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Effects of Highway Traffic Density on Particulate Matter Emission along Mararaba-Nyanya-AYA Route in Abuja, Nigeria

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Abstract: *Traffic-related emissions of Suspended Particulate Matter is becoming a global concern in urban centres. Cities in developing countries such as Nigeria are experiencing tremendous increases in traffic density with compounding issues of vehicular emissions. Abuja City is not exempted from this trend as revealed in this paper. A thirty-day monitoring of traffic density and SPM was conducted along the Mararaba-Nyanya-AYA entry route of Abuja City. Using both the descriptive (mean and standard deviation) and inferential (student t-test) statistical test, the study revealed that the highest concentration of traffic density was observed during the peak hours with mean traffic density varying from 12,328 ±2605.7 in the wet season to 9,503 ±2244 in the dry season. Similarly, the highest concentration of SPM was recorded at the varying rate of 20.8 ±3.8 µg/m^3 to 25.1 ±2.7 µg/m^3 during off-peak and peak traffic hours in the dry season. The mean concentration of SPM during peak and off-peak traffic hours in the wet (p-value = 0.000<0.05) and dry (p-value = 0.000<0.05) seasons showed significant variation. The paper concludes that the concentration of SPM along the Mararaba-Nyanya-AYA entry route is arguably determined by the rate of traffic density. It further recommends that all law enforcement agencies must ensure strict implementation of vehicle roadworthiness and ensure that only vehicles that meet emission standards are permitted to ply roads within the Abuja Capital City.*

Keywords: *Traffic Density; Suspended Particulate Matter; Vehicular Emission*

1. Introduction

Despite being a crucial requirement for human health, clean air remains the most challenging environmental problem affecting the entire globe (Okobia *et al.*, 2021). The release of harmful pollutants into the environment from various sources is a major concern in epidemiological studies because different pollutants have varying health impacts. According to reports, pollutants released from point sources can travel afar and contaminate air, making it more dangerous to human health (Ipeaiyeda and Adegboyega, 2017; Ukpere *et. al*., 2018). Among the criteria pollutants established by the World Health Organisation, Suspended Particulate Matter hereafter referred to as SPM has been recognised as the leading pollutant posing a greater threat to human lives (Hamanaka and Mutlu, 2018). According to Mukherjee *et. al.*,(2017), exposure to SPM is a common problem in urban areas attributed to increased cases of cardiovascular issues such as cardiac arrhythmias and heart attacks, as well as respiratory problems like asthma attacks and bronchitis. Most concerning is that PM with an aerodynamic diameter of 2.5 µg/m^3 or less, has been strongly linked to vehicular emissions (Cao *et. al.*, 2020).

Increased urbanisation coupled with poor development outcomes in Africa, particularly Nigeria, have resulted in traffic congestions around urban street roads, causing vehicular emissions of SPM at a quantum rate (Barone *et. al.*, 2014). This has shown that vehicular emission is a major local source of ambient air pollution (Barnes *et. al.*, 2019). Accordingly, the combined emissions of PM attributed to effects of traffic density, unpaved roads and mechanical defects such as tyre abrasion, brake wear, and poor combustion processes have reportedly contributed to increased traffic-related emissions of PM far above the World Health Organisation (WHO) global standard (Mukherjee and Agrawal, 2017). Bad fuel quality is a major cause of vehicle emissions, especially in Sub-Saharan Africa and Nigeria in particular, where the sulfur content of fuel was reportedly 204 times higher than the permitted limit in 2020 (Hirota and Kashima, 2020; Ayetor *et. al*., 2021).

Just like other megacities in Africa, Abuja City is growing at a tremendous rate of 5.15%, becoming one of the fastest-growing cities in Africa (Ajahand Obia, 2016). This growth has led to an increase in the number of car fleets, commuters and in turn, road congestion with antecedent effects of traffic-related air pollution (Ayetor *et. al.*,2021). Consequently, there is a lack of evidence-based research on the rising case of traffic density and its effects on the emission of SPM, which is already a bottleneck to effective formulation and implementation of mitigation strategies among policymakers in the Abuja Federal Capital City of Nigeria. Thus, this paper aims to bridge the gaps by quantifying traffic density and Suspended Particulate Matter (SPM) emissions along the Mararaba-Nyanya-AYA highway in Abuja City, Nigeria, in line with the following objectives;

1. Determine the mean traffic density along the Mararaba-Nyanya-AYA highway during peak and off-peak hours across wet and dry seasons.
2. Ascertain the variation of mean traffic densityalong the Mararaba-Nyanya-AYA highway during peak and off-peak hours across wet and dry seasons.
3. Determine the mean ambient concentration of SPMduring peak and off-peak hours across wet and dry seasons.
4. Compare the result in objective 3 to the Nigeria (NESREA) and WHO limit for hourly human exposure.

2. Materials and Methods

2.1. Study Area

The Mararaba-Nyanya-AYA highway is among the three major entry routes to Nigeria's Capital City (Abuja). This route is located in the eastern part of the city and the major corridor through which commuters from the Northeastern part of Nigeria gain access to the Capital City. A major traffic junction within the route was marked for the investigation of traffic density as well as the monitoring of SPM for 30 consecutive days across the wet and dry seasons respectively (Fig 1). Abuja experiences a Tropical Continental climate characterised by wet and dry seasons (Edicha and Mgbanyi, 2013). Accordingly, the average daily temperature varies from 28°C to 30°C, in the wet season and soars as high as 38°C in the dry season (Adeyeri, *et. al.*,2015), while total annual rainfall varies from 1100 mm to 1600 mm. The relative humidity varied from 30% in the dry season and 70% in the wet season. Abuja City is already experiencing an upsurge of human influx with a purported population of 2,900,631.

2.2. Methodological Design

2.2.1. Sources of Data and Sample Size

Suspended Particulate Matter (SPM) and traffic density were measured in situ (primary data source) at Karutraffic interchange, a major gridlock hotspot along the Mararaba-Nyanya-AYA Highway using mobile monitoring devices (particulate detector and traffic counter). The measurements were conducted at peak (7-10 am) and off-peak (1-3 pm) traffic hours for thirty consecutive days across wet and dry seasons.

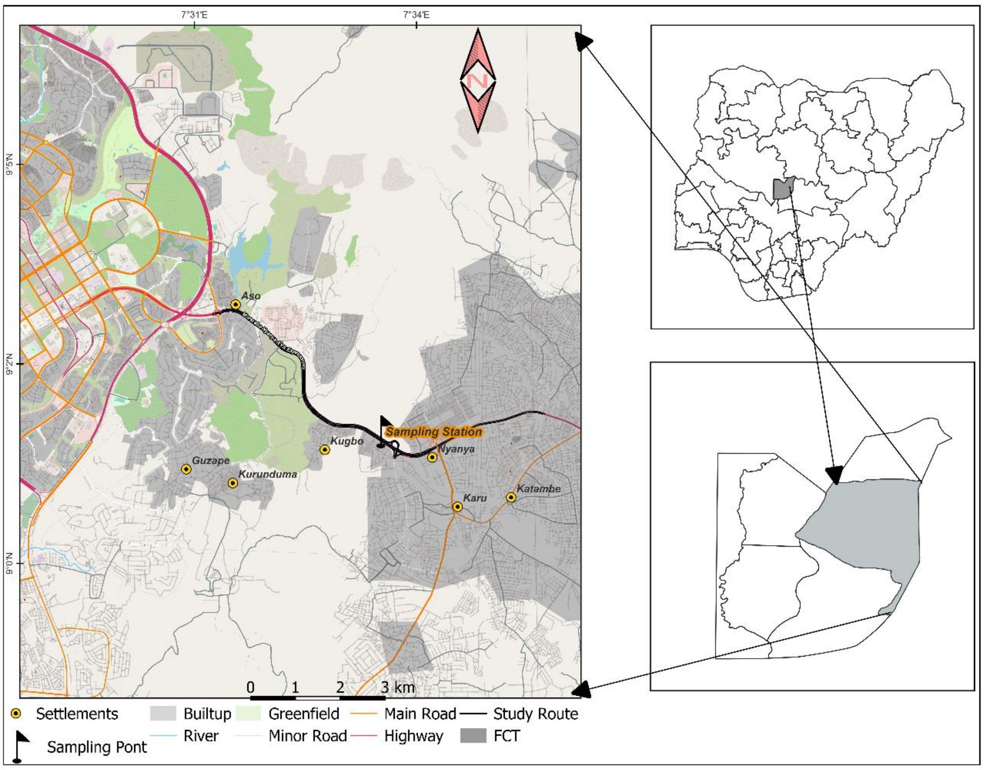

Fig1. *Study Area*

2.2.2. Sampling Technique

The measurement of SPM and traffic density along the Mararaba-Nyanya-AYA Highway was conducted in real-time. SPM was measured usinga HAZE Dust Particulate Monitor (GAXT-D-DL). The instrument was placed on a tripod of about 1.5m above ground level. The readings were obtained every 20 minutes for 2hoursand the average values were recorded as the concentration of SPM. This procedure was repeated during peak and off-peak traffic hours respectively across seasons. For traffic density count, a counter device was manned alongside the tripod and readings of vehicular movement were recorded simultaneously. The instrumentation adopted during sampling is presented in Table 1.

Table1. *Adopted Instrument*

Instrument and model	**Purpose**
Global Positioning System GPSmap 60Cx	To obtain coordinates of the sampling point
HAZE Dust Particulate Monitor (GAXT-D-DL)	To record hourly SPM concentration
Notepad/Pen 40 leaves/bic	For writing
Traffic counter	To determine the frequency rate of traffic density

2.2.3. Data Analysis

In line with the study objectives, both the descriptive (mean and standard deviation) and the inferential (student t-test) statistics were employed to draw inferences to the following null hypotheses;

1. There is no significant variation in the mean traffic densityalong the Mararaba-Nyanya-AYA highway during peak and off-peak hours across the season.
2. There is no significant variation in the mean ambient concentration of SPM during peak and off-peak hours across the season.

i. Mean

$$\bar{X} = \frac{\sum X}{N}$$

Where: $\bar{X}$ = Mean

$\sum$ = Summation of the entire data points in the data set

N = Number of data points in the data set

ii. *Standard Deviation*

$$\boldsymbol{\delta} = \sqrt{\sum \frac{(\mathbf{X} - \bar{\mathbf{X}})^2}{\boldsymbol{N}}}$$

Where: $\boldsymbol{\delta}$ = Standard Deviation

$\sum$ = Summation of the entire data points in the data set

X = Value of the ith point in the data set

$\bar{\boldsymbol{X}}$ = The mean value of the data set

N = Number of data points in the data set

iii. T-test formula

The variation in the mean traffic density and SPM along the Mararaba-Nyanya-AYA highway during peak and off-peak hours across seasons were analysed using the student t-test analysis as expressed below.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\left(\frac{\sigma_1^2}{N_1}\right) + \left(\frac{\sigma_2^2}{N_2}\right)}}$$

$\bar{x}_1$ = mean value of traffic count/SPM at peak hours -----variable 1

$\bar{x}_1$ = mean value of traffic count/SPM at off-peak hours -variable 2

σ_1^2 = the square of the standard deviation of variable 1

σ_2^2 = the square of the standard deviation of variable 2

N_1 = total number of values in variable 1

N_2 = total number of values in variable 2

3. RESULT AND DISCUSSION

3.1. Traffic Density Along the Study Route

The traffic density along the study route varied during peak and off-peak hours across seasons as shown in Fig 2. The highest concentration of traffic density was observed during the peak hours with mean traffic density varying from 12,328 ±2605.7 in the wet season to 9,503 ±2244 in the dry season. In contrast, the lowest mean traffic density of 7,673 ±1810.3 was observed during the off-peak traffic hours in the wet season compared to the mean traffic density (8,775 ±1819.8) recorded during the off-peak hours in the dry season. The result has shown clearly that the Mararaba-Nyanya-AYA highway is a major entry route into the Capital City of Abuja, accommodating high traffic density. This is a confirmation of the high traffic density of 2,871-44,039 that was reported on the same route in 2018 (Ebeshi and Ekanade, 2018). This implied that the Mararaba-Nyanya-AYA highway has been experiencing a continuous increase in traffic density over the years. Similar to this assertion, major cities in Nigeria are plagued with high traffic density, which includes the Nsukka-Enugu-Awgu route with a reported hourly mean traffic density ranging from 587─2873 and 587 (Onyeka *et. al.*, 2020).

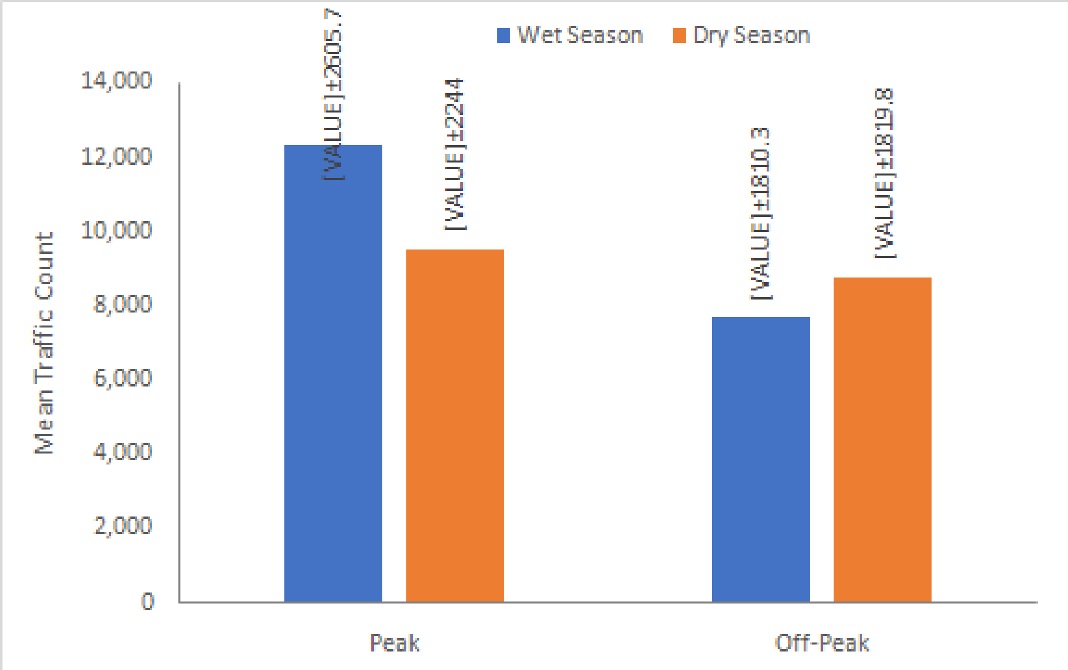

Fig2. *Mean traffic density along the Mararaba-Nyanya-AYA highway*

3.2. Variance Test of Mean Traffic Density along the Study Route

The output of the variance test showed that the traffic density recorded during traffic peak and off-peak hours was statistically significant as reflected by the p-value 0.000<0.05 in the wet season (Table 2).The significant variation in traffic density during peak and off-peak hours in the wet season may be due to inclement weather conditions. In contrast, the observed traffic density during peak and off-peak hours was not statistically significant (p-value 0.09>0.05) during the dry season. The result implied that the study hypothesis 1 is only applicable to the mean traffic density during the dry season.

Table2. *Variance test for peak and off-peak traffic density*

	Wet Season	Dry Season
Observations	30	30
Df	58	58
t Stat	7.902	1.357
P(T<=t) one-tail	0.000**	0.09
t Critical one-tail	1.676	1.674

***Significant at 95% (0.05) confidence level.*

3.3. Conformity of Mean SPM to NESREA and WHO Limit along the Study Route

The average concentration of ambient SPM along the study route varied from 19.1 ±3.8 µg/m^3 to 23.4 ±4.1 µg/m^3 during off-peak and peak traffic periods in the wet season. In contrast, a high concentration of SPM was recorded at the varying rate of 20.8 ±3.8 µg/m^3 to 25.1 ±2.7 µg/m^{3}during off-peak and peak traffic hours in the dry season(Fig 3). The result showed that traffic-related emissions of SPM is most concerning during the dry season. However, the mean concentration of SPM recorded across seasons during peak and off-peak traffic hours was within the established hourly permissible limit of WHO (50 µg/m^3) and NESREA (250 µg/m^3). This implied that SPM is not a concerned traffic-related pollutant along the Mararaba-Nyanya-AYA Highway.

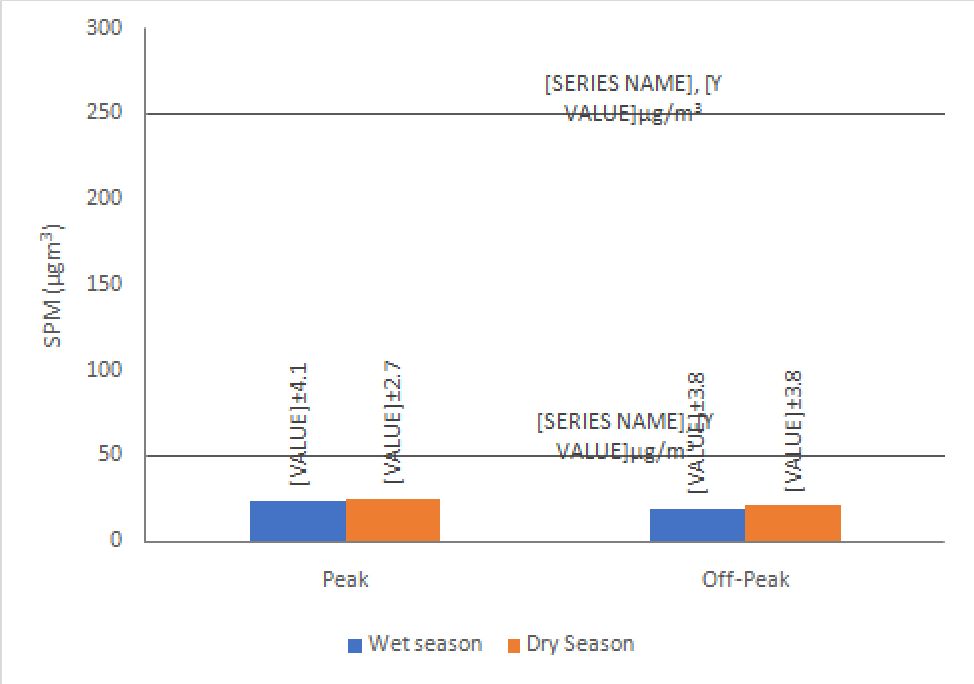

Fig3. *Mean concentration of SPM along the Mararaba-Nyanya-AYA highway*

The result agrees with the findings of 1.67 ±0.11µg/m^3 to 12.16 ±0.31µg/m^3 along major traffic routes in Enugu urban, Nsukka and Awgu town reported by Onyeka,*et. al.*, (2020). In contrast, Olayinka *et. al.*, (2015) reported elevated values of 29.5-170.8 and 51.00-642.3ppm and attributed SPM as the major air pollution along transit routes in the city of Abeokuta, Southwest Nigeria. Similarly, Ukpebor *et. al.*, (2021) reported elevated SPM varied at the range of 73.70 – 388.20µg/m^3 along major transport route junctions in Benin City, Nigeria.

3.4. Variance Test of Mean Concentration of SPM along the Study Route

The variance test result presented in Table 3 showed a significant variation in the concentration of SPM during peak and off-peak traffic hours in the wet (p-value = 0.000<0.05) and dry (p-value = 0.000<0.05) seasons respectively. This is commensurate with the high mean values of SPM recorded during the peak hours compared to the off-peak hours across seasons (Fig 3). This implied that study hypothesis 2 is rejected, thus, the mean concentration of SPM along the study route differs in relation to peak and off-peak traffic hours. This connotes that traffic-related emissions of SPM along the study route is of major concern to the health of commuters and roadside sellers particularly during peak traffic hours. This study affirms the initial fact that Nigeria is the 4th ranked country with the worst scenario of SPM-related air pollution (Ayetor *et. al.*,2021), with the country with the highest death record attributed to SPM exposure in West Africa (Adama, 2018).

Table3. *Variance test for peak and off-peak traffic density*

	Wet Season	Dry Season
Observations	30	30
Df	58	58
t Stat	-4.1532	-5.3025
P(T<=t) one-tail	0.000**	0.000**
t Critical one-tail	1.672	1.672

***Significant at 95% (0.05) confidence level.*

4. Conclusion and Recommendation

This study has shown that vehicular emissions contribute significantly to the ambient concentration of SPM along road corridors. In particular, the concentration of SPM along the Mararaba-Nyanya-AYA entry route is arguably determined by the rate of traffic density. Elevated levels of SPM were observed during traffic peak hours across the season, which was statistically verified, indicating potential risk exposure to commuters and roadside traders. This is a wake-up call for all law enforcement agencies to ensure strict implementation of vehicle roadworthiness and ensure that only vehicles that meet emission standards are permitted to ply roads within the Abuja Capital City.

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