

Polycyclic aromatic hydrocarbons in air from industrial areas in Lagos and Ogun states, Nigeria

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ABSTRACT: There is currently scarce information on the occurrence and distributions of Polycyclic Aromatic Hydrocarbons (PAHs) in the air from industrial estates in Nigeria. Hence, the present study aims to evaluate the extent and sources of pollution of polycyclic aromatic hydrocarbons in the air from some industrial estates in Lagos and Ogun States, Nigeria. Ten air samples have been collected from the industrial estates in Lagos (Ogba and Ilupeju) and ten from Ogun (Agbara and Ota) between October and November, 2014, using low volume air sampler. Also five further air samples have been collected from Epe town, located in the outskirts of Lagos, where there are no industrial activities to serve as control. The concentrations and distributions of 20 target Polycyclic Aromatic Hydrocarbons (PAHs) in the air samples have been determined by gas chromatography-mass spectrometry. The concentration of \sum_{20} PAHs ranged from 89.20 to 96.48 ng/m³ (with an average of 92.84 ng/m³) and 72.52 to 142.91 ng/m³ (with an average of 107.72 ng/m³) in the air samples from Lagos and Ogun industrial estates, respectively. The air from the control site has a total \sum_{20} PAHs concentration of 19.55 ng/m³ (9.78 ng/m³ in average). When compared with global data, these values show that the air samples have been moderately polluted. PAHs in most air samples are mainly from pyrolytic sources, which may have resulted from diesel fuel combustion and high vehicular emissions, typical of industrial activities in the area.

Keywords: air sample, combustion, gas chromatography-mass spectrometry, pollution, pyrolytic.

INTRODUCTION

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of Persistent Organic Pollutant (POPs), occurring at various concentrations in the atmosphere, soil, sediment, plant, and other environmental media. They are compounds with two to eight fused aromatic rings, made up of carbon and hydrogen (Li et al., 2005; Deng et al.,

2006). PAHs are of particular interest due to their potential health concern mainly as a result of their carcinogenic and mutagenic properties. In the atmosphere, lighter PAHs with less than 3 rings, such as phenanthrene, are partitioned between the gas and solid phases, owing to their relatively higher vapor pressure, while the heavier PAHs with more than 3 rings such as benzo[a]Pyrene (B[a]P), are mainly found in the particulate phase, primarily

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associated with particles, whose size < 1 μm (Ravindra et al., 2008; Shaokai et al., 2009). The concentration of PAHs in the atmosphere is in the order of ng m^{-3} (Hanedar et al., 2011). Over the years, there has been increasing release of potentially-hazardous PAHs into the environment as a result of industrialization. Benzo(a)pyrene (B(a)P), a five-ring PAH has been reported to be the most potent carcinogen among the PAHs, regarded as an important analytical target in airborne particulates (Shin et al., 1988). Benzo(a)pyrene is notable for being the first chemical carcinogen to be discovered (Hornback, 2006). The metabolites of PAH compounds, particularly the 7, 8-diol-9, 10-epoxide of benzo(a)pyrene are known to cause cancer (Manahan, 2000).

Atmospheric PAHs are mainly derived from incomplete combustion of fossil fuel and organic matter, gasoline exhaust, diesel, residential coal or wood combustion, and volatilization of petroleum (Shauer et al., 2001; Oda et al., 2001). The highest concentrations of atmospheric PAHs can be found in urban environments with high car traffic activity and scarce dispersion of the atmospheric pollutants (Hanedar et al., 2011). A number of researchers have also reported ship dismantling activities as a significant source of PAHs (Elife et al., 2012). Studies have identified emissions from cement plant as the major contributor to the level of Indeno (123-cd) pyrene and this also constitute major sources of coronene in addition to emission from car traffic (Daniela et al., 2014; Guofeng et al., 2014).

The widespread occurrence of PAHs has been attributed to their formation and release in all processes of incomplete combustion of organic materials. The PAHs, emitted into the air, can be transported over long distances, before being deposited into soils, vegetation, and inland waters through atmospheric precipitation (Van et al., 1997; Douben,

2003). Human exposure to polycyclic aromatic hydrocarbons may occur through food, water, air, and direct contact with materials, containing PAHs. The risk, associated with human exposure to atmospheric PAHs, is the highest in cities, considering the population density. The U.S. Environmental Protection Agency and their European Union counterpart, therefore, have classified 16 group as high-priority pollutants, as their toxicity is stronger than the others (Adeola et al., 2007).

PAH emission into the air in industrial areas of Lagos and Ogun is a matter of great environmental concern, owing to their possible adverse health effects on large population (over 23 million) of people, living in the area. At present, there is no available data on the occurrence and distributions of PAHs in air from the area. Earlier works have been limited to PAHs in other geological media such as soil, sediments, and fish in the area (Sojnu et al., 2010a; Amuda & Adelowo-Imekparia, 2007; Alani et al., 2013). Hence, the present study has been conducted to determine the occurrence, source, and ecotoxicological effects of PAHs in air from some industrial estates in Lagos and Ogun States, Nigeria.

MATERIALS AND METHODS

Air samples were collected from industrial estates in the states of Lagos and Ogun (Fig. 1). Lagos State ($6^{\circ}35'N$ $3^{\circ}45'E$) is located in the southwestern part of Nigeria with an estimated population of 23.3 million (MEPB, 2012). It is the commercial hub of Nigerian economy with a GDP above 80 Billion US dollars in 2010 (Olayiwola, 2010). Lagos is also a state with the greatest concentration of industries, with well over seven thousand medium and large-scale industries. Studies have shown that about 70-80% of the manufacturing facilities, operating in Nigeria within the medium and large-scale

industries, are located in Lagos (Osibanjo & Oketola, 2011). The major industrial estates, namely Ogba and Ilupeju, were chosen as sampling sites for the present study (Table 1 and Fig. 1). Air samples were also collected from Epe, located at the outskirts of Lagos city to serve as

control site. Ogun State is another state in southwest Nigeria ($7^{\circ} 00'N$ $3^{\circ} 35'E$), bordering Lagos state (Fig. 1). Agbara and Ota, being the major industrial estates in the state, were chosen as sampling site (Table 1 and Fig. 1), due to their large size and close proximity to Lagos state.



Fig. 1. Map of the study area showing the sampling locations

Twenty air samples were collected from industrial estates in Lagos (Ogba and Ilupeju) and Ogun (Agbara and Ota) states. They were collected during the raining season between October and November, 2014. Also, five further air samples were collected from the town of Epe, in the outskirts of Lagos, where there are no industrial activities to serve as control. Samplings were conducted continuously using Low Volume air sampler (F&J Specialty products Inc. Miami Springs Florida) at a constant volumetric flow rate of $0.049 \text{ m}^3/\text{min}$ for 24 hrs. The sampler, which was placed at 1.8 m high above ground level, was equipped with glass fibre filter (Whatman; GF/F circle 70 mm) onto which particulate matter were adsorbed. The filter, containing particulate matter, was allowed to equilibrate for 24 hrs before

the final weight was measured and recorded. Filter was kept in aluminium foils to avoid PAHs' photochemical transformation (Hanedar et al., 2011). They were stored in a freezer at $-18 \text{ }^{\circ}\text{C}$.

Prior to use, glass fibre filters were baked in a muffle furnace (model D-2804) at $450 \text{ }^{\circ}\text{C}$ for 4 hrs to remove the organic contaminant. The filters were folded and kept in an aluminium foil, which had been preheated at $100 \text{ }^{\circ}\text{C}$ for 4 hrs then stored in a desiccator prior to use. The preliminary weights of the fibres were also measured and correspondingly labelled. Anhydrous sodium sulphate (analytical grade), obtained from Sigma-Aldrich, was washed with dichloromethane and activated in an oven at $400 \text{ }^{\circ}\text{C}$ for 4 hrs. Silica gel (70–230 mm), obtained from Sigma-Aldrich, was activated at $120 \text{ }^{\circ}\text{C}$ in an oven for 12 hrs

and stored in a desiccators until use. All solvents were analytical grade and purchased from Sigma-Aldrich. De-ionized water was obtained from a nanopure water purification system. All glassware was scrupulously cleaned with detergent, rinsed first with de-ionized water and then with acetone. The cleaned glassware were then stored in aluminium foil to prevent contamination.

The filters were cut into small pieces with pre-solvent cleaned scissors, spiked with surrogate deuterated PAHs standard (naphthalene_d8, biphenyl_d10, phenanthrene_d10, chrysene_d12, benzo(a)pyrene_d12, benzo(ghi)perylene_d12), and extracted with 20 mL dichloromethane, using ultrasonic bath (3 x 15 min) at ambient temperature. The combined extracts were filtered, using a pre-extracted filter paper to remove insoluble

particles. They were concentrated to 1.5 mL, using rotary evaporator, solvent-exchanged to hexane, and stored in the refrigerator until further analysis.

The extracts were fractionated on glass columns, packed with silica gel (sigma-Aldrich 70-230 mesh, activated at 120 °C for 12 hrs) into three fractions. The saturated hydrocarbons, aromatic compounds (PAHs) and polar compounds were eluted using 20 mL of n-hexane, 70 mL mixture of n-hexane and dichloromethane (7:3, v/v) and 25 mL of acetone, respectively (Sojinu et al., 2010a; Li et al., 2005). The fractions were concentrated to 1 mL by means of a rotary evaporator, then to be transferred to 1.5 mL vial bottle and kept in refrigerator until analysis. The aromatic fractions were subsequently shipped to Guangzhou Institute of Geochemistry, China, and were kept in the refrigerator upon arrival until analysis.

Table 1. Sample locations and their coordinates

Site	Code	Date	Time (hrs)	Altitude (m)	Coordinates
OGBA					
ANWAR	OG1	19/10/2012	24	79	6° 36' 59.50"N 3° 20' 06.84"E
AKILO RD.	OG2	22/10/2012	24	77	6° 37' 03.70"N 3° 20' 13.65"E
OBA AKRAN	OG3	23/10/2012	24	72	6° 36' 30"N 3° 20' 10"E
GUINNESS RD.	OG4	24/10/2012	24	81	6° 37' 14.08"N 3° 20' 24.35"E
WAMPCO RD.	OG5	29/10/2012	24	68	6° 37' 26.52"N 3° 20' 30.41"E
ILUPEJU					
IL GRMARSCH	IL1	30/10/2012	24	63	6° 33' 19.92"N 3° 21' 14.60"E
PIL	IL2	31/10/2012	24	61	6° 33' 17.05"N 3° 21' 21.94"E
LASTMA OFFI	IL3	01/11/2012	24	68	6° 33' 29.83"N 3° 21' 23.14"E
BARRACK RD	IL4	02/11/2012	24	65	6° 33' 36.42"N 3° 21' 43.21"E
TOTAL FILLING	IL5	03/11/2012	24	67	6° 33' 32.50"N 3° 21' 50.48"E
AGBARA					
IGERE TOWN	AG1	05/11/2012	24	53	6° 32' 26.25"N 3° 04' 54.39"E
OPIC BUS STOP	AG2	06/11/2012	24	59	6° 31' 56.29"N 3° 04' 32.74"E
TITITO VILG	AG3	07/11/2012	24	57	6° 30' 58.62"N 3° 04' 50.47"E
CRYSTAL SCHL	AG4	08/11/2012	24	60	6° 30' 21.83"N 3° 05' 01.02"E
STANBIC IBTC	AG5	09/11/2012	24	63	6° 30' 16.17"N 3° 05' 10.50"E
OTA					
ABULE IGBIRA	OT1	10/11/2012	24	97	6° 40' 27.81" N 3° 12' 07.19"E
TOWER ALLU.	OT2	11/11/2012	24	90	6° 40' 25.78" N 3° 12' 05.26"E
FED. STEEL JTN	OT3	12/11/2012	24	84	6° 40' 27.42" N 3° 11' 53.60"E
ESTATE GATE	OT4	13/11/2012	24	87	6° 40' 52.72" N 3° 12' 08.22"E
SUMO STEEL JC	OT5	14/11/2012	24	76	6° 40' 13.00" N 3° 12' 02.03"E
EPE					
NAFORIJA	EP1	15/11/2012	24	60	6° 37' 37.36"N 3° 58' 58.38"E
SABIU RD.	EP2	16/11/2012	24	54	6° 37' 41.51"N 3° 58' 58.24"E
ISIAKA BADEJ	EP3	17/11/2012	24	66	6° 37' 40.42"N 3° 59' 00.24"E
ADEBOWALE	EP4	18/11/2012	24	75	6° 37' 38.48"N 3° 59' 06.60"E
POKA JC	EP5	19/11/2012	24	62	6° 37' 37.36"N 3° 58' 58.38"E

GC-MS analysis was performed on a Shimadzu model 2010 GC-MS with an HP-5MS fused silica column (30 m x 0.25 mm i.d., 0.25 μm film thickness). The chromatographic conditions were as follows: injector temperature: 100 to 280 $^{\circ}\text{C}$; oven temperature initiated at 60 $^{\circ}\text{C}$ for (1 min.), then increased to 200 $^{\circ}\text{C}$ at 5 $^{\circ}\text{C}/\text{min}$, 250 $^{\circ}\text{C}$ at 2 $^{\circ}\text{C}/\text{min}$, 280 $^{\circ}\text{C}$ at 10 $^{\circ}\text{C}/\text{min}$ (held for 20 min), and finally 290 $^{\circ}\text{C}$ at 10 $^{\circ}\text{C}$ (held for 5 min). Samples were injected with an auto sampler in the splitless/split mode with a split time of 1 min after injection. Ultra-pure Helium was used as carrier gas at a constant flow rate of 1.5 mL/min. The GC-MS analyses were operated, using Single Ion Monitoring (SIM) method at electron energy/impact 70 eV. The targeted PAH compounds were identified, based on the comparison of their retention times and fragmentation ion profile with reference standards. Quantification was carried out with a conventional internal calibration method, based on five-point calibration for individual compounds (0.1, 0.2, 0.4, 0.8, 1.8 ppm) (Wang et al., 2007).

All analytical data were subject to strict quality control with field blanks and laboratory blank analysed via each set of samples, along with the air samples, with good precision and recovery. The results, obtained from the analysis of field and laboratory blanks, showed that PAHs were present at minimum level in the field blank samples, while no traces of PAHs were observed in the laboratory blank sample, indicating no background PAH contamination with air samples or instruments, prior to the analysis. The recovery efficiency of the surrogate standard ranged from 68% to 112% in the

entire field blank. Blank spiked glass fibre filter in the laboratory had a surrogate recovery of 79% to 97%; however, the average surrogate standard recoveries, obtained in the air samples, ranged from 74% to 114%. The reporting limits were calculated from the lowest concentrations of the calibration curves, divided by the actual volume of the sampled air.

RESULTS AND DISCUSSION

The concentration of 20 target PAHs ($\Sigma_{20}\text{PAHs}$), determined in the air samples, ranged from 89.20 to 96.48 ng/m^3 (av. 92.84 ng/m^3) and 72.52 to 142.91 ng/m^3 (av. 107.72 ng/m^3) in air samples from industrial estates in Lagos and Ogun states, respectively (Table 2). The air samples from the control site (EP) had an average $\Sigma_{20}\text{PAHs}$ concentration of 19.55 ng/m^3 (Table 2) with the highest concentrations of $\Sigma_{20}\text{PAH}$, recorded in the air sample from Agbara (142.91 ng/m^3) Industrial Estate (Table 2 and Fig. 2), located in Ogun state. The lowest concentration (19.55 ng/m^3) belonged to the sample from the control site, Epe (Table 2 and Fig. 3). PAHs levels are expected to be significantly affected by proximity to emission sources, which clearly explains the low concentration, recorded in the air sample from the control site (Wang et al., 2010).

A marked distribution pattern of PAH concentrations in the air samples was apparent with predominance of 2- and 3-ring PAHs (Fig. 3). In samples from Lagos State, the 2-ring PAHs accounted for almost 24% of $\Sigma_{20}\text{PAH}$, with naphthalene dominating. However, the 3-ring PAHs constituted approximately 68% of $\Sigma_{20}\text{PAH}$ and had anthracene dominating.

Table 2. Average concentration (ng/m³) of individual Polycyclic Aromatic Hydrocarbons (PAHs) in the air samples

Compound	Abbreviation	PAHs						
		Lagos Industrial Est.			Ogun Industrial Est.			Control
		OG ^a	IL ^b	Average	AG ^c	OT ^d	Average	EP ^e
naphthalene	Nap	15.07	6.50	10.785	11.32	14.84	13.08	5.00
2-methylnaphthalene	2-MNap	6.24	5.31	5.775	8.02	14.55	11.285	3.12
1-methylnaphthalene	1-MNap	3.17	3.30	3.235	3.99	7.20	5.595	1.74
2,6-dimethylnaphthalene	2,6-DNap	2.42	1.84	2.13	3.25	5.59	4.42	1.43
2,3,5-trinaphthalene	2,3,5-TNap	nd	nd	nd	nd	2.10	1.05	nd
acenaphthylene	Ac	nd	10.06	5.03	nd	2.20	1.10	nd
fluorene	Fl	1.63	2.07	1.85	nd	3.07	1.535	nd
phenanthrene	Phe	3.43	30.05	16.74	33.22	10.86	22.04	6.44
anthracene	Ant	15.18	29.68	22.43	31.27	2.69	16.98	1.82
2-methylphenanthrene	2-MPhe	10.44	nd	5.22	2.68	2.73	2.705	nd
1-methylphenanthrene	1-Mphe	17.55	nd	8.775	13.51	nd	6.755	nd
2,6-dimethylphenanthrene	2,6-DMPhe	6.96	nd	3.48	5.37	nd	2.685	nd
fluranthrene	Flu	3.78	nd	1.89	7.39	2.1	4.745	nd
pyrene	Pyr	nd	nd	nd	10.21	1.42	5.815	nd
11H-benzo(b)fluorine	11-BbF	nd	nd	nd	1.41	nd	0.705	nd
benzo(a)anthracene	BaA	1.66	2.46	2.06	2.57	nd	1.285	nd
chrysene	Chr	1.67	5.21	3.44	2.51	nd	1.255	nd
9,10-diphenylanthracene	9,10-Dpha	nd	nd	nd	6.19	nd	3.095	nd
indeno(123-cd)pyrene	IcdP	nd	nd	nd	nd	1.59	0.795	nd
coronene	Cor	nd	nd	nd	nd	1.58	0.79	nd
Σ ₂₀ PAHs		89.2	96.48	92.84	142.91	72.52	107.715	19.55

nd means not detected, ^aOgba, ^bIlupeju, ^cEpe (Lagos state) ^cAgbara, ^dOta, (Ogun state)

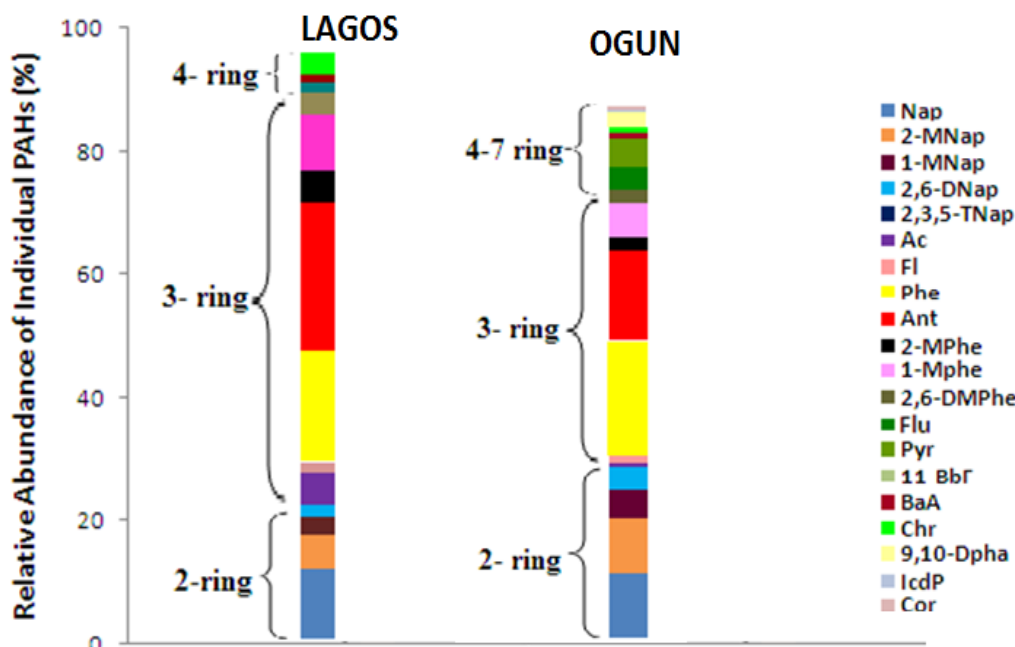


Fig. 2. Relative distribution pattern and percentage compositions of individual PAHs in air from industrial estate in Lagos and Ogun state

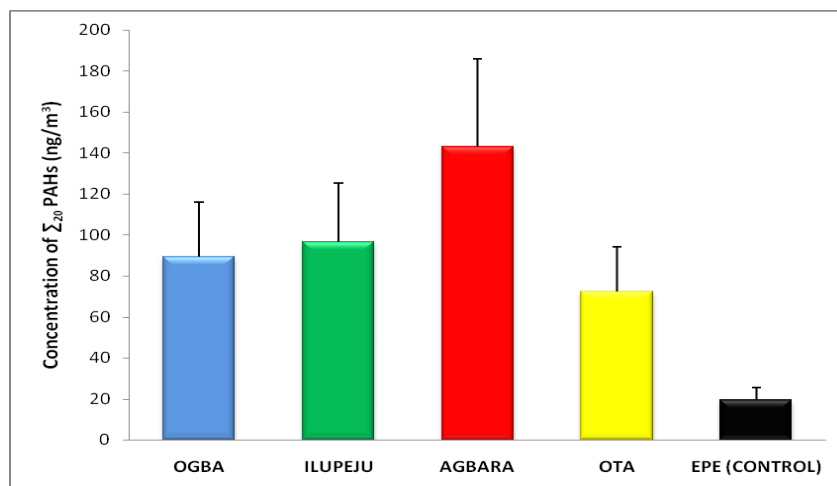


Fig. 3. Total concentrations of Σ_{20} PAHs in the air samples from the study areas. Bars and vertical lines represent Σ_{20} PAH and standard deviations, respectively.

Anthracene is a polycyclic aromatic hydrocarbon, commonly found in coal tar, which is applicable as an important intermediate in dye production. The 4-ring PAHs accounted for approximately 8% of Σ_{20} PAH (Fig. 3), while 5-7 ring PAHs were insignificant.

Chrysene is the predominant constituent in the 4-ring PAHs. It has been reported to have pyrolytic origin since it is formed during the burning or distillation of coal, crude oil, and plant material, and is known to cause cancer in laboratory animals (Satcher, 1995).

The air samples from Ogun state were dominated by 2-ring PAHs, which accounted for approximately 33% of the total Σ_{20} PAH and was dominated by naphthalene. The 3-ring PAHs constituted approximately 50% of Σ_{20} PAH with phenanthrene dominating it with about 20%. This was in contrast to what was obtained in the 3-ring of Σ_{20} PAH from Lagos State, where anthracene was predominant. The 4-ring PAHs accounted for approximately 13% of Σ_{20} PAH (Fig. 3) and had Pyrene as their dominant constituent. The 5-7 ring PAHs accounted for approximately 4% of Σ_{20} PAH in the air sample from Ogun State.

Table 3 compares the concentrations of polycyclic aromatic hydrocarbons,

determined in the present study, with global distributions patterns of PAHs in the air from other parts of the globe. The total concentrations of Σ_{24} PAH (2- to 6-ring parent and branched), recorded in the air of Naples, Italy, ranged from 2 to 130 ng/m³ (Caricchia et al., 1999). High PAHs concentrations of 1560 ng/m³ have been reported in the air from Tai Chung Industrial Park, Taiwan, with lower values in the urban area (Fang et al., 2004).

It is evident that the concentration, observed in this study is lower than those, measured in developing countries, and similar/close to the ones from the developed countries (Table 3). Several studies have reported that PAH concentration in the air from developing countries, like China, India, Taiwan, and Slovakia, are consistently higher than those, recorded in developed countries (Gary et al., 2002).

The elevated level of PAHs, observed in developing countries, has been attributed to increased use of coal as a domestic energy source (Hafner et al., 2005); however, major energy sources in most industries in Lagos and Ogun states are mainly diesel or gasoline, which has less PAHs emissions, compared to coal. The air, studied in this work, can be regarded as being moderately polluted with polycyclic aromatic

hydrocarbons, compared to similar samples from other parts of the world.

It is not enough to ascertain the presence and distribution of PAHs in the environment. Identifying the various sources of PAHs will help us know the best mitigative efforts to reduce the presence of these carcinogens.

Different PAHs diagnostic indices have been developed by previous scholars such as the ones, given in Table 4 (Sojinu et al.,

2010a; 2010b; Yunker et al., 2002; Manoli et al., 2004; Khalili et al., 1995). The BaA/(BaA + Chr) vs Flu/(Flu + Pyr) plot in Figure 4 shows the majority of PAHs in various locations to be of pyrolytic origin (Khalili et al., 1995, Sojinu et al., 2010a). Similarly, the plot of Flu/(Flu +Pyr) vs Ant/(Ant + Ph) also placed most of the PAHs in the samples in petroleum combustion section (Fig. 5).

Table 3. Global distribution of polycyclic aromatic hydrocarbon in air

Country	Area	n.	Σ PAHs (ng/m ³)	Reference
North Chinese Plain	Urban site	10	870±330	Liu et al. (2008)
North Chinese Plain	Rural site	10	710±330	Liu et al. (2008)
China	Urban		170 – 490	Simoneit et al. (1991)
Tai chung Taiwan	Urban	21	220±520	Fang et al. (2004)
Tai chung Taiwan	Rural	21	831±427	Fang et al. (2004)
Tai chung Taiwan	Industrial Park	21	1560±1240	Fang et al. (2004)
Naple Italy	Urban	24	2 – 130	Caricchia et al. (1999)
Flanders Belgium	Rural	16	114	Ravindra et al. (2006)
New Delhi India	Urban	12	668±399	Sharma et al. (2007)
Agra India	Urban		269±121	Nirat et al. (2009)
Lagos Nigeria	Industrial /Urban	20	92.84	Present study
Ogun, Nigeria	Industrial /Urban	20	107.72	Present study

n = number of samples

Table 4. Molecular indices of PAHs in the air from the study locations

Ogba	Flu/Py	Flu/(Flu+Pyr)	Ph/Ant	MPh/Ph	Ph/(Ph+Ant)	Ant/(Ant+Ph)	IcdP/(IcdP+BghiP)	BaA/(BaA+Chr)
02PM	0.80	0.44	1.01	0.13	0.50	0.50	0.49	0.51
03PM	0.55	0.35	1.01	0.13	0.50	0.50	0.88	0.51
04PM	0.62	0.38	1.01	0.41	0.50	0.50	0.01	0.36
05PM	0.56	0.36	1.03	0.44	0.51	0.49	0.14	0.28
06PM	0.00	0.98	0.02	0.00	0.02	0.98	0.00	0.51
Ilupeju								
07PM	0.56	0.36	1.01	0.42	0.50	0.50	0.33	0.35
08PM	0.37	0.27	1.01	0.64	0.50	0.50	0.00	0.53
09PM	1.62	0.62	1.01	0.38	0.50	0.50	1.00	0.32
10PM	0.56	0.36	1.01	0.37	0.50	0.50	0.00	0.34
11PM	0.56	0.36	1.01	0.35	0.50	0.50	0.14	0.56
Agbara								
12PM	0.54	0.35	0.94	0.4	0.48	0.52	0.11	0.26
13PM	0.58	0.37	0.99	0.76	0.50	0.50	0.09	0.43
14PM	0.71	0.42	1.04	5.86	0.51	0.49	0.10	0.51
15PM	1.55	0.61	4.91	0.69	0.83	0.17	0.09	0.79
16PM	2.97	0.75	1.01	0.27	0.50	0.50	0.96	0.51
Ota								
17PM	1.40	0.58	4.33	1.18	0.81	0.19	0.00	0.35
18PM	1.48	0.60	1.35	0.62	0.57	0.43	0.87	0.97
19PM	1.71	0.63	7.58	0.92	0.88	0.12	0.03	0.39
20PM	1.37	0.58	4.05	0.67	0.80	0.20	0.11	0.37
21PM	1.49	0.60	4.32	0.68	0.81	0.19	0.05	0.37

Flt/Py is the ratio fluoranthene/pyrene, Flu/(Flu+Pyr) is the ratio of fluoranthene/(fluoranthene+pyrene), Ph/Ant is the ratio of phenanthrene/Anthracene, Ph/(Ph+Ant) is the ratio of Phenanthrene/(Phenanthrene+Anthracene), IcdP/(IcdP+BghiP) is the ratio indeno(123-cd)pyrene/(indeno(123-cd)pyrene + Benzo(ghi)perylene), BaA/(BaA+Chr) is the ratio of Benzo(a)anthracene/(Benzo(a)anthracene+Chrysene).

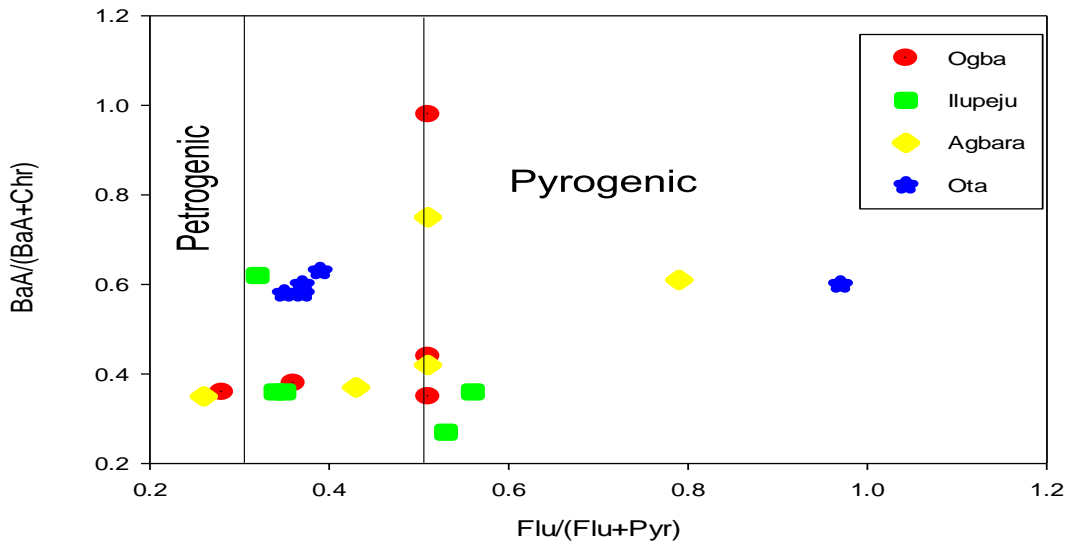


Fig. 4. The plot of BaA/(BaA+Chr) vs Flu/(Flu +Pyr) in ambient air of the study locations

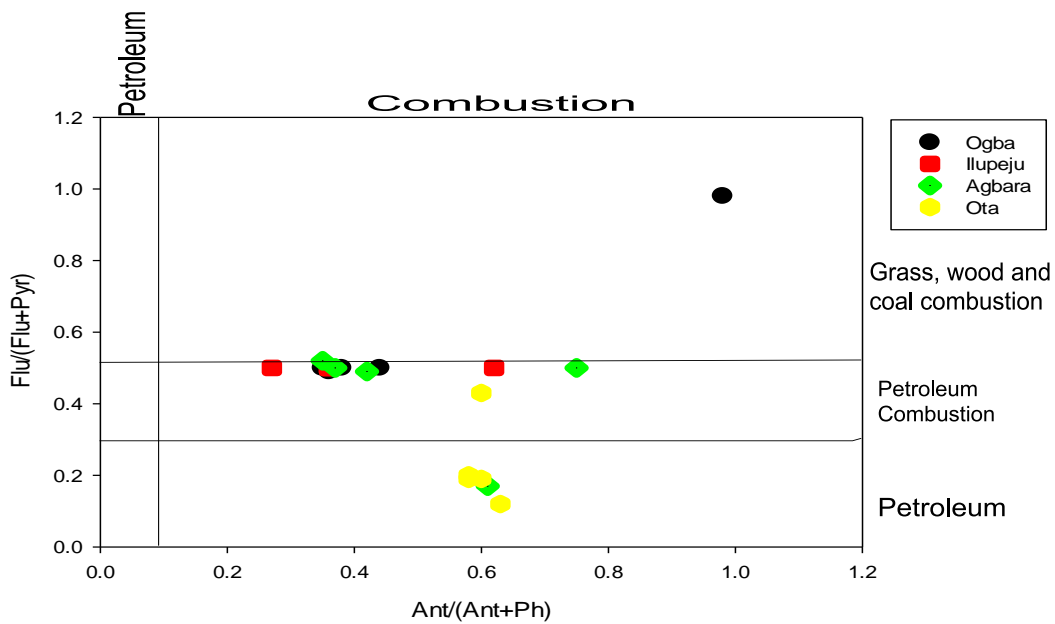


Fig. 5. The plot Flu/(Flu +Pyr) vs Ant/(Ant + Ph) in ambient air of the study locations

A more robust plot of Ph/Ant vs Flu/Py showed that virtually all the PAHs in the samples in the locations were of pyrolytic origin (Fig. 6) (Manoli et al., 2004; Yunker et al., 2002).

A further confirmation of the pyrolytic sources (liquid fuel combustion) of the PAHs in the sample is revealed through the plot of BaA/(BaA + Chr) vs Icdp/(Icdp +

Bghip) (Sojinu et al., 2010b; Yunker et al., 2002; Fig. 7).

All these indices strongly affirmed that the predominant source of PAHs in these locations was pyrolytic, chiefly from diesel fuel combustion of many of the industries that largely depend on heavy-duty power generation sets for their companies' energy demand along with high vehicular movement in the study locations.

We intend to continue to monitor this trend as efforts is geared towards the use of gas turbines to power these industrial estates by the government.

There has been strong concern about the impact and consequence of industrial pollution on ecological balance in the air over industrial towns of Lagos and Ogun states. Although, the severity of the impact depends on the concentration of the pollutant, the duration of exposure, and the susceptibility of the sensitive receptor, human, plant, animal, or building to the pollutant. However, it is of great importance to evaluate the possible impact of the PAH loads in the air on the

ecosystem, in this study. Presently, there are some difficulties to develop a quality guideline for PAHs in the air; however, Benzo(a)pyrene B(a)P has been considered to represent the best single quality indicator for PAHs compound in ambient air (Sienraa et al., 2005; WHO, 2000). Several studies and expert evaluation support the use of B(a)P as a suitable marker to set air quality standards. B(a)P, often used as an indicator of human exposure to PAHs, has been reported to have the highest carcinogenic potency with long-term persistency in the environment (Sienraa et al., 2005; WHO, 2000).

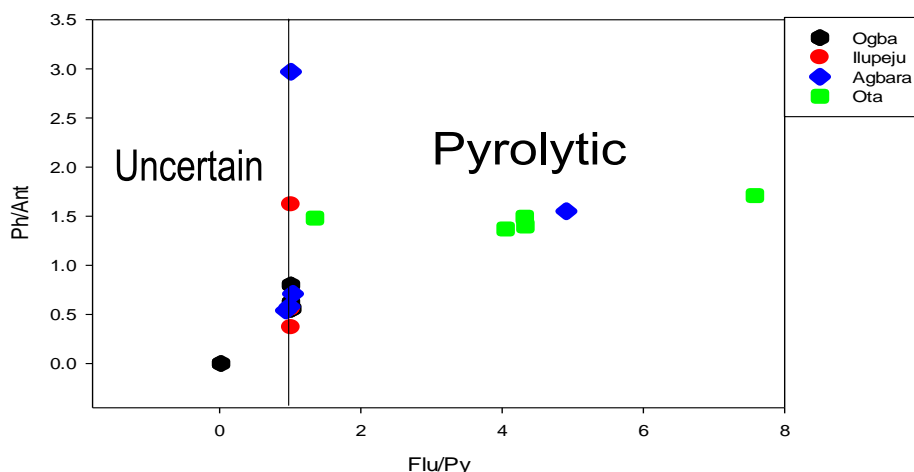


Fig. 6. The plot of Ph/Ant vs Flu/Py in ambient air of the study locations

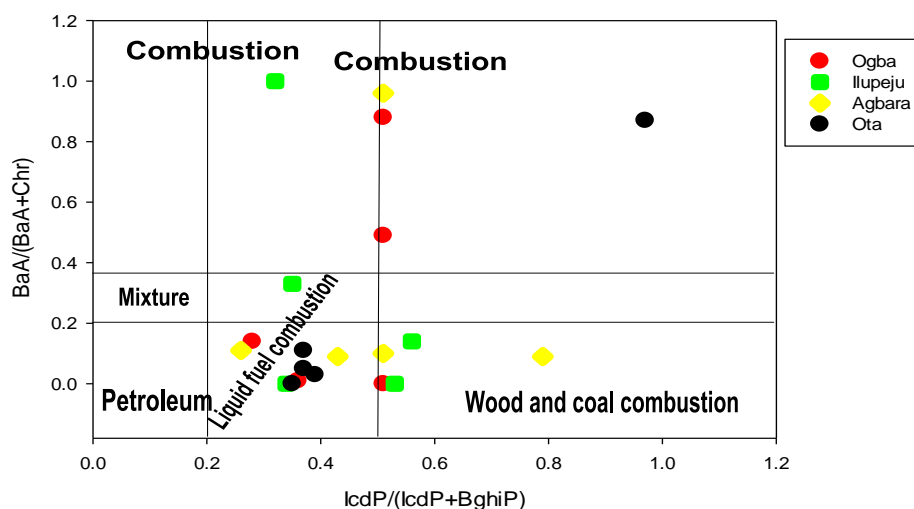


Fig. 7. The plot of BaA/(BaA + Chr) vs Icdp/(Icdp + BghiP) in ambient air of the study locations

The maximum allowable concentration (MAC) for B(a)P in the atmospheric air, recommended by World Health Organization, is 15 µg/m³ for industrial working zones' air and 0.1 µg/m³ in atmospheric air (EPAQS, 1999; WHO, 2000; EC, 2001). The B(a)P concentrations

in the present study was below the reported limit. According to the air quality guideline, which is based on allowable limit of B(a)P in some developed countries as listed in Table 5, the air samples under investigation do not seem to pose any adverse ecotoxicological problem to the biota.

Table 5. Allowable limit of B(a)P in some developed countries

Compound	Limit Value (ng/m ³)	Country	Reference
Benzo(a)pyrene	1.30	Germany	EC (2001)
Benzo(a)pyrene	1.00	Netherland	EC (2001)
Benzo(a)pyrene	1.00	Italy (1999)	Sienraa (2005)
Benzo(a)pyrene	1.00	USSR (1985)	Khesina (1994)
Benzo(a)pyrene	0.25	UK	EPAQ (1999)
Benzo(a)pyrene	0.10	Sweedden	EC (2001)
Benzo(a)pyrene	1.00	Greece	EC (2001)
Benzo(a)pyrene	1.00	Belgium	EC (2001)
Benzo(a)pyrene	n.a	Lagos	Present study
Benzo(a)pyrene	n.a	Ogun	Present study

n.a = not available

CONCLUSIONS

The present study determined the occurrence, distribution, source, and environmental impact of PAHs in the air from industrial areas in Lagos and Ogun States, Nigeria, by means of gas chromatography-mass spectrometer. The concentrations of Σ₂₀PAHs ranged from 89.20 to 96.48 ng/m³ (average: 92.84) and from 72.51 to 142.91 ng/m³ (average: 107.72) in the air of Lagos and Ogun states, respectively. A marked distribution pattern of PAH concentrations was apparent, in which 2- and 3-ring PAHs predominated all the samples. The PAHs in most of the air samples were mainly from pyrolytic source, likely to be resulted from vehicular emission, as well as diesel and fuel combustion, typical of industrial activities in the area. The studied air can be regarded as being moderately polluted, seeming to pose no serious adverse ecotoxicological problem, based on the comparison of total PAHs and B(a)P concentrations in the samples with similar samples from other parts of the world.

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