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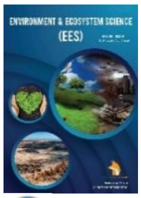

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RESEARCH ARTICLE

UNDERSTANDING THE IMPACT OF POLYCYCLIC AROMATIC HYDROCARBONS: SOIL, ENVIRONMENT, AND HUMAN HEALTH

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ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) an organic molecules with several fused aromatic rings that are known to have carcinogenic and environmental polluting qualities. The study focuses on soil toxicity, origins, routes of human exposure, and potential remediation methods of polycyclic aromatic hydrocarbons. There are several drawbacks to polycyclic aromatic hydrocarbons (PAHs), especially in soil conditions. These highly persistent organic compounds, which frequently arise from incomplete combustion of organic materials, tend to accumulate in soil over time. Because PAHs are known to be harmful and carcinogenic, this accumulation raises concerns for human health in addition to endangering biodiversity and soil quality. Furthermore, because of their propensity to contaminate groundwater, they pose a threat to aquatic ecosystems and may expose communities to additional harm. Through their detrimental effects on microbial communities, which are essential to the cycling of nutrients and the general health of the soil, PAHs can also upset important soil processes. Additionally, the adherence of PAHs to soil particles makes cleanup difficult and expensive. This hampers remediation efforts. All things considered, the fact that PAHs are found in soil emphasizes how critical it is to address their sources and put into place practical measures to lessen their negative effects on the soil, environment, and human health.

KEYWORDS

PAHs, Classification, Pyrogenic, Pseudomonas, Pollutants

1. INTRODUCTION

The rapid development and expansion of industry during the last 20 years has caused the pollution of water resources and soil, thus degrading the quality of sediments (Tuncel and Topal, 2015). This issue is of particular concern to the management of toxic compounds in the environment as they are prone to absorbing toxic compounds. Soil sediments are important sources of information related to organic compounds and their fate over long periods (Walker, 2014). When contaminated sediments become secondary sources, they may be washed away by the environment's changes (Eggleton and Thomas, 2004). One of the most notable environmental pollutants in water/sediment systems is polycyclic aromatic hydrocarbons (Montuori et al., 2016). These environmental pollutants hamper food security and food self-sufficiency (Chaurasia et al., 2020).

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds that are mainly colorless, white, or pale yellow and are formed by the separation of carbon and hydrogen atoms into two or more benzene rings (Patel et al., 2020). These pollutants are hydrophobic, lipophilic, persistent, genotoxic, carcinogenic, and toxic (Lang et al., 2008). Numerous studies have shown that they can cause cancer in humans (Richter and Howard, 2000). PAHs are persistent pollutants with a wide spectrum of biological toxicity due to their intrinsic features; removing PAHs from the environment has been a global problem. PAH contaminants are prevalent in both aquatic and terrestrial ecosystems, as well as in the atmosphere (Adeniji et al., 2019; Chaurasia et al., 2024). Because of their increased hydrophobicity and low aqueous solubility, PAHs were observed to deposit faster in soil/sediments. Because they are highly adsorbent to soil particles, the soil ecosystem serves as an ultimate sink for PAHs (Lu et al., 2011).

This study focuses on the toxicity, sources, routes of human exposure, and potential remediation techniques of polycyclic aromatic hydrocarbons (PAHs), this study aims to undertake a thorough investigation into these complex compounds. The term "PAHs" refers to a family of organic compounds that have numerous fused aromatic rings (Sahoo et al., 2020). These compounds are frequently found in a variety of environmental matrices as a result of both natural and man-made processes, including the burning of organic matter, vehicle exhaust, and industrial pollutants (Hussain et al., 2018). It is critical to comprehend the toxicity of PAHs because they have been linked to a number of harmful health effects in humans, such as mutagenicity, carcinogenicity, and abnormalities in development (Sun et al., 2021). Furthermore, identifying and reducing related health concerns requires understanding the routes by which people are exposed to PAHs, including breathing in contaminated air, consuming contaminated food and water, and coming into touch with contaminated soil or water through the skin. In addition, investigating possible remediation methods—such as physical, chemical, and biological ones—has the potential to lower PAH contamination levels in impacted areas and protect human health. This work intends to contribute to a deeper understanding of PAHs and assist the development of practical strategies for their management and mitigation through a thorough assessment of these linked elements.

2. METHODOLOGY

The article was compiled using secondary data and information from government publications, published research papers, reports from

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various organizations, and relevant websites. The data for this investigation was gathered in a methodical manner. Electronic resources like Google Scholar, PubMed, Scopus (Elsevier), Web of Science, Semantic Scholar, Academia, and other relevant websites were employed to conduct a thorough search for the body of current literature. These sources were thoroughly examined, and the results were presented in an understandable format.

3. Results and Discussion

3.1 Classification

PAHs pollution in soil is classified into 3 categories (Wu et al., 2019).

I. Unpolluted: If PAHs concentration is less than 200 ng per gram soil.

II. Weakly Polluted: If PAHs concentration is more than 200 and less than 600 ng per gram soil.

III. Heavily Polluted: If PAHs concentration is more than 1000 ng per gram soil

On the basis of their existence in higher concentration, toxicity and greater exposure recalcitrant, the United States Environmental Protection Agency (USEPA) designated 16 PAHs as priority pollutants in 1983 (Zheng et al., 2018) which are shown in Table 1.

Table 1: List of sixteen Polycyclic Aromatic Hydrocarbons (PAHs)

S.N.	Name of PAHs	Formula	Phase Distribution	S.N.	Name of PAHs	Formula	Phase Distribution
1.	Naphthalene	$C_{10}H_8$	Gas	9.	Chrysene	$C_{18}H_{12}$	Particle
2.	Acenaphthylene	$C_{12}H_{10}$	Gas	10.	Pyrene	$C_{16}H_{10}$	Particle Gas
3.	Acenaphthylene	$C_{12}H_8$	Gas	11.	Benzo(a)pyrene	$C_{20}H_{12}$	Particle
4.	Anthracene	$C_{14}H_{10}$	Particle Gas	12.	Benzo(b)fluoranthene	$C_{20}H_{12}$	Particle
5.	Phenanthrene	$C_{14}H_{10}$	Particle Gas	13.	Benzo(k)fluoranthene	$C_{20}H_{12}$	Particle
6.	Fluorene	$C_{13}H_{10}$	Particle	14.	Dibenz(a,h)anthracene	$C_{22}H_{14}$	Particle
7.	Fluoranthene	$C_{16}H_{10}$	Particle Gas	15.	Benzo(g,h,i)perylene	$C_{22}H_{12}$	Particle
8.	Benzo(a)anthracene	$C_{20}H_{12}$	Particle	16.	Indeno[1,2,3-cd] pyrene	$C_{22}H_{12}$	Particle

Source*:* (Bojes and Pope, 2007; Yan et al., 2004)

3.2 Sources of PAHs

Anthropogenic and natural emission sources are identified as the two main sources of PAH pollution. Natural emission sources, such as volcanic eruptions and forest fires, are less important while anthropogenic sources categorized as agricultural, industrial, mobile, and domestic are the major determinants of PAH pollution (Abdel-Shafy and Mansour, 2016).

An incomplete combustion by industrial activities is the major source of PAH emission. Exhaust from numerous vehicles, including planes, ships, trains, and off-road heavyweight and lightweight vehicles, is a source of mobile emissions (Srogi, 2007). Household activities such as waste burning, coal charring, wood burning, cooking on oil/gas burners and kerosene/wood stoves, and other home heating are examples of domestic emission sources. Open biomass burning and agricultural waste burning are agricultural emission sources (Ravindra et al., 2008).

PAH pollution in a rural area is mainly due to domestic and agricultural sources while in urban area it is due to industrial, mobile, and domestic sources. PAH concentration varies in all seasons; concentration is highest in winter mostly due to the incomplete combustion of fossil fuel (Miura et al., 2019). Based on the origin of production, PAHs are divided into three types:

i. Pyrogenic: These PAHs are formed at higher temperatures (350–1,200 ∘ C) under no or low oxygen level due to the incomplete combustion of fossil fuels, natural fires, thermal breakdown of petroleum and waste disposal (Abdel-Shafy & Mansour, 2016; Mojiri et al., 2019).

ii. Petrogenic: These PAHs has 2-4 rings and are formed due to petroleum transport and oil spills (Abdel-Shafy and Mansour, 2016).

iii. Biogenic: These PAHs are formed by the slow biological conversion of organic materials by microorganisms, phytoplankton, algae and plants (Mojiri et al., 2019).

3.3 Key routes of exposure to humans

PAHs are natural environmental pollutants that result from burning fossil fuels and burning various substances which are released into the atmosphere causing air, water and soil pollution (Zedeck, 1980).

Table 2: Routes and Sources of Exposure to Environmental PAHs

Route of exposure	Primary Sources of PAHs
Inhalation	Combustion of fossil fuels such as coal and petroleum products; particulate and non-particulate exposures from occupational-industrial sources to tars and fumes; wood smoke and cigarette smoke
Ingestion	Dietary; charcoal grilled foods
Dermal	Exposure to tars and soot

Note: The inhaled PAHs are deposited on airways. (Source: Burchiel and Luster, 2001)

PAHs are found in tobacco smoke, are found in charcoal-grilled foods and diesel exhaust, virtually all people are exposed to PAHs. Some populations are exposed to much higher concentrations of PAHs through inhalation and ingestion due to the use of PAHs rich heating or cooking fuels or from certain occupations associated with dermal exposure as shown in Table 2(Mumford et al., 1995; Schoket et al., 1999).

3.4 Toxic effects of PAHs

PAHs compounds have ecotoxic effects on living beings and its severity is dependent upon the mode of exposure, duration of exposure and exposure dose (Rajpara et al., 2017; Tong et al., 2018). The acute effects of PAHs include vomiting, diarrhea, confusion, skin irritation, eye irritation and inflammation. Moreover, the chronic effects include eye cataracts, kidney and liver damages, breathing problem, decreased immune function and lung malfunctions (Abdel-Shafy and Mansour, 2016). Naphthalene and benzo(a)pyrene can cause skin irritation and breakdown of red blood cells (Rengarajan et al., 2015).

PAHs can absorb UV light to become excited which reacts with oxygen forming reactive intermediates. They can damage cell membrane, nucleic acids or proteins (Yan et al., 2004; Yu, 2002). There is a significant risk of accumulation of PAHs in adipose tissue of various organs because of its high lipophilicity. Those organs (lung, skin, esophagus, colon, pancreas, and bladder) would be at high risk of tumor formation due to long-term exposure (Rajpara et al., 2017; Yu, 2002). Tong et al., (2018) suggested 45% risk of developing cancer when PAH exposure exceeds acceptable levels. PAH exposure causes a variety of non-cancer reproductive system-related health impacts in humans, including alterations in sperm quality, testicular function, and egg viability, as well as DNA damage in oocytes, ovarian damage, and other reproductive illnesses. Human research looked at things including polycystic ovary syndrome, fertility, spontaneous abortion, and preterm delivery (Bolden et al., 2017). Pre-natal exposure of PAH results low weight, premature delivery, heart malformations, low IQ, childhood asthma and behavioral problems in early age child (Rengarajan et al., 2015). High PAH exposure can result in immune system related adverse effects like hypersensitivity, autoimmunity, structural and functional changes in bone marrow (Abdel-Shafy and Mansour, 2016).

PAHs are common soil contaminants that cause changes in grain size, porosity, and water-holding capacity, as well as a negative impact on microbial diversity/population. Significant changes in permeability, volume, plasticity, and other properties are also caused, resulting in poor soil quality (Sakshi et al., 2019). PAHs do not burn easily and can persist in the environment for a long time. Moreover, the sites where hazardous wastes are disposed, one is likely to breathe PAHs as they can easily turn into vapour (Kennish, 2016). Given the enormous potential for commercial farm product development and commercialization, better PAH management techniques appear to be required (Ghimirey et al., 2023). Many crops like potato and tomato can take up the PAHs considerably from soil and ingestion of these contaminated foods have health risks (Zohair et al., 2006; Parajuli et al., 2022; Acharya et al., 2023).

3.5 Remediation

Today, the cleanup of PAH (diesel/crude oil)-contaminated soils is becoming a worldwide problem. Reclamation/remediation of PAH-polluted soils is critical, and it can be accomplished by procedures that include the removal or modification of the pollutant. Soil reclamation techniques such as physical, chemical, thermal, and biological remediation (both ex situ and in situ) have been developed (Sakshi et al., 2019).

3.5.1 Physical Treatment

For the extraction of PAHs from soils, several organic solvents (individual solvents or mixtures of solvents) and vegetable oils can be utilized. The extraction of PAHs from soils involves first desorption of the compound from the soil and then leaching of the desorbed molecule into the extraction solution. Organic additions for pollutant degradation include compost, manures, organic by-products, and so on, whereas mineral additions include sand, gypsum, coal combustion products, volcanic ash, and so on (Silva et al., 2005).

3.5.2 Thermal Treatment

Organic compounds, such as PAHs, can be degraded or volatilized by heat; these pollutants convert to gases, resulting in enhanced mobility; and these gases may be collected in wells for ex situ treatment. Thermal remediation techniques such as thermal desorption, microwave frequency heating, and vitrification have all been employed.

3.5.3 Electrokinetic Treatment

The electrokinetic technique is an in-situ remediation approach that employs direct electric current to remove organic and other pollutants (inorganic and heavy metals) from soil (Huang et al., 2012).

3.5.4 Chemical Treatment

Chemical oxidation treatment entails redox (oxidation/reduction) processes in which electrons are transferred from one chemical to another. Hazardous pollutants are converted into less harmful or nonhazardous substances using this technique (Sharma et al., 2016). Fenton's reagent uses hydrogen peroxide as oxidant, persulfate, permanganate, ozone are the other oxidizing agents which directly attacks double bonds in PAHs resulting in significant reduction of PAHs in soil. Moreover, photocatalysts can be efficiently used to stimulate oxidizing reactions (Yao et al., 1998).

3.5.5 Bioremediation

Microorganisms' natural degradative capacity, i.e., bacteria, yeasts, fungus, and algae, is exploited in bioremediation of pollutants to transform them into less hazardous chemicals or water and carbon dioxide (Alexander, 1994). According to Reda, 2009, PAHs might be degraded utilizing a variety of naturally occurring soil microbes, including those from the genera *Pseudomonas, Alcanivorax, Microbulbifer, Mycobacteria, Sphingomonas, Micrococcus, Alcaligenes, Ralstonia, Paenibacillus, Bacillus, Aeromonas, Xanthomonas, Arthrobacter, Acinetobacter, Corynebacterium Enterobacter* and others.

4. Conclusion

This research has offered a comprehensive examination of polycyclic aromatic hydrocarbons (PAHs), including topics such as their toxicity, origins, routes of human exposure, possible remedies, and influence on soil pollution. PAHs are dangerous substances that can harm people's health and the environment since they come from a variety of industrial, automotive, and natural sources. Effective mitigation methods depend on an understanding of how these chemicals penetrate soil ecosystems and then find their way into human exposure pathways. Furthermore, remediation technique research has potential for reducing PAH pollution and maintaining ecosystem health and soil quality.

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Conflict of Interest

The authors hereby declare that they possess no conflict of interest in this paper.

Data Availability Statement

The data will be available on request to the corresponding author.

Ethics Statement

The author confirm that they have adhered to the ethical policy of the journal.

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