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Spatiotemporal Inventory of Vehicular Emissions Along the Benin-Ore-Sagamu Highway Using Emission Factor Approach

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Abstract: In response to growing public health concerns regarding elevated exposure to traffic-related air pollutants and their associated adverse health effects in populations residing near major roadways, it is imperative to assess the environmental impacts of vehicular emissions as a basis for implementing effective mitigation strategies. This study employed the emission factor approach to assess how different vehicle types contribute to air pollution, specifically CO, SO_2, VOCs, PM, and CO_2, at the four traffic-congested intersections along the Benin-Ore-Sagamu highway in southwestern Nigeria. The selected sites (Okada Junction, Ore, Ijebu-Ode, and Sagamu) are key locations for analyzing the impact of vehicular emissions on air quality. Manual vehicle counts were conducted daily over one month to estimate the annual traffic volume. The recorded traffic data were integrated with pollutant-specific emission factors and the annual fuel consumption of the various vehicle categories to compute the corresponding emission rates for each air pollutant. The findings revealed that estimated annual emissions of carbon monoxide (CO), sulphur dioxide (SO_2), volatile organic compounds (VOCs), particulate matter (PM), and carbon dioxide (CO_2) ranged from 74,740 to 95,579 tons/year, 6,940 to 9,228 tons/year, 7,590 to 9,470 tons/year, 690 to 910 tons/year, and 546,000 to 744,000 tons/year, respectively. Gasoline-powered vehicles accounted for approximately 60% to 90% of total VOCs and CO emissions, whereas diesel-powered vehicles contributed between 80% and 90% of SO_2 and PM emissions. To reduce vehicular emissions, the study recommends a multifaceted approach involving stricter regulations, cleaner fuels, vehicle emission standards, and public awareness campaigns.

Keywords: *Vehicular Emissions; Traffic Volume; Gasoline-Powered Vehicles; Emission Factors; Fuel Consumption; Air Quality*

INTRODUCTION

Vehicular emission is one of the major environmental problems confronting developing countries and growing cities due to urbanization and motorization, thereby contributing a greater percentage of emissions than any other sources of air pollution (Aroh *et al.,* 2023; Shafie and Mahmud, 2021).

Vehicular emissions consist of gases and particles released into the atmosphere due to fuel combustion in motor vehicles. Studies carried out on analysis of air pollution suggest that vehicular emissions are the major contributor to the deterioration of urban air quality along with many other comparable sources and it constitutes up to 70-90 % of carbon monoxide (CO) emissions (Kumar *et al.,* 2021; Guo *et al.,* 2024; Wallington *et al.,* 2022). Human exposure to vehicular emissions can lead to various health issues, including immune system impairment, increased asthma cases, chronic bronchitis in adults, and cardiovascular diseases (Laro and Raheem, 2018; Zaheer *et al.,* 2018; Chun-Lang *et al.,* 2020; Nazar and Niedoszytko, 2022). These health impacts are largely influenced by the concentration of pollutants released into the air and the duration of time individuals spend in polluted environments (Wang *et al.,* 2023). Therefore, accurately quantifying the atmospheric concentrations of these pollutants serves as a crucial control measure for mitigating their adverse effects on human health and the environment.

There are no generalized, straightforward methods to accurately quantify the contribution of land transport, especially motor vehicles, to pollutant concentrations at the level in the atmosphere. A case-by-case evaluation is employed, using comprehensive air quality monitoring programs and emissions inventories to combat vehicular emissions. An emission inventory is a database used to account for different sources of ambient air pollutants in a geographical area over a specific period (Quoc *et al.,* 2020; USEPA, 2023). It is a crucial tool used by environmental researchers, regulatory bodies, and policymakers to understand pollution sources, and set emission reduction targets to comply with environmental laws and regulations for efficient and effective air quality management plans (Cuellar-Alvarez *et al.,* 2023; Viteri et al., 2023; Xu *et al.,* 2020). Over the years, several studies based on the use and development of emission inventories have been reported. For instance, Singh *et al.* (2022) adopted direct measurement to develop an emission inventory for road transport in India, providing recommendations for country-level fleet characterization data and post facto policy impact assessment. Wang *et al.* (2024) reported a method for developing a high-resolution vehicle emission inventory and offered detailed and accurate emission data. Pfannerstill *et al.* (2023) also contributed to understanding the emission inventory by relating VOCs emissions to transportation. Grassi *et al.* (2021) focused on the assessment of on-road mobile source emission inventory and concluded that gasoline-powered vehicles contributed majorly to CO and CO_2 emissions. Estalki and Orkomi (2024) assessed the on-road emission inventory and compatible control measures for the morning rush hour in Rasht using a simulator for emission rate estimation. In a related study, Huy *et al.* (2020) used the Inventory of Vehicle Emissions (IVE) model to estimate on-road traffic emissions to develop an emission inventory. The results indicated that compliance with emission standards would cause a reduction of 71% of emissions. Most of these studies were carried out in developed countries where existing data on emission inventories are available, unlike developing countries with no emission data.

Nigeria, a developing nation and the most populous country in Africa, is experiencing rapid population growth, with projections estimating around 239 million people by 2025 (Pontianus and Oruonye, 2021). This population surge has led to increased vehicle ownership (Ukonze *et al.,* 2020). However, most of these vehicles are aged with low-efficiency engines and high emission rates (Agarwal *et al.,* 2023). The Benin-Ore-Sagamu highway is one of the busiest routes in Nigeria as it experiences a steady influx of about 18,000 vehicles daily (Salisu and Oyesiku, 2020). Given this heavy traffic flow, the Benin-Ore-Sagamu highway environment is prone to vehicular emissions. Notably, to date, less attention has been given to vehicular emissions in Nigeria, and this negligence poses threats to human health and the ecosystem. The lack of emission data in Nigeria creates a huge gap in understanding the impacts of vehicular emissions on the air quality of most receptor communities near dense traffic areas. In bridging the gap, this research focuses on formulating a comprehensive emission inventory of air pollutants by classifying and determining the average traffic volume at some selected locations, and calculating the fuel consumed by each vehicle category, combined with an emission factor of air pollutants to estimate emission rates. The significance of this research is embedded in Sustainable Development Goals (SDGs) of SDG 11 (making human settlements safe, resilient, and sustainable) and SDG 13 (urgent action to combat climate change).

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MATERIALS AND METHODS

2.1 Sampling Sites / Locations

The Benin-Ore-Sagamu highway is a dual carriageway and perhaps one of the most important road linkages in Nigeria. The highway connects Sagamu town to Ijebu-Ode town in Ogun State through Ore town in Ondo State to Benin City, in Edo State. Figure 1 illustrates the sampling locations of the study route. The four sampling locations selected at the study routes include location A (Okada-Junction (Benin), location B (Ore), location C (Ijebu-Ode), and location D (Sagamu). These sampling locations are intersections along the highway with high traffic congestion. Benin City is the capital of Edo State, Nigeria. It is located 6º 20′21″ N, 5º 37′28″ E. and situated at an elevation of 88 m above sea level. It is the center of Nigeria's rubber industry that attracts visitors. Thus, the highway experiences a steady influx of vehicular movement daily, which invariably causes air pollution to the environment. Ore town is located in the Odigbo Local Government Area of Ondo State, Nigeria, spanning a region of 1,820 km^2. It lies at latitude 6º 44′49″ N and longitude 4º 52′34″ E. Ore is a travel stop point for travelers, hence, it experiences high traffic volume.

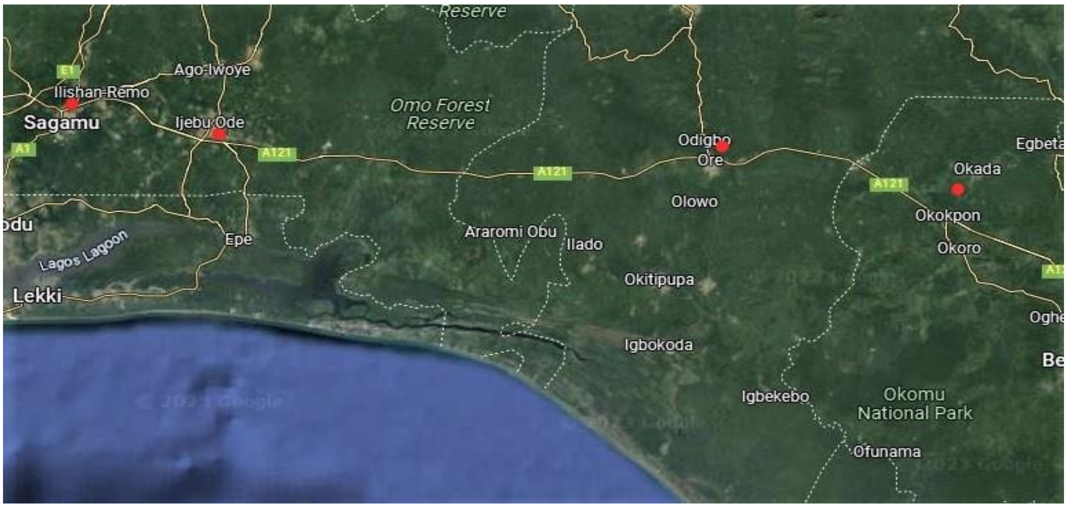

Fig.1 Map Showing the Sampling Locations (Sagamu, Ijebu-Ode, Ore, and Benin)

Ijebu-Ode is a town situated in Ogun State, Nigeria, with an estimated population of 222,653, according to the last census carried out by the Population and Housing Census, Nigeria (2006). It is located approximately 110 km northeast of Lagos by road. The geographical coordinates for Ijebu-Ode are 6° 49′81″ N and 3° 55′8″ E. Sagamu town is located within southwest Nigeria near Ibu River in Ogun State with geographical coordinates 6º 83′ 32″ N, 3º 48′41″ E. Sagamu connects three important metropolitan regions in the country Nigeria: Lagos, Ondo, and Edo State which links to the eastern and northern part of the country. The spillover effect of the growing populations in these three socio-economic states has led to increased human activities and vehicle traffic along the highway, particularly at high-traffic intersections.

2.2 Traffic Data Collection

Traffic data were collected through manual vehicle counts conducted at designated sampling locations along selected intersections of the Benin-Ore-Sagamu highway. Vehicles were categorized into four groups: motorcycles, cars, buses, and trucks/trailers. At each location, the number of vehicles in each category was recorded using tally sheets during hourly observation periods to obtain the Average Daily Traffic (ADT). These daily values were then extrapolated to estimate the Average Annual Traffic Volume (AATV), following the procedure outlined by Spack and Moreland (2019). Traffic counts were carried out for one month each during the dry and wet seasons, capturing seasonal variations in traffic flow. No abnormal traffic conditions were observed during the monitoring periods, ensuring representative data.

2.3 Emission Rates Estimation of Air Pollutants

The emission rates were determined using the emission factor approach, which estimates vehicular emissions based on activity data, by the methodology outlined by the U.S. Environmental Protection Agency (USEPA, 2024). According to Jimoda *et al.* (2009), this method for calculating emission rates is represented by Equation 2.1. The fuel consumption of the different categories of vehicles in litres per day was obtained using the method reported by Mbandi *et al.*, (2019) as expressed in equation 2.2, where the volume of fuels obtained were converted to cubic meters (m^3) per day and combined with the density of Premium Motor Spirit (PMS, 750 kg/m^3) and Automated Gas Oil (AGO, 840 kg/m^3) to determine the mass of PMS / AGO consumed per year. The fuel-based emission factors for each category of vehicle fleets used in this study were obtained from the European Environmental Agency (2016). This approach was adopted because of its effectiveness in estimating emissions from vehicular sources, particularly in the context of Nigeria, where real-time emissions monitoring and detailed vehicle-specific data are not readily available.

$$Criteria\ Air\ Pollutants\ Emitted\ in\ g/year = \frac{EF\ (g) of\ CAP}{1kg\ of\ Fuel\ Burnt} \times FC \quad (1)$$

Emission Factor (EF), $g/year\ of\ fuel\ burnt$
Criteria Air Pollutant (CAP) $g/year$
Mass of fuel consumed (FC) for each category of vehicle per year (kg)

$$FC = \frac{(TFM/_{COF})}{NOD} \quad (2)$$

FC: Volume of fuel consumed (L/day)
TFM: Total money spends on fuel per month
(# /month)
COF: Cost of fuel (# / L)
NOD: Number of days per month ($day/month$)

RESULTS AND DISCUSSION

3.1 Traffic Volume Data

The annual traffic volume used to estimate the fuel consumed by each category of motor vehicle is presented in Table-1.

Table-1 Annual Traffic Volume Data

Vehicle	Location A		Location B		Location C		Location D	
	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season
Motorcycles	18 280 704	11764 896	15 656 160	13 316 160	17 111 328	9 115 392	17 254 848	9 049 248
Cars	4 019 808	3 237 312	4 295 616	3 223 584	4 148 352	8 925 696	5 989 152	12 944 256
Buses	1 950 624	1 508 832	2 615 808	2 357 472	1 795 872	1 991 808	3 146 208	2 285 088
Trucks/Trailers	2 706 912	2 881 632	2 753 088	1 528 800	2 939 040	2 988 960	3 534 336	4 183 296
Sub-Total	26 958048	19 392 672	25 320 672	20 426 016	25 994 592	23 021 856	29 924 544	28 461 888
Total	46 350 0720		45 746 688		49 016 448		58 386 432	

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The highest annual traffic volume of 58,386,432 was obtained at location D (Sagamu), followed by location C (49,016,448), location A (46,350,720), and location B (45,746,688). The variations of vehicle percentages shared by motorcycles, cars, buses, and trucks/trailers to the total annual traffic volume across the sampling locations are shown in Fig. 2 – 5. Percentages of motorcycles, cars, buses, and trucks/trailers in dry and wet seasons at the four locations ranged between 32-68 %, 15-45 %, 7-12 %, and 7-15 %, respectively. On average, motorcycles had 55 % of the total traffic volume in all locations, while cars, buses, and trucks/trailers shared average fractions of 23 %, 9 %, and 12 %, respectively. The observed seasonal traffic volume of vehicles showed a lower traffic volume of motorcycles in the wet season than in the dry season; the lower counts in the wet season may be due to the effect of rainfall. Meanwhile, more cars were recorded during the wet season than the dry season, with an increase of over 40 %. On the contrary, buses and trucks/trailers shared lower fractions than cars in all the sampling locations. The traffic volume data obtained in this work is higher than the total daily average traffic volume data of 18,851 (i.e, 6,880,615 per year) reported for the year 2019 by Salisu and Oyesiku (2020) at the Benin-Ore-Sagamu highway. Similarly, the traffic volume data obtained in this study is also higher than the values reported by Adeke *et al.* (2018) on a major highway in Makurdi. The high increase in traffic volume in this study could result from increased population and economic growth.

3.2 Percentage of Fuel Consumed

The method outlined by Mbandi *et al.* (2019) expressed in equation 2.1 was utilized in this study to calculate the mass of fuel consumed by each vehicle type, which was then converted into the percentage of total fuel consumption. Fig. 6 shows the percentage of fuel consumed by vehicles across all locations for dry and wet Seasons. Motorcycles consistently represent a small percentage of the overall fuel consumption at each location, around 5 % or less in both seasons. The dry season typically shows a slightly higher percentage for motorcycles across locations, but their contribution remains minimal compared to larger vehicles like trucks/trailers. Cars show a moderate percentage of total fuel consumption, ranging between 20-30 % across locations. The wet season generally has a higher percentage of fuel consumption for cars, particularly at Location D, while buses contribute around 10-25 % to the total fuel consumption at each location, with a noticeable increase in the wet season. Locations C and D show higher fuel consumption percentages for buses in the wet season, indicating higher fuel consumption at these locations.

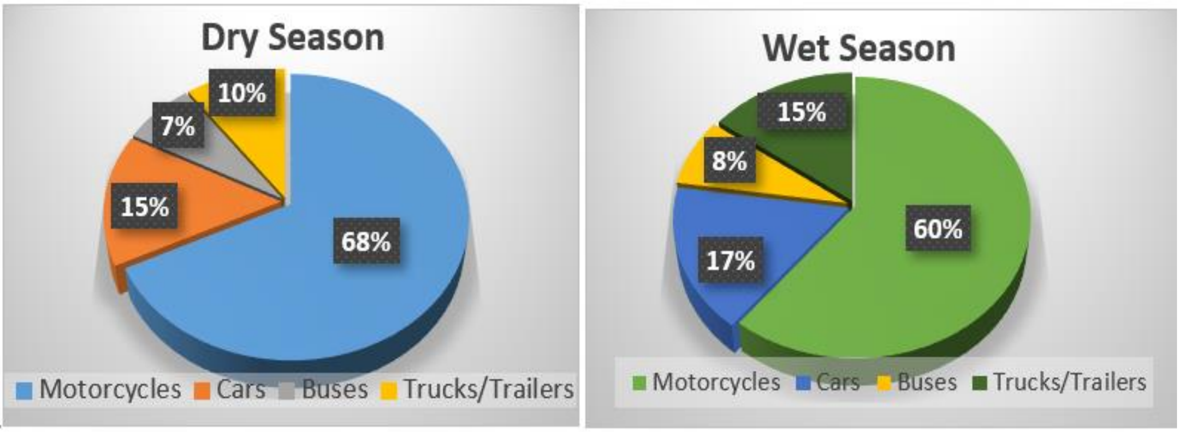

Fig. 2 Percentage Contribution of Vehicle Category at Location A in Dry and Wet Seasons

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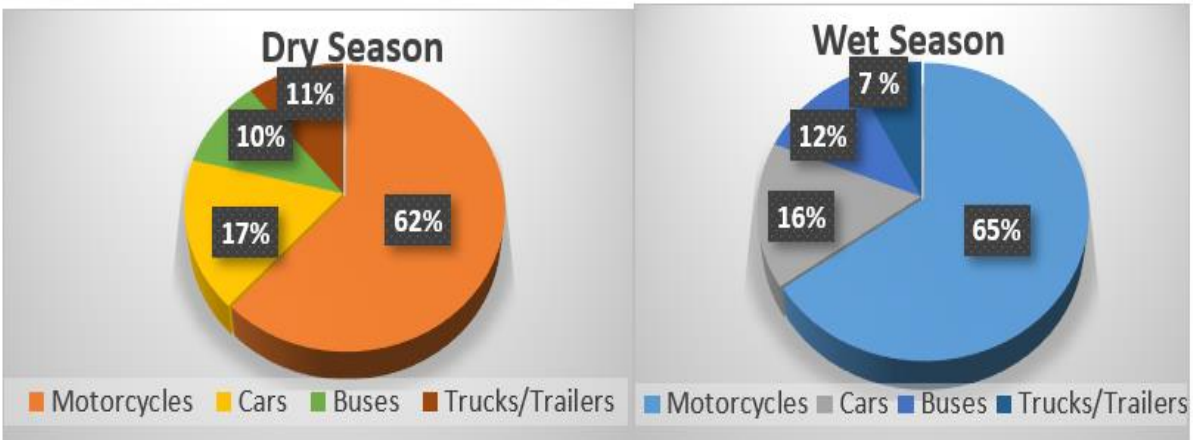

Fig. 3 Percentage Contribution of Vehicle Category at Location B in Dry and Wet Seasons

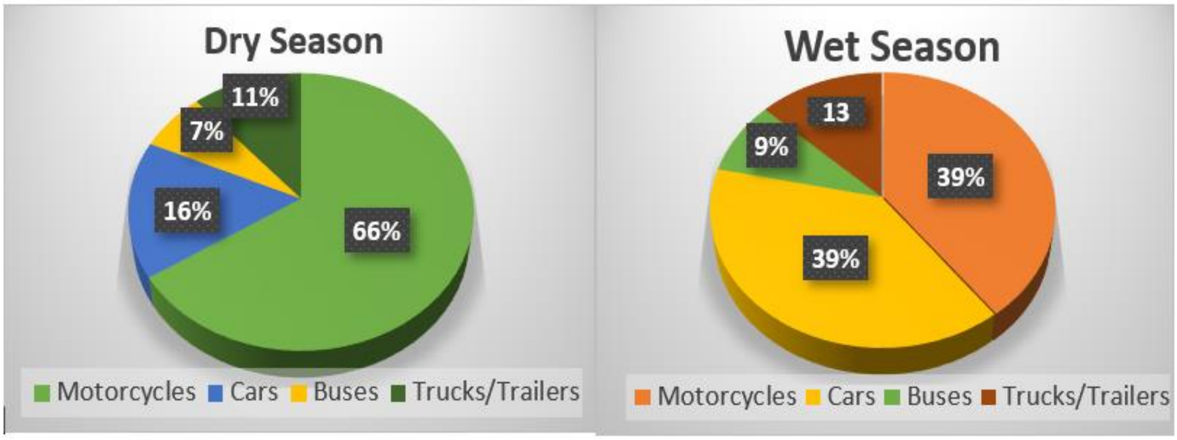

Fig. 4 Percentage Contribution of Vehicle Category at Location C in Dry and Wet Seasons

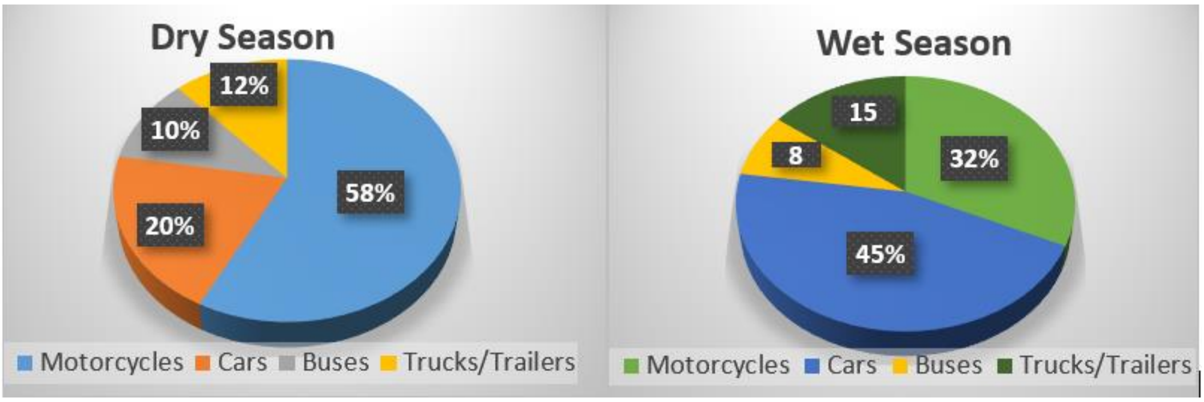

Fig. 5 Percentage Contribution of Vehicle Category at Location D in Dry and Wet Season

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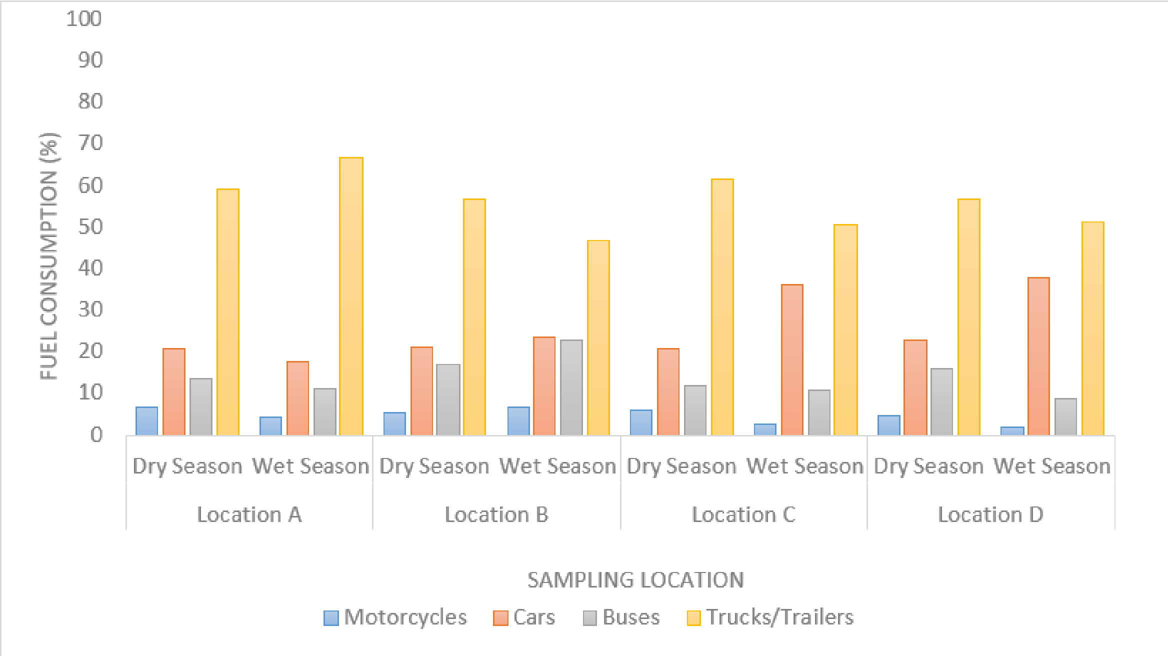
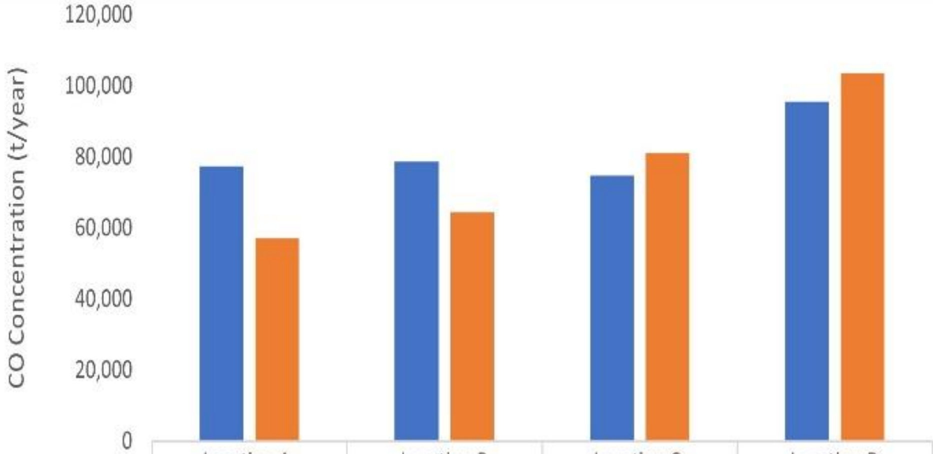


Fig. 6 Percentage Distribution of Vehicle Fuel Consumption

Trucks/trailers dominate the fuel consumption percentage across all locations, particularly in the wet season, where their contribution surpasses 60 % in most cases. The significant percentage contribution by trucks/trailers at location D highlights their dominant role in fuel consumption. The seasonal variation observation show that the wet season had higher percentages of fuel consumption across all vehicle categories, indicating greater fuel use during this period. This could be attributed to increased transportation activity during the wet season, likely caused by higher traffic volumes, longer distances travelled, and more challenging driving conditions.

3.3 Emission Rate Estimate of CO

The total annual carbon monoxide (CO) concentration estimated at all locations in the dry season ranged between (74,740 and 95,579) tons/year as seen in Fig. 7. CO levels at Location A were higher during the dry season (77,360 tons/year) compared to the wet season (57,210 tons/year). Similarly, Location B experienced higher CO concentrations in the dry season (78,750 tons/year) than in the wet season (64,420 tons/year Interestingly, Location C showed the opposite trend, with higher CO levels in the wet season (81,050 tons/year) than in the dry season. Location D had the highest CO concentrations overall, with 103,640 tons/year in the wet season and 95,579 tons/year in the dry season, indicating consistently high emissions throughout both seasons. The distribution of vehicle types contributing to CO emissions across the four locations (A, B, C, D) shows that motorcycles were the primary contributors to CO emissions, particularly during the dry season at Location A, where they accounted for 48.72 % of CO emissions, decreasing to 42.4% in the wet season. Cars contributed 22.91 % in the dry season, slightly rising to 24.95 % in the wet season. Buses maintain a stable contribution, at 20.79 % and 21.74 % in the dry and wet seasons, respectively. Similar patterns were observed at Locations B and C, with motorcycles, cars, and buses playing significant roles in CO emissions.



	Location A	Location B	Location C	Location D
Dry Season	77,360	78,750	74,740	95,579
Wet Season	57,210	64,420	81,050	103,640

Fig. 7 Total Annual CO Emission for Dry and Wet Season

In contrast, at Location D, cars emerged as the primary source of CO emissions, contributing 55.08 %, which aligns with the findings of Kumar *et al.* (2021). This shift is likely due to increased car use as motorcycle activity declined in response to rainfall. Overall, CO levels at each location are strongly influenced by the distribution of vehicle types, providing evidence that gasoline-powered vehicles are the primary contributors to CO emissions. The estimated CO values from this study are consistent with the findings of Angatha and Mehar (2020) but are lower than the CO concentrations reported by Singh *et al.* (2022) and Huy *et al.* (2020).

3.4 Emission Rate Estimate of SO_2

Fig. 8 compares the estimated total annual sulphur dioxide (SO_2) emissions across various locations and seasons. The data indicate that SO_2 emissions were recorded at all locations, with values ranging from 6,940 tons/year to 9,229 tons/year during the dry season and from 4,350 to 11,390 tons/year during the wet season. The lowest emissions were noted at Location A, with 6,940 tons/year in the dry season, and at Location B, with 4,350 t/year in the wet season. Location D recorded the highest levels of SO_2, with emissions of 9,228 t/year during the dry season and 11,390 tons/year in the wet season. At location A, Trucks/Trailers are the largest contributors to SO_2 emissions, accounting for 82.3 %, while cars, buses, and motorcycles contribute 8.75 %, 5.6 7%, and 2.75 %, respectively. In the wet season, it increased to 86.98 %, with cars contributing 6.95 %, buses 4.32 %, and motorcycles 1.75 %. At location D, Trucks/Trailers also contributed 81.36 % (7,500 tons/year), followed by cars at 9.81% (910 tons/year), buses at 6.81 % (630 tons/year), and motorcycles at 1.96 % (180 tons/year). In the wet season, Trucks/Trailers increase to 77.96 % (8,880 tons/year), while cars rise to 17.17% (1.960 tons/year). Buses contribute 4.04 % (460 tons/year), and motorcycles have the smallest share at 0.83 % (94 tons/year). It is worth noting that heavy-duty vehicles accounted for over 80 % of the emissions, while motorcycles, cars, and buses contributed less than 20 %. Heavy-duty vehicles typically run on diesel engines, which contain higher sulphur content than gasoline-powered engines, hence, this suggests that Nigerian fuels still contain significant amounts of sulphur, leading to elevated SO_2 emissions in the study area. This study was compared with a previous study by Liu *et al.* (2022), which estimated SO_2 emissions at 3.6 Gg, a value lower than that found in the present work.

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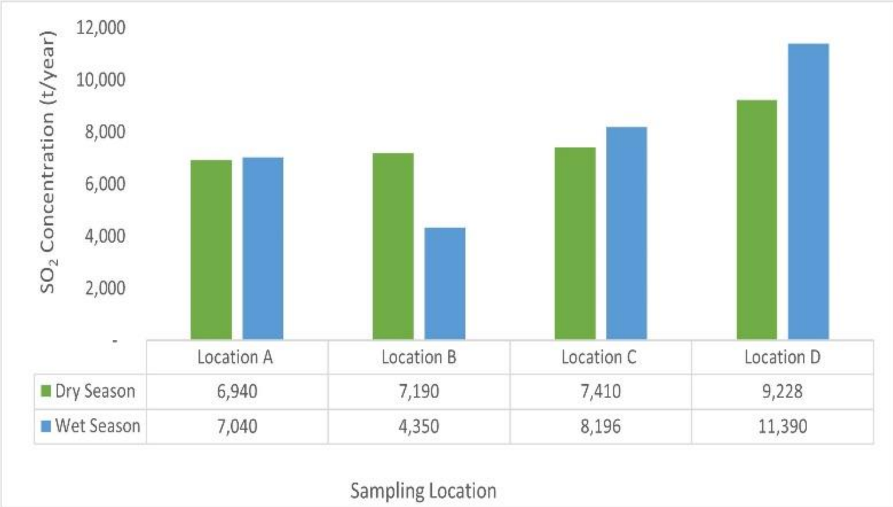

Fig. 8 Total Annual SO_2 Emission for Dry and Wet Season

3.5 Emission Rate Estimates of VOCs

The total emissions of volatile organic compounds (VOCs) across all locations for both dry and wet seasons are depicted in Fig. 9. In the dry season, the concentrations of VOCs at locations A, B, C, and D were 7,700 tons/year, 7,680 tons/year, 7,590 tons/year, and 9,470 tons/year, respectively. Meanwhile, 5,970 tons/year, 5,970 tons/year, 8,600 tons/year, and 11,310 tons/year were obtained for the wet season, respectively. The highest VOCs concentration of 9,470 tons/year was obtained in the dry season and 11,310 tons/year in the wet season at location D. A notable increase in VOC emissions of 1,730 tons/year and 1,710 tons/year was recorded at Locations A and B, respectively, during the dry season compared to the wet season. In contrast, Location D exhibited a significant decrease of 1,860 tons/year in VOC levels during the same period. This pattern highlights a clear seasonal variation in VOC concentrations; however, the extent of this variation differs across locations, likely influenced by a range of environmental factors. Motorcycles are a major source of VOCs with a higher percentage of over 44.35 % emissions during the dry season, still, their contribution significantly decreases in the wet season to 14.91 %, particularly in Location D. In contrast, cars generally see an increase of 57.06 % during the wet season, especially in Location D, where they become the primary source of VOCs. Buses maintain relatively steady percentages across most locations, though their contribution slightly declines in the wet season. Trucks/Trailers exhibit more variability, with their contribution rising in some locations (A, D) during the wet season, while decreasing in others (B, C). These seasonal shifts, particularly in motorcycles and cars, indicate that gasoline-powered vehicles are the predominant source of VOCs emissions. The value of VOCs obtained in this work is lower than the 42.8 Gg and 132.5 kt reported by Liu *et al*. (2022) and Xu *et al.* (2020), respectively.

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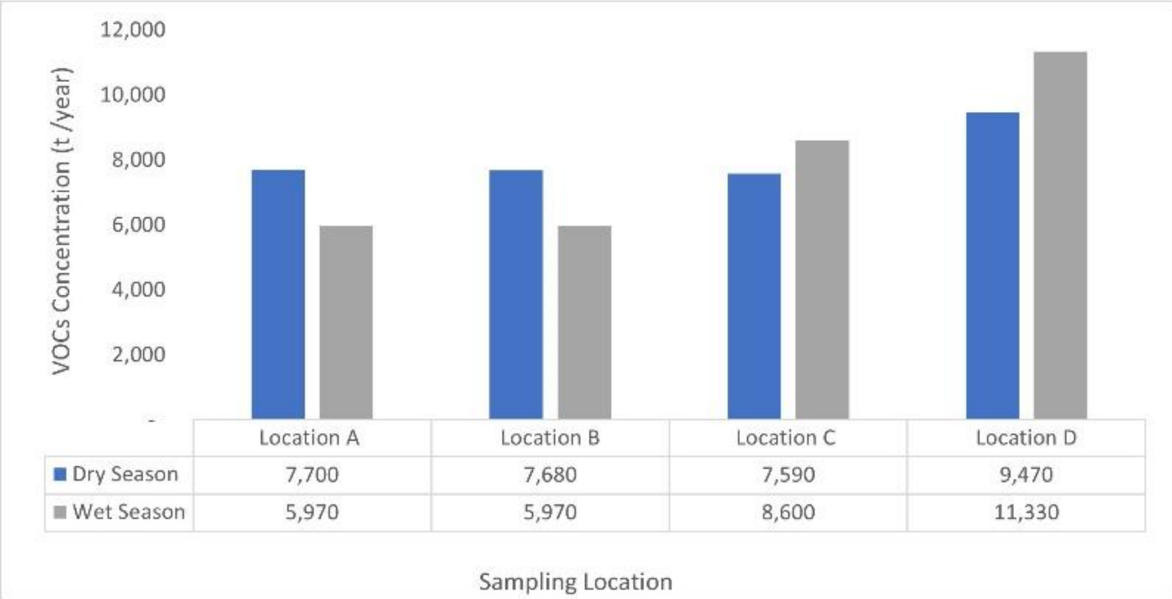

Fig. 9 Total Annual VOCs Emission for Dry and Wet Season

3.6 Emission Rate Estimates of PM

Fig. 10 presents the total PM concentrations estimated at different locations along the Sagamu-Ore-Benin expressway. PM emissions ranged from 690 to 910 tons/year during the dry season. At Location A, the PM concentration is 17 tons/year higher in the wet season compared to the dry season, although the difference is minimal, indicating relatively consistent PM levels across seasons. Location B shows a significant decrease in PM levels during the wet season. In contrast, Location C shows almost no difference in PM concentration between the dry and wet seasons, reflecting a stable PM output regardless of seasonal changes. Location D recorded the highest PM concentration at 910 tons/year in the dry season, with a notable increase in the wet season, reaching 1,050 tons/year. Trucks and trailers dominate PM emissions across all locations and seasons, consistently making up over 90 % of total emissions. Their contribution tends to increase slightly in the wet season, except at Location B, where it decreases. Motorcycles contribute a significant portion during the dry season, ranging from 5.79 % to 8.63 % across locations, but experience a sharp decline in the wet season, particularly at Location D (dropping from 6.59 % to 2.86 %) and Location C (from 7.95 % to 4 %). Cars, which contributed less overall, generally see a rise in their share during the wet season, notably at Location D, where their contribution increases from 2.19 % to 3.81 %. Buses contribute the least across all vehicle types, showing minimal seasonal fluctuation, with their share generally remaining around 1 % in both seasons.

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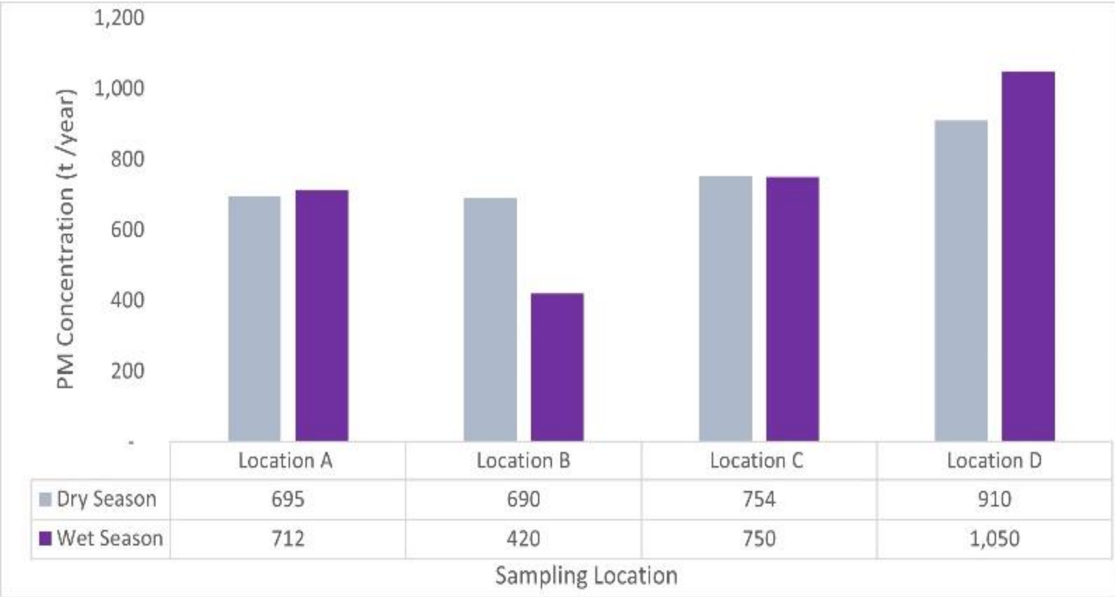

Fig. 10. Total Annual PM Emission for Dry and Wet Season

3.7 Emission Rate Estimates of CO_2

The study analyzed annual CO_2 emissions across four locations, revealing variations by season and vehicle type as depicted in Fig. 11. During the dry season, emissions ranged from 5,450 ktons/year (Location A) to 7,440 ktons/year (Location D), while in the wet season, they ranged from 3,890 ktons/year (Location B) to 9,710 ktons/year (Location D). Trucks and trailers were the largest contributors, accounting for over 50% of total emissions at all locations, with gasoline-powered vehicles contributing 42.8 %. Location D had the highest emissions, with trucks/trailers contributing 56.38 %, followed by cars, buses, and motorcycles. Compared to previous studies, emissions were lower than the 4,549.7 ktons CO_2 reported by Patino-Aroca *et al.* (2022), highlighting heavy-duty vehicles as the primary source of CO_2 emissions.

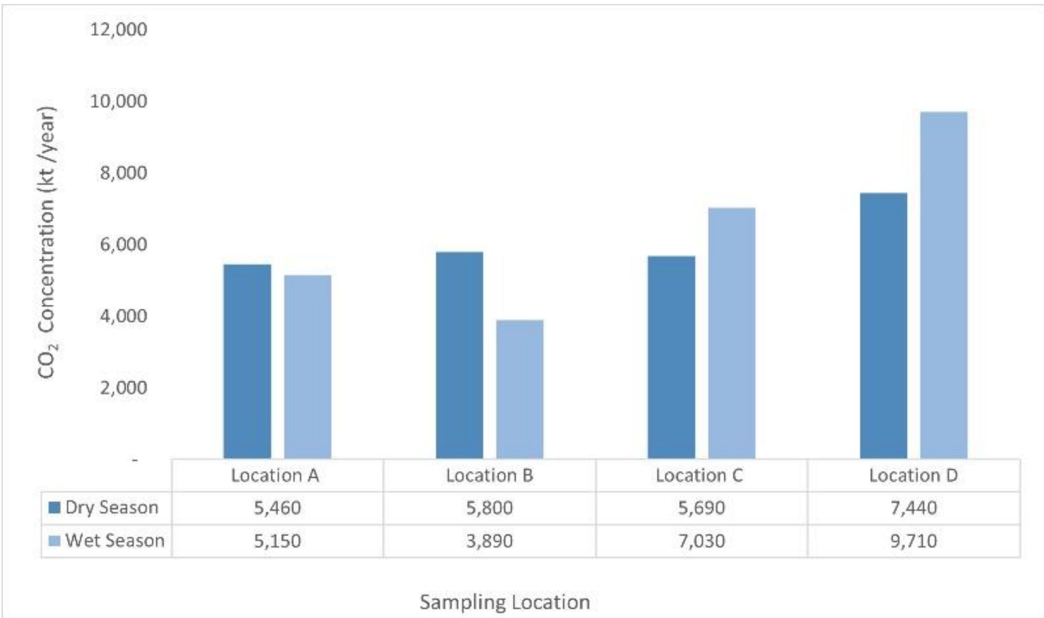

Fig. 11 Total Annual CO_2 Emission for Dry and Wet Season

Raji *et al.*, (2025). Spatiotemporal Inventory of Vehicular Emissions Along the Benin-Ore-Sagamu Highway Using Emission Factor Approach. *Nigeria Journal of Engineering Science Research (NIJESR), 8(1), 87-100.* https://doi.org/10.5281/zenodo.15829837

CONCLUSION

The study estimated vehicular emissions of CO, SO_2, VOCs, PM, and CO_2 using the emission factor approach, incorporating traffic volume and fuel consumption data. Location D recorded the highest traffic volume at 58,386,432, with motorcycles (58 %) dominating vehicle composition during the dry season. Seasonal analysis revealed reduced traffic during the wet season due to rainfall, while fuel consumption data highlighted trucks and trailers as the largest contributors, particularly during the wet season, exceeding 60 % in fuel use. Gasoline-powered vehicles accounted for approximately 80 % of VOCs and 90 % of CO emissions, while diesel-powered trucks and trailers were the primary sources of SO_2, PM, and CO_2. The findings emphasised the impact of vehicle types, fuel use, and seasonal variations on emissions. The study recommends stringent measures, such as restricting older vehicle imports, promoting cleaner fuels, and reducing traffic congestion, to mitigate vehicular pollution.

CONTRIBUTIONS TO KNOWLEDGE

This study provides a baseline vehicular emission inventory using a fuel-based approach, highlighting seasonal and location-based variations in pollutant levels along a major Nigerian highway. It identifies key vehicle contributors to emissions and offers practical recommendations for pollution control in data-limited settings.

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CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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