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RESEARCH ARTICLE

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Impacts of polycyclic aromatic hydrocarbons from vehicular activities on the ambient air quality of Lagos mega city

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Abstract

In response to the growing concern about the contribution of polycyclic aromatic hydrocarbons (PAHs) from vehicular activities in Lagos mega city and their effect on air quality, PAH emissions were estimated using the emission factors approach. To make these estimates, PAH emission factors were calculated from the profile ratio of four PAHs emitted from vehicle sources obtained from the European Environment Agency's emission inventory guidebook, whereas the total number of registered vehicles based on the type of fuel they use for a period of 10 years was obtained from Lagos State Bureau of Statistics. Vehicle emissions were estimated using a combination of individual emission factors, the total number of vehicles in use based on fuel type, and the average mileage covered. The average highest level of emission of PAHs of 3.542 kilograms (kg) for gasoline-powered vehicles was obtained in 2013, whereas the average lowest level of emission of 2.679 kg was recorded for diesel-powered vehicles in 2007. In the same manner, 2013 had highest annual average total emission of 6.384 kg, whereas the lowest annual total PAHs emission of 5.727 kg was recorded in 2007. It is therefore advised that effective control measure should be put in place by regulatory agency to prevent personnel exposure to these hazardous substances.

KEYWORDS

air quality, PAHs, pollution, vehicular activities

1 | INTRODUCTION

Lagos city in Nigeria is known for its pollution problems, which are the result of the rapid and continuous growth of its population and industrial activities. This growth has also encouraged an enormous increase in transportation. As in most cities in the world, the transportation sector in Lagos is one of the major sources of air pollution (Odekanle, Fakinle, Akeredolu, Sonibare, & Adesanmi, 2016). Factors such as traffic congestion, lack of emission controls on vehicles, and fuel quality have been found to contribute to the elevated vehicle emissions affecting air quality in big cities (Gakenheimer et al., 2002). Apart from carbon monoxide (CO), there are other air pollutants that can be emitted from vehicular sources: these include polycyclic aromatic hydrocarbons (PAHs). Contrary to the perception that diesel vehicles are the main vehicular sources of PAHs, light-duty gasoline vehicles have been found to be the most important sources of PAH emissions in some urban area (Lobscheid & Makone, 2004).

PAHs are organic compounds that, in pure form, are mostly colorless, white, or pale-yellow solids. They are a ubiquitous group of several hundred chemically related compounds, persistent in the environment, and having various structures and varied levels of toxicity (Abdel-Shafy & Mansour, 2016). PAHs are a large group of compounds, and they consist of two or more fused aromatic rings made entirely from carbon and hydrogen (Arey & Atkinson, 2003). The origin of PAHs is the incomplete combustion of various fuels. PAHs pose a serious threat to the health and the well-being of humans as they are found to be carcinogens, mutagens, and teratogens (Boström et al., 2002). Generally, PAHs are emitted by both natural and anthropogenic sources (World Health Organization, 2003). Natural sources of PAHs include forest fires, volcanic eruptions, natural losses or seepage from petroleum or coal deposits, and the like, while anthropogenic activities, such as the incomplete burning of fuels, garbage, and other organic substances, also contribute to the release of PAHs into the environment (Zhang & Tao, 2009). Some PAHs are also emitted by manufacturers, and a few are manufactured for commercial use.

PAHs have toxic effects on organisms through various actions, with the mechanism of toxicity considered to be interference with the functions of cellular membrane (Abdel-Shafy & Mansour, 2016). PAHs released into the atmosphere can travel long distances before being

EXHIBIT 1 Map of Lagos showing the study area (Atubi, 2010) [Color figure can be viewed at wileyonlinelibrary.com]

deposited by atmospheric precipitation onto the soil or vegetation or into water (Ravindra, Sokhi, & Van Grieken, 2008). When PAHs are in the ambient air, they can exist either in a vapor phase or adsorbed onto airborne particulate matter (Lima, Farrington, & Christopher, 2005). Several researchers have reported the health effects of human exposure to PAHs (Kim, Jahan, Kabir, & Brown, 2013; Srogi, 2007; Wells, McCallum, Lam, Henderson, & Ondovcik, 2010), although the health effects of individual PAHs differ (Kim et al., 2013). In the majority of the studies, human beings have been exposed occupationally through either inhalation or dermal contact (Kim et al., 2013). Boffetta, Jourenkova, and Gustavsson (1997) and Bach, Kelley, Tate, and McCrory (2003) reported that exposures of workers during coking processes in oil refineries and coal gasification plants can cause skin cancer. This claim was buttressed by Kennaway (1955), who revealed a relationship between lung cancer and working condition in a coal gasification industry. Occupational exposures may also occur in workers breathing exhaust fumes, such as mechanics, and street vendors, as well as motor vehicle drivers, including workers in mining, metal working, or oil refining (Abdel-Shafy & Mansour, 2016). An epidemiologic study by Armstrong, Hutchinson, Unwin, and Fletcher (2004) showed an increased incidence of cancer, particularly of the lungs of workers breathing exhaust fumes (such as mechanics, street vendors, or motor vehicle drivers) and those involved in mining, metal working, or oil refining. Several other studies have also provided evidence to suggest that PAHs may be teratogenic (Wells et al., 2010).

While there are many studies on the emission of PAHs through various means and sources, there is little information on the contribution of traffic and the transport sector to the release of these pollutants into the environment and the subsequent impacts on air quality. Hence, this study seeks to investigate the contribution of the transport sector to the release to PAHs for the past 10 years and the effects of these emissions on the air quality of Lagos mega city.

2 | METHODOLOGY

2.1 | Study area

Lagos city is located in the southwest region of Nigeria (**Exhibit 1**). Lagos state is Nigeria's main commercial center, where more than 70% of the nation's industrial and economic activities are carried out, which makes it the most economically important state of the country (Adebambo & Adebayo, 2009). It is one of the most important and densely populated cities in Nigeria with the worst pollution problem.

As a leading regional port and manufacturing center and home to the highest number of multinational companies in Nigeria, Lagos city is also important to the rest of West Africa (Atubi, 2010). Lagos is located on latitude 6° 22″ and 6° 4″ north and longitude 2° 42″ and 3° 22″ east and has more than 224 vehicles per kilometer compared to 15 vehicles per kilometer in other states in Nigeria (Awoyemi, Ita, Awotayo, Lawal, & Dienne, 2013). As a result, heavy traffic congestion is experienced by the more than 10 million commuters on its roads on daily basis. **Exhibit 2** shows a typical congestion situation in Lagos mega city.

2.2 | Estimation of PAHs from vehicular emissions

The annual emission of PAHs in Lagos city was estimated using a combination of the annual total registered vehicles based on fuel types for the past 10 years (see the table in **Exhibit 3**), which was obtained from Lagos State Bureau of Statistics (2017), and the PAHs' emission factors from profile ratio data for each vehicle category as proposed by the European Environment Agency (EEA) (1990, 2016). The vehicles were split into two categories: gasoline-powered and diesel-powered vehicles.

In this study, we assumed that each of the vehicles had covered an average mileage of 12 kilometers (km), and we assumed that this was

EXHIBIT 2 Typical traffic congestion in Lagos city (Odekanle et al., 2016) [Color figure can be viewed at wileyonlinelibrary.com]

EXHIBIT 3 Total registered vehicles in Lagos from 2007 to 2016 (Lagos State Bureau of Statistics, 2017)

Year	Gasoline	Diesel	Year	Gasoline	Diesel
2007	700,387	150,979	2012	809,493	160,417
2008	738,593	156,089	2013	813,826	160,344
2009	767,311	158,207	2014	810,339	161,698
2010	788,288	157,541	2015	795,064	162,182
2011	796,936	159,768	2016	793,153	163,277

EXHIBIT 4 Profile ratio for the four PAHs (EEA, 1990)

Profile ratio	Gasoline	Diesel
Benzo[b]fluoranthene	0.9	5.6
Benzo[k]fluoranthene	1.2	8.2
Benzo[a]pyrene	1.0	1.0
Indeno[123 cd]pyrene	1.4	1.4

constant for the 10 selected years (2007–2016). The average densities of gasoline and diesel fuel used in this study are 0.739 and 0.844 kilograms per liter, respectively.

The emission factors of the four PAHs selected for this study were estimated based on the emission factor of benzo[a]pyrene (B[a]P) as suggested by EEA (1990) using Equation (1). This equation has taken into consideration the type of fuel used by each of the two vehicle categories.

$$\text{Emission factor}(\text{B[b]F}) = \text{Emission factor}(\text{B[a]P}) \times \text{Profile ratio B[b]F/B[a]P} \quad (1)$$

The profile ratio of the four PAHs from vehicle source is as shown in the table in **Exhibit 4**.

It must be noted that the emission factor of (B[a]P) used in this study is 1,300 milligrams per ton (mg/ton) (EEA, 1990). The table in **Exhibit 5** shows the estimated emission factors.

The PAHs emissions are estimated using Equation (2) (EEA, 1990, 2016)

$$\text{Emission} = \text{Emission factor} \times \text{Activity} \quad (2)$$

where activity per vehicle is estimated based on the method suggested by EEA (2016) as given by Equation (3).

$$\text{Activity} = \text{Number of vehicles (Veh.)} \times \text{mileage per vehicle (km/veh)} \quad (3)$$

Combining Equations (2) and (3) with appropriate conversion factors, the emissions of the PAHs considered in this study are estimated using Equation (4):

$$\begin{aligned}\text{PAHs emission (kg)} = {} & \{\text{Emission factor (kg/ton)}\} \\ & \times \{\text{number of vehicle (veh)} \\ & \times \text{mileage (km/veh)} \times \text{density (kg/km)} \\ & \times 0.001\ \text{(ton/kg)}\} \quad (4)\end{aligned}$$

The total annual emissions of PAHs from vehicle traffic was calculated by summing annual emission from both gasoline and diesel vehicles.

3 | RESULTS AND DISCUSSION

The results of the annual PAHs emission for both gasoline and diesel vehicle type for the past 10 years in Lagos city are shown in the table in

EXHIBIT 5 Estimated PAHs emission factors

PAHs	Emission factor for gasoline vehicles (mg/ton)	(kg/ton)	Emission factor for gasoline vehicles (mg/ton)	(kg/ton)
Benzo[b]fluoranthene	1,170	1.7×10^{-3}	7,280	7.28×10^{-3}
Benzo[k]fluoranthene	1,560	1.56×10^{-3}	10,600	1.07×10^{-2}
Benzo[a]pyrene	1,300	1.3×10^{-3}	1,300	1.3×10^{-3}
Indeno[123 cd]pyrene	1,820	1.82×10^{-3}	1,820	1.82×10^{-3}

EXHIBIT 6 Annual PAHs emission (kg) in Lagos mega city

Year	Gasoline	Diesel	Total	Year	Gasoline	Diesel	Total
2007	3.048	2.679	**5.727**	2012	3.524	2.843	**6.367**
2008	3.214	2.766	**5.98**	2013	3.542	2.842	**6.384**
2009	3.340	2.804	**6.144**	2014	3.527	2.866	**6.293**
2010	3.430	2.792	**6.222**	2015	3.461	2.874	**6.335**
2011	3.469	2.831	**6.300**	2016	3.452	2.894	**6.346**

Exhibit 6. The exhibit also shows the total annual emissions from the two fuel types. The average highest PAHs emission of 3.542 kg was obtained in 2013 from gasoline vehicles. This is thought to be due to the fact that 2013 recorded the highest number of gasoline vehicles (Exhibit 3), whereas the lowest emission of 2.679 kg was recorded in 2007 (diesel-powered vehicle). Generally, it is observed that emissions of PAHs from diesel-powered vehicles were lower than emissions from gasoline-powered vehicles. This could be due to the lower number of diesel-powered vehicles in Lagos compared to gasoline-powered vehicles (**Exhibit 7**).

The highest number of registered vehicles was recorded in 2013, and this has a consequential effect on the total PAHs emissions calculated for the 10-year study period. This is why 2013 has the highest annual total PAHs emissions of 6.384 kg, which is closely followed by the emissions of PAHs of 6.367 kg, recorded in 2012. The total PAHs emission of 5.727 kg recorded in 2007 was the lowest emission of the pollutants during the 10-year study period (**Exhibit 8**). It is observed that there was a gradual increase in the annual total emission of PAHs from 2007 to 2013, a while decrease from 2013 levels was observed from 2014 to 2015 with a minor increase over 2014 and 2015 recorded in 2016 (Exhibit 8). The variation observed in the PAHs released into the atmosphere is a function of several factors, including the total number of the vehicles on the road, fuel type, and the emission factors used in the calculations.

The table in **Exhibit 9** shows a statistically significant difference in the total annual PAHs emissions from 2007 to 2016 ($p < 0.001$) as indicated by student's *t*-test.

The impact of PAHs on human health depends mainly on the length and route of exposure, the amount or concentration of PAHs one

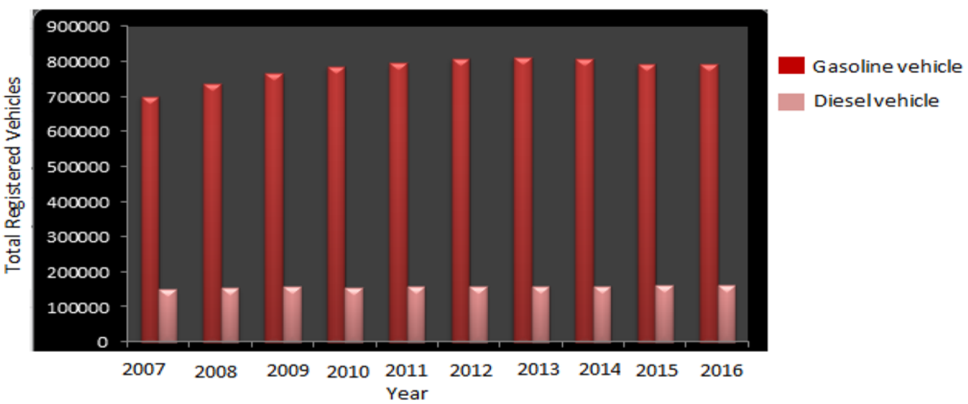

EXHIBIT 7 Annual total registered vehicles in Lagos based on fuel type [Color figure can be viewed at wileyonlinelibrary.com]

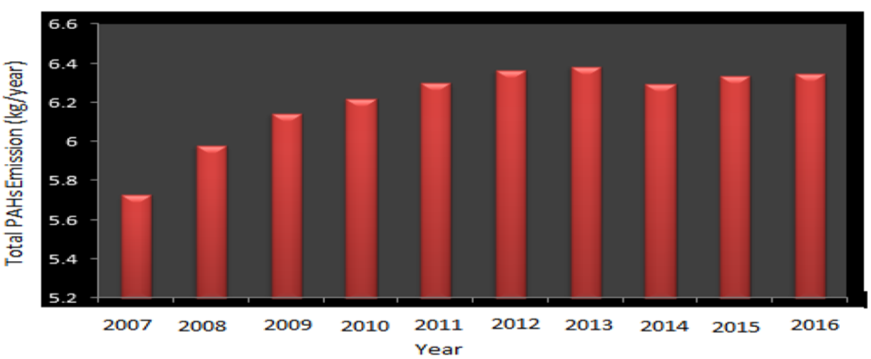

EXHIBIT 8 Total annual emissions of PAHs from vehicle in Lagos city [Color figure can be viewed at wileyonlinelibrary.com]

EXHIBIT 9 *t*-Test for paired mean PAHs emissions from the fuels

	Fuel	Mean	Standard deviation	Mean difference	d_f	*p* value
Gasoline-diesel	Gasoline	3.401	0.16			
	Diesel	2.819	0.06	0.10	18	< 0.001

is exposed to, as well as the relative toxicity of the specific PAHs (American Conference of Governmental Industrial Hygienists, 2005). The quantity of PAHs obtained in this study is far above the recommended exposure limit set by the U.S. National Institute for Occupational Safety and Health (NIOSH, 2009). It is therefore suggested as a matter of urgency that the concerned authority should come up with adequate measures to mitigate the release of these pollutants that is occurring beyond the allowable limit.

4 | CONCLUSION

This study investigates the impacts of PAHs emissions from vehicular activities on air quality in Lagos mega city. It has been revealed that although little concern has been shown regarding the release of these pollutants, especially from vehicles, the amount of PAHs that individuals are exposed to is beyond the limit set by a regulatory authority (NIOSH, 2009), and this may pose an overall health challenge if no mitigation is undertaken. It is therefore suggested that regulatory plans be put in place to reduce the impacts of PAHs emissions on the residential, commercial, and industrial areas of Lagos city.

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