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Quantification and cancer risk evaluation of polycyclic aromatic hydrocarbons in soils around selected telecom masts in Delta state, Nigeria

Onoriode Onos EMOYAN

Environmental Chemistry and Waste Management Research Group, Department of Chemistry Delta State University, P.M.B.1 Abraka, Nigeria

THE objectives of this study is to provide empirical data on the concentrations, sources and human cancer risk through non dietary ingestion dermal contact and inhalations of sixteen polycyclic aromatic hydrocarbons (16-PAHs) in soils within the vicinity of telecom masts. Quantification of PAHs was by gas chromatograph with flame ionization detector. Across all sites, 16-PAHs were detected with individual mean PAH concentration range of 0,010 (Nap, Phe, Ant, Chr and I[123-cd]P) at site 9 (control) to 1.485 mg/kg (D[ah]A) at site 4. Also, the mean Σ^{16}PAHs was highest in site 2 (10.622 mg/kg) and lowest at site 9 (0.236 mg/kg). The percentage occurrence of LPAHs and HPAHs are in range of 18.68 to 48.41% and 51.58 to 81.32% respectively. The source identification ratios show high and low temperature combustion processes as sources of PAHs. This could be from crankcase oils used in internal combustion engine and spilled diesel and oil from generator in these sites. The ILCR values through the non-dietary exposure routes are in the order of ingestion > dermal > inhalation. Analyses of variance also show significant variation ($p < 0.05$) in PAHs concentrations in respect to sites. The study found out that the cancer risk value for children was greater than adult value, and the total cancer risk values were higher than permissible limits, indicating potential for acute and chronic human cancer risk. The data generated in this study could serve as baseline reference for sitting and management of telecom masts.

Keywords: Soil PAHs, telecom mast, diesel generator, cancer risk assessment.

Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a cluster of toxic hydrophobic organic compounds with two or more benzenoid rings that are released mainly through anthropogenic and natural means, and are ubiquitously present in all environmental matrixes [1-3]. The natural sources includes emissions from coal tar, forest fires, natural gas and crude petroleum, and volcanic eruptions, while the anthropogenic sources are through emissions from man-made combustion processes, accidental releases and leakages of petroleum/fractions, production of chemical intermediates, industrial and domestic sewage sludge, agricultural and municipal runoff [4-6]. Upon PAHs deposition in the environment, their concentration and structure may alter due to abiotic and biotic processes, and because of sorption properties, soil may accumulate significant concentrations [7]. Due to PAHs ubiquitous, carcinogenic and mutagenic behavior, direct and diffuse sources, the United States Environmental Protection Agency (US-EPA) listed 16-PAHs as priority pollutants [4]. The two and three rings PAHs are known as low molecular weight PAHs (LPAHs) and those with four or more rings are known as high molecular weight PAHs (HPAHs). PAHs containing 4-6-rings are recalcitrant and more toxic than LPAHs in all environmental compartments, hence dangerous even at trace concentrations [8-12]. The number and arrangement of the rings and

the nature of the atoms in the molecule influence the physicochemical properties of PAHs, environmental fate, human and environmental health effects [15].

Soil pollution with variable PAHs from direct or diffuse sources could occur through industrialization, urbanization and modern agricultural practice [16]. This could destroy the general soil ecosystem function and ground water aquifer, leading to environment and human health effects [2,17]. In Nigeria, depending on the mast capacity and function, diesel engine generator between 15-50kVA of different brands are used to provide alternate electric energy to power equipments in telecom masts. Also, due to life-span, usage and wear and tear, these generators could spill diesel, oil and emit gaseous particles containing pollutants. The chronic nature of petroleum related pollutants and its associated environment and social health may have cumulative and deleterious effects on human health. Therefore, monitoring the levels and evaluating PAHs exposure risk in soil are essential in contemporary environmental studies. To date, several studies have documented the concentrations and human exposure risk of PAHs in different land use soils [18-28]. However, this is the first reported study on the concentrations and cancer risk assessment of PAHs in the vicinity of selected telecom masts soil. Understanding the spatial occurrence and sources of PAHs in soils within telecom masts would help to identify pollution index from diesel engine generator, and potential occupational exposure risk. Therefore, the objectives of this study were to determine the: (1) spatial concentrations of 16-PAHs in the vicinity of selected telecom masts, (2) to identify their origin and (3) evaluate human exposure cancer risk through non dietary ingestion dermal contact and inhalations. This study was conducted as a preliminary survey on PAHs occurrence and possible cancer risk in soils in the vicinity of telecom masts. This would assist engineers in planning and development of appropriate management operations for telecom masts, and help to protect the soil from long-term PAHs accumulation.

Materials and Methods

Study area sampling.

The study sites are telecom masts located in Delta State situated in the Niger Delta, Nigeria as presented in Figure 1. The telecom masts are located within residential and commercial areas. Using standard quality control technique, a composite sample was derived from quadruplet soil samples collected in eight experimental sites and a control site at 0-30 cm. The collected samples were stored below 4 ^{0}C in the dark before extraction and analysis.
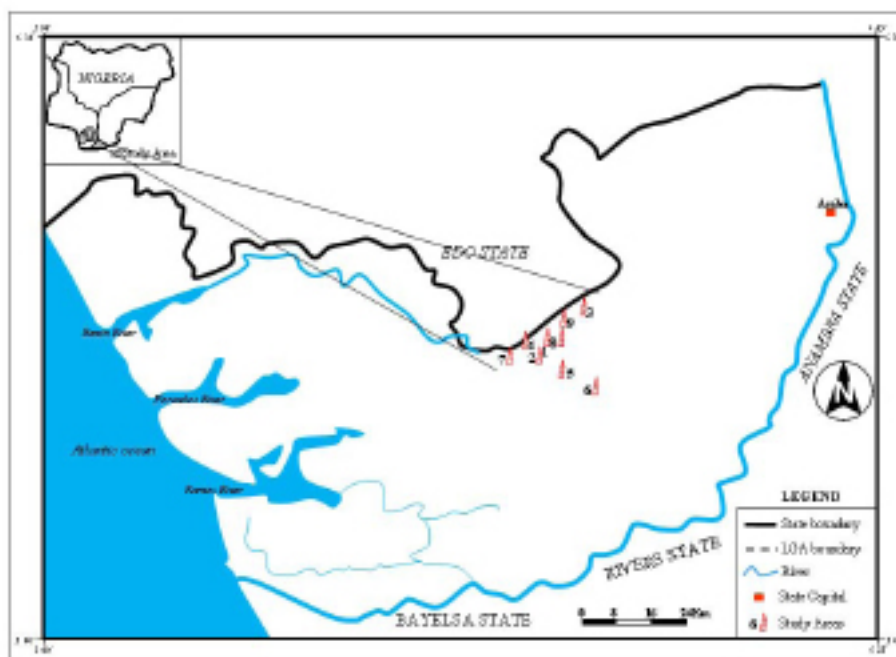

Fig. 1. Map of Delta State showing sample sites.

Sample extraction and PAHs analysis

Sample extraction and analysis for PAHs concentration was carried out according to the published method of US_EPA; Tesi, et. al., [29,30]. The [16]PAHs determined are naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), fluorine (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Flt), pyrene (Pyr), chrysene (Chr), benzo (a) anthracene (B[a]a), benzo (b) fluoranthene (B[b]F), benzo (k) fluoranthene (B[k]F), benzo (a) pyrene (B[a]P), dibenzo (ah) anthracene (D[ah]A), indeno (123-cd) perylene (I[123-cd]P) and benzo (ghi) perylene (B[ghi]P). The extraction of PAHs from the samples was carried out in a soxhlet extraction apparatus with 100 mL methylene – Chloride, using the US EPA-3550C-Ultrasonic extraction method. A mass of 10 g of the soil sample was mixed with the same quantity of Na_2SO_4. The mixture was extracted by ultrasonication with 50 mL of n-hexane/dichloromethane (1:1 v/v) for 30 min at 30 °C. This process was repeated three times, the extracts were filtered. The extract were allowed to settle and filtered through a Whatman 41 filter paper. The filtrate was concentrated to 1 mL using a rotary evaporator and purified by solid phase extraction with silica gel and alumina. PAHs were thereafter eluted using 15 mL hexane and dichloromethane (1:1). The eluted fraction was evaporated to 0.5 mL using nitrogen gas. Using te PAHs modified method 8015B.The resulting extracts were analyzed for PAHs using HP 5870C gas chromatograph (HP 5870C Palo Alto, C A, USA) fitted with a flame ionization detector (FID). Helium was used as a carrier gas with a linear velocity of 30 cm/s. Separation was carried out using HP5 (cross-linked PHME siloxane) column with dimensions of 0.25 μm × 30 m and 0.25 μm film thickness. The initial column temperature was increased from 100 °C to 310 °C at 4 °C/min as final temperature. The injector temperature and injection volume were 250 °C and 2.0 μL in the split-less mode respectively. The determination of PAHs was carried out by external calibration obtained with PAH.

Source Identification

Isomer pair ratio is a diagnostic marker of specific PAHs used as source label of PAHs [31-41]. Also, to confirm the source signature, the total index (a normalized limit value for low and high temperature source) derived from the sum of single index was applied [42,43].

Human Health-Risk Assessment from PAHs Exposure

Human exposure risk from PAHs was evaluated by applying the UCL 95% concentration of the PAHs. In order to quantify and compare the human health risks from exposure to PAHs contamination in this study, incremental Life Cancer Risk (ILCR), BaP mutagenic equivalent factor (BaP_{MEF}), B[a]P toxic equivalent factor [BaP_{TEF}], and non-cancer risk-Hazard index (HI) were calculated. The variables in equations 1-11 are as defined in US-EPA, 2009; Emoyan, et. al and Iwegbue, et al [44-46]. The toxicological variables for the estimation of human health risk arising from exposure from observed PAHs are in accordance with the recommended limits [24,30,47]. The ILCR value $\leq 10^{-6}$ is suggestive of very low risk; 10^{-6} to 10^{-4} show low risk; $>10^{-4}$ to 10^{-3} indicative of moderate risk; $>10^{-3}$ to 10^{-1} indicative of high risk and $\geq 10^{-1}$ show very high risk. The value 10^{-6} is considered carcinogenic target risk.

Incremental Lifetime Cancer Risk (ILCR) Evaluation from PAHs

Assessment of the ILCR and total cancer risk arising from ingestion, inhalation and dermal contact were evaluated using equations 2-5

$$\text{ILCR}_{in} \quad \frac{Csoil \times IngR \times EF \times ED \times CF \times SFO}{BW \times AT} \quad (1)$$

$$\text{ILCR}_{inh} = \frac{Csoil \times EF \times ED \times IUR}{PEF \times AT*} \quad (2)$$

$$\text{ILCR}_{derm} = \frac{Csoil \times SA \times AF \times ABS \times EF \times ED \times CF \times SFO \times GIABS}{BW \times AT} \quad (3)$$

$$\text{Total Cancer Risk} = \text{ILCR}_{Ing} + \text{ILCR}_{Inh} + \text{ILCR}_{Derm} \quad (4)$$

Where: ILCR_{ing}, ILCR_{inh} and ILCR_{derm} are the incremental lifetime cancer risk through ingestion, inhalation and dermal contact respectively; CF is conversion factor 1×10^{-6}.

Assessment of average daily exposure and hazard indices of PAHs

The average daily exposures for the three pathways were calculated as the chronic daily intake using equations 5-7 while the hazard quotient (HQ) and hazard index (HI) in terms of ingestion, inhalation and dermal contact were calculated from equations 5-9.

For non-cancer risk,

$$\text{CDI}_{ing\text{-}nc} = \frac{C \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (5)$$

$$\text{CDI}_{inh\text{-}nc} = \frac{C \times InhR \times EF \times ET \times ED}{PEF \times 24 \times AT_{nc}} \quad (6)$$

$$CDI_{dermal-nc} = \frac{C \times SA \times AF \times ABSd \times EF \times ED}{BW \times AT_{nc}} \times 10^{-6} \quad (7)$$

$$HQ = \frac{CDInc\,CDInc}{RfD\,RfD} \quad (8)$$

Hazard index (HI) = $\sum HQ = HQ_{ing} + HQ_{inh}$ HQ_{inh} + HQ$_{dermal}$ (9)

B[a]P Mutagenic Equivalent [BaP$_{MEQ}$]

The B[a]P mutagenic equivalent (BaP$_{MEQ}$) for the individual PAHs was evaluated using:

$$BaP_{MEQ} = \Sigma\, C_i \times BaP_{MEF} \quad (10)$$

Where: BaP$_{MEF}$ = mutagenic potency relative to BaP and C$_i$ = each PAH concentration.

B[a]P toxic equivalent [BaP$_{TEQ}$]

The B[a]P toxic equivalent [BaP$_{TEQ}$] for each PAH was computed using:

$$BaP_{TEQ} = \Sigma\, C_i \times BaP_{TEF} \quad (11)$$

Where: BaP$_{TEF}$ is the cancer potency relative to B[a]P and C$_i$ is the individual PAH concentration

Quality control and data analysis

Chemicals and solvents used were of chromatographic grade, and were procured from suppliers as follows: Alumina and silica gel (BDH Chemicals,Poole England), acetone (Rieldel-de, Haen, Seelze, Germany), anhydrous sodium sulphate (purity 99 %) dichloromethane (E-Merck, Mumbai, India) and n-hexane (Sigma-Aldrich, Darmstadt ,Germany). Deuterated PAHs were added as internal standards. Field duplicate sample collection precision, GC-FID system operation performance with regards to timing, temperature and calibration were checked. The laboratory methods, surrogate recoveries, duplicate analysis and descriptive statistics were performed using SPSS version 19.

Results and Discussion

Spatial concentration of PAHs in the sites

In this study, 16-PAHs were quantified in soil samples collected from the vicinity of nine telecom masts. Summary of descriptive statistics for concentrations of individual and sum of ^{16}PAHs (Σ^{16}PAHs) compounds are presented in Table 1. Across all sites, the mean concentration of individual PAH compound are in range of 0,010 (Nap, Phe, Ant, Chr and I[123-cd]P) at site 9 (control) to 1.485 mg/kg (D[ah]A) at site 4. Generally, the mean concentration of individual PAH show that Nap, Phe, Ant, Chr and I[123-cd]P are in range of 0.010 (site 9) to 0.805 (site 2),

0.868 (site 2), 1.232 (site 7), 0.583 (site 5) and 0.554 mg/kg (site 6) respectively. Also Acy, Flt, B[b]F and D[ah]A mean concentrations are in range of 0.018 (site 9) to 0.921 (site 4), 0.939 (site 2), 0.853 (site 5) and 1.485 mg/kg (site 4) respectively. The mean concentrations of Ace, Pyr, B[k]F and B[ghi]P are in range of 0.012 (site 9) to 1.045 (site 2), 0.730 (site 8), 0.447 (site 4) and 0.634 mgkg (site 8) respectively. While Flu, B[a]A and B[a]p mean concentrations range from 0.024 (site 9) to 0.364 (site 2), 0.552 (site 5) and 1.232 mg/kg (site 1) respectively. As shown in Table 1 and Figure 2, individual and total mean ^{16}PAHs were highest in site 2 (10.622 mg/kg) and lowest at site 9 (0.236 mg/kg) in the following order: site 2 > 4 > 5 > 8 > 3 > 7 > 6 > 1 > 9. The observed high concentration of PAHs in site 1-8 relative to site 9 could be related to the pollution index associated with the operational age of the telecom masts. The concentration patterns of individual PAH in this study show a comparative abundance of carcinogenic PAHs at all sample sites. The concentrations of total mean 16-PAHs in this study are similar to reported studies in urban soils. For example, Iwegbue et. al., [24] reported Σ^{16}PAHs concentration range between 0.188 and 0.684 mg/kg in selected urban soils in Niger Delta Nigeria. Also, Kumar, et. al [19] reported Σ^{16}PAHs concentration range of 0.016 and 0.254 mg/kg in urban roadside soils of Kuruksheta India. Banger, et. al., [18] reported PAHs concentration range between 0.251 and 0.236 mg/kg in urban soil Miami, Florida United States of America. Furthermore, Skrbic, et. al., [26] reported PAHs concentrations in urban soil of Novi Sad Sebia, in range of 0.022 to 2.247 mg/kg.

In relation to difference in set objectives, derivation methods, and regulatory applications, developed soil regulatory guidelines and limits of PAHs for soil protection in different countries varied widely [48-51]. In this study, individual PAH and Σ^{16}PAHs results were compared with national and international regulatory guidelines for different land use since telecom masts are sited across all land use. As shown in Figure 2, it could be observed that Σ^{16}PAHs concentrations range of 5.365 to 10.622 mg/kg at all sites except site 9 (0.236 mg/kg) are above Sebian maximum allowed concentrations (MAC) of 1.00 mg/kg [26,52]. The implication is that, the functional properties of soil and sustainable soil quality are threatened at site 1-8, Also, Dutch government recommendation of National Maximum Values (NMV) for land use show that Σ^{16}PAHs concentration range at site 9 is suitable for all land

applications (1.5 mg/kg), site 1,3,5-8 are suitable for residential use (< 6.8 mg/kg), while site 2 and 4 falls within residential applications and suitable limits for industrial use (< 40 mg/kg) [26]. Individual PAH were also considered in comparison of results in this study with recommended guidelines. Results show that the BaP mean concentration range of 0.024- 1.232 mg/kg falls within the Germany 0.30 - 1.00 mg/kg class of soils having problems which needs urgent attention in order to avoid future challenges [51]. This study found that the mean Σ^{16}PAHs at all sites except the control site were greater than the target value of 1.00 mg/kg [53]. The background value of PAHs in a typical soil ranged between 0.001 and 0.010 mg/kg [54,55]. The concentrations of $\sum^{16}$PAHs obtained in this study were above the background value suggesting that the sites are contaminated with PAHs. Also, results show that individual and total mean PAHs are above the Canadian, Danish, US-EPA and Netherlands maximum permissible limits for residential, park and direct contact soil [4]. Ecotoxicological significance of PAHs levels in this study in comparison with recommended guidelines is that, harmful effects are likely in site 1-8. The occurrence profile of PAHs in this study was further describe using the compositional pattern based on the number of aromatic rings
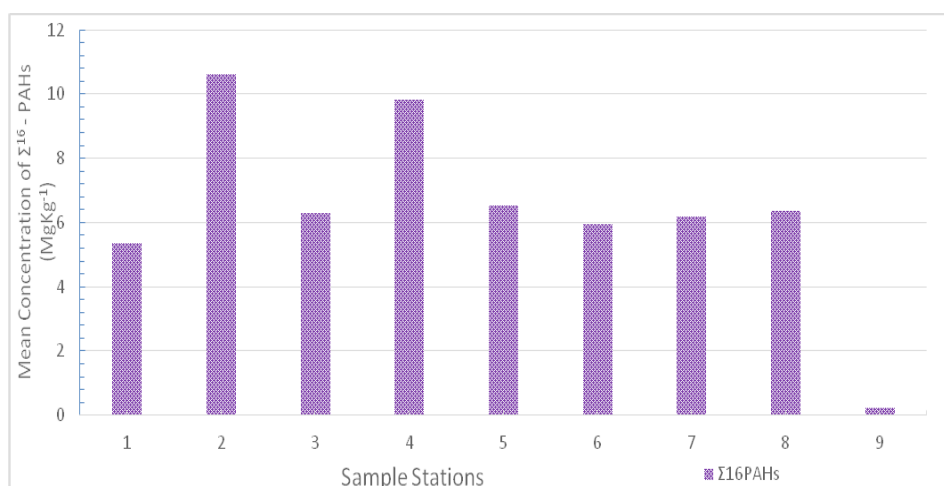

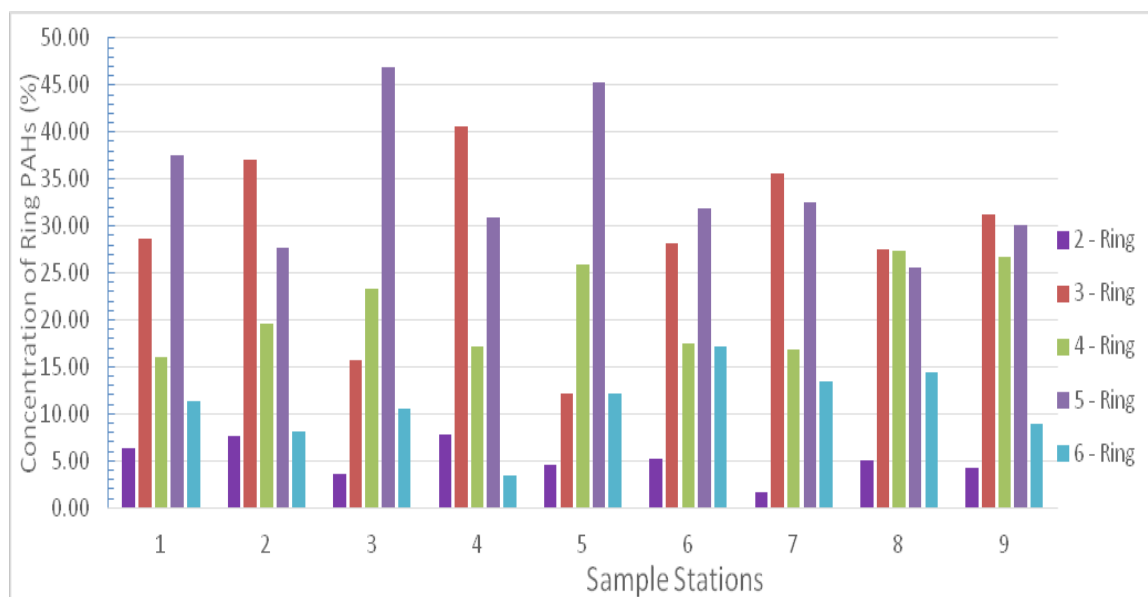Fig. 2. Mean concentration of Σ^{16} PAHs in this study.

Fig.3. Concentration of Ring PAHs in this study .

TABLE 1. Summary of descriptive statistics of PAHs spatial concentrations in this study (mean in mg/kg).

	Nap	Acy	Ace	Flu	Phe	Ant	Flt	Pyr	B[a]A	Chr	B[b]F	B[k]F	B[a]P	I[123cd}P	D[ah]A	B[ghi]p
Site 1																
Mean	0.340	0.411	0.196	0.166	0.273	0.494	0.237	0.104	0.279	0.245	0.255	0.193	1.232	0.265	0.331	0.346
CV%	18.2	121.8	112.3	182.5	75.4	94.2	82.3	39.6	96.1	120.5	86.6	155.9	99.8	101.8	77.6	113.2
Site 2																
Mean	0.805	0.811	1.045	0.364	0.868	0.840	0.939	0.233	0.436	0.473	0.035	0.378	1.152	0.339	1.374	0.531
CV%	82.5	68.3	83.0	146.9	71.1	70.3	105.2	114.8	144.2	120.7	56.3	47.6	120.5	180.2	122.8	97.2
Site 3																
Mean	0.227	0.309	0.123	0.049	0.177	0.330	0.100	0.304	0.522	0.536	0.718	0.323	0.804	0.436	1.102	0.227
CV%	62.4	183.0	101.5	89.9	86.5	167.8	142.2	187.1	143.9	171.7	190.9	172.9	59.6	132.5	63.5	100.4
Site 4																
Mean	0.764	0.921	0.999	0.356	0.774	0.945	0.914	0.055	0.362	0.363	0.025	0.447	1.089	0.034	1.485	0.297
CV%	92.0	65.4	92.5	152.3	89.1	58.7	111.2	95.6	184.6	164.1	53.1	107.3	125.0	48.8	103.1	116.8
Site 5																
Mean	0.298	0.107	0.184	0.191	0.144	0.164	0.202	0.355	0.552	0.583	0.853	0.163	1.141	0.452	0.795	0.336
CV%	5.5	85.9	124.1	152.9	84.4	129.6	100.7	151.3	131.4	153.3	152.6	192.3	82.7	124.3	85.6	117.0
Site 6																
Mean	0.309	0.503	0.181	0.033	0.400	0.555	0.161	0.231	0.325	0.322	0.130	0.284	0.958	0.554	0.527	0.470
CV%	56.7	99.6	73.9	53.4	62.5	97.5	90.4	117.0	73.3	100.4	96.7	97.3	106.4	95.5	162.2	103.5
Site 7																
Mean	0.104	0.279	0.245	0.255	0.193	1.232	0.265	0.331	0.346	0.104	0.279	0.245	0.255	0.314	1.232	0.512
CV%	39.6	96.1	120.5	86.6	155.9	99.8	101.8	77.6	113.2	39.6	96.1	120.5	86.6	71.4	99.8	84.5
Site 8																
Mean	0.325	0.139	0.167	0.169	0.273	1.006	0.371	0.730	0.287	0.355	0.127	0.248	0.211	0.284	1.036	0.634
CV%	77.3	75.0	89.1	147.2	105.0	108.0	158.6	101.8	134.5	77.2	88.4	113.0	109.6	96.7	101.4	104.4
Site 9																
Mean	0.010	0.018	0.012	0.024	0.010	0.010	0.018	0.012	0.024	0.010	0.018	0.012	0.024	0.010	0.018	0.012
CV%	42.5	77.0	15.1	86.0	42.5	42.5	77.0	15.1	86.0	42.5	77.0	15.1	86.0	42.5	77.0	15.1

in Σ^{16}PAHs as shown in Figure 3.

The percentage occurrence of 2-ring PAH (Nap) are in range of 1.68 to 7.78%, while the Σ^3-ring PAHs (Acy+Ace+Flu+Phe+Ant) are in range of 12.11 to 40.63%. The occurrence of Σ^4ring PAHs (Flt+Pyr+BaA+Chr) range from 16.12 to 27.41% while the Σ^5-ring PAHs (BbF+BkF+BaP+DahA) range from 25.50 to 46.88%. The Σ^6-ring PAHs (IndP+BghiP) range from 3.37 to 17.24%. The highest (46.88%) and lowest (1.68%) occurrence of ring PAHs were observed in site 3 and 7 respectively. Similarly across all sites, the percentage distributions of LPAHs and HPAHs are in range of 18.68 to 48.41% and 51.58 to 81.32% respectively, with average enrichment of 33.53% and 66.47% Figure 4. Analyses of variance also show that PAHs concentration varied significantly ($p < 0.05$) with reference site. This study revealed that LPAHs exhibit low coefficient of variation (CV) relative to high CV in HPAHs, Table 1. The high CV in HPAHs over HPAHs could be adduced to the heterogeneous nature and high adsorption of HPAHs onto fine soil matrix, hence the variability. In contrast to pedological soil, soils in the study sites could be regarded as disturbed soil (containing building concrete or cement rubble, underground pipes, tanks wires and contaminants) with high pH [56].

The significance of observed PAHs concentration is significant in that, soils in the sites could enhance high permeability rate of observed PAHs from top to sub soil and ultimately contaminate ground water resources in areas were telecom masts are sited near shallow ground water aquifer. Also, since PAHs are relatively easily degraded through abiotic and biotic pathways, and depending on favorable soil constituents and properties, observed PAHs could restrict options available for land reuse due to possible potential hazards (direct ingestion mainly children and animals, inhalation of dust particles and vapor, uptake by plants and subsequent consumption by animals and man, phytotoxicity, deterioration of building materials, fires and explosion and dermal contact) associated with PAHs contaminated soil [56]. Similarly, observed Σ^{16}PAHs concentrations and predominance of carcinogenic PAHs could accumulate and persist in soil, and subsequently bio-accumulate in living tissues through exposure(s) within the sites. However, enrichment of high concentration of carcino-

genic PAHs in this study is not sufficient proof for human health risk, hence the application of human health risk assessment criteria.

PAHs sources identification
  Isomer pair ratio

The composition of PAHs may have undergone transformation before and after deposition in soil [7]. Therefore, it is important to determine the potential sources of soil PAHs in order to minimize PAHs generation, associated harmful effects in terrestrial and aquatic ecosystem and determine if site remediation strategies are needed. Results of isomeric ratio used for source evaluation of PAHs in this study are shown in Table 2. Results show that BaA/(BaA+Chr) ratios are > 0.35, this indicates coal and biomass combustion sources which suggest petroleum origin. IndP/(IndP+BghiP) ratios are between range of 0.10 and 0.66, suggesting combustion of coal, wood and grass that indicate petroleum combustion source. The Ant/(Ant+Phe) ratios are > 0.1, suggesting combustion processes. Flt/(Flt+Pyr) ratio range between 0.25 and 0.80, suggesting mixed sources of liquid fossil fuel and petroleum combustion. The ΣLPAHs/ΣHPAHs ratios are < 1, this implies fossil fuel or wood combustion is the source of PAHs. The total index value is in range of 9.80 to 14.37 with average total index of 11.16, this suggests that PAHs contamination of these sites originated from high temperature combustion process. Though it may be difficult to ascertain the actual source of PAHs because environmental samples may contain PAHs from multiple anthropogenic and natural sources, there is high probability that anthropogenic PAHs may dominate in urban soil [26,28]. Therefore, the isomer pair ratios in this study show a combination of multiple sources derived from high-temperature condensation of LPAHs and combustion of solid and liquid fossil fuel with dominance of pyrolitic PAHs. Pyrolitic and petrogenic PAHs could co-exist and originate from crankcase and other lubricating oils used in diesel powered internal combustion engine [31]. The significance of computed isomer ratios in this study, suggest multiple sources of PAHs arising from gaseous emissions from low and high temperature combustion of petroleum products, wood, coal and biomass, waste incineration and oil and diesel spill from generators in telecom mast, Table 2.
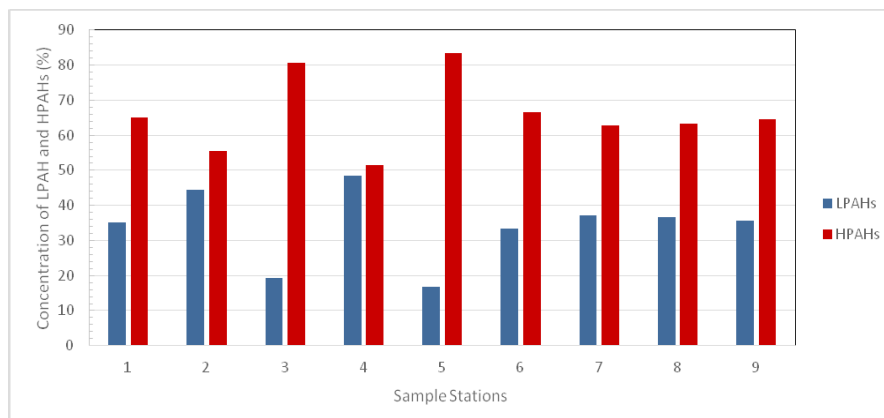
Fig. 4. Concentration of LPAH and HPAHs in this study.

TABLE 2. Diagnostic ratios of PAHs in soils around telecom masts in this study.

	1	2	3	4	5	6	7	8	9
BaA/(BaA+Chr)	0.53	0.48	0.49	0.50	0.49	0.50	0.77	0.45	0.71
IndP/(IndP+BghiP)	0.43	0.39	0.66	0.10	0.57	0.54	0.38	0.31	0.45
Ant/(Ant+Phe)	0.64	0.49	0.65	0.55	0.53	0.58	0.86	0.79	0.50
Flt/(Flt+Pyr)	0.70	0.80	0.25	0.94	0.36	0.41	0.45	0.34	0.61
LMW/HMW	0.54	0.80	0.24	0.94	0.20	0.50	0.59	0.49	0.53
COMB PAHs/Σ^{16}PAHs	0.59	0.43	0.63	0.36	0.71	0.58	0.43	0.51	0.58
BaP/BghiP	3.56	2.17	3.54	3.66	3.39	2.04	0.49	0.33	2.04
Total Index	11.71	10.10	10.91	10.56	9.80	10.44	14.37	11.56	10.99

Principal component analysis (PCA)

In this study, three PCA component factors were obtained as presented in Table 3. Factor 1 have high loading which comprises of Ace, Phe, Flt, Nap, Acy, Flu, B[k]f and D[ah]A, and low loading of B(a)A B(b)F, Chr and B(a)P, these accounted for 47.46% of the total variation. Factor 2 accounted for 70.04% of the entire variance with high loading of B(a)A, Chr B(b)F, I(123-cd)P and B(a)P. Factor 3 accounted for 87.60% and is characterized with high loading of B(ghi)P, Pyr and Ant. The congener components in Factors 1-3 are products of wood, coal and diesel combustion, and vehicular traffic emissions [19, 21, 32, 33]. Therefore, the PCA revealed that pyrogenic processes such as combustion of fossil fuel, gaseous emissions from vehicular exhaust and petrogenic processes are the sources of PAHs in the study area.

Pearson correlation coefficients (PCC)

The relationship among individual PAH congeners was evaluated using Pearson Correlation Coefficient (PCC). This is to determine the possible sources on the assumption that two or more PAHs congener may correlate due to atmospheric behavior and/or common origin, [4]. The correlation matrix of individual PAH congeners in this study are presented in Tables 4. Significant correlation (**P < 0.01, *P < 0.05) was obtained among the 16-PAHs compounds. The correlation matrix among PAHs were grouped as strong (0.91 – 0.99), moderate (0.71 – 0.90) and good (0.50 - 0.71). The selected correlations among Nap, Acy, Flu, Phe and Ant, Ace, Flt, Pyr, B(a)A, Chr, B(a)A, B(k)F, B(a)P, B(k)F, D(a)A, I(123cd)P and B(k)F and between LPAHs and HPAHs congeners suggest that PAHs originate in this study from a common source. The associated PAHs in the Pearson Correlation Coefficients are derived from high-temperature pyrolitic and petrogenic combustion of liquid and solid fossil fuels. However, pyrogenic and petrogenic PAHs could also co-exist in lubricating and crankcase oils used in diesel powered combustion engines. The mixed occurrence of PAHs sources in this study could be adduced to multiple depositions of gaseous particles containing PAHs from high and low temperature combustion of liquid fossil fuel, and petroleum product spills within telecom

masts in the study sites, [31, 32, 33].

PAHs Human health risk assessment procedure
  Incremental life cancer risk of PAHs

The ILCR through soil ingestion, inhalation, and dermal contact for an adult and infant in this study are presented in Table 5, the obtained ILCR values are in the range of 3.01×10^{-4} to 1.68×10^{-2}, 4.23×10^{-10} to 2.39×10^{-8} and 1.56×10^{-4} to 8.74×10^{-3} for adult and 4.36×10^{-3} to 2.44×10^{-1}, 3.84×10^{-10} to 2.17×10^{-8}, and 1.59×10^{-3} to 8.90×10^{-2} for infants. The observed ILCR concentration through the three exposure routes are in order of ingestion > dermal contact > inhalation. The total cancer risk values in all sites are in range 4.57×10^{-4} to 2.56×10^{-2} for adults and 5.95×10^{-3} to 3.34×10^{-1} for infant. The total cancer risk for an adult was less than that of children. This may be related to the high probability of dermal contact of infants with soil and dust particles [57]. According to the lifetime cancer risk based values classified by New York States Department of Health (YSDH), ($\geq 10^{-1}$ = very high, > 10^{-3} to 10^{-1} = high $\geq 10^{-4}$ to 10^{-3} = moderate, 10^{-6} to 10^{-4} = low and $\leq 10^{-6}$ = very low). The total cancer risk values obtained in this study falls within moderate to very high category

[58]. Similarly, the total cancer risk for infant and adult in the study sites are greater than the acceptable value of 1×10^{-6}, indicating that the study sites have potential for human carcinogenic risk indicated as acceptable target excess risk-based action values (1×10^{-6}) for exposure stipulated by US-EPA [59]. The obtained results shows that total cancer risk values were in agreement with those reported in contaminated soils from Hong Kong [60] metropolitan soils from China [61 flood plain and urban soils from Nigeria, [24,30,45].

The results of non-carcinogenic risk of PAHs evaluated using the hazard indexes in this study are presented in Table 6. The hazard quotients followed the order HQIng > HQDerm>HQlnh for both adult and child sceneries. The ingestion route is the main route of exposure of PAHs in these soils. The hazard index for adult ranged from 4.27×10^{-3} at site 9 to 2.19×10^{-1} at site 2, while the hazard index for infants range from 3.41×10^{-2} at site 9 to 1.74 at site 2. The hazard index values obtained at all the sites for both child and adult case were < 1, indicating that there is no non-carcinogenic risk associated with PAHs exposure

TABLE 3. PCA factor loadings after Varimax with Kaizer of PAHs in soils around Telecom masts.

	Component		
	1	**2**	**3**
Ace	.983	-.043	.015
Phe	.972	.005	.079
Flt	.962	-.083	.160
Nap	.956	.151	.018
Acy	.954	.018	-.072
Flu	.828	-.044	.279
B[k]F	.824	.281	.287
D[ah]A	.680	.252	.529
B[a]A	.301	.903	.207
Chr	.319	.887	.068
B[b]F	-.394	.831	-.067
I[123cd]p	-.200	.771	.298
B[a]P	.577	.619	-.343
B[ghi]P	.277	.162	.859
Pyr	-.257	.287	.853
Ant	.494	-.241	.779
% Variance	47.460	22.588	17.551
Cumulative %	47.460	70.047	87.598

TABLE 4. Pearson's correlation coefficients .

	Nap	Acy	Ace	Flu	Phe	Ant	Flt	Pyr	B[a]a	Chr	B[b]f	B[k]f	B[a]p	I[123cd]p	D[ah]a	B[ghi]p
Nap	1.000															
Acy	.887**	1.000														
Ace	.936**	.899**	1.000													
Flu	.768**	.665*	.860**	1.000												
Phe	.961**	.945**	.955**	.752**	1.000											
Ant	.390	.458*	.476*	.653*	.505*	1.000										
Flt	.940**	.848**	.979**	.895**	.944**	.571*	1.000									
Pyr	-.108	-.359	-.239	-.002	-.162	.381	-.082	1.000								
B[a]a	.382	.270	.275	.332	.273	.124	.248	.318	1.000							
Chr	.503*	.264	.296	.218	.337	-.088	.293	.341	.883**	1.000						
B[b]f	-.304	-.415	-.404	-.239	-.466	-.405	-.440	.254	.697*	.588*	1.000					
B[k]f	.796**	.854**	.762**	.611*	.825**	.613*	.757**	.077	.565*	.515*	-.128	1.000				
B[a]p	.659*	.623*	.488*	.361	.551*	-.089	.420	-.287	.615*	.652*	.253	.510*	1.000			
I[123cd]p	-.081	-.090	-.249	-.245	-.082	-.032	-.270	.442	.645*	.555*	.549*	.157	.352	1.000		
D[ah]a	.632*	.587*	.695*	.749**	.641*	.714**	.725**	.319	.626*	.481*	.034	.847**	.220	.079	1.000	
B[ghi]p	.345	.241	.254	.435*	.391	.763**	.375	.700*	.344	.255	-.138	.458*	.106	.473*	.514*	1.000

**Pearson correlation significant at 0.01 level of significant
*Pearson correlation significant at 0.05 level of significant

TABLE 5 . Incremental Life Cancer Risk of PAHs in soils around telecom masts in this study.

SITES	CHILD				ADULT			
	ILCRING $\times 10^{-1}$	ILCRINH $\times 10^{-8}$	ILCRDERM $\times 10^{-2}$	Total Cancer Risk $\times 10^{-1}$	ILCRING $\times 10^{-2}$	ILCRINH $\times 10^{-8}$	ILCRDERM $\times 10^{-3}$	Total Cancer Risk $\times 10^{-2}$
1	1.53	1.31	5.59	2.09	1.06	1.45	5.49	1.61
2	2.44	2.15	8.87	3.32	1.68	2.37	8.71	2.55
3	1.94	1.71	7.06	2.64	1.34	1.89	6.93	2.03
4	2.45	2.17	8.90	3.34	1.69	2.39	8.74	2.56
5	1.98	1.72	7.22	2.70	1.37	1.90	7.09	2.08
6	1.48	1.29	5.40	2.02	1.02	1.42	5.30	1.55
7	1.48	1.33	5.38	2.02	1.02	1.47	5.28	1.55
8	1.23	1.12	4.48	1.68	8.49×10^{-3}	1.23	4.40	1.29
9	4.36×10^{-3}	3.84×10^{-10}	1.59×10^{-3}	5.95×10^{-3}	3.01×10^{-4}	4.23×10^{-10}	1.56×10^{-4}	4.57×10^{-4}

Non-Carcinogenic risk of PAHs

TABLE 6. Non-carcinogenic risk of PAHs in soils around telecom mast in this study.

SITES	CHILD				ADULT			
	HQING $\times 10^{-1}$	HQINH $\times 10^{-4}$	HQDERM $\times 10^{-3}$	HI $\times 10^{-1}$	HQING $\times 10^{-2}$	HQINH $\times 10^{-4}$	HQDERM $\times 10^{-4}$	HI $\times 10^{-2}$
1	6.28	2.22	1.84	6.30	7.85	1.01	3.28	7.89
2	17.4×10^{-1}	5.28	5.13	17.4×10^{-1}	2.17×10^{-1}	2.45	9.13	2.19×10^{-1}
3	4.85	1.52	1.41	4.87	6.06	6.88×10^{-5}	2.51	6.09
4	16.1×10^{-1}	5.07	4.75	16.2×10^{-1}	2.02×10^{-1}	2.32	8.46	2.03×10^{-1}
5	5.82	1.83	1.67	5.84	7.28	8.92×10^{-5}	2.98	7.32
6	6.55	2.11	1.95	6.57	8.19	9.39×10^{-5}	3.48	8.23
7	5.99	9.04×10^{-5}	1.74	6.01	7.49	3.86×10^{-5}	3.09	7.52
8	8.87	2.11	2.56	8.89	1.11×10^{-1}	1.02	4.57	1.11×10^{-1}
9	3.40E-02	7.12×10^{-6}	9.79×10^{-5}	3.41×10^{-2}	4.25×10^{-3}	3.14×10^{-6}	1.74×10^{-5}	4.27×10^{-3}

in this study except site 2 and 4 for infants.

Bap-Toxic Equivalence and Bap Mutagenic Equivalence of PAHs

The BaP toxic equivalence (BaPTEQ) and BaP mutagenic equivalence (BaPMEQ) are presented in Tables 7. The BapTEQ values ranged between 47 and 2611 mg/kg, with significant contribution from BaP, BkF, BbF, BaA, IndP and DahA. The BaPMEQ obtained values ranged between 40 and 1749 mgkg^{-1}. Like BaPTEQ, Bap, BbF, BaA IndP and DahA also contributed significant proportion

to the BaPMEQ. The BaPTEQ and BaPMEQ obtained in this study were similar to values reported in other studies [24, 57]. The total cancer risk levels obtained from the three exposure routes are greater than the permissible value of 10^{-6} as the target excess cancer risk. This could promote human carcinogenic risk through occupational exposure by residence within the study area. The implication of observed total cancer risk is that, the derivable human health effects from PAHs mixtures could be acute or chronic.

TABLE 7. BaPTEQ and BaPMEQ of PAHs in soils around telecom masts in this study

SITE	BaA	Chr	BbF	BkF	BaP	IndP	DahA	BaPTEQ	BaA	Chr	BbF	BkF	BaP	IndP	DahA	BaPMEQ
1	27.90	0.25	25.5	1.93	1232	26.5	331	1645	22.9	4.17	63.7	21.2	1232	82.2	96	1522
2	43.6	0.47	3.45	3.78	1152	33.9	1374	2611	35.8	8.05	8.6	41.6	1152	105	399	1749
3	52.15	0.54	71.78	3.23	804	43.6	1102	2077	42.8	9.11	179	35.6	804	135	320	1525
4	36.2	0.36	2.48	4.47	1089	3.4	1485	2620	29.7	6.2	6.19	49.2	1089	10.5	431	1621
5	55.2	0.58	85.3	1.63	1141	45.2	795	2124	45.2	9.91	213	17.90	1141	140	231	1798
6	32.53	0.32	13.0	2.84	958	55.4	527	1589	26.7	5.47	32.4	31.21	958	172	153	1378
7	34.58	0.10	27.90	2.45	255	31.4	1232	1583	28.4	1.76	69.8	27.0	255	97	357	836
8	28.7	0.35	12.7	2.48	211	28.4	1036	1319	23.5	6.0	31.6	27.3	211	87.9	300	687
9	2.35	0.01	1.80	0.12	23.5	0.95	18.0	47	1.93	0.16	4.50	1.27	23.5	2.95	5.22	40

Conclusions and Recommendation

This study is the first in Nigeria to advance the knowledge about the concentrations, sources and human cancer risk of ^{16}PAHs in soils within the vicinity of telecom masts. Results show that PAHs concentrations varied and were remarkably higher than some reported studies, and were also higher than recommended target limits for unpolluted soil. Nap, Phe, Ant, Chr and I[123cd]P show lowest concentration at site 9 (control), while D[ah]A show highest concentration at site 4. The compositional pattern of PAHs revealed the abundance of 3-6 ring PAHs above recommended guidelines for soil use. Source identification shows that petrogenic and pyrolitic processes are the sources of PAHs, which could be adduced to spilled diesel and oil in crankcase oils of generators at telecom masts. The ILCR values through the three unintentional exposure routes are in the order of ingestion > dermal > inhalation. The study found out that the cancer risk values were greater than the permissible target limits indicating acute and chronic human cancer risk, while the total cancer risk value for children was greater than adult value. Data from this study could serve as baseline reference for planning and operation of telecom mast. To avoid environmental pollutants generation, it is recommended that telecom masts should be connected to the national grid or use of solar panels for alternative source of electrical energy. Also, since electrical and electronic appliances are known to contain hazardous and toxic persistence organic compounds, further studies should be carried out on the concentrations, human cancer and environmental risk of PCBs, dioxin-like PCBs, PBDEs, bisphenols, and phthalates in soils within the vicinity of telecom masts.

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