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Effect of Haulage Vehicle Activities on Ambient Air Pollutants at a Large Haulage Vehicle Park in Nigeria

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Abstract

Activities at large haulage vehicle parks contribute to environmental pollution in Nigeria through ambient air pollutants. This research seeks to evaluate the harmful effects of the air pollutants released by a haulage vehicle park situated along a major highway that serves as a critical transportation artery connecting Lagos to other areas of Nigeria. Thus, the effect of haulage vehicle activities on ambient air pollutants at a large haulage vehicle park in Oke-Ese, Ilesha, Nigeria, was investigated. Following the collection of all samples, an analysis was carried out on them, involving polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs). The amount of PAHs at this location was measured using a standardized method from the Environmental Protection Agency, employing a sensitive testing technique that can detect tiny amounts (0.5-50 pg/µl) of these pollutants. Similarly, the VOCs analysis was quantified by selected ion monitoring. Quantification of the ions (m/z) was performed using a carrier gas at a flow rate of 1 mL/min. ∑ PAHs concentration of old haulage trucks (13.06 $\mu g/m^3$) was greater than that of new haulage trucks (10.49 $\mu g/m^3$) and commercial buses (12.46 $\mu g/m^3$), while the exhaust pipe in each case emitted most ∑ PAHs and VOCs, with the ripple effect evident in ambient air and surrounding buildings. The concentration of 1,3-butadiene was higher in the old haulage trucks than in others. The study underscores the imperative need for regulatory measures to tackle the substantial impact of haulage vehicles on air pollution in order to preserve the air quality and ensure the well-being of individuals who use the major highway adjacent to the vehicle park.

Categories: Environmental and Sustainable Engineering, Environmental Engineering and Sustainability
Keywords: volatile organic compound, polycyclic aromatic hydrocarbon, haulage vehicle, environmental pollution, global warming

Introduction

The transportation sector plays a vital role in driving economic progress and development globally. In Nigeria, haulage vehicles are the cornerstone of the transportation industry, serving as the primary means of transporting goods and materials nationwide. With the decline of rail transportation, Nigeria has become increasingly reliant on heavy-duty haulage vehicles to transport commodities across the country [1]. Since the collapse of rail transportation, heavy-duty haulage vehicles have become the primary mode of transporting goods and commodities in Nigeria [2]. Polycyclic aromatic hydrocarbons (PAHs) are a broad group of chemicals formed during the incomplete combustion of organic materials, including coal, oil, gas, waste, tobacco, and charbroiled meat. PAHs can arise from natural sources like volcanic eruptions and forest fires or human activities like fossil fuel combustion, industrial processes, vehicle exhaust, aviation emissions, and cigarette smoking. Although cigarette smoke poses the highest exposure risk to humans, vehicle exhaust is the main contributor to PAHs in the environment, emphasizing the need for environmentally friendly transportation solutions to mitigate the impact of PAHs on human health and the environment [3-5].

Volatile organic compounds (VOCs) are a class of organic chemicals that easily evaporate at room temperature, contributing to poor air quality both indoors and outdoors. This diverse group of chemicals includes a broad range of substances with varying origins and impacts. The operation of large haulage vehicles, in particular, has been linked to increased levels of ambient air pollutants, which can have harmful effects on both human health and the environment. Large haulage vehicle parks, where vehicles are stored, loaded, and maintained, are recognized as significant sources of air pollution in urban areas. In Nigeria, air pollution is a major environmental and public health concern, especially in urban areas where vehicle emissions are a primary source of pollutants. The increase in air pollutants has been linked to various health problems, including respiratory and cardiovascular diseases [6]. The transportation sector, particularly in urban areas with heavy vehicle traffic, plays a significant role in this pollution. Large haulage vehicle parks, often situated in urban areas, can significantly impact local air quality due to the large number of vehicles and activities. In recent years, the issue of air pollution from haulage vehicle activities has received increased global attention, with studies highlighting its impact on air quality. Furthermore, air pollution can have devastating effects on the environment, including damage to crops, vegetation, and buildings [7-10].

There are numerous studies documented in literature on activities affecting the air quailty. Adetona et al. [11] examined the vehicular emissions in Lagos Metropolis using a longitudinal design. The researchers gathered data on the road network, gas concentrations, vehicle statistics, and fuel usage at 11 sampling points. They analyzed the levels of five harmful gases: carbon monoxide, VOCs, nitric oxide, hydrogen sulfite, and sulfur dioxide (SO_2). The results showed that carbon monoxide levels exceeded safe limits, especially during morning peak hours. Additionally, Toyota LiteAce was the most common commercial vehicle, with 74% of them running on petrol. Notably, 91% of drivers experienced health issues due to air pollution at least once a month. To address this, the study suggests regular maintenance of commercial vehicles and public awareness campaigns to reduce emissions. Moreover, the government is urged to establish an efficient mass transit system to decrease individual vehicles and motorcycles on the roads, thereby reducing harmful emissions [12].

Elehinafe et al. [13] review the air quality along major cities in Nigeria, where many haulage vehicles operate. The research showed that the levels of particulate matter (PM), nitrogen oxides (NOx), and SO_2 were significantly elevated on the highway compared to surrounding areas, indicating that haulage vehicle activities are a major contributor to air pollution. Similarly, Ho and Lee [14] investigated the impact of haulage vehicle activities on air quality in Hong Kong. By monitoring PM (PM10 and PM2.5), NOx, and SO_2 levels at two locations within the port - one near a haulage vehicle park and a reference location farther away - the study revealed that PM10, PM2.5, and NOx levels were substantially higher near the haulage vehicle park, underscoring the harmful effects of haulage vehicle activities on air quality [15,16].

The emissions from haulage vehicles are a substantial contributor to air pollution, which poses significant threats to both environmental sustainability and human well-being. Despite the gravity of this issue, there is a notable lack of data on ambient air pollutant levels in truck parks, particularly in Ilesha, Osun State, Nigeria, which has one of the highest densities of heavy-duty trucks in Nigeria [6]. This research seeks to address this knowledge gap by investigating the impact of haulage vehicle activities on ambient air pollutants at a major truck park in the area, where activities like loading, offloading, and maintenance have been reported to have severe environmental and health consequences. By analyzing the correlation between pollutant concentrations and haulage vehicle activities, this study aims to provide actionable insights for policymakers, environmental agencies, and transportation industry stakeholders to mitigate emissions and enhance air quality. Additionally, this research will contribute to the existing body of knowledge on air pollution and its effects on human health and the environment in Nigeria, with a specific emphasis on the transportation sector.

Materials And Methods

Sample Area Description

The study was carried out at a representative tipper truck park located along the Lagos-Ibadan dual carriage highway, precisely at kilometer 56 in Ilesha, Osun State, Nigeria's southwestern region. This park serves as a parking lot or a designated area for leaving vehicles. The park's geographic coordinates are 7.624274º and 4.739087º, and it covers an area of approximately 500 m^2. This park serves as a vital hub for trucks in the community, providing a convenient stopover for trucks and tippers en route to Akure and other destinations. To ensure accurate sampling, the research team strategically selected sampling points early in the morning, taking into account factors such as wind direction, the number of trucks parked, and the distances between each vehicle. A Google Map detailing the sampling locations is detailed in Figure *1*.

Materials

FIGURE 1: Google Map of sampling locations

The research employed a range of materials, including 30 Whatman cellulose filters, each measuring 25.4 mm in diameter; a rotary vane vacuum pump; a specially designed mechanical probe; a high-accuracy weight balance (Mettler Toledo, Columbus, OH, USA); a Varian 3800/4000 gas chromatograph-mass spectrometer, comprising a mass spectrometer; and an Elepaq gasoline generator (model 8KVA-sv22000E2), which provided a dependable power supply for the equipment. An assembly of all equipment used in air sampling and the probe used for the study are presented in Figure *2*.

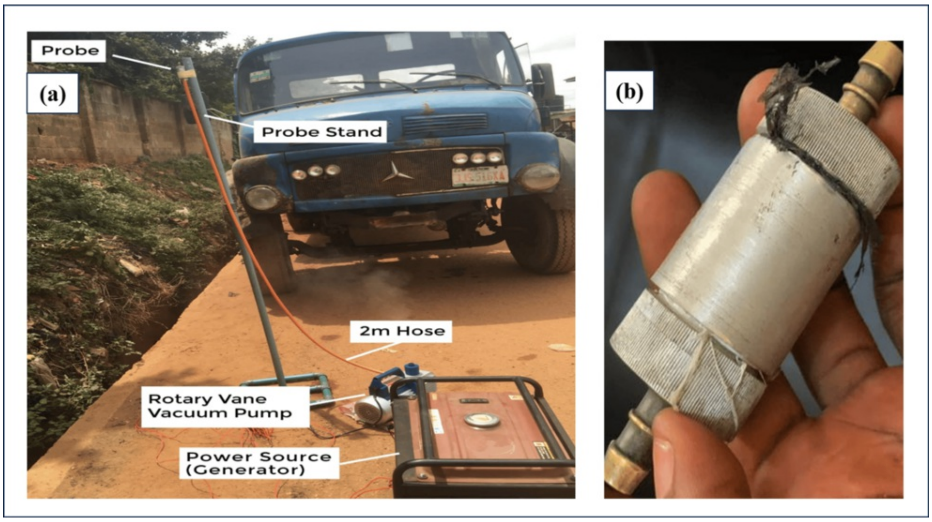

FIGURE 2: (a) A gas chromatograph-mass spectrometer assembly for air sampling and (b) a probe

Sampling Procedure

A truck park with a capacity for up to 40 vehicles was chosen as the sampling location. Using the Global Positioning System (GPS), the geographical coordinates of the area and 10 sampling points were recorded, covering the area from the park entrance to the shed where truck drivers gather before departing. The sampling took place during the rainy season, with daytime temperatures ranging from 22°C to 32°C and nighttime temperatures ranging from 22°C to 27°C. Humidity levels were monitored using a mobile weather application, showing morning readings of 60-62%, afternoon readings of 54-57%, and evening readings of 75-88%. Sample filters, pre-weighed and labeled, were sealed in airtight containers and transported to the sampling sites. Sampling occurred from early morning (7-8 am) to evening (5-6 pm), with strategic sampling points selected based on wind direction, the number of trucks parked, and the distances between each vehicle.

A rotary vane vacuum pump with a 1 hp power output and a flow rate of 12 m^3/min was used to collect air samples from the haulage vehicle park. The pump sucked in air, which was then trapped by a Whatman cellulose filter paper inserted into a custom-made mechanical probe with an inner diameter of 25.4 mm. The probe featured two openings - an inlet and an outlet - and was linked to a 10 mm hose with secure clips on both ends. The hose was connected to the pump inlet, and a specially designed stand held the probe steady during the sampling process. The park was measured and divided into 10 equal parts, yielding 10 sampling points. The GPS coordinates of the site and each sampling point were documented, along with wind speed, temperature, and humidity readings at each location.

The filter papers were fitted properly into the probe to trap contaminants from entering the vacuum system, and then the lid was properly covered. A Teflon tape was wound around the thread to prevent air leakage during suction process. Then, the pump was connected to a power source (a gasoline generator) and turned on. The open probe allowed air to flow into the vessel, and the vacuum created by the pump drew air through the inlet and into the sampling filter. The process took place for 10 min where the probe was suspended on the stand and the upper part of the probe faces the atmosphere. After 10 min, the pump was turned off, and the filter paper was removed from the probe and placed into a drug bag, which was sealed to avoid contamination with the environment. Another filter paper was placed into the probe, and the whole process was repeated three times at one sampling point. Three different source samples were obtained when the probe was placed in different places: (1) the exhaust pipe of the truck for 10 min; (b) when the probe was placed into atmospheric air for 10 min (100 m away from the source); and (c) when the sampling was obtained when air samples were taken at residential buildings around the park environment (500 m away from the source). For comparison, the investigation was performed for 10 old and 10 new haulage trucks. Similarly, 10 haulage trucks and commercial trucks were also investigated. Summarily, the data average was calculated after collecting the sample for 2 days to capture the variability in air pollution levels caused by different types of vehicles at different operating conditions.

Standards Preparation

A precise amount of a PAH-free sample blank was added to a 2-ml amber vial and fortified with a standard PAH mixture to create a calibration standard. To ensure an even distribution of the standard compounds, a small amount of methanol and methylene chloride was carefully added to the vial, just above the sample surface. The vial was then sealed and regularly shaken to facilitate thorough mixing. The sample was left at room temperature for an extended period (over 5 days) to allow the PAHs to distribute uniformly, after which the vial was opened to allow the solvent to evaporate completely. Each calibration standard was then stored at a temperature between −10°C and −20°C, shielded from light and moisture. Two calibration standards were prepared with concentrations of 3.82 and 1.99 pg/µl. Following the same procedure, internal calibration standards containing deuterated naphthalene, anthracene, and benzo[a]anthracene were also prepared to serve as reference points for quantification. The concentration of each internal standard ash sample was 5.01 pg/µl. The specifications for gas chromatography-mass spectrometry (GC-MS) for analyzing PAHs are presented in Table *1*.

Instrument	Varian GC/MS 4000/3800
Column	HP-1MS (cross-linked PH ME siloxane) 19091S-933
Film dimension	0.25 µm, length: 3.0 m, column ID: 0.25 mm
Injection method	Splitless mode
Carrier gas	Nitrogen (1.2 ml/min)
Injection temperature	250ºC
MS mode	Selective ion monitoring mode
Interface temperature	200ºC

TABLE 1: GC-MS specifications for polycyclic aromatic hydrocarbons

GC-MS: gas chromatography-mass spectrometry

The concentration of each analyte was determined by applying Equation 1, which calculates the amount of analyte or hydrocarbon range present based on the proportional relationship between peak response areas. This calculation isolated the peak areas of the target analytes, disregarding any signals from the solvent front and surrogate compound, to provide an accurate measurement of each analyte's quantity in the sample. By excluding extraneous signals, the equation precisely quantified the analytes of interest, yielding a reliable determination of their concentrations in the sample.

$$C_f = \frac{A(p)x\ Rf\ x\ Vf\ x\ D_f\ x\ 1000}{Wi} \quad (1)$$

where:

A(p): the measured peak area

Wi: the initial weight of the extracted sample in grams (dry weight)

Vf: the final volume of the extract in milliliters

Df: the dilution factor (if the sample or extract was diluted)

Rf: the response factor derived from the calibration standard calculation

PAHs Extraction Procedure

The extract underwent a comprehensive analysis using GC-MS, utilizing an HP-1MS column and stationary phase. This configuration enabled the precise separation and identification of the extract's components, allowing for a detailed analysis of its chemical composition. The sample was examined using a targeted approach, with nitrogen as the carrier gas, in selected ion monitoring (SIM) mode. Before analysis, the GC-MS instrument was calibrated with a series of standard solutions containing 18 target PAH compounds at various concentrations (ranging from 0.5 to 50 pg/µl) to establish a reference point. Internal standards were also added at fixed levels to ensure accuracy. The instrument was then calibrated using the least-squares method, prioritizing precision at lower concentrations. This rigorous calibration process enabled the GC-MS instrument to precisely identify and quantify the target PAH compounds in the sample. A 2.0 µl sample extract was injected into the gas chromatograph using splitless mode, with the injector heated to 250°C. The column temperature was programmed to follow a gradient, increasing from 70°C to 260°C at 10°C/min, then to 300°C at 5°C/min, and finally maintained at 300°C for 8 min. Helium was used as the carrier gas, flowing at a constant rate of 1.0 ml/min. The solvent delay was set to 7 min, and a brief detection time of 0.1 s was used for each mass-to-charge (m/z) value. The MS transfer line was maintained at 250°C, and quantification was performed using the SIM mode, referencing a standard calibration curve.

The resulting concentrations of PAH constituents were then analyzed using mathematical ratios to identify and diagnose their sources, and the sources were apportioned based on the outcomes of the PAH class ratios. The quantitative analysis of PAHs was carried out using calibration data from a standard solution containing 16 Environmental Protection Agency (EPA)-specified PAHs. The detection limits for these PAHs using GC-MS SIM mode ranged from 0.5 to 50 pg/µl, depending on the individual PAH's boiling point. To quantify the PAHs, the peak area ratio of each PAH was compared to its corresponding deuterated standard. This involved determining the response factors (RFs) for each PAH by preparing a standard solution containing equal amounts of each PAH and deuterated PAH. The RF for each PAH was calculated by dividing the area of the chromatographic peak for the PAH by the area of the peak for the corresponding deuterated PAH. The RF for each compound was then averaged from three runs using the formula (Equation 2), ensuring accurate quantification of the PAHs in the sample. This approach enabled precise determination of the PAH concentrations in the sample, taking into account the varying detection limits and RFs for each compound.

$$RF = \frac{AREA_{(PAH)}}{AREA_{PAH-d}} \quad (2)$$

In cases where a deuterated standard was not available for a specific PAH, a nearby deuterated PAH in the chromatogram was utilized as a proxy to determine the RF. Following GC-MS analysis, the peak areas of the extracted ions for all analytes (AREA analyte) and the deuterated internal standards (AREAIS) added to the pad were quantified. The concentration of each PAH component was then calculated using Equation 3. This approach enabled the quantification of PAHs even when a matching deuterated standard was not available, by using a nearby deuterated PAH as a substitute. The peak areas of the analytes and internal standards were used to calculate the concentration of each PAH component, ensuring accurate quantification.

$$PAH = \frac{(AREA_{(analyte)}/\ AREA_{IS})/RF\ x\ IS}{No.\ of\ sample} \quad (3)$$

Volatile Organic Hydrocarbons Procedure

A Varian 3800/4000 gas chromatograph-mass spectrometer was employed for the analysis, utilizing electron impact ionization at 70 eV. The mass spectrometer scanned an m/z ratio range of 35-280 atomic mass units. The temperature at the interface between the gas chromatograph and mass spectrometer was set at 200°C, while the ion source temperature was maintained at 195°C. The gas chromatograph injection port was heated to 250°C for thermal desorption of the sample. Separation of the sample components was achieved using a 60-m-long DB-1 capillary column (J&W Scientific, Folsom, CA, USA), with a diameter of 0.32 mm and a thickness of 1 µm. The column oven temperature was initially held at 40°C for 4 min, then ramped up to 190°C at a rate of 7°C/min, and finally to 250°C at 10°C/min. Quantification of the sample components was performed using SIM, with the specific ions (m/z) listed below. High-purity nitrogen gas (99.995%) was used as the carrier gas at a flow rate of 1 ml/min, with an outlet split flow of 10 ml/min and septum purge flow of 3 ml/min.

Results

Polycyclic Aromatic Hydrocarbons

The PAHs results of sample locations for old haulage trucks and new haulage trucks are presented in Table *2*, while the PAHs results of haulage trucks and commercial buses are presented in Table *3*. The analysis shows that all 16 priority PAHs were detected in varying amounts across the sampling sites, indicating their widespread presence in the air. Naphthalene (NAP), fluorene (FLU), chrysene (CHRY), and benzo[g,h,i]perylene (B[ghi]P) were the most prevalent and abundant congeners. In contrast, benzo(a)anthracene and dibenzo(a,h)anthracene, a 5-ring PAH, were completely absent from all the samples, underscoring the diverse and uneven distribution of PAHs in the atmosphere. The average total PAH concentrations (∑ PAHs) are also presented for new and old haulage trucks, as well as haulage trucks and commercial buses, at the exhaust outlet, ambient air, and residential areas.

B[ghi]P was the predominant compound at the exhaust outlets of old trucks. This prevalence was also observed in ambient air and surrounding residential buildings, indicating a widespread impact. Similarly, B[ghi]P and other potent compounds were the dominant PAH congeners at the older haulage trucks, constituting a significant portion of the total PAH burden in that environment. The heightened levels of these congeners at the sampling sites can be ascribed to a combination of natural factors and human activities, such as industrial operations and vehicular traffic, which have a cumulative and intensifying impact [16-18]. The total PAH concentrations (∑ PAHs) found in this study, ranging from 7.04 to 11.06 µg/m^3, are comparable to those reported in similar areas of Nigeria (0.7-720 µg/m^3), such as the southern parts of Nigeria, which share similar developmental characteristics [19]. In comparison, a region with intense industrial activity had an average ambient air PAH concentration of 175 ± 47 ng/m^3, which is significantly lower than the urban average of 817 ng/m^3 (0.817 ± 0.33 µg/m^3) and greater than the rural average of 11.06 µg/m^3 observed in this study. In other reports, the main factors behind PAH emissions were diesel- and gasoline-powered vehicles, biomass and coal combustion, and the iron and steel industry, consistent with previous reports [20].

This study identified the combustion of petrol and diesel, as well as the burning of solid waste, as the main contributors to PAH emissions. This finding align with previous research that has consistently shown high levels of PAHs in urban environments, exceeding the safe limit of 1 ng/m^3 established by the EPA [21-23], which presents a significant risk to public health and well-being. In contrast, moderate PAH levels were found in this study, but continued environmental pollution could lead to a cumulative increase in PAH levels over time. Improper waste disposal, including plastics, metals, and other materials, in residential areas also contributes significantly to the benzo(a)pyrene (BaP) increment in urban areas, with a high recorded waste incineration sites across Nigerian cities. The prevalent use of firewood for cooking and the frequent forest fires resulting from subsistence farming activities in rural areas are probable contributors to the elevated levels of BaP. Notably, BaP was absent in the control location. It is important to recognize that air pollution has been acknowledged and recorded as a major environmental issue in Osun State [20], emphasizing the necessity for effective measures to address this problem and minimize its impacts.

PAHs	Exhaust Pipe		Ambient Air		Residential Building	
	OHT	NHT	OHT	NHT	OHT	NHT
Naphthalene	1.62 ± 0.045	1.54 ± 0.011	1.28 ± 0.013	1.23 ± 0.021	0.21 ± 0.010	0.20 ± 0.006
Acenaphthylene	1.11 ± 0.023	1.16 ± 0.023	0.96 ± 0.023	0.77 ± 0.032	0.91 ± 0.023	0.84 ± 0.07
Acenaphthene	0.39 ± 0.032	0.34 ± 0.091	0.32 ± 0.002	0.24 ± 0.021	0.39 ± 0.006	0.76 ± 0.003
Fluorene	1.26 ± 0.081	1.22 ± 0.021	1.15 ± 0.055	1.04 ± 0.027	1.04 ± 0.044	1.00 ± 0.014
Phenanthrene	0.14 ± 0.021	1.06 ± 0.027	0.46 ± 0.018	1.01 ± 0.038	0.37 ± 0.067	0.25 ± 0.035
Pyrene	0.56 ± 0.038	0.44 ± 0.003	0.81 ± 0.021	0.54 ± 0.011	0.74 ± 0.040	0.56 ± 0.011
Fluoranthene	ND	ND	ND	ND	ND	ND
Anthracene	0.29 ± 0.056	0.28 ± 0.023	0.20 ± 0.013	0.19 ± 0.081	0.24 ± 0.011	0.17 ± 0.022
Benzo[k]fluoranthene	0.75 ± 0.011	0.69 ± 0.020	0.54 ± 0.021	0.51 ± 0.007	0.66 ± 0.001	0.64 ± 0.006
Benzo[a]pyrene	0.11 ± 0.001	0.07 ± 0.003	0.04 ± 0.003	0.03 ± 0.001	0.02 ± 0.033	0.02 ± 0.001
Chrysene	3.20 ± 0.020	1.16 ± 0.023	1.11 ± 0.001	1.07 ± 0.004	1.07 ± 0.003	0.88 ± 0.051
Benzo[a]anthracene	ND	ND	ND	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND	ND	ND	ND
Benzo[g,h,i]perylene	2.50 ± 0.083	2.43 ± 0.023	1.54 ± 0.003	1.01 ± 0.031	1.05 ± 0.008	0.89 ± 0.008
Dibenzo[a,h]anthracene	ND	ND	ND	ND	ND	ND
Benzo[b]fluoranthene	0.10 ± 0.005	0.07 ± 0.003	0.06 ± 0.001	0.06 ± 0.013	0.07 ± 0.003	0.06 ± 0.001
∑ PAHs	13.06	10.49	8.6	7.83	6.95	6.42

TABLE 2: PAHs results of sample locations for old and new haulage trucks (μg/m³)

ND: not detected, NHT: new haulage trucks, OHT: old haulage trucks, PAHs: polycyclic aromatic hydrocarbons

PAHs	Exhaust Pipe		Ambient Air		Residential Building	
	HT	CB	HT	HT	HT	CB
Naphthalene	1.53 ± 0.001	1.46 ± 0.012	1.21 ± 0.032	1.16 ± 0.003	0.14 ± 0.006	0.13 ± 0.021
Acenaphthylene	1.05 ± 0.022	1.10	0.91 ± 0.07	0.73 ± 0.07	0.86 ± 0.07	0.79 ± 0.07
Acenaphthene	0.37 ± 0.061	0.32 ± 0.013	0.30 ± 0.078	0.23 ± 0.045	0.37 ± 0.011	0.72 ± 0.056
Fluorene	3.19 ± 0.021	2.15 ± 0.073	1.09 ± 0.021	0.98 ± 0.005	0.98 ± 0.054	0.95 ± 0.045
Phenanthrene	1.11 ± 0.012	1.00 ± 0.002	0.44 ± 0.001	0.96 ± 0.023	0.35 ± 0.07 ± 0.012	0.24 ± 0.009
Pyrene	0.53 ± 0.090	0.42 ± 0.079	0.77 ± 0.032	0.51 ± 0.012	0.70 ± 0.041	0.53 ± 0.009
Fluoranthene	ND	ND	ND	ND	ND	ND
Anthracene	0.27 ± 0.011	0.26 ± 0.023	0.19 ± 0.072	0.18 ± 0.061	0.23 ± 0.055	0.16 ± 0.021
Benzo[k]fluoranthene	0.71 ± 0.014	0.65 ± 0.072	0.51 ± 0.006	0.48 ± 0.003	0.62 ± 0.002	0.61 ± 0.004
Benzo[a]pyrene	0.10 ± 0.071	0.09 ± 0.043	0.16 ± 0.011	0.15 ± 0.005	0.19 ± 0.001	0.16 ± 0.002
Chrysene	1.13 ± 0.022	1.10 ± 0.071	1.05 ± 0.056	1.01 ± 0.071	0.50 ± 0.063	0.53 ± 0.011
Benzo[a]anthracene	ND	ND	ND	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND	ND	ND	ND
Benzo[g,h,i]perylene	2.36 ± 0.032	2.30 ± 0.023	1.46 ± 0.054	0.96 ± 0.021	0.99 ± 0.077	0.84 ± 0.070
Dibenzo[a,h]anthracene	ND	ND	ND	ND	ND	ND
Benzo[b]fluoranthene	0.09 ± 0.001	0.07 ± 0.011	0.06 ± 0.001	0.07 ± 0.001	0.07 ± 0.005	0.06 ± 0.002
∑ PAHs	12.46	10.92	8.13	7.41	6.02	5.52

TABLE 3: PAHs results of haulage trucks and commercial bus (µg/m³)

CB: commercial buses, HT: haulage trucks, ND: not detected; PAHs: polycyclic aromatic hydrocarbons

Volatile Organic Compound

The VOCs results of sample locations for haulage truck and commercial buses are presented in Figure *3*, while the VOCs results of sample locations for old and new haulage trucks are presented Figure *4*. The data collected from the haulage vehicle's exhaust pipe showed the highest levels of VOCs for haulage trucks and commercial buses. Then, the ambient air and residential building samples had significantly lower VOC levels, respectively. Notably, the VOC concentrations from haulage vehicles were substantially higher than those from commercial buses. The combustion process was found to release alarming amounts of 1,3-butadiene, a toxic chemical that poses a significant threat to human health. According to the EPA, the safe exposure level for 1,3-butadiene can be determined by its inhalation reference concentration, which estimates the maximum amount of the chemical that humans can safely inhale over a lifetime without increasing their risk of developing cancer or other serious health problems [24,25]. In essence, the EPA has set a safety threshold for 1,3-butadiene exposure to mitigate the risks associated with long-term exposure to this harmful substance.

Given the presence of 1,3-butadiene among the identified VOCs, it poses the greatest risk, even at very low concentrations, due to its potential for continuous inhalation. Therefore, it is alarming that 1,3-butadiene had the highest concentration among all evaluated haulage trucks, with levels decreasing in the order of exhaust pipe, ambient air, and residential buildings. In other words, 1,3-butadiene is a highly hazardous compound that can be produced through the combustion process, and its high concentration in haulage trucks is a significant concern due to its potential for continuous exposure and harmful effects [26]. Additionally, the analysis revealed that older haulage trucks emitted higher levels of 1,3-butadiene compared to newer trucks, while the concentrations in residential and ambient air were lower than those in the exhaust pipe (Figure *4*). A comparative analysis of new and old haulage trucks was conducted, considering the source of the samples: exhaust pipe, ambient air, and residential buildings. The results showed a consistent trend, where the number and concentrations of VOCs emitted during combustion were significantly higher in older trucks than in newer ones. Consequently, it can be asserted that newer haulage trucks possess two noteworthy benefits: reduced maintenance requirements and lower emissions of harmful

VOCs during combustion, relative to older trucks. The research methodology, spanning from sample preparation to analysis, was characterized meticulously, with the GC-MS analysis being conducted manually with utmost precision and attention to details

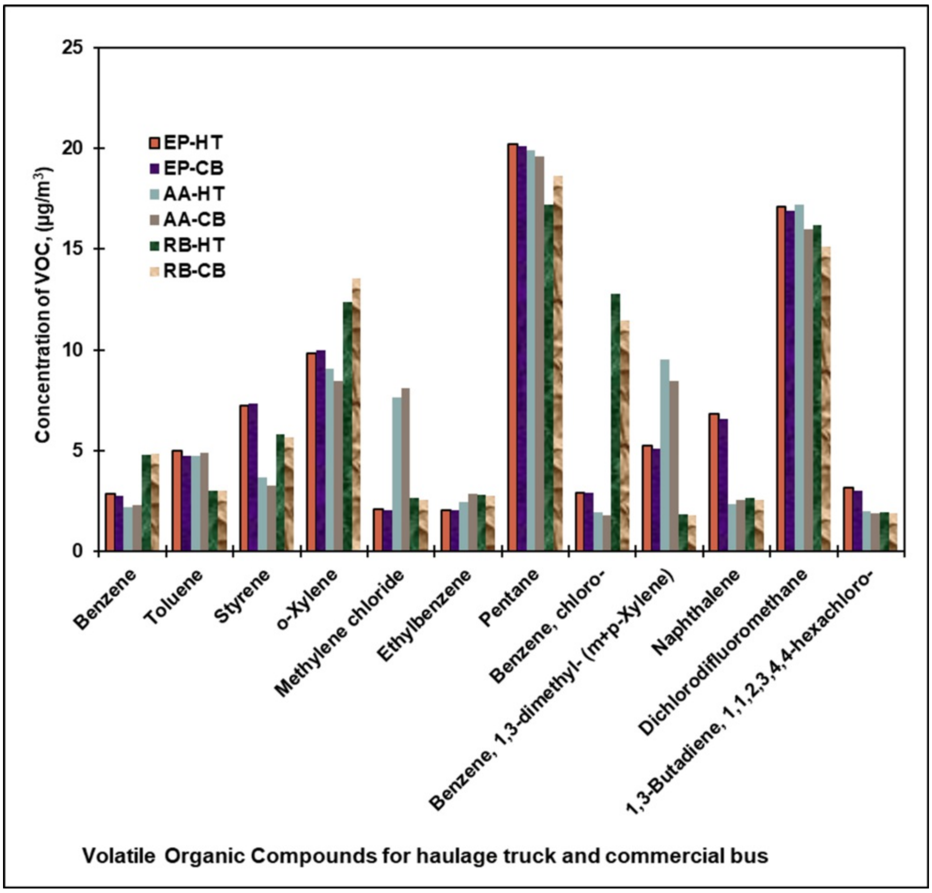

FIGURE 3: VOCs results of sample locations for haulage truck and commercial bus (µg/m³)

EP-HT: exhaust pipe for haulage trucks, EP-CB: exhaust pipe for commercial buses, AA-HT: ambient air for haulage trucks, AA-CB: ambient air for commercial buses, RB-HT: residential building for haulage trucks, RB-CB: residential building for commercial buses, VOCs: volatile organic compounds

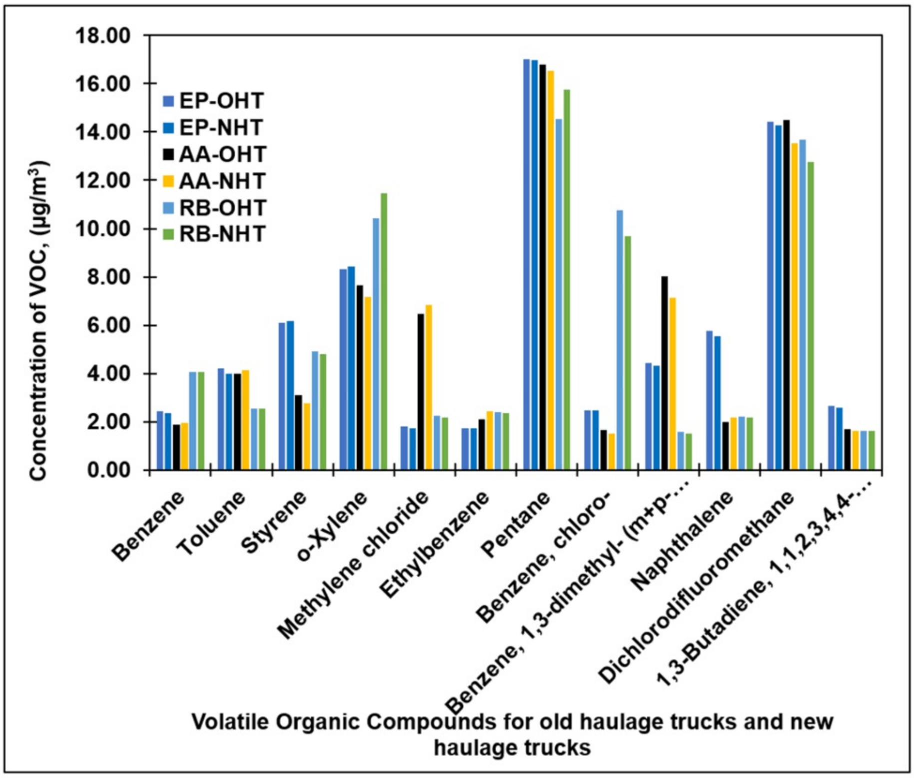

FIGURE 4: VOCs results of sample locations for old haulage truck and new haulage truck (µg/m³)

EP-OHT: exhaust pipe for old haulage trucks, EP-NHT: exhaust pipe for new haulage trucks, AA-OHT: ambient air for old haulage trucks, AA-NHT: ambient air for new haulage trucks, RB-OHT: residential building for old haulage trucks, RB-NHT: residential building for new haulage trucks, VOCs, volatile organic compounds

Discussion

Although haulage vehicles play a crucial role in our daily lives due to their efficiency, their emissions continue to pose significant environmental and health risks, including air pollution, toxic fumes, and climate change. Nevertheless, as the world becomes more conscious of the importance of environmental protection and sustainability, governments and organizations are taking steps to implement policies aimed at reducing vehicle emissions and promoting eco-friendly practices. By examining emissions from haulage trucks and commercial cars from various sources (exhaust pipes, the atmosphere, and residential areas), we measured the number of harmful VOCs released during combustion. While some vehicles emitted relatively low levels of VOCs, sport cars and commercial vehicles generally produced fewer VOCs than haulage trucks. Notably, certain non-truck vehicles emitted VOCs at extremely low levels, suggesting that their chemical composition (a three-carbon polymer backbone with an ester group) promotes cleaner burning. However, this does not necessarily mean that commercial buses are a safer alternative to haulage vehicles, as they also exhibit similar drawbacks during fuel combustion, such as harmful emissions.

This research revealed that when fuel in haulage trucks and commercial buses is combusted, they release 1,3-butadiene, a recognized cancer-causing agent, at levels exceeding safety limits. This is due to the repeated presence of the 1,4-butanediol group during combustion. Moreover, the levels of other harmful VOCs emitted by these haulage trucks remain alarmingly high, surpassing the safety thresholds set by Okonkwo et al. [27] for ambient conditions. Additionally, existing commercial buses have been found to be just as toxic as haulage vehicles, owing to the hazardous chemicals used in their manufacturing process as supported by Okonkwo et al. [27]. As a result, new methods that prioritize safer materials and minimize environmental impact must be explored to enhance combustion efficiency and lower CO_2 emissions. One potential solution is implementing a composting system for regular maintenance, which could replace the current flawed emission process. Moreover, both governments and individuals must work together to raise awareness and reduce greenhouse gas emissions. By doing so, we can also decrease the production of harmful substances [27]. Notably, commercial buses offer a significant advantage over haulage vehicles, as they consume less fuel and emit fewer CO_2 emissions, making them a more environmentally friendly option.

In this study, we were able to measure the amounts of harmful VOCs released during the incomplete burning of both commercial and haulage vehicles, a milestone achievement. However, more research is needed to develop a comprehensive incineration scale that takes into account the incomplete combustion of materials and its impact on VOC emissions under various conditions. Additionally, further investigation into the production of truck haulage is necessary to minimize VOC emissions during incineration to levels that are considered safe and environmentally friendly.

Conclusions

The study focused on investigating the effect of haulage vehicle activities on ambient air pollutants, specifically PAH and VOC emissions, at a large haulage truck park. For comparison, the impact of haulage trucks was compared to commercial buses as well as old and new haulage trucks. The findings of the study provide valuable insights into the potential environmental impacts of such activities on air quality. A thorough analysis of toxic VOCs released during the burning of haulage vehicles and commercial buses was conducted using GC-MS. Comparing the samples obtained directly from the exhaust pipe of the trucks, ambient air, and residential buildings, haulage trucks emitted more VOCs than commercial buses, which contained harmful chlorine and aromatic compounds. Old haulage trucks also emitted more VOCs than the new trucks. Additionally, the ambient air and residential areas had lower VOC levels compared to the exhaust outlets of both vehicle types. Although samples taken from exhaust pipes had the highest VOCs, the ripple effect was also found in the ambient air and surrounding residential buildings, revealing the impact of continuous exposure to harmful compounds. It was observed that older vehicles with outdated engine technologies and inadequate maintenance exhibited higher emission rates compared to newer, well-maintained vehicles. This suggests that new haulage trucks and commercial buses have a relatively lower environmental impact compared to old haulage vehicles. Further research is necessary to enhance the clean burning performance of both haulage and commercial buses, leading to a more sustainable future. Reducing emissions requires consideration of several key factors, including the vehicle's age, the type of engine used, the quality of fuel consumed, and the regularity and quality of maintenance performed, all of which have significant impact on the level of emission produced.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

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