



# Insight into the metropolitan levels, spatial distribution and health risks of polycyclic aromatic hydrocarbons in roadside soil of Ibadan, Nigeria

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## Abstract

This study examined the distribution, sources, levels and health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in roadside soil of Ibadan metropolis. Six locations were chosen based on heavy traffic density, industrial activities and low traffic density. Samples were collected at five different spots at each location on monthly basis for the period six month covering the two seasons. The concentrations of PAHs in roadside soil were analysed using Gas Chromatography–Flame Ionization Detector. The PAHs ranged from 0.54 mg/kg to 1156 mg/kg. The PAHs were more predominant in roads with heavy traffic density. The total concentration of the 16 PAHs ranged from 232 mg/kg to 990 mg/kg. The distribution of PAHs ring size is in the order 6 ring > 5 ring > 4 ring > 3 ring > 2 ring. Among the PAHs compounds, Benzo(g,h,i)perylene was predominant. Carcinogenic fraction of PAHs represent 81.1% of the total PAHs. The total concentration of carcinogenic PAHs ranged from 196 mg/kg to 728 mg/kg. Benzo(a)pyrene was found in all the locations ranging from 26.0 to 46.0 mg/kg. The monthly increasing order of  $\Sigma$  16 PAHs is November > June > July > August > December > January. Lower molecular weight (LMW) PAHs were more abundant in dry season than wet season while higher molecular weight (HMW) PAHs were more abundant in wet season than dry season. The source diagnostic ratios analysis indicated the PAHs are more of pyrogenic source. Cancer health risk assessment of PAHs showed that children of the study area are more vulnerable to cancer than adult. The study revealed increasing accumulation of carcinogenic PAHs in roadside soil in Ibadan metropolis.

**Keywords** Polycyclic aromatic hydrocarbons (PAHs) · Carcinogenic · Roadside soil · Pyrogenic · Health risk assessment

## Introduction

In this contemporary times, advancement in technology has greatly improved owing to urbanization that leads to the introduction of pollutants into the environment (Olukanmi and Adeoye 2012). Urban areas are characterized with dense population hence increasing economic and industrial activities of residents (Luo et al. 2012). In addition, as a result of that the quality of urban environments most especially developing countries has deteriorated (Brown and Peake 2006). Urban soil is more exposed to polycyclic aromatic hydrocarbons (PAHs) owing to effluents from industries,

emissions from vehicles, power plants, residential heating, road by products, such as wearing of tires and components of asphalt (Banger et al. 2010).

It has been estimated that more than 600 million all over the world are exposed to hazardous level of vehicular pollution which can pose threat to environment health and this is expected to increase as vehicle ownership increases over the world (Han and Naeher 2006). Many developing cities lack access to land that can be converted to garages and parks, thereby major highways are occupied by motorists with an alarming rate that going to be extraordinary (Olukanmi and Adeoye 2012). Developing countries do not really have measures of checking vehicular pollution which leads to the increase of levels of pollution (Abam and Unachukwu 2009). Regulating bodies in Nigeria such as Federal Environmental Protection Agency (FEPA) and National Environmental Standards and Regulations Enforcement Agencies (NESREA) are in charge of enforcing environmental laws so as to control individuals, industries and organizations from

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polluting the environment. Nevertheless, these responsibilities were constrained to the control of air, water, noise pollution, waste disposal and oil spillage. There was no consideration given to soil pollution (Olukanmi and Adeoye 2012).

Vast industrial development globally has led to the identification and increasing understanding of interrelationship between pollution, public health and environment (Adebisi and Fayemiwo 2010). For a long period now, industrial contamination has been identified as a major factor that causes the degradation of the environment around us most especially the ground that we live on, the air we breathe in and the water we drink (Adebisi and Fayemiwo 2010). Industrial activities are responsible for discharging wastes that contain poisonous substances into the environment. During industrial processes, effluents are unavoidable. Effluents from different industries may differ in composition owing to source of production (Kaur et al. 2013).

Environmental pollution by toxic persistent organic pollutants such as PAHs is a major problem faced by major cities in developing countries in the past three decades (Adedosu et al. 2015). The contamination of roadside soil with PAHs has been of great concern over the years owing to their carcinogenic, genotoxic and persistence in the environment. The presence of PAHs in the environment has been of scientific interest in recent times because of their potential to bioaccumulate and persist. PAHs have been known to be a cause of neurological problems, reproductive problems, distortion of DNA, liver abnormalities skin diseases, black lung, emphysema and some other terminal diseases (Banger et al. 2010). Benzo(a)pyrene is the most studied PAH and has been set as a marker for PAHs concentration because it is practically unavoidable by human beings (Benson et al. 2017).

Levels and profiles of PAHs have been analyzed in soils from different land uses such as big cities and industrial or agricultural soils around the world hence revealing that, in general, the greatest amounts of PAHs are found in big cities and heavy industrial areas (Nadal et al. 2007; Agarwal et al. 2009; Jiang et al. 2009). Adedosu et al. (2015) carried out a research on the distribution, sources and toxicity potentials of PAHs in soil around the vicinity of Oshogbo, Nigeria. The total PAHs concentrations that were found in the soil ranged from 0.11374 mg/kg to 5.6491 mg/kg with a mean concentration of 0.0718 mg/kg and 0.35307 mg/kg. The concentration of PAHs in Oshogbo soil samples based on the ring size were in the order of  $3 > 4 > 5 > 6 > 2$ . Maisto et al. (2006) stated that total PAHs were 2–20 times greater in the urban areas of Naples, Italy, than the park soils that were 12 km away. Correspondingly, Baek et al. (1991) reported that the urban soils near the highways were greatly polluted. In New Orleans, Wang et al. (2008) detected the highest amounts of PAHs in soils close to the roads (7.189 µg/kg) than open spaces that were 10 m away from the roads (2.404 µg/kg).

Furthermore, results were shown by Wilcke (2000), who informed that PAH levels declined exponentially with increase in distance from the roads due to the reduced vehicular emissions. In Northern Germany, Krauss and Wilcke (2003) found out that the PAHs in industrial soils ( $> 10$  µg/kg) were eightfold greater than the park soils (1.9 µg/kg) while the lowest quantities were observed in agricultural soils (0.64 µg/kg) whereas Morillo et al. (2008) did not observe any significant differences in PAHs in agricultural, road sides, and park soils in Sevilla, Spain. The release of pollutants such as heavy metals and PAHs in the urban centres such as Ibadan as a result of anthropogenic activities is on the increase and may pose a serious threat to the quality of life of inhabitants. The chief causes of worldwide total atmospheric emission of PAHs has been 65% attributed to residential/commercial biomass burning; 13.6% attributed to open-air burning; and 12.8% attributed to petroleum consumption by motor vehicle (Shen et al. 2013). Many of the PAHs and heavy metals have damaging effects on living things including humans such as respiratory, immunological, neurological, genotoxic, and reproductive hazards. It has been recounted that definite PAHs metabolites interact with deoxyribonucleic acid (DNA) and are genotoxic, producing distortions and inherited genetic damage in human (Tisbart and Gennadiev 2013). Ana et al. (2010) reported one to four ratio of cancer case in University of Port-Harcourt Teaching Hospital (UPTH) and University College Hospital (UCH), Ibadan at the rate of 904 and 3521, respectively; and cancer owing to prostate and breast higher in Ibadan (79.1%) than in Port-Harcourt (75.4%); cancer of the eyes more predominant in Ibadan (7.3%) while Port-Harcourt (1.7%) but lung and skin cancers more rampant in Port-Harcourt than in Ibadan.

An assessment of environmental risk that is caused by soil contamination with PAHs and heavy metals is of paramount importance because of resulting health hazards. It is, therefore, envisaged that the findings of this study will provide baseline information about PAHs and also provide additional policy and decision making tools for relevant government agencies. Researchers who are interested in the PAHs and metal contamination level within the study area could also benefit from the findings of this study. The objectives of this study are to investigate the occurrence, concentration and pollution status of PAHs and to conduct health risk assessment of PAHs in roadside soil of selected areas in Ibadan.

## Materials and methods

### Description of study area

Ibadan, the State capital of Oyo State is an ancient city that is located in the South Western region of Nigeria. It

was formerly the capital territory of then western region administrative headquarters (ETHICS, 2016). Ibadan is the third most populated city (3,565,108) in Nigeria after Lagos (9,000,000) and Kano (3,626,068) (World Population Review 2018). Ibadan, South-Western Nigeria has a total area 3080 km<sup>2</sup> and density of 250 km<sup>2</sup>. 128 km inland north-east of Lagos and 530 km southwest of Abuja. It is located between longitudes 3° 15' and 4° 00' E and latitudes 7° 15' and 7° 30' N (Ogungbuyi et al. 2013).

Six major roads within Ibadan metropolis were chosen for this study (Fig. 1). The sample locations were chosen based on traffic volume density and heavy industrial activities. These are: residential and heavy traffic density (Mokola, Ojoo, and Iwo) high traffic density (Lagos–Ibadan express roads), low traffic density, i.e., uncontaminated reference point (Benue road, University of Ibadan) and industrial site (Seven-Up road, Oluyle Industrial Estate). Choice on sampling locations was made after a cautious survey of the traffic densities, industrial distribution pattern covering the entire city of Ibadan. Table 1 presents the traffic volume count (h<sup>-1</sup>) of the selected roads considered in this study and their coordinates.

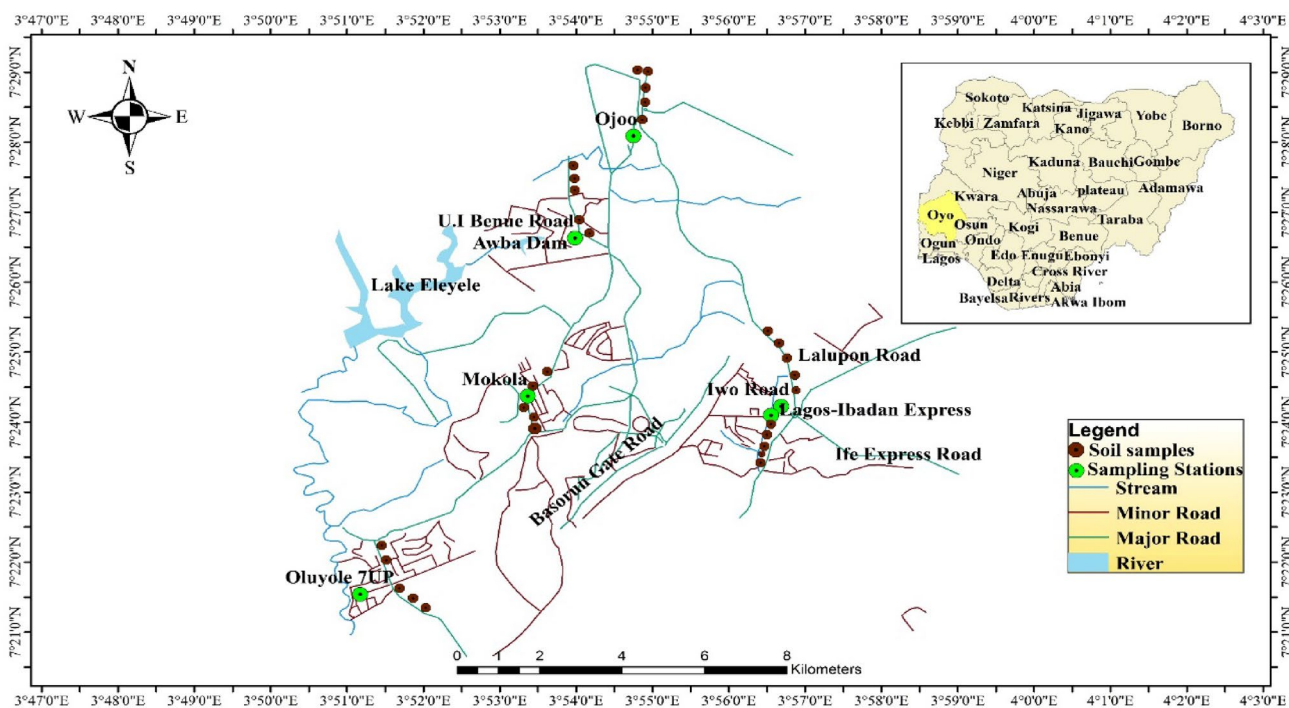
**Sample collection, handling and preservation**

Samples were collected on monthly basis for the period of 6 months; and included two consecutive seasons—dry (November, December and January) and wet (June July

**Table 1** Traffic volume count and GPS location of the sampling sites

Locations	Traffic volume count (h <sup>-1</sup> )	GPS location
Iwo road	1856	3° 57' 31 E 7° 24' 52 N
Ojoo road	2168	3° 54' 16 E 7° 20' 21 N
Benue road (UI)	72	3° 52' 55 E 7° 19' 58 N
Mokola road	1816	3° 53' 24 E 7° 224' 4 N
Lagos–Ibadan express road	3188	3° 51' 42 E 7° 25' 18 N
Seven up road	224	3° 50' 43 E 7° 21' 31 N

and August). Each sample location for each month, five samples were collected. Samples were collected using hard brush and a packer then out into a well labelled cellophane bag. After the five samples were collected from a particular sampling site, a composite sample was made, then placed in a wooden box and transported to the laboratory at ambient temperature for pre-treatment and analysis. The samples were air dried at ambient temperature and then kept in a neat cupboard under room temperature. Preceding the extraction, soil samples were air-dried openly on the benches in the laboratory for 5 days. The dried soil samples were then sieved using a 0.2 mm sieve.



**Fig. 1** Map of Ibadan showing the sampling locations

## Analytical reagents and their source

n-Hexane was purchased from Park Scientific Ltd., Northampton, United Kingdom and Merck (Germany). Silical gel (60–100) mesh was supplied by Sigma Aldrich, South Africa which was used for column chromatography. Granular anhydrous sodium sulphate was supplied by MERCK Germany.

## Extraction and clean-up of sampling

The soil extraction process involved the use of a Soxhlet extractor. About 20 g of the soil samples placed in a thimble were introduced into the Soxhlet apparatus with 150 mL of the extracting solvent (n-Hexane). The extraction lasted for about 3 h with repeated refluxing.

Clean-up was done to remove other contaminants such as lipids and pigments that had been extracted with PAHs. This was done using column packed with silica gel. The silica gel used for the clean-up was activated, after heating to 150–160 °C. The clean-up column (size 15 × 1 cm internal diameter) was prepared by slurring about 10 g of activated silica gel (about 100–200 mesh) with n-hexane into a chromatographic column. About 1 g of anhydrous sodium sulphate was added to the top of the column to absorb all traces of water. The column was then packed with activated silica gel then pre-eluted with n-hexane. The concentrated extracts were transferred quantitatively to the top of the column with additional n-hexane. About 1 mL elution of the analytes was accomplished with n-hexane thereby leaving the interfering compounds on the column. Then the resulting extract after clean-up was then analyzed for PAHs using Gas Chromatography–Flame Ionization Detector.

## Gas chromatography analysis of sample extracts

The gas chromatography used was Agilent GC-7890A coupled with flame ion detector (FID). The separation was carried out on an HP5 (30 m × 320 μm × 0.25 μm) fused silica capillary column. 1.0 μL of the extract was injected using split injection mode. Helium was used as the carrier gas at a flow rate of 1.2 mL/min and nitrogen was used as the make-up gas. The oven temperature was programmed from 60 °C (held for 1 min) to 210 °C at a rate of 12 °C/min to 320 °C at 8 °C/min held for 5 min.

## Quality control

The identification of PAHs were by comparison of sample retention times with that of the USEPA standard mix. Procedural blanks were also analyzed together with the samples. The concentrations of the PAHs in the method blanks were found to be below the detection limit and no interferences were detected. Limit of Detection (LOD) was calculated

three times the noise of the chromatogram in a sample that is blank. Limit of Quantification (LOQ) was calculated as ten times the standard deviation of the blank (Table 2).

## Calculations of health risk assessment

### Toxic equivalence concentration (TEQ)

The carcinogenic potency of benzo(a)pyrene, B(a)P has been highlighted as group 1 carcinogen and its metabolites are known for destroying DNA and it also induces mutation (Mumtaz and George 1995; Obini et al. 2013). To assess the human health risk of carcinogenic PAHs that contains mixtures, usually total potency equivalence (TPEs) are used to relate the carcinogenic potential of other PAHs to that of benzo(a)pyrene (IPCS 1998). The TPEs values are calculated as the summation of the total concentration of each of the carcinogenic with the toxicity equivalent factors for each PAHs IS expressed as

$$TEQ = \sum (PAH_i \times TEF_i)$$

where  $PAH_i$  = concentration of individual carcinogenic polycyclic aromatic hydrocarbons.  $TEF_i$  = toxic equivalent factor (potency relative to benzo(a)pyrene).  $TEQ$  = toxic equivalence (Orisakwe et al. 2015).

**Table 2** Main quality control parameters of GC–FID used

PAHs	Retention time (min)	Limit of quantification (mg/kg)	Limit of detection (mg/kg)
Naphthalene	6.530	7.653	2.296
Acenaphthylene	9.432	8.490	2.547
Acenaphthene	9.611	8.643	2.593
Fluorene	10.536	8.633	2.590
Anthracene	12.049	7.660	2.298
Phenanthrene	12.366	7.917	2.375
Fluoranthene	14.341	7.817	2.345
Pyrene	15.092	7.877	2.363
Benz(a)anthracene, (BaA)	17.668	7.203	2.161
Chrysene	17.896	8.107	2.432
Benzo(b)fluoranthene, (BbF)	19.714	6.370	1.911
Benzo(k)fluoranthene (BkF)	20.036	6.550	1.965
Benzo(a)pyrene (BaP)	21.041	6.860	2.058
Indeno(123-cd)pyrene (IP)	22.906	9.907	2.972
Dibenz(ah)anthracene(DahA)	23.286	10.20	3.059
Benzo(ghi)perylene (BghiP)	23.772	9.727	2.918

### Cancer risk assessment of PAHs

The relationship below can be used to calculate the cancer risk:

$$\text{Exposure dose} = \frac{\text{Concentration} \times \text{Intake Rate} \times \text{Conversion Factor} \times \text{Exposure factor}}{\text{Body Weight}}$$

where Concentration = concentration of total toxicity equivalent of benzo(a)pyrene. Intake Rate = Adult 0.0001 kg/day, Child 0.0002 kg/day. Body Weight = Adult 70 kg, Child 15 kg. Exposure Factor = 350 days/year.

$$\text{Cancer Risk Estimation} = \frac{\text{Exposure Dose} \times \text{Number of years of contact with PAHs} \times \text{CPF}}{\text{Average life time}}$$

where CPF = Cancer Potency Factor for benzo(a)pyrene, 7.3. Number of years of contact with PAHs = Assumed to be 30 years. Average Life Time = Assumed to be 55 years.

### Health Risk Assessment of PAHs in the Soil

The method described by Gržetić and Ahmed Ghariani (2008) was employed to calculate the chronic daily intake for both carcinogenic and non-carcinogenic health risk.

### Statistical analysis

The obtained data were subjected to descriptive statistical analysis (95% confidence limit). The computations were achieved using Statistical Package for Social Sciences (SPSS 20) to determine the mean, standard deviation and mean values of PAHs concentration in roadside soil. To have an insight into the inter-element relationship, Two-tailed Pearson linear correlation matrix was generated from the data. Classification was based on the degree of correlation (*r*) according to (Sebaiwa, 2016):

Value of <i>r</i>	Degree of correlation
± 1	Perfect correlation
± 0.90 or more	Very high degree of correlation
± 0.75 to ± 0.90	Sufficiently high degree of correlation
± 0.60 to ± 0.75	Moderate degree of correlation
± 0.30 to ± 0.60	Only the possibility of correlation
Less than ± 0.30	Possibly no correlation
0	Absence of correlation

### Results and discussion

#### Distribution and concentration of polycyclic

#### aromatic hydrocarbons

The concentrations and distribution of the 16 EPA priority PAHs in Ibadan roadside soil is presented in Table 3. The

result showed that all the 16 USEPA priority PAHs were detected in the soil at varied concentrations. The overall mean concentrations of the total PAHs in all the selected locations in Ibadan metropolis ranged from 232 mg/kg in Seven-up (Oluyole Estate) to 990 mg/kg at Mokola road. The mean concentration of Ojoo road was low followed by Iwo road followed by Lagos–Ibadan express road and Benue road, UI. The trend observed in Mokola, Lagos–Ibadan express, Iwo and Ojoo roads may be attributed to heavy traffic density, burning of refuse, high volume of filling stations, mechanical workshops paramount in all these locations. Seven up road (Oluyole) an industrial estate, hence effluents from industries around must have contributed to the levels of PAHs in the roadside soil. The data obtained for each location was subjected to one way ANOVA. The result showed that all the PAHs were not significantly different from one another ( $P < 0.05$ ).

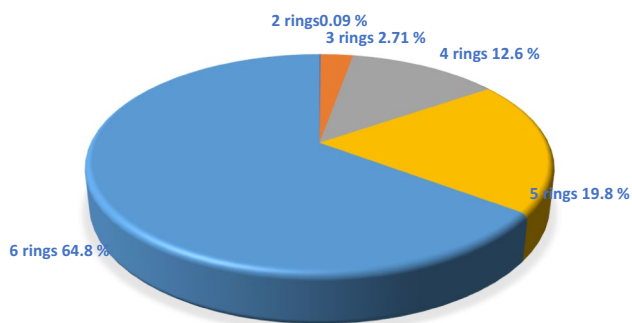
In all these locations, Benzo(g,h,i)perylene had the highest total concentration (1156 mg/kg) followed by Indeno(1,2,3-cd)pyrene (358 mg/kg); and the lowest acenaphthene (0.54 mg/kg). Indeno(1,2,3-cd)pyrene (65.6 mg/kg) was predominant at Iwo road; Benzo(g,h,i)perylene (63.6 mg/kg) at Ojoo road, Benzo(g,h,i)perylene (112 mg/kg) and Indeno(1,2,3-c,d)pyrene (92.4 mg/kg) at Benue road. All PAHs compounds were detected at Mokola road and ranged from Acenaphthene (0.3 mg/kg) to Benzo(g,h,i)perylene (770 mg/kg). Naphthalene and Acenaphthene were found to be below detection level at Lagos–Ibadan express road while other compounds detected ranged from Phenanthrene (1.02 mg/kg) to Benzo(g,h,i)perylene (85.9 mg/kg). Naphthalene, Acenaphthylene and Fluorene were found to be below detection level at Seven up road (Oluyole Estate) but Benzo(g,h,i)perylene was found to be the most abundant PAHs (63.0 mg/kg) while Acenaphthene (0.24 mg/kg) was the lowest concentration of PAHs present in Seven up road (Oluyole Estate).

**Table 3** PAHs concentration in Ibadan roadside soil (mg/kg)

PAHs	Iwo	Ojoo	UI	Mokola	Lag-Ib exp	Seven up	Σ PAHs
Napthalene	BDL	BDL	1.43 ± 3.50 <sup>a</sup>	0.77 ± 1.90 <sup>a</sup>	BDL	BDL	<b>2.2</b>
Acenapthylene	0.59 ± 1.46 <sup>a</sup>	BDL	1.01 ± 1.89 <sup>a</sup>	4.48 ± 10.3 <sup>a</sup>	1.09 ± 1.70 <sup>a</sup>	BDL	<b>7.17</b>
Acenapthene	BDL	BDL	BDL	0.30 ± 0.73 <sup>a</sup>	BDL	0.24 ± 0.59 <sup>a</sup>	<b>0.54</b>
Fluorene	0.14 ± 0.33 <sup>a</sup>	3.14 ± 7.35 <sup>a</sup>	1.65 ± 3.13 <sup>a</sup>	8.23 ± 13.3 <sup>a</sup>	4.76 ± 11.7 <sup>a</sup>	BDL	<b>17.9</b>
Phenanthrene	BDL	0.52 ± 1.28 <sup>a</sup>	BDL	8.98 ± 17.9 <sup>a</sup>	1.02 ± 2.50 <sup>a</sup>	1.88 ± 4.60 <sup>a</sup>	<b>12.4</b>
Anthracene	3.94 ± 2.50 <sup>a</sup>	2.87 ± 2.50 <sup>a</sup>	7.40 ± 12.22 <sup>a</sup>	2.69 ± 2.36 <sup>a</sup>	6.42 ± 11.5 <sup>a</sup>	2.07 ± 3.18 <sup>a</sup>	<b>25.4</b>
Fluoranthene	1.35 ± 1.54 <sup>a</sup>	2.48 ± 1.40 <sup>a</sup>	1.72 ± 2.83 <sup>a</sup>	1.53 ± 3.03 <sup>a</sup>	2.89 ± 4.93 <sup>a</sup>	5.42 ± 11.3 <sup>a</sup>	<b>15.4</b>
Pyrene	22.2 ± 14.8 <sup>a</sup>	25.2 ± 23.7 <sup>a</sup>	23.6 ± 27.0 <sup>a</sup>	34.4 ± 32.2 <sup>a</sup>	29.0 ± 22.5 <sup>a</sup>	26.8 ± 50.1 <sup>a</sup>	<b>161</b>
Chrysene	4.60 ± 3.10 <sup>a</sup>	3.33 ± 3.60 <sup>a</sup>	1.79 ± 2.72 <sup>a</sup>	4.70 ± 6.85 <sup>a</sup>	9.55 ± 8.01 <sup>a</sup>	6.19 ± 9.49 <sup>a</sup>	<b>30.2</b>
B(a)A	9.45 ± 6.21 <sup>a</sup>	13.0 ± 12.5 <sup>a</sup>	6.13 ± 12.2 <sup>a</sup>	20.4 ± 38.0 <sup>a</sup>	16.5 ± 25.6 <sup>a</sup>	21.3 ± 40.1 <sup>a</sup>	<b>86.8</b>
B(b)F	15.0 ± 24.3 <sup>a</sup>	15.5 ± 13.2 <sup>a</sup>	9.11 ± 12.4 <sup>a</sup>	23.8 ± 26.9 <sup>a</sup>	14.4 ± 22.5 <sup>a</sup>	13.7 ± 11.0 <sup>a</sup>	<b>114</b>
B(k)F	26.6 ± 28.6 <sup>a</sup>	16.8 ± 20.5 <sup>a</sup>	51.5 ± 51.9 <sup>a</sup>	16.6 ± 13.9 <sup>a</sup>	35.9 ± 32.6 <sup>a</sup>	12.0 ± 15.0 <sup>a</sup>	<b>159</b>
B(a)P	29.2 ± 23.6 <sup>a</sup>	26.0 ± 21.3 <sup>a</sup>	32.8 ± 17.5 <sup>a</sup>	37.9 ± 17.2 <sup>a</sup>	22.1 ± 22.8 <sup>a</sup>	46.0 ± 80.9 <sup>a</sup>	<b>194</b>
I(1,2,3-cd)P	65.6 ± 32.4 <sup>a</sup>	60.2 ± 11.8 <sup>a</sup>	92.4 ± 90.4 <sup>a</sup>	50.9 ± 37.3 <sup>a</sup>	63.5 ± 61.2 <sup>a</sup>	24.9 ± 27.5 <sup>a</sup>	<b>358</b>
D(a,h)A	1.18 ± 2.29 <sup>a</sup>	1.62 ± 3.96 <sup>a</sup>	BDL	4.11 ± 6.60 <sup>a</sup>	2.30 ± 3.60 <sup>a</sup>	9.22 ± 22.6 <sup>a</sup>	<b>18.4</b>
B(ghi)P	62.0 ± 40.2 <sup>a</sup>	63.6 ± 42.3 <sup>a</sup>	112 ± 126 <sup>a</sup>	770.6 ± 38.2 <sup>a</sup>	85.5 ± 68.3 <sup>a</sup>	63.0 ± 85.6 <sup>a</sup>	<b>1156</b>
Σ 16 PAHs	<b>242 ± 181</b>	<b>234 ± 123</b>	<b>343 ± 361</b>	<b>990 ± 267</b>	<b>294 ± 314</b>	<b>232 ± 362</b>	<b>2335</b>
Σ 3-ring PAHs	<b>4.67 ± 4.29</b>	<b>6.53 ± 11.1</b>	<b>10.1 ± 17.2</b>	<b>24.6 ± 44.6</b>	<b>13.3 ± 27.4</b>	<b>4.19 ± 8.37</b>	<b>63.39</b>
Σ 4-ring PAHs	<b>37.6 ± 25.7</b>	<b>44.0 ± 41.2</b>	<b>33.2 ± 44.8</b>	<b>61.0 ± 80.1</b>	<b>57.9 ± 61.0</b>	<b>59.7 ± 111</b>	<b>293.4</b>
Σ 5-ring PAHs	<b>72.0 ± 78.8</b>	<b>59.9 ± 59.0</b>	<b>93.4 ± 81.8</b>	<b>82.4 ± 64.6</b>	<b>74.7 ± 81.5</b>	<b>80.9 ± 130</b>	<b>463.3</b>
Σ 6-ring PAHs	<b>128 ± 72.6</b>	<b>124 ± 54.1</b>	<b>204 ± 216</b>	<b>822 ± 75.5</b>	<b>149 ± 130</b>	<b>87.9 ± 113</b>	<b>1514</b>
Σ LMW PAHs	<b>42.3 ± 30.0</b>	<b>50.5 ± 52.3</b>	<b>44.7 ± 65.5</b>	<b>86.4 ± 127</b>	<b>71.2 ± 88.4</b>	<b>63.9 ± 119</b>	<b>359</b>
Σ HMWPAHs	<b>200 ± 151</b>	<b>184 ± 113</b>	<b>297 ± 298</b>	<b>904 ± 140</b>	<b>224 ± 212</b>	<b>169 ± 243</b>	<b>1978</b>
Σ CPAHs	<b>214 ± 161</b>	<b>200 ± 129</b>	<b>306 ± 313</b>	<b>728 ± 185</b>	<b>250 ± 245</b>	<b>196 ± 292</b>	<b>1894</b>

Mean with different letter of the alphabet for each column are significantly different ( $P < 0.05$ ) from each other

Σ CPAHs sum of carcinogenic PAHs, Σ 16 PAHs sum of 16 EPA priority PAHs, Σ LMW PAHs sum of low molecular weight, Σ HMWPAHs sum of high molecular weight, BDL Below detection limit



**Fig. 2** Percentage distribution of PAHs based on ring size in the soil sample

The two-ring PAH, naphthalene was found below detection limit in all the locations except for Benue road UI and Mokola road. The percentage contribution of two-ring PAH is 0.09% (Fig. 2) to the total Σ 16 PAHs concentration. The three-ringed PAHs (acenapthylene, acenapthene, fluorene, phenanthrene and anthracene) were detected in all

the selected locations in Ibadan metropolis. Three-ringed PAHs constituted 2.71% of the Σ 16 PAHs of the locations. All the locations had three-ring PAHs not more than 8 mg/kg. It was noticed that anthracene was predominant than the other three-ringed PAHs constituting about 1.1% of the Σ 16 PAHs of the locations. Acenapthene constituted about 0.02% of the Σ 16 PAHs. Anthracene was detected in all the locations 1.09% of the Σ 16 PAHs. Higher anthracene concentration was observed in Benue road UI compared to other locations. Phenanthrene was found below detection at Iwo road and Benue road UI but constitute about 0.53% of the Σ 16 PAHs. Fluorene was found in all the locations except for Seven-up road Oluyole estate constituting about 0.77% of the Σ 16 PAHs.

Four-ringed PAHs (fluoranthene, pyrene, chrysene and Benz(a)anthracene) made up 12.6% of the Σ 16 PAHs of the locations. All the four-ringed PAHs were found in all the locations. Of all the four-ringed PAHs, Benz(a)anthracene was the most dominant. Fluoranthene was found in all the locations constituting about 0.66% of the Σ 16 PAHs. Pyrene was likewise found in all the locations constituting

about 6.90% of the  $\Sigma$  16 PAHs. Chrysene constituted about 1.29% of the  $\Sigma$  16 PAHs of the locations. Benz(a)anthracene constituted about 3.71% of the  $\Sigma$  16 PAHs. Netherlands Ministry of Housing Spatial Planning and the Environment (1994) stipulated that the total concentration of ten PAHs, i.e., naphthalene, anthracene, phenanthrene, fluoranthene, benzo(a)anthracene, chrysene, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene, and ind(1,2,3-cd)pyrene in soil should not exceed the maximum value of 1000  $\mu\text{g}/\text{Kg}$ . The  $\Sigma$ PAHs 16 in each of these locations were below 1000  $\mu\text{g}/\text{Kg}$ . The Institute of Soil Science and Plant Cultivation, Poland classification indicated that soils with total PAHs less than 1000  $\mu\text{g}/\text{Kg}$  (dw) can be considered to be unpolluted (Sieciechowicz et al. 2014). The established target for PAHs in uncontaminated soil by the Dutch government is 20–50  $\mu\text{g}/\text{Kg}$  (Van Brummelen et al. 1996) while typical concentration of PAHs in arable topsoil in Sweden is given as 200  $\mu\text{g}/\text{Kg}$  (Berset and Holzer 1995). Therefore, all the study locations were considered polluted.

The concentration of five-ringed PAHs (Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene and Dibenz(a,h)anthracene) constitute about 19.8% of the  $\Sigma$  16 PAHs of the locations. All the five-ringed were present in all the locations while Benzo(a)pyrene was the most abundant of all compared to others. Benzo(b)fluoranthene constitute about 4.88% of the  $\Sigma$  16 PAHs of the locations. Benzo(k)fluoranthene constitute about 6.81% of the  $\Sigma$  16 PAHs of the locations. Benzo(a)pyrene constitute about 8.31% of the  $\Sigma$  16 PAHs of the locations.

Six-ringed PAHs is made up of Indeno(1,2,3-c,d)pyrene and Benzo(g,h,i)perylene only. The percentage contribution of six-ringed PAH is 64.8% to the total  $\Sigma$  16 PAHs concentration. Indeno(1,2,3-c,d)pyrene constitute about 15.3% of the  $\Sigma$  16 PAHs of the locations while Benzo(g,h,i)perylene constitute about 49.5% of the  $\Sigma$  16 PAHs of the locations. It was noticed that Benzo(g,h,i)perylene was more abundant in all the locations than Indeno(1,2,3-c,d)pyrene. In general, the distribution of PAHs according to their ring size occurs in the following order  $6 > 5 > 4 > 3 > 2$ . USEPA had classified seven PAHs (BaP, BkF, DahA, BaA, IP and BghiP) as probable carcinogenic (Lunch 2005). Out of seven EPA identified PAHs four are five ringed, two are six ringed, and one of them is four ringed. All these seven compound were found in this study. This revealed that percentage of high carcinogenic in the soil within Ibadan metropolis were quite high. Kumar et al. (2014) reported similar findings in their study of PAHs in roadside soil of developing cities of northern India.

The distribution of high molecular weight PAHs ( $\Sigma$ HMW) and low molecular weight PAHs ( $\Sigma$ LMW) in the roadside soil samples of the selected locations in Ibadan

(Table 3) showed that  $\Sigma$ HMW (1978 mg/kg) were more abundant than  $\Sigma$ LMW (359 mg/kg). The function of microbial degradation during the wet season might be the responsible factor for the shift from low molecular weight to high molecular weight.

### Monthly variations of PAHs in Ibadan roadside soil

Table 4 presents the monthly variations of PAHs in roadside soil. The PAHs range values (mg/kg) are as follows: June (0.53–93.7); July (BDL–87.6); August (BDL–71.6); November (BDL–107); December (BDL–62.2) and January (BDL–34.8). The  $\Sigma$  16 PAHs on ranged from 124 mg/kg in January to 435 mg/kg in November.

In this study, the highest concentration of  $\Sigma$  16 PAHs was recorded in November. The increasing order of  $\Sigma$  16 PAHs is November > June > July > August > December > January. Considering the fact that November is the beginning of dry season that comes after wet season, high concentration might be as a result of sedimentation during the wet season while low values recorded in December and January might be due to thermal degradation of the pollutants. It was noticed from the result that LMW PAHs were more abundant in dry season than wet season. This could be as a result of the accumulation of the contaminants on the roadside top soil. HMW PAHs were more abundant in wet season than dry season. This could be as a result of rainfall which may have assisted in bringing down the particulate matters released into the atmosphere to settle onto the soil (Chun 2011). HMW PAHs being more abundant in wet season may also be due to the fact that HMW PAHs have greater hydrophobicity ( $\log K_{OW} > 5$ ) and less water solubility which probably results in their slow biodegradation and lower volatility (Wilcke 2000). Ajayi et al. (2017) reported that LMW PAHs were more abundant in wet season than dry season while HMW PAHs were almost equal during wet and dry season.

The data obtained on monthly basis was subjected to one way ANOVA which showed that Anthracene and B(a)P were significantly different at  $P < 0.05$  level. Furthermore, the Duncan multiple range test showed that Fluorene, Fluoranthene, Pyrene, Chrysene, B(k)F, B(a)P and I(123-cd)P particularly varied significantly from 1 month to the other. This clearly indicated non-uniformity in the release of these contaminants into roadside soil of Ibadan metropolis.

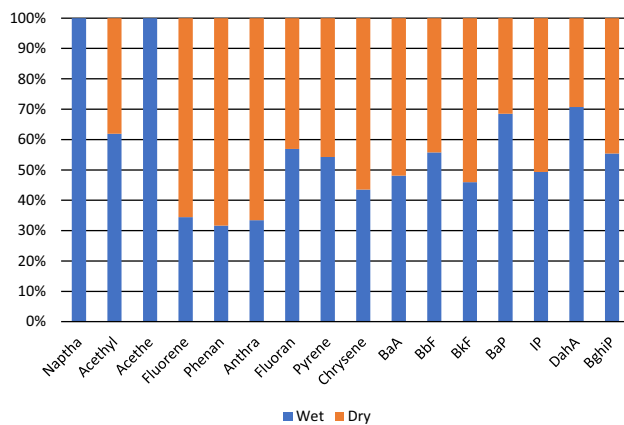
### Seasonal variation of PAHs in roadside soil

Sampling periods was broadly divided into two seasons in this study: dry (November, January and December), and wet (June, July and August). A hundred percent (100%) stacked column chart was further used to described seasonal variation of PAHs to compare the percentage that each compounds contribute to the total and change over

**Table 4** Monthly variation of PAHs (mg/kg) in roadside soil

PAHs	June	July	August	November	December	January
Napthalene	0.77 ± 1.90 <sup>a</sup>	BDL	1.43 ± 3.50 <sup>a</sup>	BDL	BDL	BDL
Acenaphthylene	4.45 ± 10.3 <sup>a</sup>	BDL	BDL	1.54 ± 1.96 <sup>a</sup>	1.19 ± 1.84 <sup>a</sup>	BDL
Acenaphthene	0.53 ± 0.84 <sup>b</sup>	BDL	BDL	BDL	BDL	BDL
Fluorene	3.10 ± 6.44 <sup>ab</sup>	3.02 ± 7.40 <sup>ab</sup>	0.12 ± 0.30 <sup>a</sup>	11.6 ± 14.9 <sup>b</sup>	0.21 ± 0.50 <sup>a</sup>	BDL
Phenanthrene	3.38 ± 5.28 <sup>a</sup>	0.52 ± 1.28 <sup>a</sup>	BDL	7.48 ± 18.3 <sup>a</sup>	1.02 ± 2.50 <sup>a</sup>	BDL
Anthracene	3.92 ± 2.64 <sup>a</sup>	1.42 ± 1.45 <sup>a</sup>	3.16 ± 2.14 <sup>a</sup>	13.6 ± 13.5 <sup>b</sup>	1.86 ± 2.21 <sup>a</sup>	1.48 ± 3.61 <sup>a</sup>
Fluoranthene	6.93 ± 10.7 <sup>b</sup>	1.67 ± 2.28 <sup>ab</sup>	0.16 ± 0.40 <sup>a</sup>	4.85 ± 4.57 <sup>ab</sup>	1.24 ± 1.19 <sup>ab</sup>	0.55 ± 0.87 <sup>a</sup>
Pyrene	39.9 ± 45.9 <sup>ab</sup>	30.1 ± 20.0 <sup>ab</sup>	17.4 ± 11.0 <sup>a</sup>	51.5 ± 32.3 <sup>b</sup>	14.0 ± 12.4 <sup>a</sup>	8.26 ± 13.7 <sup>a</sup>
Chrysene	6.82 ± 9.58 <sup>ab</sup>	3.70 ± 2.80 <sup>ab</sup>	2.60 ± 1.76 <sup>ab</sup>	10.2 ± 7.78 <sup>b</sup>	5.20 ± 6.57 <sup>ab</sup>	1.65 ± 2.87 <sup>a</sup>
B(a)A	25.3 ± 39.4 <sup>a</sup>	12.7 ± 9.98 <sup>a</sup>	3.80 ± 2.22 <sup>a</sup>	30.6 ± 41.7 <sup>a</sup>	6.04 ± 6.64 <sup>a</sup>	8.40 ± 10.7 <sup>a</sup>
B(b)F	9.17 ± 14.1 <sup>a</sup>	19.3 ± 19.4 <sup>a</sup>	22.6 ± 15.9 <sup>a</sup>	22.3 ± 25.3 <sup>a</sup>	2.15 ± 2.67 <sup>a</sup>	15.9 ± 23.2 <sup>a</sup>
B(k)F	35.1 ± 31.0 <sup>ab</sup>	21.6 ± 19.5 <sup>ab</sup>	16.5 ± 20.6 <sup>ab</sup>	49.5 ± 51.8 <sup>b</sup>	29.7 ± 30.7 <sup>ab</sup>	6.95 ± 5.16 <sup>a</sup>
B(a)P	71.9 ± 69.7 <sup>b</sup>	41.5 ± 18.6 <sup>ab</sup>	19.4 ± 14.5 <sup>a</sup>	24.2 ± 15.5 <sup>a</sup>	19.4 ± 14.6 <sup>a</sup>	17.5 ± 23.4 <sup>a</sup>
I(1,2,3-cd)P	57.6 ± 34.6 <sup>ab</sup>	63.3 ± 33.7 <sup>ab</sup>	55.5 ± 34.5 <sup>ab</sup>	97.2 ± 87.3 <sup>b</sup>	55.7 ± 57.4 <sup>ab</sup>	28.3 ± 38.5 <sup>a</sup>
D(a,h)A	12.0 ± 21.6 <sup>a</sup>	1.03 ± 2.53 <sup>a</sup>	BDL	3.78 ± 6.32 <sup>a</sup>	1.62 ± 3.96 <sup>a</sup>	BDL
B(g,h,i)P	93.7 ± 76.7 <sup>a</sup>	87.6 ± 21.5 <sup>a</sup>	71.6 ± 44.8 <sup>a</sup>	107 ± 128 <sup>a</sup>	62.2 ± 69.8 <sup>a</sup>	34.8 ± 39.9 <sup>a</sup>
Σ 16 PAHs	375 ± 380	287 ± 160	214 ± 152	435 ± 449	201 ± 213	124 ± 162
Σ LMW PAHs	95.1 ± 133	53.1 ± 45.2	28.7 ± 21.3	131 ± 135	30.8 ± 33.9	20.3 ± 31.8
Σ HMW PAH	279 ± 247	234 ± 115	243 ± 131	304 ± 314	170 ± 179	104 ± 130

Mean with different letter of the alphabet for each column are significantly different ( $P < 0.05$ ) from each other  
 Σ 16 PAHs sum of 16 EPA priority PAHs, Σ LMW PAHs sum of low molecular weight, Σ HMWPAHs sum of high molecular weight, BDL below detection limit

**Fig. 3** Seasonal variation of PAHs in roadside soil of Ibadan metropolis

time (Fig. 3). This result revealed that about two-third of the PAHs compounds examined were above 50% in the wet season. PAHs are lipophilic. The variance in PAHs levels in soil during these two seasons might be attributed to the features of discrete locations, vehicular, population density, prevalent activities, and metrological conditions during the period. Pollutants such as PAHs in runoff and their

**Table 5** Diagnostic ratio of PAHs in Ibadan metropolis

Location	Ant/(Ant + Phen)	Flt/(Flt + Pyr)	B(a)A/B(a)A + Chr	Phen/Ant
Iwo road	1.00	0.06	0.67	0.00
Ojoo road	0.84	0.09	0.80	0.18
Benue road UI	1.00	0.07	0.77	0.00
Mokola road	0.23	0.04	0.81	3.34
Lag-Ibd Express	0.86	0.09	0.63	0.16
Seven up road	0.52	0.17	0.77	0.91

Anthracene (Ant), Phenanthrene (Phen), Fluoranthene (Flt), Benzo(a) Pyrene (B(a)A), Chrysene (Chr)

binding capability always lead to build-up of pollutants in the soil. This could be the attributive factor of higher concentration of PAHs isomers in wet season than dry season. Three of the lower molecular weight PAHs (naphthalene, acenaphthylene and acenaphthene) were predominant in the wet season. Adeyi and Oyeleke (2017) reported that lower molecular weight PAHs have significant acute toxicity to aquatic organisms while higher molecular weight do not but are carcinogenic.



## Diagnostic nature of PAHs in roadside soil

PAHs in soil can be either from pyrogenic source or petrogenic source. Whichever source the PAHs are coming from can be differentiated by the use of diagnostic indices or ratios. The values of the diagnostic ratio obtained in this study is shown in Table 5.

The ratio of Ant/(Ant + Phen) in all locations were greater than 0.1 and ranged from 0.23 at Mokola to 1.00 at UI and Iwo roads, respectively. All the locations indicated pyrogenic source since their values were greater than 0.1. The Flt/(Flt + Pyr) ratio ranged from 0.04 at Mokola to 0.17 at Seven up (Oluyole Estate). The ratio of all the locations were greater than 0.4 thereby indicating that the PAHs in all the locations were from pyrogenic source. B(a)A/B(a)A + Chr ratio of all locations ranged from 0.67 at Iwo to 0.81 at Mokola roads, respectively. All the locations indicated pyrogenic source since B(a)A/B(a)A + Chr ratio for all the locations were greater than 0.35. Phen/Ant in all the locations were less than 10 and ranged from 0.00 at Iwo road to 3.34 at Mokola road, respectively. All the locations indicated pyrogenic source since their values were less than 10. The four source diagnostic indices calculated for the six locations showed that the source of PAHs in the soil of all the selected locations are from pyrogenic source.

Low Molecular Weight (LMW) PAHs such as naphthalene, acenaphthalene, fluorene, phenanthrene and anthracene are known as the general markers of petrogenic origin of PAHs contamination in soils. High Molecular Weight (HMW) such as pyrene, benzo(a)anthracene, fluoranthene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene are known as typical markers of pyrogenic origin of PAHs concentration (Zakaria et al. 2002; Vinas et al. 2009). Barran-Berdon et al. (2012) reported about Mexico soil that PAHs in the locations are from both pyrogenic and petrogenic source just like this present study.

## Pearson correlation coefficient (*r*) of individual PAHs in Ibadan roadside soil

The result of the two-tailed Pearson Correlation matrix of PAHs that were analyzed are shown in Table 6. A perfect positive correlation is indicated between anthracene with B(k)F ( $r = 0.98$ ). There is mostly a high degree of positive correlation between the PAHs, namely, D(a,h)A with I(1,2,3-cd)P (0.93) and B(g,h,i)P with B(k)F (0.91) at  $p = 0.05$  level of correlation significance. Likewise, there is a sufficient high correlation and it is observed between acenaphthylene with fluoranthene (0.90), phenanthrene

(0.85), pyrene (0.85) acenaphthene with phenanthrene (0.83), B(a)P (0.82), anthracene with I(1,2,3-cd)P (0.83) and B(g,h,i)P 0.90, fluoranthene with D(a,h)A (0.85) and B(k)F with I(1,2,3-cd) (0.88) at  $p = 0.05$ . The rest do not have correlation but have negative correlation instead. There is negative correlation between I(1,2,3-cd)P with B(a)A (-0.88) at  $p = 0.01$ . The above associations can be elucidated in terms of a common source or they have chemical similarities (Adamu et al. 2017). Hence, the positive correlations found between PAHs indicates that they have common source.

## Health risk assessment

Toxic equivalence factor is commonly used in evaluating occupational and environmental health risk connected to exposure to aerial mixture of PAHs. The toxic equivalence factor of the selected locations in Ibadan metropolis is presented in Table 7. The toxic equivalence concentration of Indeno(1,2,3-c,d)P (358) happens to be the highest of all the seven carcinogenic. The toxic equivalence concentration of PAHs in all the locations are Benzo(a)anthracene (86.8); Benzo(a)pyrene (194); Benzo(b)fluoranthene (114); Benzo(k)fluoranthene (159); Chrysene (30.2) and Dibenz(a)anthracene (18.4). All the seven carcinogenic PAHs are highly predominant in Seven up (Oluyole Estate) than any other location hence having the highest TEQ value (62.5 mg/kg). This may be attributed to industrial activities that are being carried out at 7up that gives room for the introduction of PAHs into the environment. Mokola, Iwo, Ojoo are locations characterized by heavy traffic, this explains why this location had high toxic equivalence. High TEQ values (283.6) were also reported from Holy Shrine in Iran which happens to have heavy traffic volume reported by (Najmeddin et al. 2018). It can be inferred that the presence of PAHs in this environment can be attributed to many sources. It can be as a result of incomplete combustion, burning of bushes, leaching from locations highly concentrated especially in the wet season.

Figure 4 shows the concentration of carcinogenic PAHs at each of the selected locations in Ibadan metropolis. The concentration of carcinogenic PAHs at locations were: Iwo road (214 mg/kg); Ojoo (200 mg/kg); Benue road, UI (306 mg/kg); Lagos–Ibadan express (250 mg/kg) and the lowest concentration of carcinogenic PAHs was recorded at Seven up Oluyole Estate) (196 mg/kg). The total concentration of carcinogenic PAHs in the roadside soil was 1894 mg/kg. This presented 81.1% of the total PAHs concentration detected in Ibadan roadside soil. The highest concentration of carcinogenic PAHs (728 mg/kg) was recorded in soil at Mokola attributed with high traffic density.

**Table 6** Pearson correlation coefficient of individual PAHs in Ibadan roadside soil

	Naph	Acethyl	Aceth	Fluo	Phenan	Anthrac	Fluoran	Pyrene	Chrysene	B(a)A	B(b)F	B(k)F	B(a)P	I(123 cd)P	D(ah)A	B(ghi)P
Naph	1.00	0.36	0.08	0.23	0.23	0.51	-0.44	0.09	-0.61	-0.40	-0.26	0.62	0.19	0.61	-0.36	0.79
Acethyl		1.00	0.49	0.90 <sup>a</sup>	0.85 <sup>a</sup>	0.05	-0.42	0.85 <sup>a</sup>	0.21	0.38	0.58	0.01	0.02	0.03	-0.04	0.14
Aceth			1.00	0.38	0.83 <sup>a</sup>	-0.64	0.36	0.73	0.10	0.81	0.46	-0.62	0.82 <sup>a</sup>	-0.71	0.77	-0.35
Fluo				1.00	0.80	-0.04	-0.37	0.88	0.19	0.42	0.51	-0.12	-0.16	0.12	-0.10	0.06
Phenan					1.00	-0.43	-0.14	0.91 <sup>a</sup>	0.07	0.65	0.68	-0.44	0.42	-0.37	0.34	-0.21
Anthra						1.00	-0.37	-0.29	0.00	-0.64	-0.58	0.98 <sup>b</sup>	-0.52	0.83 <sup>a</sup>	-0.66	0.90 <sup>a</sup>
Fluoran							1.00	0.04	0.42	0.59	-0.37	-0.42	0.52	-0.74	0.85 <sup>a</sup>	-0.28
Pyrene								1.00	0.38	0.77	0.51	-0.37	0.23	-0.40	0.38	-0.12
Chrysene									1.00	0.58	0.13	-0.18	-0.19	-0.44	0.38	-0.23
B(a)A										1.00	0.40	-0.74	0.49	-0.88 <sup>a</sup>	0.84 <sup>a</sup>	-0.53
B(b)F											1.00	-0.58	0.06	-0.34	0.10	-0.65
B(k)F												1.00	-0.43	0.88 <sup>a</sup>	-0.69	0.92 <sup>b</sup>
B(a)P													1.00	-0.60	0.78	-0.19
I(123cd)P														1.00	0.93 <sup>b</sup>	0.75
D(ah)A															1.00	-0.49
B(ghi)P																1.00

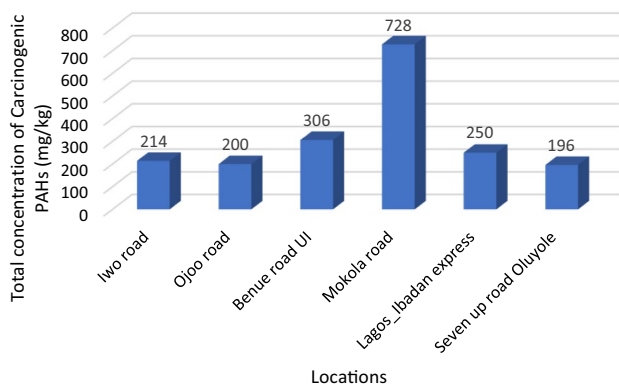
<sup>a</sup>Correlation is significant at the 0.05 level (2-tailed)

<sup>b</sup>Correlation is significant at the 0.01 level (2-tailed)

**Table 7** Carcinogenic potency of PAHs in roadside soil in Ibadan metropolis

PAHs	TEF	Iwo	Ojoo	UI	Mokola	Express	Seven up	Level of carcinogenic PAHs (mg/kg)
B(a)P	1.00	29.2	26.0	32.8	38.0	22.1	46.0	<b>194</b>
B(a)A	0.10	0.95	1.30	0.61	2.04	1.65	2.13	<b>86.8</b>
B(k)F	0.10	2.67	1.68	5.15	1.66	3.59	1.20	<b>159</b>
B(b)F	0.10	1.50	1.55	0.91	2.38	1.44	1.37	<b>114</b>
Chry	0.01	0.05	0.03	0.02	0.05	0.10	0.06	<b>30.2</b>
D(a,h)A	1.00	1.18	1.62	0.00	4.11	2.30	9.22	<b>18.4</b>
I(c,d)P	0.10	6.56	6.02	9.24	5.09	6.35	2.49	<b>358</b>
TEQ (mg/kg)		<b>42.0</b>	<b>38.2</b>	<b>48.8</b>	<b>53.3</b>	<b>37.5</b>	<b>62.5</b>	<b>960</b>

TEQ toxic equivalence, TEF toxic equivalent factor, ΣCPAHs ΣCPAHs sum of carcinogenic PAHs



**Fig. 4** Concentration of carcinogenic PAHs at each of the selected locations in Ibadan metropolis

**Cancer risk assessment**

Notably, an excess life time cancer risk of  $\geq 10^{-6}$  has been considered as insignificant and  $\geq 10^{-4}$  as significant (Man et al. 2013). Canadian soil guidelines for the protection of environmental and human health considers a cancer risk of  $\geq 10^{-5}$  at a site that is contaminated as insignificant (CCME 2010). However, majority of regulating bodies cite an Incremental Lifetime Cancer Risk (ILCR) between  $10^{-6}$  and  $10^{-4}$  for potential risk (Xia et al. 2010). Table 8 presents the cancer risk estimation of PAHs for adults and children. The cancer risk calculated for Iwo road for children was  $8.37 \times 10^{-7}$  while that of adult is  $7.8 \times 10^{-6}$ . These values lies within the standard established by USEPA (2009). This implies that if both adult and children that resides in Iwo

road are exposed to PAHs for the next 30 years, they are not likely to be threatened with cancer but there is probability of having cancer after being exposed for a longer period of time.

At Ojoo, the calculated cancer risk for children was  $7.81 \times 10^{-6}$  while that of adult was  $7.6 \times 10^{-7}$ . These two values were below the risk level of  $10^{-6}$  as established by the US Environmental Protection Agency (2009). Similarly, at Benue road UI, Mokola and Lagos-Express, the values obtained for their cancer risk were below the risk level of  $10^{-6}$  that has been established by USEPA, hence, might not pose health risk for about 30 years, but might pose health challenge after a longer time. However, considering Seven up (Oluyole Estate) location, the calculated cancer risk for children was  $1.16 \times 10^{-5}$  which falls within the range that can be cancerous over a period of time. This implies that when children are being exposed to PAHs for the speculated period of time they are likely to have cancer but it is not so for adults because the calculated cancer risk falls below the level that can cause cancer. The result of this study was similar to the human cancer risk resulted from PAHs exposure in urban soils of Beijing, China (Peng et al. 2011), and also urban surface dust of Guangzhou, China (Wang et al. 2011).

**Conclusion**

Road side soil are prone to contamination owing to deposition of particulate matters emitted by vehicles most especially where petroleum and related products are being used and sold. The degree of contamination and health risk posed

**Table 8** Cancer risk estimation for the selected locations

Population group	Estimated cancer risk for soil sample					
	Iwo	Ojoo	UI	Mokola	Lag-Ibd exp	Seven up
Children	$7.81 \times 10^{-6}$	$7.09 \times 10^{-6}$	$9.06 \times 10^{-6}$	$9.9 \times 10^{-6}$	$6.96 \times 10^{-6}$	$1.16 \times 10^{-5}$
Adult	$8.37 \times 10^{-7}$	$7.6 \times 10^{-7}$	$9.71 \times 10^{-7}$	$1.06 \times 10^{-6}$	$7.46 \times 10^{-7}$	$1.24 \times 10^{-6}$

by trace PAHs in some selected roads within Ibadan. The study established the impact of heavy traffic volume and industrial activities on the soil quality and human health within Ibadan metropolis. It can be suggested from this study that Ibadan roadside soil is contaminated with PAHs. The PAHs ranged from 0.54 mg/kg to 1156 mg/kg. The PAHs were more predominant in roads with heavy traffic density. The total concentration of the 16 PAHs ranged from 232 mg/kg to 990 mg/kg. The distribution of PAHs ring size is in the order 6 ring > 5 ring > 4 ring > 3 ring > 2 ring. Among the PAHs compounds, Benzo(g,h,i)perylene was predominant. The Carcinogenic fraction of PAHs represent 81.1% of the total PAHs. The total concentration of carcinogenic PAHs ranged from 196 mg/kg to 728 mg/kg. Benzo(a)pyrene was found in all the locations ranging from 26.0 to 46.0 mg/kg. The highest concentration of  $\Sigma$  16 PAHs was recorded in November. The monthly increasing order of  $\Sigma$  16 PAHs is November > June > July > August > December > January. LMW PAHs were more abundant in dry season than wet season while HMW PAHs were more abundant in wet season than dry season. The Source Diagnostic ratios analysis indicated that the PAHs resulted majorly from pyrogenic sources which includes emissions from vehicles and industrial wastes. Roadside soil can act as vital non-point sources of air and water pollution. Consequently, inhabitants within the vicinity with industrial situation and heavy traffic density may be threatened with health risk owing to the accumulation of carcinogenic PAHs in roadside soil. It is, therefore, recommended that effective management system of the soil should be employed by the government and standard bodies.

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**Data availability** The data used to support the findings of this study are included within the article.

## Declarations

**Conflict of interest** The authors declare no conflicts of interest.

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