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Occurrence of polycyclic aromatic hydrocarbons in Nigeria's environment: A review

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ABSTRACT

The occurrence and levels of polycyclic aromatic hydrocarbons (PAHs) in Nigeria's environment were reviewed in this study. A survey of the literature showed that a considerable number of reports exist on the presence of PAHs in Nigerian soil, water and sediments. Information on the presence of PAHs in the country's air- shed exists but in very limited number. The sources of PAHs are ubiquitous and their concentrations in the country's environment are above the permissible limit set for the pollutant by European Union, the United Kingdom, China and the World Health Organization in most instances. There is practically an absence of regulatory standards for PAHs in ambient air and soil in Nigeria. More studies on source apportionment are needed to be able to ascertain the sources of PAHs and their respective contributions to ambient air concentration. Considering the ubiquitous sources of PAHs, their reported elevated levels in the few publications available in the literature and their carcinogenic and mutagenic tendencies, there is the need for policy makers to drive research on PAHs in Nigeria with a view to setting regulatory standards for the individual carcinogenic PAHs as well as the total PAHs concentrations allowable in different media. Due to the low level of public awareness on the risks and hazards associated with an exposure to PAHs, there is a need to deepen advocacies on polycyclic aromatic hydrocarbons and their public health concerns.

Introduction

Environmental pollution by chemical contaminants is a subject of continuous investigation globally due to the deleterious effects of the pollutants on human and environmental health. There are varieties of these chemical pollutants ranging from particulate matter, heavy metals, black carbon, soot, oxides of sulphur, oxides of nitrogen, volatile organic compounds, hydrocarbons and persistent organic pollutants etc. One of these pollutants (Polycyclic Aromatic Hydrocarbons (PAHs)) is the focus of this review. PAHs constitute a group of over 100 organic compounds which are mostly colourless but could sometimes have white or yellow colouration [1]. They are ubiquitous and could be from natural or anthropogenic sources. Typical natural sources of PAHs include volcanic eruptions, open burning and seepage or loss from deposit of coal or petroleum [1,28].

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The anthropogenic sources of PAHs are due to human activities and are usually associated with incomplete combustion or thermal decomposition processes involving organic materials [1,10,38,45]. Hence; the activities involved in the processing of crude oil, tar sands, bitumen, coal, gas and utilization of refined petroleum products are the major anthropogenic sources of PAHs. Other sources include burning of medical and municipal wastes, vegetations and biomass in general [3,4].

Apart from viewing their sources as either anthropogenic or natural; PAHs sources can also be classified as pyrogenic, petrogenic or biological [36]. Pyrogenic PAHs are products of destructive distillation of carbon containing compounds. This involves high temperature-low/no oxygen (350 °C $\leq$ T $\geq\leq$ 1200 °C degradation of organic compounds [1]. Petroleum refining operation of cracking and conversion of coal to coke are typical examples in this category. Formation of PAHs can also take place at temperatures between 100 °C and 150 °C usually during storage, conveyance and utilization of crude and refined petroleum products. Such sources that lead to low temperature emission of PAHs are said to be petrogenic [1]. Lastly, biological processes leading to the formation of PAHs do occur during biomass decay and via some microbial activities.

The chemical structure of PAHs is usually depicted as a fusion of at least two benzene rings to which hydrogen and carbon are attached. It could also be in the form of pentacyclic rings in straight, angular or cluster pattern [32,46,53] and [27]. PAHs do not accommodate heteroatom neither do they carry substituent [21]. They may be classified as light (small) or heavy (large) PAHs depending on their molecular weight and number of aromatic rings. Light PAHs are those having six rings or less while heavy PAHs are those with more than six rings [1]. Some possible structural arrangements and orientations that polycyclic aromatic hydrocarbons may assume have been reported by Di-Toro et al. [13] and Arey and Atkinson [8].

The interest in PAHs is as a result of their toxicity and properties, such as low water solubility, high affinity for lipids and tendency to be adsorbed to particulate matter account for their persistence in the environment, long range transport, accumulation in the soil and hazardous nature. Their transformation into alkylated derivatives is also a reason for their toxicity. The World Health Organization and the United States presently regulate sixteen of them which are regarded as priority PAHs and those in this category include Acenaphthene (ACE), Acenaphthylene (ACY), Anthracene (ANTH), Benzo[a]anthracene (B[a]A), Benzo[a]pyrene (B[a]P), Benzo[b]fluoranthene (B[b]F), Benzo[k]fluoranthene (B[k]F), Benzo[g,h,i]perylene (B[ghi]P), Chrysene (CHRY), Dibenz[a,h]anthracene (D[ah]A), Fluoranthene (FLTH), Fluorene (FLU), Indeno[1,2,3-c,d]pyrene (IND), Phenanthrene (PHEN), Pyrene (PYR) and Naphthalene (NAP) [52]. Through many years of eco-toxicity studies, seven of the PAHs, namely Benzo[b]fluoranthene (B[b]F), Benzo[k]fluoranthene (B[k]F), Benzo[a]pyrene (B[a]P), Indeno[1,2,3-c,d]pyrene (IND), Benzo[a]anthracene (B[a]A), Chrysene (CHRY), and Dibenz[a,h]anthracene (D[ah]A) have been identified and profiled as potent carcinogens, mutagens and teratogens. The structural views of these PAHs have been reported by Abdel- Shafy and Mansour [1].

In spite of the health risks associated with PAHs, public awareness on their nature, toxicity and presence in the Nigeria's environment is still very low. This might not be unconnected with the absence of regulatory frame work on permissible limits of PAHs in different aspects of Nigeria's environment. This review is an attempt to aggregate evidences on the presence, ubiquitous sources and concentrations of PAHs in Nigeria's environment. Due to their eco-toxicity and reported human health risks based on epidemiology studies, a renewed call is being made to the experts and policy makers to urgently develop a regulatory frame work for permissible levels of PAHs from emitting sources and the environment at large.

Description of the Nigeria

Nigeria is located in the western part of African and has approximately 200 million citizens using the 2006 official census figures and the population growth rate of about 2.3–2.5%. It is located at 3º and 14º East Longitude and 4º and 14º North Latitude and bounded in the North by Chad and Niger Republic while Benin Republic, Cameroun and Atlantic Ocean are the western, eastern and southern borders, respectively. Nigeria presently has 36 federating States and Federal Capital Territory located in Abuja. The country is often grouped along six geo-political zones which are North-West, North-Central, North-East, South-West, South-South and South- East. Rivers Niger and Benue, the two biggest rivers meet at Lokoja in Kogi States before descending to the Atlantic Ocean in the Niger-Delta region. The Niger- Delta region houses the oil and gas deposit, major refineries, LNG as well as petrochemical plants. Ondo State in the western part also has oil and bitumen fields while Lagos and Ogun axes house the bulk of industrial hubs. The capital of each State is always the epic center of commercial activities. Farming (crop and animal) is the primary occupation of the Nigerian people. The map of Nigeria showing the different States and Regions is shown in Fig. 1.

Concentrations and evidences of PAHs in Nigeria's air shed

Air quality is the state of healthfulness of air. The presence of contaminants in air usually affects its quality and poses serious public health concern. The atmosphere is the chief medium through which pollutants are dispersed and transported to other media either on a local, regional or global scale. Nigeria has huge deposits of coal, bitumen, tar sand, crude oil and gas which are largely domiciled in the Niger Delta region of the country. It operates an economy which depends almost unilaterally on fossil fuel. It is also among the top seven gas flaring countries in the world. Hence, the storage, processing, transportation and utilization of these products and their derivatives are the chief contributors of PAHs to the country's air shed.

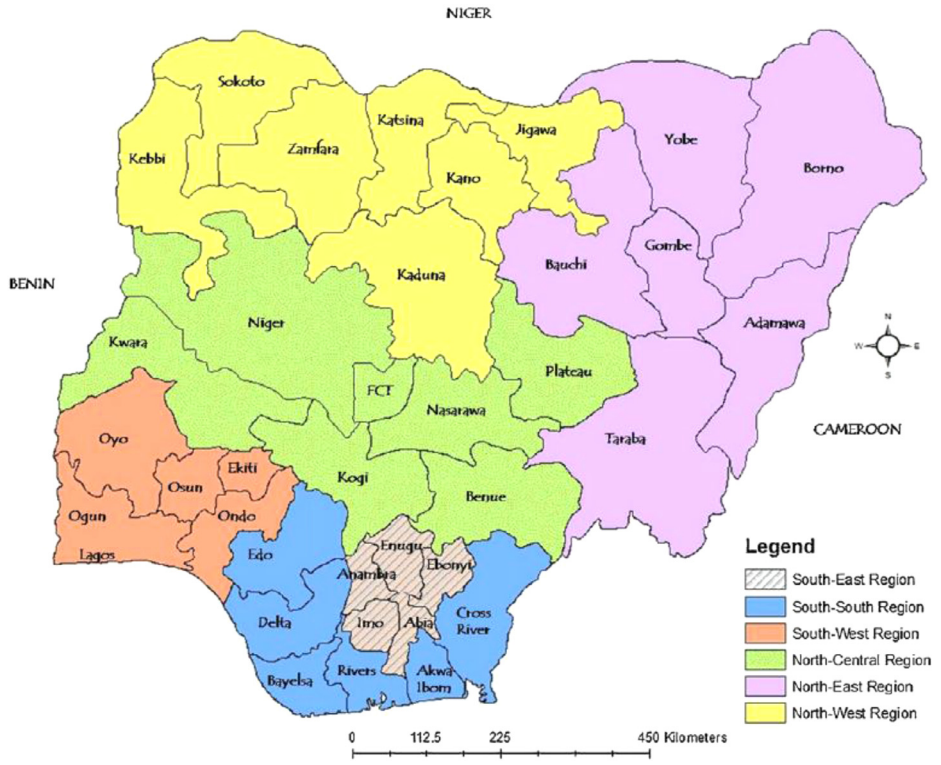

Fig. 1. Map of Nigeria showing the states and regions.

The presence of PAHs in the ambient air of oil producing communities is therefore expected. Ana et al. [7] reported that the ambient air levels of PAHs in some oil producing communities in Eleme Local Government Area were very much higher than those of non-oil producing communities. The average concentration of PAHs for the oil producing communities which house oil wells, refinery, fertilizer and petrochemical plants was reported to be 7.2 $\mu g/m^3$ while that of non oil producing communities was 0.17 ng/m^3. Benzo (a) pyrene, Benzo (k)fluoranthene, pyrene and indeno[1,2,3-cd] pyrene which are carcinogenic were reported to be predominant in the air samples analyzed.

Apart from the oil and gas industry activities, ambient air PAHs are also impacted by open burning of municipal and medical wastes as well as biomass burning of all sorts. Adesina et al. [3] studied the presence of alkyl-naphthalene in the stack gas and ambient air in the neighbourhood of a medical waste incinerator and reported low concentrations of alkyl-naphthalene. Continuous exposure to low doses of the pollutant over an extended period could however trigger a chronic disease condition. In another report by Adesina et al. [4], the presence of dibenzo(a,h)anthracene, indeno[1,2,3-cd] pyrene, Benzo(a) pyrene, benzo[a]anthracene, chrysene, benzo[b] fluoranthene, and benzo[k]fluoranthene around a municipal dump-site in the neighbourhood of Afe- Babalola University, Nigeria was established. Dibenzo(a,h)anthracene was reported to have the highest concentration of about 0.72 $\mu g/m^3$. The presence of PAHs in the smoke of biomass used for domestic cooking has also been observed. The commonly used biomass materials in Nigeria include firewood, sawdust, charcoal, palm kernel shell etc. Olabemiwo and Ogunsola [37] reported the presence of Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)Fluorene and Benzo(k)fluoranthene in wood charcoal and palm kernel shell although in varying concentrations.

Industrial clusters and vehicular emissions also play vital role in the contamination of ambient air by PAHs. The average concentrations of PAHs in the ambient air around some industrial complexes in Lagos and Ogun States Nigeria were 92.8 ng/m^3 and 107.72 ng/m^3, respectively [44]. The air samples were said to be moderately contaminated with likely sources being pyrolytic fuel combustion in utility equipment (generators and boilers) and heavy duty haulage vehicles which are always indisputably associated with industrial areas. Vehicular emission from road transportation system constitutes another source of PAHs emission to the ambient air in Nigeria. Fakinle et al. [19] applied emission inventory approach to determine the contributions of vehicular activities to ambient levels of PAHs in Lagos over a 10 year period (2007-2016). The annual concentrations of PAHs during the period ranged between 5.727 and 6.338 kg.

Quite a number of atmospheric sources of PAHs have not been investigated in Nigeria. These include fossils (kerosene and liquefied petroleum gas) and biomass (sawdust, firewoods, wood pellet, palm kernel shell) which are used for domestic cooking purposes. Other sources include burning of expired automobile tires either during riots or for de-furring of animals. Fairly used tires are used in large quantities in Nigeria but their eventual disposal through open burning is a huge source of

atmospheric PAHs. There are still very limited studies on atmospheric PAHs and source apportionment studies are practically absent. Research direction in atmospheric PAHs in the country needs to focus more on source emission inventory, receptor modeling and source apportionment.

Concentrations and evidences of PAHs in Nigeria's aquatic system

There are no lack of evidences for the presence and contamination of various water resources in Nigeria by PAHs. Water bodies in the oil producing communities of Niger Delta are prone to PAH contamination from occurrence, processing and utilization of fossil fuels and their derivatives. Asagbra et al. [9] detected up to nine of the priority PAHs in the water samples taken from Ubeji River in Warri, Delta State Nigeria. Light molecular weight PAHs were reported to be predominant. A mean PAH concentration of 34 ng/ml was obtained with naphthalene having the highest concentration among the observed PAHs. Nwaichi et al. [33] also confirmed the predominance of heavy molecular weight PAHs in samples of three coastal waters collected from the oil producing regions of Nigeria. Ihunwo et al. [24] found up to eleven PAHs in the waters of Woji Creeks. The concentrations of PAHs in the water and sediment samples ranged between 6.029 and 29.257 ppm and 1809.08 - 1809.08 ppm over a 3 –month period. Mean concentration of PAHs up to 27. 353 μg/L was predicted by Agbozu et al. [6] for water of River Ethiope in the Niger Delta region. Other reports regarding the presence of elevated levels of PAHs in the waters of the Niger-Delta region of Nigeria abound in the literature [12,25]. The sources of PAHs in the oil rich regions are largely petrogenic and pyrogenic [6,11,26].

Apart from the oil producing communities of Nigeria, the presence of PAHs in waters of non-oil producing areas of the country has also been confirmed. Adekunle et al. [2] investigated the presence of PAHs in groundwater in Ife- North Local Government Area of Osun State, a non-industrial area in Nigeria and confirmed the predominance of light PAHs which exceeded WHO specified limit of 10 μg/L across dry and wet seasons. Olayinka et al. [39] found out that the carcinogenic risks associated with consumption of water in Atlas Cove area of Lagos State exceeded the USEPA acceptable limit. The water samples were reported to contain PAHs concentrations between 46 and 507 μg/L with the light PAHs being predominant. Ibigbami et al. [22] observed the presence of carcinogenic PAHs in the water of Egbe Dam in Ekiti State Nigeria. A study of water samples from Rivers Niger and Benue located in the North- Central region of Nigeria revealed the presence of several PAHs with Benzo [a]pyrene, a known carcinogen occurring at levels that could pose risks to human and animal health [15]. The occurrence of PAHs in the waters of non-oil producing areas could be from multiplicity of sources including bush burning for agricultural purposes, waste disposal via open burning, use of herbicide, pesticides or fertilizers on agricultural lands, industrial manufacturing processes, transportation systems, auto-mechanic repair sites etc. The mechanisms of transportation of PAHs into aquatic systems could be by atmospheric deposition from air, surface water run-off from polluted land and leaching into underground water.

Concentrations and evidences of PAHs in Nigeria's soil

The pollution of Nigeria's soil by PAHs is supported by a few research reports. Emoyan et al. [16] reported serious PAHs contamination of the soils around some fuel stations in Abraka, Nigeria. Adeyi and Oyeleke [5] investigated the impact of open dumping and burning of e-wastes on soil PAHs concentration in Ibadan and Lagos. The concentrations of PAHs in the top soils (0 – 30 cm depth) were observed to range between 1664 and 2224 μg/kg. Parra et al. [42] identified 15 of the priority PAHs and reported concentrations of PAHs between 489 and 5616 μg/kg in soils around a dumpsite in Awotan –Asunle, an area in the southwestern region of Nigeria which is known for extensive open dumping of wastes. Indeno[1,2,3-c,d]pyrene, coronene, and phenanthrene were the PAHs with highest concentrations. Iwegbue et al. [29] identified all the 16 priority PAHs in urban street dusts of Lagos, the concentrations of which ranged from 545 to 10785 μg /kg, 289 to 17943 μg/ kg and 616 to 13174 μg/ kg for industrial, commercial, and residential areas, respectively. The concentrations of PAHs in urban street dust of Lagos were found to be higher than those of other world's urban cities. Enuneku et al. [17] also reported the total PAHs concentration for the soils in the oil producing community of Warri. A total PAHs concentration up to 1230.98 μg/kg was obtained for the area with Benzo(a)anthracene reaching 338.81μg/kg and found in all the sampling locations. Some specific sources and activities aiding the release of PAHs into Nigeria's environments are as summarized in Table 1 and Fig. 2 a–f.

Major routes of exposure to PAHs in Nigeria

As discussed in sections 3.0–5.0, the sources of PAHs in Nigeria's environment are ubiquitous. Human exposure to PAHs could occur by direct inhalation of polluted air, ingestion of contaminated substances, skin contact with PAH polluted environment as well as smoking of cigarettes. Ingestion of PAHs in Nigeria could occur through consumption tuber crops, fruits, fish and meats. Meats from goats, cow and bush animals are delicacies in Nigeria but the process of removing their furs usually involves the use of expired automobile tires or kerosene as fuel [35].

Nwaichi and Ntorgbo [33] studied the PAH contamination of tuber (yam and cassava) and fruit (pawpaw and orange) crops in two oil producing communities of Nigeria and observed an elevated level of carcinogenic PAHs. The highest total PAHs concentrations obtained in yam, cassava, pawpaw and oranges from the two communities were 4.321, 3.200, 19.003

Table 1
Specific sources of PAHs emissions in Nigeria.

Sources of PAHs	Specific Activities Promoting Emission of PAHs	Literature Evidence
Vegetation burning	Vegetation burning for agricultural land clearing, hunting of bush animals, promotion of growth of fresh forage for animal feed.	Faboya et al. [20]
Domestic energy	Kerosene, firewood, sawdust and charcoal burning are the dominant energy sources for domestic cooking.	Olabemiwo and Ogunsola [37]
Municipal waste disposal	This is done principally via open dumping and burning in Nigeria.	Adesina et al.[4]; Okedere et al. [34]
Medical wastes disposal	Use of locally fabricated incinerators in very few tertiary health facilities and open burning by majority of hospitals.	Adesina et al. [3]
Wood waste disposal	Open burning of sawdust at sawmills as a means of disposal.	Adeyi and Oyeleke [5]
Electronic wastes disposal	Open burning	Adeyi and Oyeleke [5]
Expired automobile tyre	Disposal of tyre by open burning and burning of tyre during riot and protests	Okonkwo et al. [35]
meat processing	De-furring of animals by burning with auto-tyres or kerosene	Okonkwo et al. [35]
Auto mechanic shops	Engine oil, brake oil, transmission fluids, diesel and gasoline either spill during repairs or disposed by pouring on the ground	
Traffic exhaust	Motorcycles, cars, light trucks and heavy duty haulage trucks running on gasoline or diesel are predominantly used for transportation in Nigeria	Fakinle et al. [19]
Industrial manufacturing	Operation of utilities like generators and boilers are common features of industrial manufacturing in Nigeria.	Salaudeen et al. [44]
Oil and gas industry	Reservior seepage, rig losses and spills, pipeline rupture and explosion, loading spills and losses, refinery losses, gas flaring, bitumen and tar sand processing and storage losses, losses at depots, tanker accidents and explosion during transportation, evaporative losses during transportation, offloading and dispensing at gas stations	Ana et al. [7]

and 7.004 mg/kg, respectively. Iwegbue et al. [28] found an elevated level of 16 priority PAHs in the honey samples collected from different geopolitical zones of Nigeria. The least (97.2 μg/kg) and highest (1980 μg/kg) concentrations of PAHs were found in the honey samples collected from South-West Nigeria. Effiong et al. [14] reported the presence of PAHs in three commercially harvested fishes from estuaries in South-South region of Nigeria. Olayinka et al. [39] found about 11.89–71.06 mg/kg concentration of PAHs in fish harvested in Lagos. Meat, fish and other edible items are usually prepared via charcoal or wood smoking in Nigeria. Food items processed via these means have been reported to contain elevated levels of PAHs which increase progressively with smoking duration. Other reported contamination of food by PAHs exists in the literature [23,41]. An exposure to PAHs could happen through ingestion of contaminated food items. It could also happen in the occupational and non-occupational environment through inhalation of PAH lading air or via skin contact with PAHs polluted soil.

Human toxicology and exposure to PAHs in Nigeria

PAHs have been reportedly found in the human body. Quite a number of studies have established a link between an exposure to PAHs and different body ailments and diseases although these types of studies are not many in Nigeria. Report by Wirnkor et al. [51] found carcinogenic PAHs concentration ranging between 53.48 and 70.8 μg/dL and 94.98–115.04 μg/dL in the blood and urine samples of about 36 children investigated in Imo State Nigeria. In another study by Olabanji et al. [40], up to fourteen PAHs were found in the samples of blood taken from neurology patients. The concentrations of pyrene, fluoranthene and acenaphthene found in the blood plasma were 2.96–236.86 ng/ml, 1.96–11.55 ng/ml and 11.08–1.81 ng/ml, respectively. The obtained values were reported to be significant and attributable to the patient's condition.

Review of regulatory frameworks for PAHs in Nigeria

Research reports have established the presence of carcinogenic PAHs in Nigeria's environment with the contributing sources being ubiquitous. These reports have confirmed an elevated level of carcinogenic PAHs in water, air, soil, and food items. Toxicology studies in Nigeria have also found high concentration of these hazardous pollutants in the human blood and urine samples [40,51]. The toxicity and health risk potentials have been shown to be very high for PAHs. Although, there is dearth of information on the association between a disease condition and an exposure to PAHs in Nigeria, global epidemiology studies have associated increasing risks of cancers and other diseases to exposure to carcinogenic PAHs. Despite this, there is presently no indigenous regulatory frame work and permissible limit for the assessment and management of PAHs in the country. Monitoring and enforcement of PAHs emission compliance are non-existent. Parra et al. [42] and Ana et al. [7] established the absence of source apportionment and comprehensive public health studies on the effect of PAHs in the oil producing communities of Nigeria. The absence of regulatory standard on the permissible level of PAHs for air and soil in Nigeria has been raised by [4,17,29].

a: Scene of municipal wastes burning in Nigeria

b: Open burning of sawdust in Nigeria

c: Scene of gas flare in Nigeria

d: Pollution by oil spillage in Nigeria

e: Bush burning scene in Nigeria

f: Firewood as domestic energy source

Fig. 2. (a). Scene of municipal wastes burning in Nigeria Source: bioenergyconsult.com (b): Open burning of sawdust in Nigeria
(e): Bush burning scene in Nigeria
https://www.vanguardngr.com/2021/02/kwara-loses-n27-6m-property-to-bush-burning/
(f): Firewood as domestic energy source
https://time.com/4305412/nigeria-women-firewood-health-risks/.
Source: https://guardian.ng/property/lagos-experts-warn-against-burning-of-sawdust-propose-disposal-method/ (c): Scene of gas flare in Nigeria (d): Pollution by oil spillage in NigeriaSource: https://www.bloomberg.com/news/articles/2020-06-17/clean-up-of-oil-spills-in-nigeria-lacks-progress-groups-say

A call is being made for an urgent environmental and public health measure to address the absence of regulatory standards for PAHs in the country. While the study into the occurrence of PAHs in Nigeria's space should continue, more efforts are needed in the area of monitoring, source apportionment, regulatory limits and enforcement. While working on the regulatory framework, a paradigm shift in the management of municipal wastes from open dumping and burning to modern technologies may also be necessary. This may be achieved by stepping up public awareness on the likelihood of an exposure to carcinogenic PAHs from the practice of open burning of wastes. The country also needs to initiate bioremediation processes aimed at cleaning the soil in the heavily polluted areas of the country to safeguard public health. Literature evidences regarding the levels of PAHs in Nigeria's environment are summarized in Table 2. Clearly, the permissible limits for the total

Table 2
Reported concentrations of PAHs in Nigeria's environment.

Medium	Description of Sampling Location	Pollutant	Reported Concentration in Nigeria	Author	Nigerian Standard	Standard(s)
Air	Around oil and gas facilities	Benzo[a]pyrene	16000 ng/m^3	Ana et al. [7]	Nil	1.0 ng/m^3 0.25 ng/m^3
Air	Around oil and gas facilities	Benzo[k]pyrene	3100 ng/m^3	Ana et al. [7]	Nil	
Air	Around oil and gas facilities	Benzo[k] fluoranthene	24000 ng/m^3	Ana et al. [7]	Nil	
Air	Around oil and gas facilities	Indeno[1,2,3-cd] pyrene	4100 ng/m^3	Ana et al. [7]	Nil	
Air	Around oil and gas facilities	total PAHs	9.2 ug/m^3	Ana et al. [7]		[a]10 ng/m^3
Air	Around medical wastes	Benzo[a]pyrene	5.7 ng/m^3	Adesinal et al. [3]	Nil	[b]1.0 ng/m3 [c]0.25 ng/m3
Air	Municipal wastes	Benzo[a]pyrene	0.1 ug/m^3	Adesinal et al. [4]	Nil	1.0 ng/m^3 0.25 ng/m^3
Air	Industrial area	total PAHs	92.84–107.72ng/m^3	Salaudeen et al. [44]		10 ng/m^3
Soil	Municipal wastes	Benzo[a]pyrene	0.45 mg/kg	Adesinal et al. [4]	Nil	[d]0.12 mg/kg [e]0.3 mg/kg [f]0.5 mg/kg
Soil	Urban street dust	Total PAHs	289–7,943 ug/kg	Iwegbue et. [29]	Nil	
Run off Water	Non- industrial area	total PAHs	100–15,810 ug/L	Ogunfowokan et al. [55]		[g]0.005ug/L [h]10ug/L [i]50ng/L
Run off Water	Industrial area	total PAHs	73,720 ug/L	Ogunfowokan et al. [55]		0.005ug/L 10ug/L 50ng/L
Water	Around Bitumen field	total PAHs	11.2–341.5 ug/L	Olajire et al.[56]		0.005ug/L 10ug/L 50ng/L
Ground Water	Non- industrial area	total PAHs	118.96 ug/L	Adekunle et al.[2]		0.005ug/L 10ug/L 50ng/L

[a] China- [31]
[b] EU and WHO - [7, 43, 49]
[c] UK – [48]
[d] Netherlands – [30]
[e] Sweden – [47]
[f] Canada – [18]
[g] WHO –drinking water [2, 50]
[h] WHO –ground water [2]
[i] WHO –surface and coastal water [39]

and individual carcinogenic PAHs set by the World Health Organization, European Union and some developed countries of the world were exceeded markedly by the PAHs in Nigeria's environment.

Conclusion

The occurrence and concentration of polycyclic aromatic hydrocarbons in Nigeria's environment have been reviewed. Evidence points to ubiquitous sources and elevated concentrations of these hazardous organic pollutants in Nigeria's air, soil, water, food and human body. Majority of the reported concentrations of PAHs in Nigeria's environments were above the allowable permissible limits set for the pollutant in the developed nations of the world. In spite of this, there are no regulatory frameworks in place for the management and control of the pollutant in Nigeria. To address this, there is a need for robust emission inventory of PAHs in Nigeria. Also, more studies are needed in the area of source apportionment to ascertain the source attributions. Policy makers need to deepen awareness on the public health concerns and risks associated with an exposure to PAHS while also driving researches that will help in formulating emission and permissible concentrations in all the media of exposure.

Declaration of Competing Interest

The authors declare no conflict of interest.

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