Quantitative Analysis of Diurnal Variations of Particulate Loads at Selected Road Traffic Junctions in Ogbomoso, Nigeria

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ABSTRACT

Air pollution encompasses the contamination of the atmosphere by a broad range of harmful substances, such as particulate matter (PM), which can trigger adverse effects on human health, the environment, and the climate, compromising ecosystem balance and sustainability. This study investigated the ambient concentration of particulates with an aerodynamic diameter of less than 2.5 and 10 µm (PM2.5, PM10). Six traffic junctions (hotspots) and a control point were selected in Ogbomoso metropolis, Southwestern Nigeria. A DM10 particulate monitor was employed to collect comprehensive data of the particulates on weekdays and weekends, for two consecutive weeks, covering morning, afternoon, and evening periods, to capture diurnal variations in PM concentrations. The results of the study revealed significant spatial and temporal variations in PM2.5 concentrations, which range from 6.86 to 92.91µg/m3 and 17.86- 140.28µg/m3 for PM10. At several locations, particularly Takie and Wazo, PM2.5 levels exceeded the WHO air quality standard of 15 µg/m³, especially during peak traffic hours. Takie recorded a peak PM2.5 concentration of 88.1 µg/m³, while Wazo reached 52.25 µg/m³ at midday. Based on these findings, road traffic activities greatly influence the ambient particulate load, harming the lives of the residents.

INTRODUCTION

Air pollution, a global environmental and public health crisis, poses a significant threat to human well-being and ecosystem balance (World Health Organization, 2021). It is a major environmental and health concern, causing an estimated 7 million premature deaths worldwide annually (WHO, 2016). The World Health Organization (WHO) reports that 90% of the global population breathes polluted air, with low- and middle-income countries disproportionately affected (WHO, 2018). Among numerous sources contributing to air pollution, road traffic junctions have emerged as critical hotspots due to the concentration of vehicular emissions in confined spaces (Barregård et al., 2018). The combination of traffic congestion, urban canyon effects, and poor road infrastructure at traffic junctions creates a unique microenvironment that exacerbates air pollution (Gehrig et al., 2017; Kumar et al., 2016). Air pollution is the contamination of the indoor and outdoor environment by any chemical, physical, or biological agent that modifies the natural characteristics of an atmosphere. Air pollution encompasses a complex mixture of pollutants, including particulate matter (PM), nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO), and ozone (O3) (Li et al., 2020). These pollutants emanate from various sources, including industrial activities, fossil fuel combustion, agricultural practices, and waste management (Pope and Dockery, 2006).

Pollution due to vehicular transportation remains a threat to environmental health problem which is expected to increase reasonably as the motor vehicle population rises (Raji et al., 2021). The growth in the vehicle population and the corresponding emissions, engine oil and fuel leakage, brake and tire wear, has led to the degradation of the air quality, which in turn affect man and his environment (Nathaniel and Xiaoli, 2020).

As a result, traffic junctions are major sources of pollutants, such as particulates, nitrogen dioxide, volatile organic compounds, polycyclic aromatic hydrocarbons, and carbon monoxide. Some researchers like Oyebamiji (2023) and Alamu et al. (2019) reported high concentrations of pollutants (CO, VOCs, NOx, SOx and heavy metals) in dense traffic highways in Ogbomoso. Therefore, a need to assess the particulate load to safeguard the populace in these traffic-congested areas, to provide a template for stakeholders in the environmental sector to take appropriate control measures to attenuate its effects on human health and the environment.

MATERIALS AND METHODS

Study Area

The study area is Ogbomoso, a city in Oyo state of south south-western region, Nigeria. The city is characterized by its unique geography and road network, as shown in Figures 1 and 2. Ogbomoso has become a hub for economic and social development in the region. The study was conducted in six road traffic junctions in Ogbomoso, Nigeria. The selected junctions are LAUTECH Main Gate, Takie, Starlight, Federal, Wazo junction and UnderG 1500 Junction (due to their high traffic congestion). The control point is a street along UnderG road (600m from Wazo), where there is little vehicular activity.

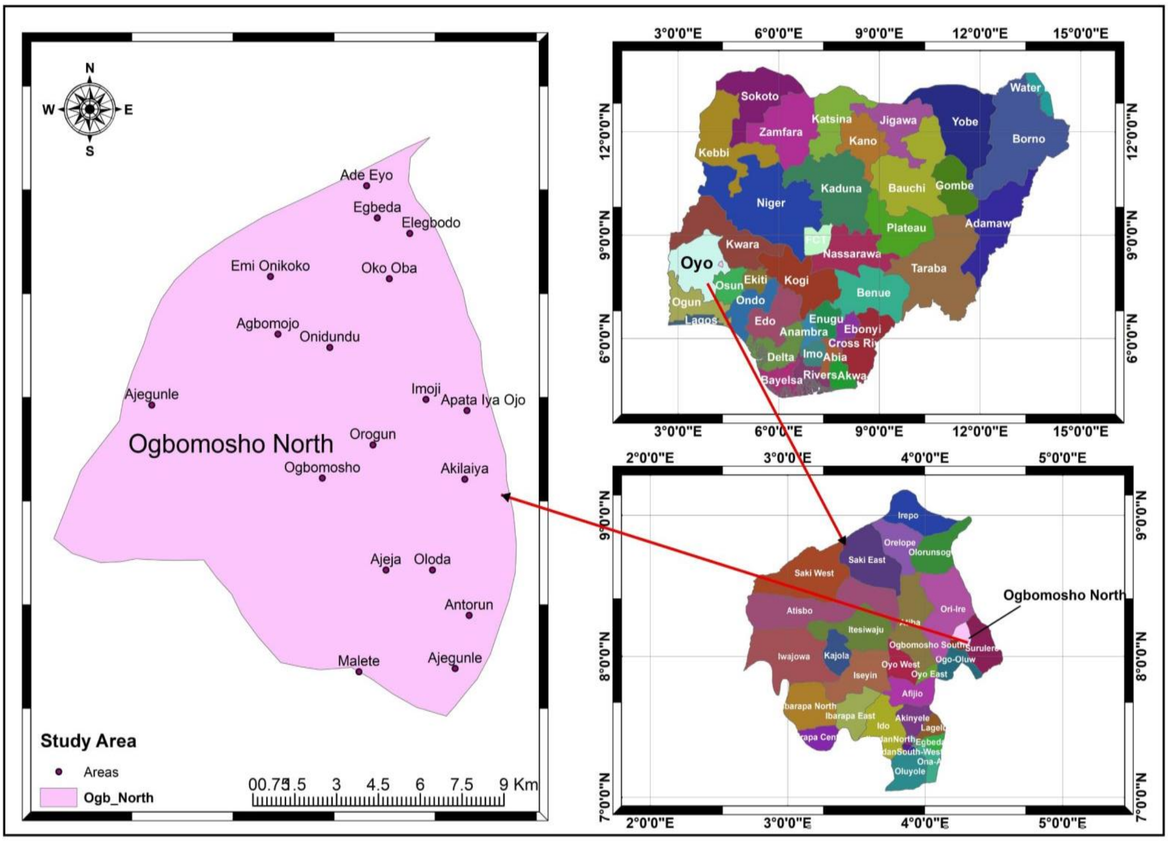

Figure 1: Map of Ogbomoso

Figure 2: Map of selected junctions

Road Traffic Volume: Heavy traffic is a daily occurrence at the selected junctions owing to their connections to major commercial areas. The traffic count (traffic flow per hour) was manually done over a period of 14 days in the morning, afternoon and evening hours, whereby, the vehicles were categorized as cars/buses, trucks and motorcycles (bikes) as shown in Table 1.

Table 1: Traffic Count

Sampling Location	Morning hours			Afternoon hours			Evening hours		
	Cars/Buses	Trucks	Bikes	Cars/Buses	Trucks	Bikes	Cars/Buses	Trucks	Bikes
Takie	363	85	231	309	53	98	355	71	201
Federal	254	71	95	233	59	71	306	78	113
Starlight	341	52	106	188	32	101	231	67	240
UnderG	302	-	248	114	5	121	184	4	265
Main Gate	295	25	183	103	26	97	203	31	248
Wazo	306	73	179	221	89	85	239	61	198
Control	55	-	17	39	-	49	55	-	83

Data Collection

Particulate matter (PM) sampling was conducted using a particulate monitor (Model: DM106; Voltage DC5V, PM2.5 range 0-999µg/m3) at the selected site, with three readings per day, thrice a week for 2 weeks. Three days of monitoring were considered adequate for this study because the days represented the typical busy days of the week, which are Monday, Wednesday and Saturday. The sampling schedule consisted of morning (7-8 am), afternoon (12-1 pm), and evening (5-6 pm) sessions to assess the concentrations throughout the day. This is to compare the results of the busy hours (7-8 am and 5 pm) and non-busy hours (12-1 pm). During each visit, the particulate counter recorded concentrations of PM_{10} and $PM_{2.5}$. The average particulate matter concentration data collected for the sample junctions over the three different collection periods were extrapolated to a 24-h averaging period using Equation (1), an atmospheric stability dependent equation and compared to air quality guidelines in Table 2.

$$C_0 = C1F \quad (1)$$

$$F = \left(\frac{t_1}{t_0}\right)^n \quad (2)$$

Table 2: Air quality standards for criteria air pollutants by the USEPA and WHO

C_0 is the shorter averaging time concenmnnltration, and C1 is the longer averaging time concentration

t_1 is the longer averaging time, t0 is the shorter averaging time, and

n is the stability-dependent exponent given as 0.28

Table 2: Air quality standards for criteria air pollutants by the USEPA and WHO

Air pollutants	WHO AQG	USEPA AQG
PM_{10}	45 µg/m^3 (24 h mean)	45 µg/m^3 (24 h mean)
	15 µg/m^3 (annual mean)	15 µg/m^3 (annual mean)
$PM_{2.5}$	5µg/m^3 (annual mean)	12 µg/m^3 (annual mean)
	15 µg/m^3 (24 h mean)	15µg/m^3 (24 h mean)

RESULTS AND DISCUSSION

The University Waste Collections System

As shown in Table 1, there are variations in the traffic counts in the study area at an hour averaging period. The number of cars was highest in all locations, which implies that, majority of the residents are car owners and also, those locations are the main transportation routes for travelers moving in and out of the city (Takie, Federal and Wazo). The second highest is bike, which is a common means of transportation. Some residents often prefer to move with motorcycles, as it is not affected during traffic gridlocks. Overall, traffic counts lower in the afternoon due to reduced activities, as most people are already in their workplaces, while the peak periods (morning and evening hours), students and workers leave and return to their homes.

Tables 3 and 4 summarize the average particulate matter (PM) concentrations measured at various sampling sites and the control points. On Day 1, the highest PM2.5 concentration was recorded at Takie at 7 AM (88.1 µg/m^3) and Main gate at 12 pm (63.6 µg/m^3). On Day 2, the peak PM2.5 concentration was observed at Federal at 7 AM (85.25 µg/m^3) and Starlight at 12 pm (109 µg/m^3).

Table 3: Concentrations of PM2.5

Sampling points	Weekdays (µg/m³) Day 1	Day 2	Weekend (µg/m³)	Average (µg/m³)	T (°C)	R H (%)
			7 am			
Takie	88.1	75.05	41.2	68.12	21.4	77.4
Federal	72.4	53.5	85.25	70.38	20.9	80
Starlight	70	46.85	40.3	52.38	24.1	74.2
UnderG	55.35	41.65	49.7	48.9	23.1	68.4
Main gate	44.4	45.75	47.45	45.87	21.3	79.2
Wazo	39.15	82.2	73	64.78	21.9	78.4
Control	11.5	17.9	23.1	17.5	22.2	85
			12 pm			
Takie	40	16.4	79.7	45.37	30	62.7
Federal	32.1	25.3	59.9	39.1	28.6	64.7
Starlight	40.05	48.4	109	65.82	32.2	56.1
UnderG	35.5	45.55	47.55	42.87	25.9	73.2
Main gate	42.45	63.6	65.55	57.2	26.2	69.5
Wazo	57.25	50.5	80.75	62.83	25.8	69.6
Control	23.3	18.6	28.2	23.37	21	80
			5 pm			
Takie	62.75	83.7	95.8	80.75	28.5	61.1
Federal	46.3	46.45	196.05	92.27	27.1	63.2
Starlight	52.5	70.55	78.9	67.32	30.8	58.1
UnderG	36.25	44.65	44	41.63	25.1	70
Main gate	62.85	71.9	87.05	79.93	26.4	70.5
Wazo	41.2	76.55	72.25	63.33	25.7	68.8
Control	19.5	13.8	16.5	16.6	22.1	81

Overall, Saturday (Day 2) had the highest average PM2.5 concentration. For PM10, the highest concentrations were recorded at Takie on Day 1 at 7 AM (114 µg/m³) and Wazo at noon (74.4 µg/m³). On Day 2, the highest PM10 concentration was recorded at Wazo at 7 AM (104.9 µg/m³), followed by Takie (96.65 µg/m³). At noon, the Main gate had the peak concentration of 81.9 µg/m³, followed by Wazo (66.85 µg/m³). At 5 PM, Takie recorded the highest concentration of 115.15 μg/m³, followed by Wazo (98.3 μg/m³), likely due to factors like unpaved roads and heavy traffic.

Table 4: Concentrations of PM10

Sampling points	Weekdays (μg/m³) Day 1	Day 2	Weekend (μg/m³)	Average (μg/m³)	T (°C)	R H (%)
			7 am			
Takie	114	96.65	52.4	87.63	21.4	77.4
Federal	92.3	68.15	82.6	81.01	20.9	80
Starlight	90	59.65	54.5	68.05	24.1	74.2
UnderG	70.9	53.3	83.85	69.35	23.1	68.4
Main gate	56.95	59.2	60.3	58.71	21.3	79.2
Wazo	50	104.9	94.4	83.1	21.9	78.4
Control	19.5	23.2	29.7	24.13	22.2	85
			12 pm			
Takie	44.8	20.25	92.55	52.53	30	62.7
Federal	41	32.1	73.2	48.77	28.6	64.7
Starlight	51.15	61.75	152.6	88.5	32.2	56.1
UnderG	47.2	55.1	57.15	53.15	25.9	73.2
Main gate	54.6	81.9	84.2	73.57	26.2	69.5
Wazo	74.4	66.85	102.3	81.18	25.8	69.6
Control	16.1	22.9	35.7	24.9	21	80
			5 pm			
Takie	80.55	115.15	121.6	105.77	28.5	61.1
Federal	59.85	59.75	228.9	146.63	27.1	63.2
Starlight	67.3	91.4	110.75	89.82	30.8	58.1
UnderG	58	56.8	56.7	57.17	25.1	70
Main gate	75.45	93.05	103.05	90.52	26.4	70.5
Wazo	55.95	98.3	87.3	80.52	25.7	68.8
Control	30.7	21.7	21.3	24.57	22.1	81

On Day 3, at 7 AM, Wazo had the highest PM10 concentration of 94.4 µg/m³, followed by Under-G (83.85 µg/m³). At noon, Starlight recorded the peak concentration of 152.6 µg/m³, followed by Wazo (103.3 µg/m³), again potentially influenced by road conditions and traffic. The highest PM2.5 concentrations were consistently observed at Takie and Wazo, with mean values ranging from 23.3 to 88.1 µg/m³. These elevated levels, particularly during AM peak traffic hours, are likely attributable to factors such as vehicular emissions, resuspended road dust, and industrial activities. This study revealed slight variations in vehicular volume across the selected study locations. It was also revealed that vehicular volume was higher during the morning peak period than in the evening peak period. This study's finding agrees with the previous research findings of Obadina et al. (2018), whose study revealed that the volume of vehicular traffic (VVT) was higher in the morning than evening.

Contrary to expectations, research has shown that temperature and relative humidity have a significant impact on PM2.5 and PM10 concentrations. As shown in Table 4, the relative humidity values were at their lowest by 5 pm, resulting in a rise in PM10 concentration. This study's findings align with those of Giri et al. (2008), which suggest that changes in meteorological conditions, such as temperature and humidity, contribute to fluctuations in PM10 levels. Similarly, PM10 concentrations peaked at Takie and Wazo, with mean values ranging from 16.1 to 115.15 µg/m³. The results of this study are consistent with those reported in a similar study conducted in Choba, Port Harcourt (Rosemary et al., 2023). Both studies found elevated levels of particulate matter (PM2.5 and PM10) at traffic junctions, highlighting the significant impact of vehicular emissions on air quality.

Figures 3 and 4 show the comparison with WHO standards, which are 15µg/m³ and 45µg/m³, respectively. For PM2.5, they all exceeded the limit, but Starlight showed a very significant exceedance of the limit, which is a result of the low dispersion of air at the junction. For PM10, all locations except Federal exceeded the limit, which was a result of high traffic density. The control point has the lowest concentration of all the locations, which corroborates the fact that high vehicular activities greatly impact environmental air quality.

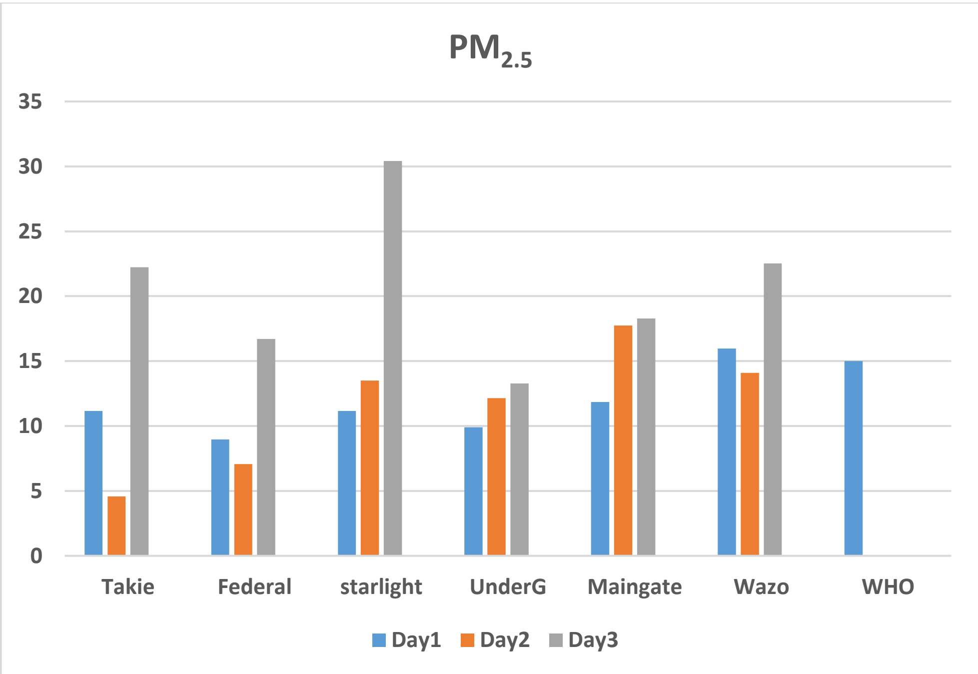

Figure 3: Comparison of PM2.5 with WHO standards

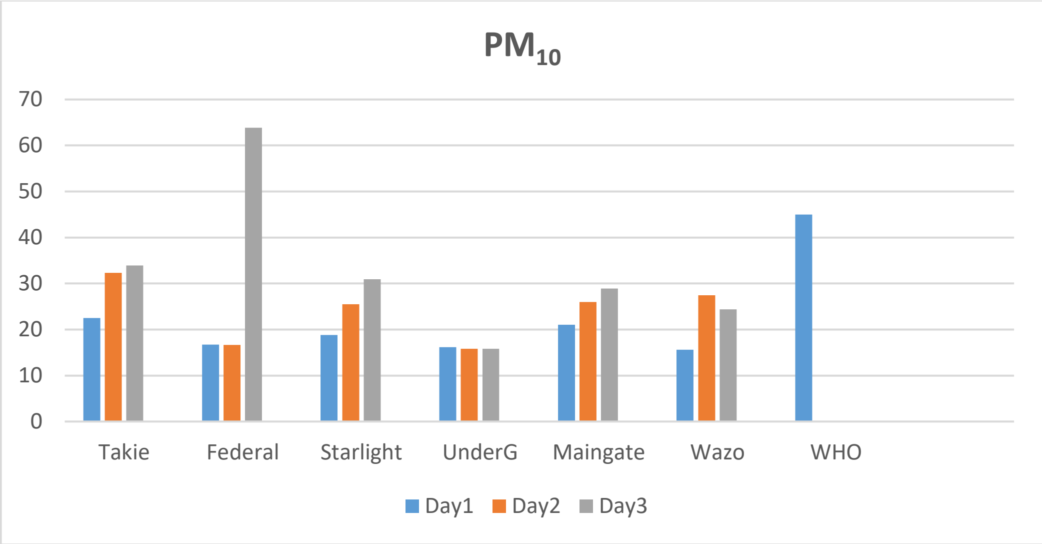

Figure 4: Comparison of PM10 with WHO standards

CONCLUSION

The findings indicate that the levels of particulate matter at these junctions exceed the World Health Organization standards, suggesting poor air quality. The results also reveal significant variations in particulate matter concentrations across the studied junctions. Comparison with a control highlights the impact of particulates from traffic-related activities on air quality. The study's outcome underscores the need for effective measures to mitigate air pollution and improve public health in Ogbomoso, particularly at major road traffic junctions.

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