Polycyclic aromatic hydrocarbon contamination in water, sediments and aquatic life of Nigerian inland and coastal waters

Onome Augustina Bubu-Davies *, Benjamin Bameyi Otene and Mpakaboari Vellington Cephas Ebini

*Corresponding author: O. A. Bubu-Davies
Department of Fisheries and Aquatic Environment, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria.

Abstract

**Background and Objective:** Polycyclic aromatic hydrocarbons (PAHs) are a group of different chemicals that are formed during incomplete combustions of organic substances but few to be mention such as cigarettes, coal etc. They are usually found as a mixture containing two or more compounds such as soot. The emissions of PAHs in Nigeria have contributed significantly to the environment and live of aquatic organisms. Thus, this paper reviewed the contamination of polycyclic aromatic hydrocarbon (PAHs) in the water, sediments and organisms in inland and coastal waters.

**Methodology:** Literatures of relevant and previous studies of polycyclic aromatic hydrocarbons in the water, sediment and organism within and outside Nigeria were reviewed.

**Results:** The contamination of polycyclic aromatic hydrocarbons (PAHs) was known to be carcinogenic, mutagenic, teratogenic and can cause adverse effect on human health, wildlife and aquatic lives with no report on mammals in the aquatic environments.

**Conclusion and Recommendation:** Polycyclic aromatic hydrocarbons (PAHs) reviewed displayed different effects caused in the lives of human and aquatic organism based on the concentration level. Their sources were more of anthropogenic than natural source with varied concentrations at various source points due to different activities in question. The positive impact of polycyclic aromatic hydrocarbon on fish and other aquatic organisms as a result of bioconcentration, biotransformation and biomagnification become a threat to humans that rely on eighty percent of aquatic resources. Therefore, conceived efforts should be made to reduce these effects, general public monitoring of polycyclic aromatic hydrocarbon on discharge sources in the biosphere.

**Keywords:** PAHs; Pollution; Aquatic organisms; Aquatic environments; Nigeria

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a group of chemicals that are formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances, such as tobacco and charbroiled meat (1). PAHs are a class of organic compounds consisting of two or more aromatic ring fused together. They are found everywhere and mostly hydrophobic in nature, capable of bio-accumulating in animal and human tissues (2). Polycyclic aromatic hydrocarbons (PAHs) are classified as persistent organic pollutants commonly occurring in the environment and are considered to be one of the most difficult organic contaminants to treat (3; 4; 2).
Polycyclic aromatic hydrocarbons (PAHs) are toxic and pose a significant environmental risk to public health (5) and emitted during forest fires, volcanic eruptions, fossil fuels and wood combustion, industrial processes and cooking (6). In the atmosphere, these compounds undergo photochemical and chemical oxidation reactions with nitrogen oxides (NOX), atmospheric oxygen (O2), sulfur oxides (SOX) and hydroxyl radical (OH) producing more toxic compounds (7). PAHs are also manufactured for use as pesticide, pharmaceutical and dye making industries (8). The presence of PAHs in the environment has increased over the years, where its concentrations may have stabilized globally due to recent air and water quality regulations (9).

Contamination is the introduction of unwanted substances by man into the environment in a very low concentration which is not toxic to biotic organism but change the natural structure (10). PAHs are contaminants which occur in all parts of the environment; atmosphere, inland and sea waters, sediments, soils and vegetation (11). (12) reported that the contamination of Polycyclic Aromatic Hydrocarbons (PAHs) in the environment is a serious environmental issue. Thus, PAH bioaccumulates in the environment hence, coastal and marine sediments become the ultimate sinks for such compound (13).

Fishes and other aquatic organisms are liable to environmental contaminants, PAHs thus raising a public health concern as it serves as essential food for body growth to human. Consequently, PAHs have short residence time in the water column due to volatilization and oxidation, and can quickly be eliminated from the system (14). However, deposited PAHs in the sediments are remobilized into water column and become available to fish and other aquatic organisms (15). Thus, the lipophilic nature of PAHs makes it easier to penetrate biological membranes and accumulate in organisms (16).

Inland waters of Nigeria are marked with two major rivers called River Niger/Benue and Chad systems. PAHs contamination and pollution were due to urbanization, industrialization and trade growth. Hence, few hence inland waters across the Niger Delta and few others drain directly into the Atlantic Ocean while other flowing waters at long last empty into the Chad Basin or down the lower Niger and then to the sea.

1.1. Structure of PAHs

![Figure 1](https://example.com) The structure of the sixteen (16) studied PAHs. Source: (17)
2. Sources of polycyclic aromatic hydrocarbon (PAHs)

There are two major sources of PAHs which include the natural sources and the anthropogenic sources.

![Diagram of PAH sources]

**Figure 2** Natural and anthropogenic sources of PAHs

### 2.1. Natural sources

The natural sources are also known as pyrogenic; volcanoes and hydrothermal processes are natural emission sources of PAHs (18; 19; 20; 21). PAH from forest fires and volcanic activities do not significantly contribute to the overall PAH emission (22; 23).

### 2.2. The anthropogenic sources of PAHs

There are techniques used to differentiate the different anthropogenic sources of PAHs (pyrogenic, petrogenic and pyrogenic) sources of PAHs, based on the amounts of relative molecular weight either high or low. According to (24) low molecular weight (LMW) PAHs compounds predominate in petrogenic sources while high molecular weight (HMW) compounds predominate in pyrogenic sources. These are subcategorised into;

#### 2.2.1. Pyrolytic (pyrogenic)

PAHs are produced during incomplete combustion of fossil fuel, biomass burning, coal and organic matter (25). The formation of these compounds during gasification and combustion have been reported (26; 27).

#### 2.2.2. Petrogenic

This is derived from slow maturation of organic matter under geothermal gradient conditions, petroleum spillage (28; 29; 30; 31).

#### 2.2.3. Diagenetic

It is well known that PAHs are formed in large quantities as the result of secondary thermochemical reactions at temperatures over 700°C (32). Products derived from biogenic precursors (33; 24). Sources of environmental PAHs could be evaluated using ratio of different PAHs compounds (30).
3. PAHs Contamination

Contamination of PAHs in the world environments includes inland streams, rivers and marine environments has been reported by several authors (34; 35; 36; 37). PAHs are released into the environment in large quantities by various human activities and they may have additive or synergistic effects with other environmental contaminants (38). The deposition of contaminants led in the differences of PAHs distribution at different depth intervals (39).

3.1. PAHs in the Water

Aquatic ecosystems with high PAHs concentration might pose potential ecological risk, causing carcinogenic, mutagenic, and toxic effects on aquatic organisms (40). According to (41) body burden are present in high affinity for suspended particles in water and eventually go under the bottom sediments of rivers. The concentrations of different PAH fractions and the sum total of PAHs detected in different aquatic environment varies (42). PAHs decreases in water with increasing molecular weight with respect to its solubility (43, 44) resulting to its low concentration in water column (45). The hydrophobic nature of PAHs in surface water or groundwater indicates pollution (43).

**Table 1 PAHs in some Nigeria inland waters**

| S/no. | Location                     | Level of PAHs          | References |
|------|------------------------------|------------------------|------------|
| 1.   | Oburun Lake Bayelsa          | Low                    | (1)        |
| 2.   | Makurdi River                | High                   | (46)       |
| 3.   | Makurdi River                | PAHs below maximum conc.| (46)       |
| 4.   | Num River, Bayelsa State     | Average                | (47)       |
| 5.   | Ekpan River, Delta State     | Low                    | (48)       |
| 6.   | Benue River                  | Low                    | (49)       |
| 7.   | Warri River at Ubeji, Delta State | Low    | (50)       |
| 8.   | Lagos lagoon                 | High                   | (51)       |

3.2. PAHs in Aquatic Live

Aquatic lives such as fishes are extensively used for environmental monitoring as good indicators of water pollution (52,53). The concentration of PAHs in the aquatic environments appear to show seasonal variation on aquatic organisms which may be influenced by number of factors (54).

Some aquatic organisms precisely fish, can be exposed to PAHs depending on its formation and the ability to metabolize body burden in water and sediments. Thus, fish appears to be the most important source of animal protein, and provides over sixty percent of animal protein intake (55). (56) reported that pelagic fishes are susceptible to very low concentration of PAHs as compared to demersal fishes. Thus, PAHs accumulate in certain tissues with the highest proportions found in the liver of vertebrates or the hepato-pancreas of invertebrates (57). Lipid-rich tissues preferentially accumulate PAHs because of their strong hydrophobic nature (58). Food consumption has been identified as an important pathway of human exposure to many contaminants including PAHs (59).
Table 2 Contamination of PAHs is some fishes in Nigeria

| S/No. | Location                              | Species                        | Level of PAHs | References |
|-------|---------------------------------------|---------------------------------|---------------|------------|
| 1.    | Akure                                 | *Clarias gariepinus*            | High          | (60)       |
| 2.    | "                                     | Croaker (*Pseudotolithus senegalensis*) | High          | (60); (8) |
| 3.    | "                                     | Mackerel                        | High          | (60); (8) |
| 4.    | "                                     | Jackfish                        | High          | (60)       |
| 5.    | Mushin, Lagos                         | *O. niloticus*                  | High          | (8)        |
| 6.    | "                                     | Herring                         | Average       | (8)        |
| 7.    | "                                     | Horse mackerel                  | Average       | (8)        |
| 8.    | "                                     | Blue whitting                   | Average       | (8)        |
| 9.    | Bodo and Kaa rivers, Rivers State     | Catfish *Chrysichthys nigrodigitatus* | High          | (61)       |
| 10.   | Qua Iboe River                        | Atlantic croacker (*Micropogonias undulatus*) | High          | (62)       |
| 11.   | "                                     | Tilapia (*Oreochromis niloticus*) | High          | (62)       |
| 12.   | "                                     | Yellow tail (*Seriolala landi*)  | High          | (62)       |
| 13.   | Warri River at Ubeji, Delta State     | *Tilapia zillii, Oreochromis niloticus and Hemiochromis fasciatus* | Low           | (50)       |

Table 3 Aquatic life criteria for PAHs (μg/L)

| PAH            | Freshwater (chronic) | Freshwater (phototoxic) |
|----------------|----------------------|-------------------------|
| Naphthalene    | 1.00                 | NR                      |
| Acenaphthene   | 6.00                 | NR                      |
| Fluorene       | 12.00                | NR                      |
| Phenanthrene   | 3.00                 | NR                      |
| Anthracene     | 4.00                 | 0.10                    |
| Pyrene         | NR                   | 0.02                    |
| Fluoranthene   | 4.00                 | 0.20                    |
| Benz[a]pyrene  | 0.01                 | NR                      |

Source: [63]

3.3. PAHs in the Sediment

PAHs in sediment have been studied extensively around the world and many of them show temporal trends corresponding to the vertical distributions in sediment (64–66). Polycyclic aromatic hydrocarbons (PAHs) are found in all compartments of the environment and tend to adsorb to aquatic sediments (67–68). Polycyclic aromatic hydrocarbons (PAHs) tend to be attracted to stable particles in the water which settles in the sediment and thereafter,
remobilized into water column and become available to fish and other aquatic organisms (15). The bottom sediments is the habitat of many aquatic organisms and are known as potential reservoir of petroleum hydrocarbons in marine environments, posing risk of bioaccumulation (69; 70). Fluoranthene is one of the high molecular weight PAHs that resist biodegradation and tend to accumulate in sediment (71).

However, some fish species can be exposed to PAHs present in the sediments and the PAH level of concentration trust greatly on the ability of the aquatic organisms to metabolize them (72).

**Table 4** Contamination of PAHs in the sediments of Nigeria waters

| S/no. | PAHs | Location | Level of PAHs | References |
|-------|------|----------|--------------|------------|
| 1.    | All PAHs | Ethiope River<br>Delta State | Low | (73) |
| 2.    | Naphthalene, (Acy), (Ace), etc | Warri River at Ubeji, Delta State | High | (50) |
| 3.    | Anthracene, Fluoranthene, [2H12] and [2H10] | Sediments from Imo River | High near the fish settlement (study area) | (74) |
| 4.    | PAHs | Makurdi River | High | (75) |
| 5.    | Acenaphthene, fluoranthene, 2-Methylnaphthalene and naphthalene | Benue River | Low | (49) |

### 4. Uses of PAHs

The major emission of PAHs is the incomplete combustion of organic matter which includes coal, oil and wood etc. They are mostly used as intermediaries in pharmaceutical, agricultural product, photographic products, thermosetting plastic, lubricating materials, and other chemical industries (76). Some uses of PAHs are presented in Table 5.

**Table 5** Summary of some PAHs and their uses

| S/No. | PAHs | Uses |
|-------|------|------|
| 1.    | Acenaphthene | Manufacturing of dyes, plastic, diluents, pharmaceutical and Pesticides, processing of certain foods, pigments and diluents For wood preservatives. |
| 2.    | Anthracene | It is used in the manufacture of some dyes and the wood preservative creosote. |
| 3.    | Chrysene | Manufacture of dyes, pharmaceuticals and agrochemicals, it is also use as a fumigant in households, soil museum etc |
| 4.    | Fluorene | To repel moths/ insects attacks |
| 5.    | Naphthalene | Manufacture of pesticides and resins |
| 6.    | Phenanthrene Pyrene | Manufacture of pigments |

Source (76)
5. Effects of PAHs

There has been alarming awareness on the concern of PAHs to human health, even at minute concentration. They tend to increase over time because they are known to be carcinogenic, mutagenic, teratogenic and can cause adverse effect on human health, wildlife and aquatic lives as in Table 6. Aquatic organism bio-accumulate PAHs because they have membranes that are easily penetrated by PAHs due to their lipophilicity. Hence, dietary intake of PAHs via fish and water is a public health concern (77). Adverse effects of PAHs were also observed in human and aquatic organisms which include growth reduction (78), endocrine alteration (79), malformations of embryo and larvae (80-81) and DNA damage (82).

Table 6 Effects of PAHs on health

| S/No. | PAHs                        | Effects                                                                 | References |
|-------|-----------------------------|-------------------------------------------------------------------------|------------|
| 1.    | Anthracene                  | Toxic, skin sensitizer, eye irritation, nausea, vomiting, diarrhea and confusion. | (83)       |
| 2.    | Acenaphthylene Benzo (a) anthrance Benzo(a)fluoranthene | Toxic, eye irritation. Toxic, carcinogenic, heart malformations, childhood asthma, skin irritations. | (76) and (84) |
| 3.    | Pyrene                      | Toxic                                                                    | (69)       |
| 4.    | Benzo(a)pyrene              | Toxic, eye irritation                                                     | (69), (84) |
| 5.    | Benzo(j)fluoranthene Benzo(b)fluoranthene Napththalene | Toxic, carcinogenic, tumors of the gastrointestinal tract and lungs | (76), (84) and (69) |
| 6.    | Dibenz(a,h)anthracene       | Toxic, tumors of the breast, lungs, toxic, carcinogenic, skin irritants, breakdown of red blood cells, heart malformations, childhood asthma, eye irritation, nausea, vomiting, diarrhea and confusion. | (69)       |

6. Conclusion

This article reveals that anthropogenic sources of polycyclic aromatic hydrocarbons (PAHs) release greater volume than natural sources of PAHs. Automobile, industries, vehicles, cooking (electric appliances and gas burning) and cigarettes emissions are the major sources of PAHs. PAHs can be transported long distances in the atmosphere and removed from it through precipitation and dry deposition and final end point of PAHs is transported into surface waters by volatilization and erosion of PAHs bonded particulate materials in biosphere.

6.1. Recommendations

- Nigeria government should set up a regulatory standard that are relevant to PAHs exposures in the environments.
- Government should establish ambient water quality criteria to protect aquatic live and human health from the effects of PAH exposure.
- Filtration of industrial emissions should be taken into account.
- Treatment of industrial effluents must be carried out strictly, particularly Nigeria and other developing countries.
- Rural and urban enlightenment programme on the awareness of PAHs toxicity in aquatic organism, human health and the environments is of importance.
Compliance with ethical standards

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Disclosure of conflict of interest
No conflict of interest to be declared.

References

[1] Davies OA, Abolude DS. Polycyclic Aromatic Hydrocarbons (PAHs) of Surface Water from Oburun Lake, Niger Delta, Nigeria. App. Sci. Report. 2016;13(1): 20-24.

[2] Zheng XJ, Blais JF, Mercier G, Bergeron M, Drogui P. PAH removal from spiked municipal wastewater sewage sludge using biological, chemical and electrochemical treatments. Chemos. 2007; (68): 1143-1152.

[3] Cerniglia CE. Biodegradation of polycyclic aromatic hydrocarbons. Biodegrad. 1992; 3:351-358.

[4] Weissenfels WD, Klewer HJ, Langhoff J. Adsorption of polycyclic aromatic hydrocarbons (PAHs) by soil particles: influence on biodegradability and biotoxicity. Appl. Microbiol. Biotechnol. 1992; 36: 689-696.

[5] Chen SC, Liao CM. Health risk assessment on human exposed to environmental polycyclic aromatic hydrocarbons pollution sources. Sci. Tot. Envir. 2006;366: 112-123.

[6] Singh Lochan, Varshney Jay G, Agarwal Tripti. Polycyclic aromatic hydrocarbons' formation and occurrence in processed food. National Institute of Food Technology Entrepreneurship and Management, Kundli, Sonipat, Haryana 131028, India. Food Chemistry. 2015;199:768-781.

[7] Naccari C, Cristani M, Giffrè F, Ferrante M, Siracusa L, Trombetta D. PAHs concentration in heat-treated milk samples. Food Research International. 2011; 44(3): 716-724.

[8] Igwe JC, Odo EO, Okerere SE, Asuquo EE, Nnorom IC, Okpareke OC. Levels of polycyclic aromatic hydrocarbons (PAHs) in some fish samples from mushin area of Lagos, Nigeria. Terrestrial and Aquatic Environmental Toxicology. 2010;6(1): 30-35.

[9] Fernandez P, Vilanova RM, Martinez C, Appleby P, Grimalt JO. The historical record of atmospheric pyrolytic pollution over Europe registered in the sedimentary PAH from remote mountain lakes, Environmental Science and Technology. 2000; 34: 1906-1913.

[10] Davies OA, Kpikpi P. B. and Amachree D. Contamination of dioxin in water, sediment and organism in inland waters: A Review. Sumerianz Journal of Scientific Research. 2019;2 (12):183-190.

[11] Wild SR, Jones KC. Polynuclear aromatic hydrocarbons in the United Kingdom environment: A preliminary source inventory and budget. Environ. Pollut. 1995; (88): 91-108.

[12] UNEP (2013). Environmental risks and challenges of anthropogenic metals flows and cycles. Retrieved from https://www.resourcepanel.org/reports/environmental-risks-and-challenges-anthropogenic-metals-flows-and-cycles on 25th August, 2020.

[13] Yu SH, Wong YS, Tam NFY. Degradation of polycyclic aromatic hydrocarbons by a bacterial consortium enriched from mangrove sediments. Environmental international. 2005; 31(2):149-154.

[14] US, GS. Polycyclic aromatic hydrocarbons in water, sediment, and snow, from lakes in Grand Teton National Park, Wyoming, in: D.T. Rhea, R.W. Gale, C.E. Orazio, P.H. Peterman, D.D. Harper, A.M. Farag (Eds.), Final Report, USGS-CERC-91344 for Polycyclic aromatic hydrocarbons in water, sediment, and snow, from lakes in Grand Teton National Park, Wyoming, U.S. Geological Survey, Columbia Environmental Research Center, United States. 2005; 1-29.

[15] Ekere NR, Yakubu NM, Oparanzie TJ, Heidioha JN. Levels and risk assessment of polycyclic aromatic hydrocarbons in water and fish of Rivers Niger and Benue confluence Lokoja, Nigeria. Journal of Environmental Health Science and Engineering. 2019;17:383-392.

[16] Tuvikene A. Response of fish to polycyclic aromatic hydrocarbons (PAHs). Ann. Zool. Fennici. 1995; (32): 295-309.
[17] EPA. Regulations for small engines are at 40 CFR 90, 103. In: Igwe, J.C. and Ukaogo, P. O. (2015). Environmental effects of polycyclic aromatic hydrocarbons. Journal of Natural Sciences. 2001; 5(7):117-131.

[18] Chrysikou L, Gemenetzis P, Kouras A, Manoli E, Terzi E, Samara C. Distribution of persistent organic pollutants, polycyclic aromatic hydrocarbons and trace elements in soil and vegetation following a large scale landfill fire in northern Greece. Environment International. 2008; 34: 210–225.

[19] Choi SD. Time trends in the levels and patterns of polycyclic aromatic hydrocarbons (PAHs) in pine bark, litter, and soil after a forest fire. Science of the Total Environment. 2014; 470–471, 1441–1449.

[20] Domingos M, Bulbovas P, Camargo CZS., Aguiar-Silva C, Brandao SE, Dafre-Martinelli M, Figueiredo AMG. Searching for native tree species and respective potential biomarkers for future assessment of pollution effects on the highly diverse Atlantic Forest in SE-Brazil. Environmental Pollution. 2015; 202: 85–95.

[21] Kong S, Li X, Li L, Yin Y, Chen K, Yuan L, Ji Y. Variation of polycyclic aromatic hydrocarbons in atmospheric PM2.5 during winter haze period around 2014 Chinese Spring Festival at Nanjing: Insights of source changes, air mass direction and firework particle injection. Science of the Total Environment. 2010; 520: 59–72.

[22] Schuetzle D, Jensen TE, Ball JC. Polar polynuclear aromatic hydrocarbon derivatives in extracts of particulates: Biological characterization and techniques for chemical analysis. Environ. Int. 1985; 11: 169-181.

[23] Ogunfowokan AO, Asubiojo OI, Fatoki OS. Isolation and determination of polycyclic aromatic hydrocarbons in surface runoff and sediments. Water Air Soil Pollut. 2003; 147: 245-261.

[24] Soclo HH, Garrigues PH, Edward M. Origin of polycyclic aromatic hydrocarbons (PAHs) in coastal marine sediments, Case studies in Cotonou (Benin) and Aquitaine (France) areas. Marine Pollution Bulletin. 2000; 40 (5): 387-396.

[25] Linnitsky W. The formation and occurrence of polynuclear aromatic hydrocarbons associated with food. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis. 1991; 259(3-4): 251-261.

[26] Mastral A, Calleman M. A review on polycyclic aromatic hydrocarbons (PAHs) emission from Energy generation. Environmental Science and Technology. 2000; 34 (15): 3051-3057.

[27] Richter H, Howard JB. Formation of polycyclic aromatic hydrocarbons and their growth to soot- a review of chemical reaction pathways. Progress in Energy and Combustion Science. 2000;26(4):565-608.

[28] Magi E, Bianco R, Ianni C, Di Carro M. Distribution of polycyclic aromatic hydrocarbons in the sediments of the Adriatic Sea. Environ. Pollut. 2002; 119(1): 91–98.

[29] Chen SJ, Luo XJ, Mai BX, Sheng GY, Fu JM, Zeng EY. Distribution and mass inventories of polycyclic aromatic hydrocarbons and organochlorine pesticides in sediments of the pearl river estuary and the Northern South China Sea. Environ. Sci. Technol. 2006; 40(3): 709–714.

[30] Yunker MB, Macdonald RW, Vingarzan R, Mitchell RH, Goyette D, Sylvester S. PAHs in the Fraser River basin: a critical appraisal of PAH ratios as indicators of PAH source and composition. Org. Geochem. 2002; 33(4): 489–515.

[31] Kafizadeh F. Distribution and sources of polycyclic aromatic hydrocarbons in water and sediments of the Soltan Abad River, Iran. Egyptian Journal of Aquatic Research. 2010; (41): 227-231.

[32] Ledesma EB, Marsh ND, Sandrowitz AK, Wornat MJ. Global kinetic rate parameters for the formation of polycyclic aromatic hydrocarbons from the pyrolysis of catechol, A model compound representative of solid fuel moieties. Energy and Fuels. 2004;16 (6): 1331 -1336.

[33] Baumann P, Budzinski H, Garrigues P. Polycyclic aromatic hydrocarbons in sediments and mussels of the western Mediterranean Sea. Envr. Toxicol. Chem. 1998;17: 765–776.

[34] Shi Z, Tao S, Pan B, Fan W, He XC, Zuo Q, Wu SP, Li BG, Cao J, Liu WX, Xu FL, Wang XJ, Shen WR, Wong PK. Contamination of rivers in Tianjin, China by polycyclic aromatic hydrocarbons. Environ. Pollut. 2005;134(1): 97–111.

[35] Degger N, Wepener V, Richardson BJ, Wu RSS. Brown mussels (Perna perna) and semi-permeable membrane devices (SPMDs) as indicators of organic pollutants in the South African marine environment. Mar. Pollut. Bull. 2011;63: 91–97.
[36] Zeng S, Zeng L, Dong X, Chen J. Polycyclic aromatic hydrocarbons in river sediments from the western and southern catchments of the Bohai Sea, China: toxicity assessment and source identification. Environ. Monit. Assess. 2013;185(5): 4291-4303.

[37] Karaca G, Tasdemir Y. Temporal and spatial variations in PAH concentrations in the sediment from the Nilüfer Creek in Bursa, Turkey. J. Environ. Sci. Heal. A. 2010;49(8): 900 - 912.

[38] Ujovwundu CO, Ogbede JU, Igwe KO, Okwu GN, Agha NC, Okechukwu RI. Quantitative assessment of polycyclic aromatic hydrocarbons and heavy metals in fish roasted with firewood, waste tyres and polyethylene materials. Biochemistry and Analytical Biochemistry. 2014; 4(1):1-8.

[39] Oyo-Ita IO, Oyo-Ita OE. Historical trend of polycyclic aromatic hydrocarbons contamination in recent dated sediment core from the Imo River, Southeast Nigeria. World Journal of Research and Review. 2017;5(4): 5-24.

[40] Ikenaka Y, Sakamoto M, Nagata T, Takahashi H, Miyabara Y, Hanazato T, Ishizuka M, Isobe T, Kim J, Chang K. Effects of polycyclic aromatic hydrocarbons (PAHs) on an aquatic ecosystem: Acute toxicity and community-level toxic impact tests of benzo(a)pyrene using lake zooplankton community. The Journal of Toxicological Sciences. 2010; 38(1):131-136.

[41] Farshid K, Amir HS, Rokhsareh M. Determination of polycyclic aromatic hydrocarbons (PAHs) in water and sediments of the Kor River, Iran. Middle- East Journal of Scientific Research. 2001; 10(1):1-7.

[42] Awe AA, Opeolu BO, Olatunji OS, Fatoki OS, Jackson VA, Snyman RG. Occurrence of PAHs in water samples of the Diep River, South Africa. Water SA. 2020; 46(1): 80–93.

[43] WHO. Polynuclear aromatic hydrocarbons in Drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality, World Health Organization, Geneva. 2003.

[44] Nikolau A, Kostopoulou M, Lofrano G, Meric S. Determination of PAHs in marine sediments: Analytical methods and environmental concerns. Global NEST Journal. 2009; 11(4): 391-405.

[45] Nasr IN, Arief MH, Abdel-Aleem AH, Malhat FM. Polycyclic aromatic hydrocarbons (PAHs) in aquatic environment at El Menošiya Governorate, Egypt. J. Applied Sciences Re. 2010;6(1): 13–21.

[46] Itodo AI, Sha’Ato R, Arowojolu MI. (2018). Polycyclic aromatic hydrocarbons in water samples from a Nigerian bitumen seepage: Gas chromatography– mass spectrometry quantification. Bangladesh J. Sci. Ind. Res. 2018;53(4): 319–326.

[47] Leizou, Kaywood Elijah and Muhammad Aqeel Ashraf. Distribution, Compositional Pattern and Potential to human exposure of PAHs in Water, Assam, India. Environmental Science. 2013; 3, 1:10–16.

[48] Duke O. Source determination of polynuclear aromatic hydrocarbons in water and sediment of a creek in the Niger Delta region. African Journal of Biotechnology. 2015;7(3):282-285.

[49] Arowojolu MI, Tongu SM, Itodo AU, Yinusa SI, Basheeru KA, Mejida S. Determination of polynuclear aromatic hydrocarbons in water and sediment of River Benue in Makurdi metropolis, Nigeria. Chemical Science International Journal. 2018;22(2): 1-10.

[50] Asagbra MC, Adebayo AS, Anumudu CJ, Ugwumba OA, Ugwumba AAA. Polycyclic aromatic hydrocarbons in water, sediment and fish from the Warri River at Ubeji, Niger Delta, Nigeria, African Journal of Aquatic Science. 2015.

[51] Benson NU, Essien JP, Asuquo PE, Erabor AL. Occurrence and distribution of polycyclic aromatic hydrocarbons in surface microlayer and subsurface seawater of Lagos lagoon, Nigeria. Environmental Monitoring and Assessment. 2014;186 (9):5519-5529.

[52] Bouloubassi I, Saliot A. Investigation of anthropogenic and natural organic inputs estuarine sediments using hydrocarbon markers(NAH, LAB, PAH). Oceanologica Acta. 2010;16(2):145-161.

[53] Bouloubassi I, Méjanelle L, Pete R, Fillaux J, Lorre A, Point V. Transport by sinking particles in the open Mediterranean Sea: A1 yeasirediment trap study. Mar. Pollut. Bull. 2006; 52:560–571.

[54] Atuanya El, Nzogu NA. Evaluation of bacteriological and mercury level in cod (Gadus morhua) and saithe (Pollachius virens) stockfish sold in Benin City, Edo State. Nigeria. International Journal of Advanced Research. 2013; 1: 211–214.

[55] Koranteng KA, Hutchful G, Tetebo AY. Information on Fisheries in Ghana. Ministry of Food and Agriculture, The Directorate of Fisheries. 2004;10.
[56] Klumpp, D., Huasheng, H., Humphrey, C., Xinhong, W., Codi, S. (2002) Toxic contaminants and their biological effects in coastal waters of Xiamen, China. I. Organic pollutants in mussel and fish tissues. Marine pollution bulletin, 44(8), 752-760.

[57] Nyarko E, Botwe BO, Klubi E. Polycyclic aromatic hydrocarbon (PAHs) levels in two commercially important fish species from the Coastal Waters of Ghana and their carcinogenic health risks. West African Journal of Applied Ecology. 2001; 19: 53–66.

[58] Umeh GI. Impacts of petroleum hydrocarbons on fish communities of river Areba, Niger Delta, Southern Nigeria. Tropical Freshwater Biology. 2009;18(1): 79–91.

[59] Cheung KC, Leung HM, Kong KY, Wong MH. Residual levels of DDTs and PAHs in freshwater and marine fish from Hong Kong markets and their health risk assessment. Chemosphere. 2007;66: 460–468.

[60] Akpambanga VOE, Purcarob G, Lajidea L, Amooa IA, Conteb LS, Moret S. Determination of polycyclic aromatic hydrocarbons (PAHs) in commonly consumed Nigerian smoked/grilled fish and meat. 2009.

[61] Ikue GS, Monanu MO, Onuah CL. Bioaccumulation of polycyclic aromatic hydrocarbon in tissues (gill and muscles) of (catfish) Chrysichthys nigrodigitatus from crude oil polluted water of Ogoniland, Rivers State, Nigeria. Journal of Applied Life Sciences International. 2010;6(3):1-6.

[62] Okpashi VE, Ogugua VN, Ubani SC, Ujah II, Ozioko JN. Estimation of residual polycyclic aromatic hydrocarbons concentration in fish species: Implication in reciprocal corollary. Cogent Environmental Science. 2017; 3: 1303979.

[63] Environment Canada. Ambient water quality criteria for polycyclic aromatic hydrocarbons (PAHs). Environmental Protection Division, Government of British Columbia, Canada. 1993.

[64] Ke L, Yu H, Wong S, Tan Y. Spatial and vertical distribution of polyaromatic hydrocarbons in Mangrove sediments. Sci. Tot. Environ. 2010; 340:177-187.

[65] Guo JY, Wu FC, Luo XJ, Liang Z, Liao HQ, Zhang RY. Anthropogenic input of polycyclic aromatic hydrocarbons into five lakes in western China. Environ. Pollut. 2010;158(6): 2175-2180.

[66] Zhang R, Zhang F, Zhang T. Sedimentary records of PAHs in a sediment core from tidal flat Haizhou Bay, China. Sci. Tot. Environ. 2013; 450:280-288.

[67] Liu Z, Zhang H, Tao M, Yang S, Wang L, Liu Y, Ma D, Zhiming H. Organochlorine pesticides in consumer fish and mollusk of Liaoning province, China: distribution and human exposure implication. Arch. Environ. Contam. Toxicol. 2007; (59): 444-453.

[68] Oyo-Ita OE, Oyo-Ita IO, Ugim SU. Distribution and sources of polycyclic aromatic hydrocarbons and sterols in termite nest, soil and sediment from Great Kwa River, SE. Niger Delta, Nigeria. Environmental Monitoring and Assessment. 2012;185(2):1413-1426.

[69] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Total Petroleum Hydrocarbons (TPH), U.S. Department of Health and Human Services, Public Health Service, Washington Wash, USA. 1999.

[70] Muthukumar A, Idayachandiran G, Kumaresan S, Kumar TA, Balasubramanian T. Petroleum hydrocarbons (PHC) in sediments of three different ecosystems from Southeast Coast of India. International Journal of Pharmaceutical & Biological Archives. 2013; 4(3):543-549.

[71] Ryan B. Source apportionment of polycyclic aromatic hydrocarbons in sediment cores from the Humber estuary using molecular distribution. M. Sc. Thesis presented to school of School of Environmental Sciences, University of East Anglia, Norwich. 2013;73.

[72] Plaza-Bolanos P, Frenich AG, Vidal JL M. Polycyclic aromatic hydrocarbons in food and beverages. Analytical Methods and Trends, J. of Chromatogr. 2010; 1217: 6303 – 6326.

[73] Ogbozu I, Edjere O, Asibor G, Otolu S, Bassey U. Source predictions of polycyclic aromatic hydrocarbon (PAHs) concentration in water, sediment and biota (Fishes) from Ethiope River, Delta State, Southern Nigeria. Journal of Ecology and Natural Environment. 2020;12(4):140-149.

[74] Dosunmu I00, Oyo-Ita OE. Source apportionment and distribution of polycyclic aromatic hydrocarbons in Imo river sediments near Afam power station, S.E. Nigeria: molecular index and multi-variate approaches. Global Journal of Pure and Applied Sciences. 2015; 18 (3&4):135-149.
U. Itodo, R. Sha’Ato and M. I. Arowojolu. Distribution of polycyclic aromatic hydrocarbons (PAHs) in soil samples from regions around Loda-Irele bitumen field, Nigeria. Pak. J. Anal. Environ. Chem. 2019; 19 (1):71 – 78. http://doi.org/10.21743/pjaec/2018.06.07

ATSDR, 2010. Toxicological Profile for Plutonium. Agency for Toxic Substances and Disease Registry

Mzoughi N, Chouba L. Heavy metals and PAH assessment based on mussel caging in the north coast of Tunisia (Mediterranean Sea). Int J Environ Res. 2012;6(1):109–18.

Christiansen JS, George SG. Contamination of food by crude oil affects food selection and growth performance, but not appetite, in an Arctic fish, the polar cod (Boreogadus saida). Polar Biol. 1995; 15: 277–281.

Meador JP, Sommers FC, Ylitalo GM, Sloan CA. Altered growth and related physiological responses in juvenile Chinook salmon (Oncorhynchus tshawytsha) from dietary exposure to polycyclic aromatic hydrocarbons (PAHs). Can. J. Fish. Aquat. Sci. 2006; 63: 2364-2376.

Carls MG, Holland L, Larsen M, Collier TK, Scholz NL, Incardona JP. Fish embryos are damaged by dissolved PAHs, not oil particles. Aquat. Toxicol. 2008; 88: 121–127.

Camus L, Olsen GH. Embryo aberrations in sea ice amphipod (Gammarus Wilkitzki) exposed to water soluble fraction of oil. Mar. Envr. Res. 2008;66: 221-222.

Caliani I, Porcelloni S, Mori G, Frenzilli G, Ferraro M, Marsili L, Casini S, Fossi MC. Genotoxic effects of produced waters in mosquito fish (Gambusia affinis). Ecotoxicology. 2009; 18: 75-80.

ATSDR, 2009. Toxicological Profile for Aluminum. Agency for Toxic Substances and Disease Registry

Luch A. The carcinogenic effect of Polycyclic Aromatic Hydrocarbon. London Imperial College Press. 2005; 2(1).