of PM concentrations. These statistics included measures such as the mean, as well as the minimum and maximum values. PM concentrations at the study locations were compared with international air quality standards established by the World Health Organization (WHO). Specifically, the 24-hour average PM concentrations were assessed for compliance with the recent WHO guidelines for $PM_{2.5}$ (15µg/m³) and PM_{10} (45µg/m³).

Air Quality Index (AQI) for $PM_{2.5}$ and PM_{10} across both bus stations were calculated using the 24-hour average concentration values in conjunction with the breakpoint concentration ranges for $PM_{2.5}$ and PM_{10} defined by the United States Environmental Protection Agency (U.S. EPA) in 2006, as outlined in Table 1. The AQI for each pollutant was determined using Equation 1 (U.S. Environmental Protection Agency, 2016), as shown below:

$$AQI_P = \frac{AQI_{high} - AQI_{low}}{BP_{high} - BP_{low}} (C_P - BP_{low}) + AQI_{low} \qquad (1)$$

Where

AQI_P = the index for pollutant P

C_P = the truncated concentration of pollutant p

BP_{high} = the concentration breakpoint that is greater than or equal to Cp

BP_{low} = the concentration breakpoint that is less than or equal to Cp

AQI_{high}= the AQI value corresponding to BP_{high}

AQI_{low} = the AQI value corresponding to BP_{low}

Table 1: The U.S. EPA's table of breakpoints (Mintz, 2018)

O_3 (ppb) 8-hr	O_3 (ppb) 1-hr	$PM_{2.5}$ (µg/m³) 24-hr	PM_{10} (µg/m³) 24-hr	CO (ppm) 8-hr	SO_2 (ppb) 1-hr; 24-hr	NO_2 (ppb) 1-hr	AQI	AQI Category
0-54	-	0.0-9.0	0-54	0.0-4.4	0-35	0-53	0-50	Good
55-70	-	9.1-35.4	55-154	4.5-9.4	36-75	54-100	51-100	Moderate
71-85	125-164	35.5-55.4	155-254	9.5-12.4	76-185	101-360	101-150	Unhealthy for Sensitive Groups
86-105	165-204	55.5-125.4	255-354	12.5-15.4	186-304	361-649	151-200	Unhealthy
106-200	205-404	125.5-225.4	355-424	15.5-30.4	305-604	650-1,249	201-300	Very Unhealthy
-	405-604	225.5-325.4	425-604	30.5-50.4	605-1,004	1,250-2,049	301-500	Hazardous

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3. RESULTS AND DISCUSSION

3.1 AIRBORNE PM LEVELS AND AQI AT CENTRAL BUS STATION

Table 2 summarizes the particulate matter concentrations recorded at Central bus station. The overall average concentrations of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} for the week were 15.40 μg/m³, 27.60 μg/m³, and 31.38 μg/m³, respectively. The highest daily average particulate matter concentrations were recorded on Tuesday, with $PM_{1.0}$ at 34.33 μg/m³, $PM_{2.5}$ at 62.33 μg/m³, and PM_{10} at 68.00 μg/m³, while the lowest daily averages were observed on Thursday, with $PM_{1.0}$ at 7.00 μg/m³, $PM_{2.5}$ at 12.67 μg/m³, and PM_{10} at 15.67 μg/m³. Significant fluctuations were observed, attributed to variations in traffic patterns, particularly during weekends and associated local events.

Also, the maximum daily AQI for $PM_{2.5}$ and PM_{10} with values 155.79 and 57.43 respectively, were observed on Tuesday while the minimum daily AQI for $PM_{2.5}$ and PM_{10} with values 57.65 and 14.51 respectively, were observed on Thursday (Table 3).

Table 2: Airborne particulate matter levels at Central bus station

Day	Particulate Matter Concentrations in μg/m³											
	7am – 11am			12am – 4am			5am – 9am			Average Daily		
	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	$PM_{1.0}$	$PM_{2.5}$	PM_{10}
Tue	25.00	49.00	46.00	32.00	50.00	61.00	46.00	88.00	97.00	34.33	62.33	68.00
Wed	21.00	32.00	43.00	7.00	10.00	14.00	21.00	51.00	46.00	16.33	31.00	34.33
Thurs	6.00	12.00	14.00	5.00	8.00	10.00	10.00	18.00	23.00	7.00	12.67	15.67
Fri	9.00	12.00	22.00	9.00	20.00	19.00	10.00	15.00	18.00	9.33	15.67	19.67
Sat	11.00	17.00	23.00	10.00	16.00	22.00	9.00	16.00	20.00	10.00	16.33	21.67
Sun	40.00	65.00	22.00	43.00	55.00	25.00	36.00	53.00	31.00	39.67	57.67	26.00
Mon	24.00	35.00	30.00	11.00	19.00	18.00	16.00	21.00	22.00	17.00	25.00	23.33
Min.	6.00	12.00	14.00	5.00	8.00	10.00	9.00	15.00	18.00	**7.00**	**12.67**	**15.67**
Max.	25.00	49.00	46.00	32.00	50.00	61.00	46.00	88.00	97.00	**34.33**	**62.33**	**68.00**
Mean	14.40	24.40	29.60	12.60	20.80	25.20	19.20	37.60	40.80	**15.40**	**27.60**	**31.87**

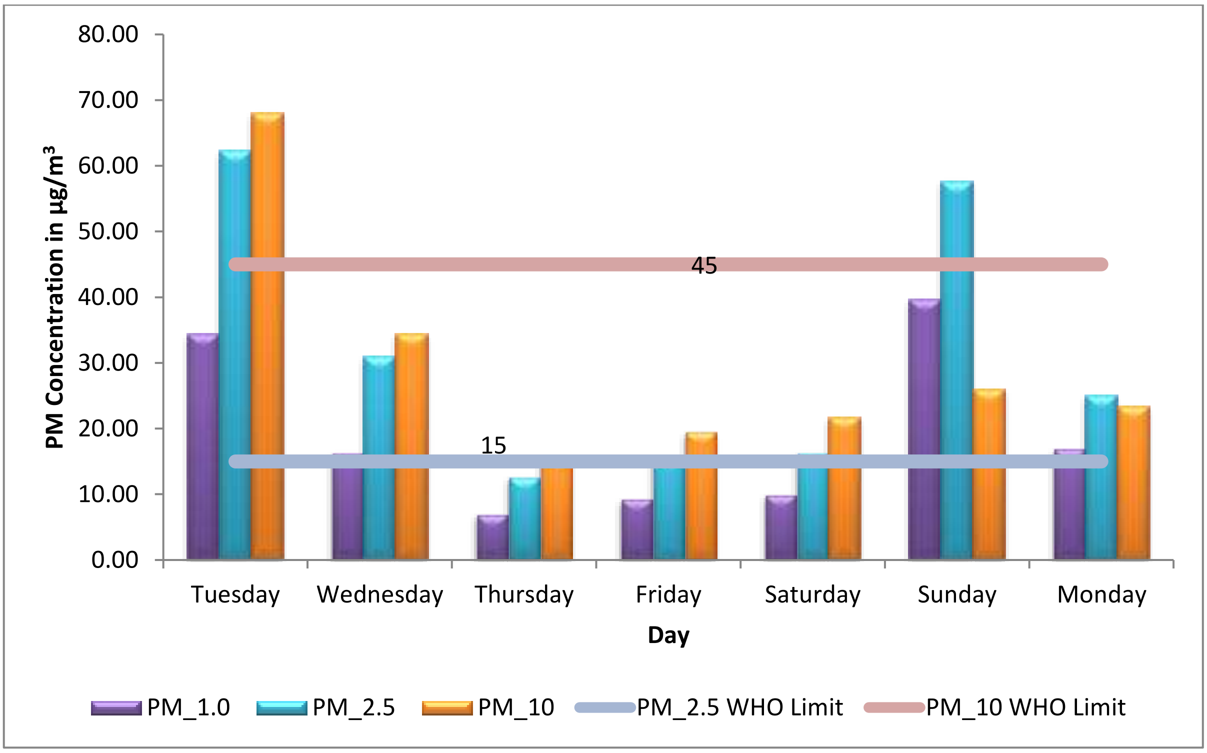

Figure 3: Comparison of particulate matter concentrations at Central bus station

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Figure 3 compares averaged daily particulate matter concentrations to the 2021 WHO limits for $PM_{2.5}$ and PM_{10}. Only on Thursday was the average daily $PM_{2.5}$ concentration (12.67µg/m^3) below the WHO limit. However, PM_{10} concentrations only exceeded the recommended level on Tuesday.

Table 3: Daily Air Quality Index at Central Bus Station

Day	Daily Air Quality Index			
	$PM_{2.5}$		PM_{10}	
	AQI	Category	AQI	Category
Tue	155.79	Unhealthy	57.43	Moderate
Wed	91.80	Moderate	31.79	Good
Thurs	57.65	Moderate	14.51	Good
Fri	63.24	Moderate	18.21	Good
Sat	64.47	Moderate	20.06	Good
Sun	152.52	Unhealthy	24.07	Good
Mon	80.62	Moderate	21.60	Good
Min.	57.65		14.51	
Max	155.79		57.43	
Mean	95.16	Moderate	26.81	Good

3.2 AIRBORNE PARTICULATE MATTER LEVELS AT SHELL BUS STATION

Table 4 provides a detailed overview of PM concentrations at Shell Bus Station. Average concentrations of $PM_{1.0}$ (17.71 µg/m^3), $PM_{2.5}$ (30.33 µg/m^3), and PM_{10} (37.24 µg/m^3) were notably higher than those recorded at Central Bus Station, indicating worse air quality. The highest daily average concentrations for $PM_{1.0}$ (34.67 µg/m^3) and $PM_{2.5}$ (74.67µg/m^3) were reported on Tuesday while for PM_{10} (78.00 µg/m^3) was reported on Wednesday, suggesting heavy traffic influences.

Table 5 shows that the maximum daily AQI for $PM_{2.5}$ and PM_{10} with values 164.44 and 62.38 respectively, were observed on Tuesday while the minimum daily AQI for $PM_{2.5}$ and PM_{10} with values 60.13 and 16.67 respectively, were observed on Thursday.

Table 4: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} Concentrations at Shell Bus Station

Day	Particulate Matter Concentrations at Shell Bus Station											
	7 AM – 11 AM			12 PM – 4 PM			5 PM - 9 PM			Average Daily		
	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	$PM_{1.0}$	$PM_{2.5}$	PM_{10}
Tue	48.00	91.00	88.00	32.00	84.00	71.00	24.00	49.00	55.00	34.67	74.67	71.33
Wed	22.00	34.00	45.00	19.00	29.00	38.00	49.00	65.00	151.00	30.00	42.67	78.00
Thurs	9.00	15.00	18.00	5.00	10.00	11.00	11.00	17.00	25.00	8.33	14.00	18.00
Fri	10.00	19.00	22.00	16.00	17.00	33.00	11.00	18.00	24.00	12.33	18.00	26.33
Sat	17.00	33.00	38.00	9.00	17.00	23.00	8.00	14.00	19.00	11.33	21.33	26.67
Sun	24.00	35.00	30.00	11.00	19.00	17.00	16.00	21.00	12.00	17.00	25.00	19.67
Mon	10.00	13.00	23.00	10.00	21.00	20.00	11.00	16.00	19.00	10.33	16.67	20.67
Min	**9.00**	**13.00**	**18.00**	**5.00**	**10.00**	**11.00**	**8.00**	**14.00**	**12.00**	**8.33**	**14.00**	**18.00**
Max	**48.00**	**91.00**	**88.00**	**32.00**	**84.00**	**71.00**	**49.00**	**65.00**	**151.00**	**34.67**	**74.67**	**78.00**
Mean	**20.00**	**34.29**	**37.71**	**14.57**	**28.14**	**30.43**	**18.57**	**28.57**	**43.57**	**17.71**	**30.33**	**37.24**

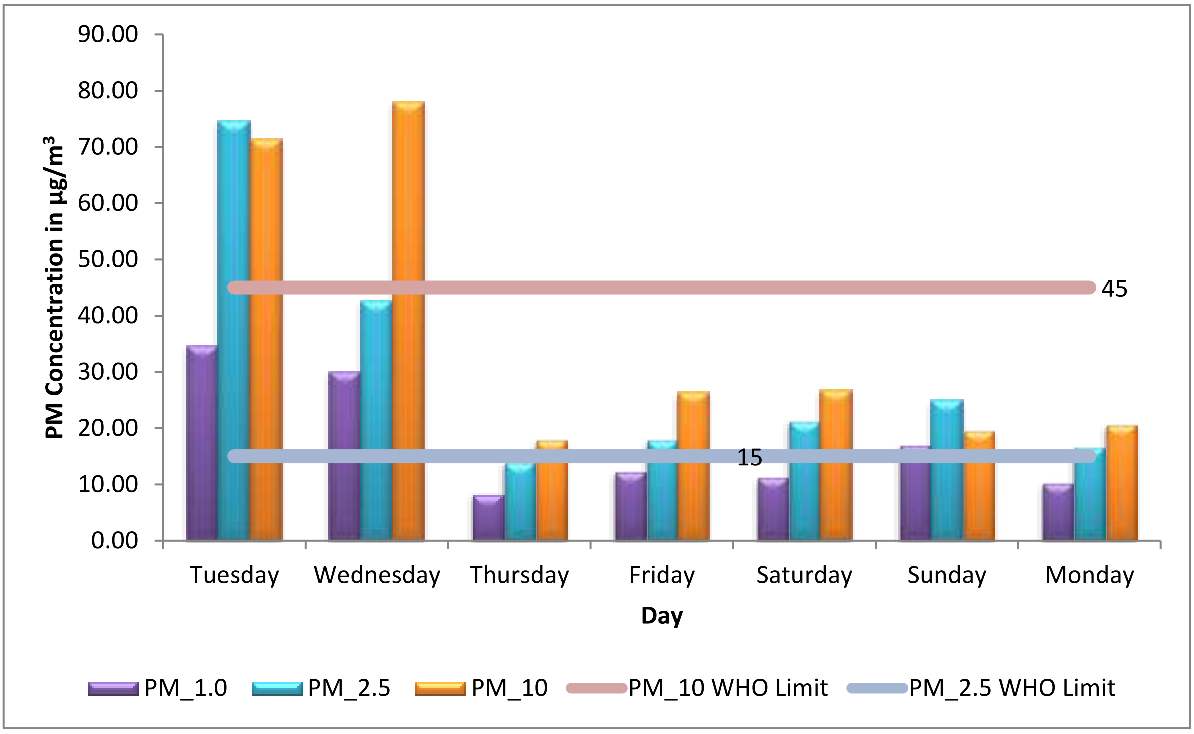

Figure 4: Bar chart representation of particulate matter concentrations at Shell bus station

Figure 4 compares averaged daily particulate matter concentrations to the 2021 WHO limits for $PM_{2.5}$ and PM_{10}. As with Central Bus Station, only Thursday noted an average daily $PM_{2.5}$ concentration below the WHO limit. Also, the average daily PM_{10} concentrations observed on Tuesday and Wednesday at Shell bus station were above the WHO limit.

Table 5: Daily Air Quality Index at Shell Bus Station

Day	Daily Air Quality Index			
	$PM_{2.5}$		PM_{10}	
	AQI	Category	AQI	Category
Tue	164.44	Unhealthy	59.08	Moderate
Wed	118.65	Unhealthy for sensitive groups	62.38	Moderate
Thurs	60.13	Moderate	16.67	Good
Fri	67.58	Moderate	24.38	Good
Sat	73.79	Moderate	24.69	Good
Sun	80.62	Moderate	18.21	Good
Mon	65.10	Moderate	19.14	Good
Min.	60.13		16.67	
Max	164.44		62.38	
Mean	90.05	Moderate	32.08	Good

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Table 6: Summary table of PM Concentration at both locations

Parameters	Statistics	Central Bus Station	Shell Bus Station
PM1.0	Min	7.00	8.33
	Max.	34.33	34.67
	Mean	15.40	17.71
PM2.5	Min.	12.67	14.00
	Max.	62.33	74.67
	Mean	27.60	30.33
PM10	Min.	15.67	18.00
	Max.	68.00	78.00
	Mean	31.87	37.24

4. CONCLUSION AND RECOMMENDATION

4.1 CONCLUSION

The analysis of airborne particulate matter concentrations at key transportation stations in Freetown reveals alarming levels of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} that consistently exceed the World Health Organization's (WHO) recommended guidelines. The findings indicate a significant deterioration in air quality, posing serious health risks to the local population and commuters. The elevated levels of particulate matter, particularly during peak traffic hours, underscore the urgent need for effective interventions to mitigate air pollution in the region.

4.2 RECOMMENDATIONS

1. Implement stricter vehicle emissions standards:
   - Enforce regulations that limit emissions from vehicles, particularly in high-traffic areas.
2. Promote cleaner public transportation options:
   - Encourage the use of public transportation, cycling, and walking to reduce vehicular emissions.
3. Conduct regular air quality monitoring in high-traffic areas:
   - Establish a systematic approach to monitor air quality at various locations to track improvements and identify pollution hotspots.
4. Raise community awareness about air pollution risks and mitigation strategies. Increase Community Awareness:
   - Launch educational campaigns to inform the public about the health impacts of air pollution and promote actions to reduce exposure.
5. Collaborate with Stakeholders:
   - Engage local government, NGOs, and community groups in developing and implementing air quality improvement strategies.

AUTHOR CONTRIBUTIONS

M.M.A. designed the study, contributed to the data collection and analyses, and was lead author of the manuscript. S.L. coordinated the data collection. Both authors contributed to the study design and manuscript preparation and have read and agreed to the published version of the manuscript.

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DATA AVAILABILITY STATEMENT

All relevant data used in this study are included in the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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