Journal of Geoscience and Environment Protection, 2022, 10, 137-144
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Polycyclic Aromatic Hydrocarbons in Water: A Review of the Sources, Properties, Exposure Pathways, Bionetwork and Strategies for Remediation

I. O. Alaekwe[1]*, O. Abba[2]

[1]Department of Chemistry, Federal University Gusau Zamfara State, Gusau, Zamfara State
[2]Department of Microbiology, Federal University Gusau Zamfara State, Gusau, Zamfara State
Email: *iykemome.io@gmail.com, oluchijoan@gmail.com

How to cite this paper: Alaekwe, I. O., & Abba, O. (2022). Polycyclic Aromatic Hydrocarbons in Water: A Review of the Sources, Properties, Exposure Pathways, Bionetwork and Strategies for Remediation. *Journal of Geoscience and Environment Protection, 10,* 137-144.
https://doi.org/10.4236/gep.2022.108010

Received: October 3, 2021
Accepted: August 26, 2022
Published: August 29, 2022

Abstract

Polycyclic aromatic hydrocarbons (PAHs) are by-products arising from incomplete combustion. These organic chemicals substances are found almost everywhere and pose a risk to human health because of their potentially hazardous nature and bioavailability in the environment as determined by several regulatory agencies such as US Environmental Protection Agency (US-EPA), US Department of Health and Human Services (DHHS), International Agency for Research on Cancer (IARC) and the National Agency for Food and Drug Administration and Control (NAFDAC). The paper is aimed at studying polycyclic aromatic hydrocarbons in water. The possible sources, chemistry, risk and remediation strategies for polycyclic aromatic hydrocarbons in water have been considered. Studies have shown that exposure to PAHs at levels above the maximum contaminant level for relatively short periods will cause damage to the red blood cells leading to anaemia; suppressed immune system. Long-term exposure to Benzo(a)pyrene at levels above the maximum contaminant level has the potential to cause developmental and reproductive defects as well as cancer. US-EPA, IARC and DHHS has sets a maximum contaminant level (MCL) for benzo(a)pyrene, the most carcinogenic PAH, at 0.0002 mg/L, 0.0001 mg/L for benz(a)anthracene, 0.0002 mg/L for benzo(b)fluoranthene, benzo(k)fluoranthene, and chrysene. 0.0003 mg/L and 0.0004 mg/L have been set for dibenz(a,h)anthracene and indeno (1,2,3-c,d)pyrene respectively. Sustained barn on smoking in public places and burning of word, use of concretes in road construction as against the traditional surfacing of roads using coal tar as well as cars running on compressed natural gas (CNG) or liquefied petroleum gas (LPG) can form part of the preventive strategies.

Keywords

Aromatic Hydrocarbon, Bionetwork, Remediation, Compressed Natural Gas, Environmental Protection

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are hazardous organic chemicals consisting of two or more benzenoid groups (Marce & Borrull, 2000). They are ever-present pollutants in our surroundings, released during incomplete combustion or via industrial processes and are characterized by high mutagenic and carcinogenic potential (Abdulazeez, 2017; Ayoub & Ahmed, 2019).

They have been considered earlier to form only during high-temperature chemical decomposition of organic materials (700˚C), but the discovery of complex mixtures of wide molecular weight range polycyclic aromatic hydrocarbon in fossil fuels has concluded that pyrolysis of organic materials even at low-temperatures (100˚C - 150˚C) can lead to the production polycyclic aromatic hydrocarbons. Different types of polycyclic aromatic hydrocarbons are formed based on combustion temperature; high-temperature combustion creates a more complex polycyclic aromatic hydrocarbons and low-temperature combustion gives rise to simple polycyclic aromatic hydrocarbons (Tobiszewski & Namieśnik, 2012).

There are some compounds within the wide range of PAH compounds that are toxic, persistent, and regarded as pollutants therefore are being regulated. Sixteen PAHs have been designated as priority pollutants by the United State Environmental Protection Agency (US-EPA, 2007). The extensive occurrence, mutagenic, carcinogenic and teratogenic effects of PAHs in the environment have made them worthy to be given more attention (Freitag et al., 1985). The widespread occurrences of PAHs have been attributed to its formation and release in all processes of incomplete combustion of organic materials. The properties and environmental fate of PAHs are dependent on the number of benzene rings in their structure and the molecular weight. High molecular weight PAHs are compounds with four or more benzene rings fused together, while the low molecular weight compounds consist of two or more fused benzene rings (Law et al., 2000). The low molecular weight PAHs are less persistent, highly volatile, slightly soluble in water and less carcinogenic but are toxic to aquatic organisms since they accumulate in their tissues and affect humans adversely upon consumption (Law et al., 2000).

2. Chemistry of Polycyclic Aromatic Hydrocarbons

The most common PAHs are anthracene, benzo(a)pyrene, chrysene, fluorine and pyrene (EPD, 2011). Others include; tetracene, Benzo[k]fluoranthene, Benzo[c]fluorine, Phenanthrene (**Figure 1**). PAHs exist in the air, water, soil and

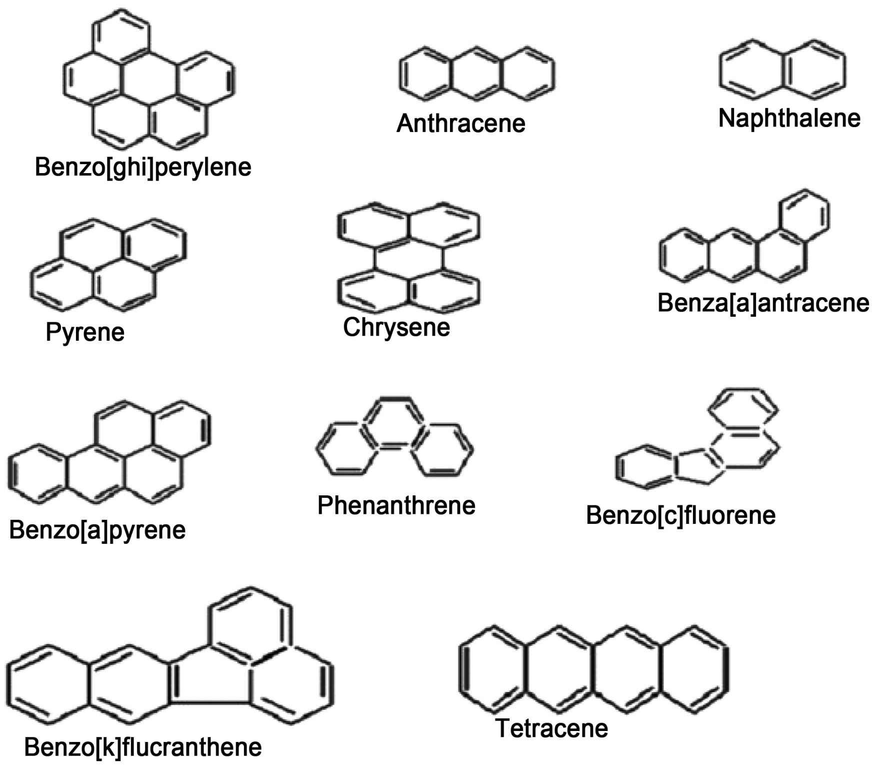

Figure 1. Structure of some common polycyclic aromatic hydrocarbons (Harvey, 1998; Adeniji et al., 2017).

sediments at low concentrations with high thermal stability (Johnsen et al., 2005). They can undergo volatilisation, photolysis, oxidation, biodegradation in surface water and bind to suspended particles or sediments or accumulate in aquatic organisms (ATSDR, 1995). Although the solubility of PAHs in pure water is very low, they may be solubilised by such materials as detergents, or they may otherwise occur in aqueous solution associated with or adsorbed on to a variety of colloidal materials or biota and are thus transported through the water environment (Andelman & Suess, 1970). There are two major sources of PAHs in drinking water. Contamination of raw water supplies from natural and man-made sources and leachate from coal tar and asphalt linings in water storage tanks and distribution lines (EPA, 2002).

Apart from highly industrially polluted rivers, the concentrations of individual PAHs in surface and coastal waters are generally = 50 mg/l (WHO, 1997). Concentrations above this level indicate contamination by PAHs mainly through industrial point sources and shipyards, atmospheric deposition and urban runoff. Elevated concentrations of PAHs were observed in rainwater and especially in snow and fog (WHO, 1997). This may be as a result of the adsorption of the compounds to air particles, which diffuses into the water during rains. Two ringed PAHs and to some extent three-ringed PAHs as shown **Figure 2** dissolve in water, making them more available for biological uptake and degradation (Mackay & Callcott, 1998; Johnsen et al., 2005; Choi et al., 2010).

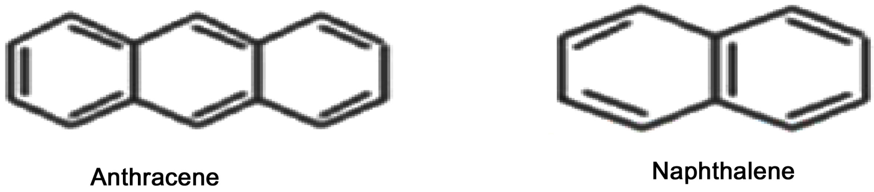

Figure 2. A Structure of three-ringed and two-ringed PAH.

3. Sources of Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons are formed and introduced into the environment through both natural and anthropogenic sources (Lau et al., 2010). PAHs can be produced geologically when organic sediments are chemically transformed into fossil fuels found primarily in natural sources (Ravindra et al., 2008). Natural sources include; air from volcanoes and forest fires. Anthropogenic PAHs arising from man's activities in his environment some of which are shown in Figure 3 includes:

- Cigarette smoke.
- Asphalt roads, coke, crude oil, creosote, roofing tar.
- Residential wood burning (Lau et al., 2010).
- Emissions from automobiles and power generating sets.
- Forest fires (Lau et al., 2010).
- Charbroiled meat.
- Discharges from industrial plants and wastewater treatment plants.
- Hazardous waste sites, coal gasification sites, smokehouses, aluminium production plants (IDPH, 2020).

4. Bionetwork

Cancer is a primary human health risk associated with exposure to pollutants. Benzo(a)pyrene is the most common PAH to cause cancer in animals. Repeated skin contact to the PAH naphthalene can result in skin inflammation. Breathing or swallowing large amounts of PAHs can cause the breakdown of red blood cells (Shashi et al., 2014). Exposure to PAHs has also been linked with cardiovascular disease and poor foetal development (Korashy & El-Kadi, 2006; Suades-González et al., 2015).

Studies have shown that when people are exposed to benzo(a)pyrene, at levels above the maximum contaminant level for relatively short periods, the red blood cells are damaged leading to anaemia; suppressed immune system. Long-term exposure to Benzo(a)pyrene at levels above the maximum contaminant level has the potential to cause developmental and reproductive defects as well as cancer (EPA, 2002).

Like every other pollutant, the health effects of exposure to PAHs depend on how much PAHs has entered the body, duration of exposure to PAHs, and the way the body responds to exposure.

Figure 3. (a) Construction using coal tar. https://www.pettypictures.com/asphaltlaying; (b) man smoking cigarette. https://www.discovery.com/mansmokingcigratte; (c) smoke from exhaust. https://www.scannernews.com/smokefromcarexhaust; (d) charbroiled/grilled foodstuff. https://www.goodhomekeeping.com/charbroiled/grilledfoodstuff.

5. Standards and Regulations for PAHs Exposure in Drinking Water

The United States government agencies have established standards that are relevant to PAHs exposures in drinking water. The maximum contaminant level goal for benzo(a)pyrene in drinking water is 0.2 parts per billion (ppb). However, EPA had in 1980 developed ambient water quality criteria to protect human health from the carcinogenic effects of PAH exposure. The recommendation was a goal of zero (non-detectable level for carcinogenic PAHs in ambient water). EPA, as a regulatory agency, sets a maximum contaminant level (MCL) for benzo(a)pyrene, the most carcinogenic PAH, and five other carcinogenic PAHs. The maximum contaminant level set by EPA is as shown in Table 1.

6. Remediation Strategies for PAHs in Water

As a result of their hydrophobic nature and high affinity to particulate matter, PAHs can be removed from water sources by adsoption. A study has revealed that phenanthene, fluoranthene and pyrene can effectively be removed from water by batch sorption processes using lightweight expanded clay aggregate (LECA) as sorbent (Nkansah et al., 2012).

Table 1. MCL for some PAHs.

PAHs	MCL (mg/l)
Benzo (a) pyrene	0.0002
Benzo (a) anthracene	0.0001
Benzo (b) fluoranthene	0.0002
Benzo (K) fluoranthene	0.0002
Chrysene	0.0002
Dibenz (a,h) anthracene	0.0003
Indeno (1,2,3-c,d) pyrene	0.0004

http://www.epa.gov.

Remediation can also be achieved by chemical treatment using Fenton's reagent, hydrogen peroxide, ozone and activated persulphate to generate reactive free radicals capable of attacking the aromatic structure of PAHs (Huling & Pivetz, 2006).

Biostimulation methods such as biosparging can be employed to deliver oxygen into groundwater, soil and sediments to stimulate aerobic degradation of PAHs in sites with limited supply of oxygen (Breedveld & Sparrevik, 2000).

7. Conclusion

Polycyclic aromatic hydrocarbons (PAHs) in the environment particularly in water bodies deserve attention as this appears to be their fastest route into the human body. This is due to the fact that water plays a major role in mans daily dietary needs. Investigations by various scholars across the globe have revealed the presence of PAHs in environmental samples. Their bioavailability, disposition and metabolism in organisms are therefore important for environmental monitoring purposes. To this effect therefore, government should sustain the barn on smoking in public places, wood burning. The use of concrete or interlocking stones should be encouraged in road construction as against the traditional surfacing of roads using coal tar. Cars running on fossil fuels can be made to run on compressed natural gas CNG or liquefied petroleum gas (LPG) which is a purer form of energy. Recent advances in car technology are already going green in terms of energy thus rechargeable and solar powered cars are already available. Effluents from industries should at all times be recycled.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abdulazeez, T. L. (2017) Polycyclic Aromatic Hydrocarbons. A Review. *Cogent Environmental Science, 3,* Article ID: 1339841.

https://doi.org/10.1080/23311843.2017.1339841

Adeniji, A. O., Okoh, O. O., & Okoh, A. I (2017). Analytical Methods for Polycyclic Aromatic Hydrocarbons and Their Global Trend of Distribution in Water and Sediment: A Review. In M. Zoveidavianpoor (Ed.), *Recent Insights in Petroleum Science and Engineering*. IntechOpen. https://www.intechopen.com/books/recent-insights-in-petroleum-science-and-engineering/analytical-methods-for-polycyclic-aromatic-hydrocarbons-and-their-global-trend-of-distribution-in-wa https://doi.org/10.5772/intechopen.71163

Agency for Toxic Substance and Disease Registry (ATSDR) (1995). *Toxicological Profile for PAHs*. Division of Toxicology, US Department of Health and Human Services, Public Health Service.

Andelman, J. B., & Suess, M. J. (1970). Polynuclear Aromatic Hydrocarbons in the Water Environment. *Bulletin of the World Health Organization, 43,* 479-508.

Ayoub, B., & Ahmed, Y. (2019). Polycyclic Aromatic Hydrocarbons (PAHs) and Their Influence to Some Aquatic Species. In M. Ince, O. K. Ince, & G. Ondrasek (Eds.), *Biochemical Toxicology: Heavy Metals and Nanomaterials*. IntechOpen. https://www.intechopen.com/books/biochemical-toxicology-heavy-metals-and-nanomaterials/polycyclic-aromatic-hydrocarbons-pahs-and-their-influence-to-some-aquatic-species

Breedveld, G. D., & Sparrevik, M. (2000). Nutrient-Limited Biodegradation of PAH in Various Soil Strata at a Creosote Contaminated Site. *Biodegradation, 11,* 391-399. https://doi.org/10.1023/A:1011695023196

Choi, H., Harrison, R., Komulainen, H., & Delgado Saborit, J. (2010). *Polycyclic Aromatic Hydrocarbons. WHO Guidelines for Indoor Air Quality: Selected Pollutants*. World Health Organization.

Environmental Progress Directorate (EPD) (2011). *What Are Polycyclic Aromatic Hydrocarbons?* http://www.nehc.med.navy.mil/downloads/ep/posters/PAHsml.pdf

Environmental Protection Agency Fact Sheet (EPA) (2002). http://www.envirotool.msu.edu/factsheets/contaminants/benzopyrene

Freitag, D., Ballhorn, L., Geyer, H., & Korte, F., (1985). Environmental Hazard Profile of Organic Chemicals. *Chemosphere, 14,* 1589-1616. https://doi.org/10.1016/0045-6535(85)90014-1

Harvey, R. G. (1998). Environmental Chemistry of PAHs. In A. H. Neilson (Ed.), *PAHs and Related Compounds: Chemistry. The Handbook of Environmental Chemistry* (pp. 1-54). Springer. https://doi.org/10.1007/978-3-540-49697-7_1

Huling, S. G., & Pivetz, B. E. (2006). *In-Situ Chemical Oxidation (No. EPA/600/R-06/072)*. Environmental Protection Agency Washington DC Office of Water.

Illinois Department of Public Health (IDPH) (2020). https://www.idph.state.il.us/cancer/factsheets/polycyclicaromatichydrocarbons.12/04/2020

Johnsen, A. R., Wick, L. Y., & Harms, H. (2005). Principles of Microbial PAH Degradation in Soil. *Environmental Pollution, 133,* 71-84. https://doi.org/10.1016/j.envpol.2004.04.015

Korashy, H. M., & El-Kadi, A. O. S. (2006). The Role of Aryl Hydrocarbon Receptor in the Pathogenesis of Cardiovascular Diseases. *Drug Metabolism Reviews, 38,* 411-450. https://doi.org/10.1080/03602530600632063

Lau, E. V., Gan. S., & Ng, H. K. (2010). Extraction Techniques for Polycyclic Aromatic

Hydrocarbons in Soils. *International Journal of Analytical Chemistry, 2010,* Article ID: 398381. https://doi.org/10.1155/2010/398381

Law, J. R., Kelly, C., Baker, K., Jones, J., Melutosh, A. D., & Moffat, C. F. (2000). Toxic Equivalency Factors for PAH and their Applicability in Shell Fish Monitoring Studies. *Journal of Environmental Monitoring, 4,* 383-388. https://doi.org/10.1039/b200633m

Mackay, D., & Callcott, D. (1998). Partitioning and Physical Chemical Properties of PAHs. In A. Neilson (Ed.), *PAHs and Related Compounds. The Handbook of Environmental Chemistry* (pp. 325-345). Springer. https://doi.org/10.1007/978-3-540-49697-7_8

Marce, R. M., & Borrull, F. (2000). Solid Phase Extraction of Polycyclic Aromatic Compounds. *Journal of Chromatography A, 885,* 273-290. https://doi.org/10.1016/S0021-9673(00)00428-3

Nkansah, M. A., Alfred, A. C. Tanja, B., & George, W. F. (2012) The Use of Lightweight Expanded Clay Aggregate (LECA) as Sorbent for PAHs Removal from Water. *Journal of Hazardous Materials, 217-218,* 360-365. https://doi.org/10.1016/j.jhazmat.2012.03.038

Ravindra, K., Sokhi, R., & Van Grieken, R. (2008). Atmospheric Polycyclic Aromatic Hydrocarbons: Source Attribution, Emission Factors and Regulation. *Atmospheric Environment, 42,* 2895-2921. https://doi.org/10.1016/j.atmosenv.2007.12.010

Shashi, N. K., Pankaj, V., Banajit, B., & Arun, K. J. (2014) Health Risk Assessment of Polycyclic Aromatic Hydrocarbons: A Review. *Journal of Pathology and Toxicology, 1,* 16-30.

Suades-González, E., Gascon, M., Guxens, M., & Sunyer, J. (2015). Air Pollution and Neuropsychological Development: A Review of the Latest Evidence. *Endocrinology, 156,* 3473-3482. https://doi.org/10.1210/en.2015-1403

Tobiszewski, M., & Namieśnik, J. (2012). PAH Diagnostic Ratios for the Identification of Pollution Emission Sources. *Environmental Pollution, 162,* 110-119. https://doi.org/10.1016/j.envpol.2011.10.025

US Environmental Protection Agency (US-EPA) (2007). *Method 8270 Semivolatile Organic compounds by Gas Chromatography/mass Spectrometry*. EPA. http://www.dep.state.fl.us/waste/quick_topics/publications/pss/pcp/procedures/EPA_8270D.pdf

WHO (1997). *Non-Heterocyclic Polycyclic Aromatic Hydrocarbons*. Geneva World Health Organization, International Programmes on Chemical Safety.