Emerging Contaminants and Associated Treatment Technologies

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Ubiquitous Polycyclic Aromatic Hydrocarbon Contamination

Recent Perspectives

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Polycyclic Aromatic Hydrocarbons in Industrial Wastewater

Amanpreet Kaur, Aayasha Negi, Neha Bhatt, Man Vir Singh, Jitendra Pal Singh, and Santosh Kumar Verma

Abstract

Polycyclic aromatic hydrocarbons (PAHs) belong to a group of organic pollutants known for their persistence in the environment and frequently detected in industrial wastewater, attributed to their extensive application in the petrochemical, pharmaceutical and manufacturing sectors. These compounds pose significant threats to environmental and human health due to their carcinogenic, mutagenic, and toxic properties. Industrial activities like fossil fuel combustion, coal processing and petroleum refining result in elevated PAH levels in wastewater, potentially causing aquatic pollution and bioaccumulation in living organisms. Traditional approaches to treating wastewater, including coagulation, sedimentation, and biological methods, are frequently ineffective in fully removing PAHs. Considering the negative impacts of PAHs, it is crucial to identify and remove these compounds from water through dependable methods. A range of physical, chemical and biological approaches for the treatment of PAH-contaminated water has been explored. This chapter examined the occurrence of

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PAHs in industrial wastewater, their detrimental impacts on organisms, and the treatment approaches employed to address them. Future investigations ought to concentrate on creating economical and environmentally sustainable methods to address PAH contamination, thereby safeguarding both environmental integrity and public health.

Keywords

Polycyclic aromatic hydrocarbons • PAH sources in industry • PAH removal techniques • Advanced oxidation processes • Bioremediation

Introduction

Global industries are increasingly recognizing the critical significance of water in productivity and profitability. A multitude of nations have begun to experience water scarcity. Manufacturing, energy generation, and global material transportation are significantly dependent on water. Due to escalating economic pressures, industrial water usage has surged significantly (Abdel-Shafy and Mansour 2016). The global population has doubled in recent decades, leading to a sixfold rise in water usage. By the year 2025, it is anticipated that Asian and African countries would experience water shortages. Consequently, if the industrial water allocation increases from the current 5% to 17% by 2025, it would significantly jeopardize the water allocated for agricultural use. Consequently, several countries have enacted measures to control PAH pollution (Adeniji et al. 2023). The U.S. EPA has classified 16 PAHs as major pollutants owing to their significant health and environmental hazards. The carcinogenic properties of PAHs, have generated significant concern. Benzo[a]pyrene is a carcinogen, demonstrating significant evidence of its carcinogenicity in humans and animal models (Gupta and Gupta 2015). Methylated PAHs (Me-PAHs), a subset of PAH derivatives, exist in the environment analogous to their unsubstituted equivalents. Although research has examined the occurrence of PAH in industrial effluent sources, such as coking and landfill effluents (Krishnan et al. 2017), the behavior and transformation processes of PAHs in paper-making wastewater (PMWW) remain inadequately known. PMWW is characterized by complex complexes of inorganic and organic materials, including high levels of organic carbon and chemical oxygen demand. Each paper mill consumes significant volumes of water, ranging from 5 to 300 m^3 every ton of pulp produced. Medium-sized mills produce roughly 2000 m^3 of effluent per day (Ren et al. 2019). PAHs were reported to be the part of effluent and sludge samples of a paper industry in 2018 (Gupta 2018). Water supplies are strained by industrial activity, climate change, pollution, and increasing energy demands. A substantial quantity of water used in companies culminates in industrial effluent, then discharged into the ecosystem, elevating considerable problems and generating numerous threats (Berardi et al. 2019). This is particularly applicable to the chemical and related industrial industries. Consequently, it is essential to endeavor to minimize water use and to treat wastewater to render it reusable or, at the very least, less detrimental to the environment. Water is extensively used in chemical and related process industries, rendering them water-intensive. Its usual uses include serving as a solvent and cleaning agent, coolant, and water from boiler. These requirements are fulfilled using the finite sources of freshwater. Industrial effluent is a significant contaminant of aquatic ecosystems. Industrial activities generate significant quantities of pollutants, so damaging air and water (Bokade and Bajaj 2023). The discharge of substantial quantities of industrial wastewater into aquatic environments necessitates the implementation and design of tailored treatment processes for each effluent procedure. The volume of wastewater generated varies by the technological sophistication of processes across industries, although it may be mitigated by advancements in industrial technology (Chen et al. 2019). Industries are swiftly advancing, using substantial quantities of freshwater as both a raw resource and cooling agent. During industrial processes, various raw and intermediate products, and waste are introduced into the water. Despite being an inevitable result, wastewater significantly contributes to the contamination of aquatic habitats (García et al. 2020). From all waste-producing businesses, pharmaceutical sector, wood treatment and preservation industries, Dye, paint and plastic manufacturing plant generate the most dangerous wastewater (Singh et al. 2018, 2020). These industries are where wastewater treatment is crucial. This chapter offers an extensive analysis of the presence and dynamics of PAHs in industrial effluent. It examines the origins and properties of PAHs, delineates their toxicological importance, and emphasizes contemporary analytical and remediation strategies (Gbeddy et al. 2020). Table 6.1 summarize different PAH generated from industrial waste water. This chapter seeks to synthesize existing information to provide effective monitoring and management techniques aimed at mitigating PAH pollution and safeguarding environmental and public health.

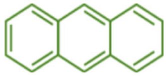
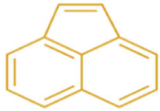
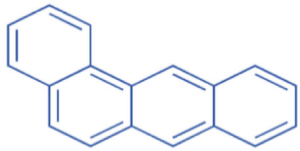
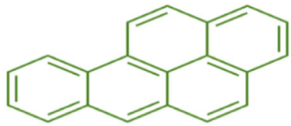
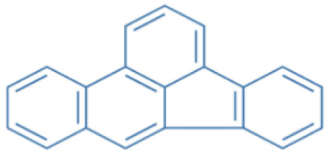
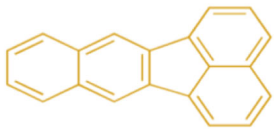
Different Kinds of Wastewaters Containing PAHs

PAHs are prevalent in many industrial and municipal effluent streams as a result of their extensive production during the combustion and chemical processing of organic substances. The kinds and amounts of PAHs fluctuate markedly based on industrial activities, raw materials used, and treatment techniques implemented (Al Farraj et al. 2019).

Petrochemical and Oil Refinery Wastewater

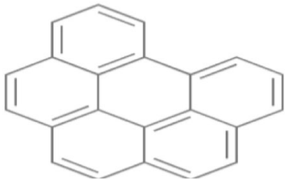
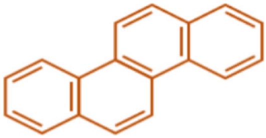
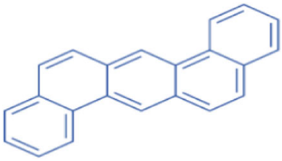
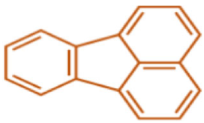
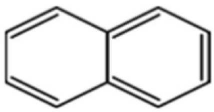
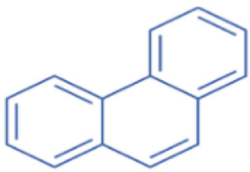
The water generated from operations like water injection and drilling while petroleum extraction is greasy and often includes both organic and inorganic substances. Produced water comprises pollutants such as dissolved and distributed petroleum compounds, dissolved sedimentary minerals, production chemical substances, industrial solids, and gaseous components (Ghosal et al. 2016). Oil

Table 6.1 Different PAH generated from industrial waste water

PAHs	Formula	Molecular weight	Structure	References
Anthracene	$C_{14}H_{10}$	178.2		Ansari et al. (2023)
Acenaphthene	$C_{12}H_{10}$	154.2		Ghasemi et al. (2017)
Acenaphthlene	$C_{12}H_8$	152.18		He et al. (2020)
Benzo (a) anthracene	$C_{18}H_{12}$	228.3		Kuppusamy et al. (2017)
Benzo (a) pyrene	$C_{20}H_{12}$	252.3		Ansari et al. (2023)
Benzo (b) fluoranthene	$C_{20}H_{12}$	252.3		Dai et al. (2022)
Benzo (k) fluoranthene	$C_{20}H_{12}$	252.3		Ghasemi et al. (2017)

(continued)

Table 6.1 (continued)

PAHs	Formula	Molecular weight	Structure	References
Benzo (ghy) perylene	$C_{22}H_{12}$	276.3		Ansari et al. (2023)
Chrysene	$C_{18}H_{12}$	228.2		Gupta and Gupta (2016)
Dibenz (a,h) anthracene	$C_{22}H_{14}$	278.3		He et al. (2020)
Fluoranthene	$C_{16}H_{10}$	202.2		Abdullah et al. (2020)
Naphthalene	$C_{10}H_8$	128.91		Sun et al. (2019)
Phenanthrene	$C_{14}H_{10}$	174.2		Kuppusamy et al. (2017)

components in solution are organic substances that are soluble in generated water, including benzenol, carboxylic acids, and low molecular weight aromatic compounds. PAHs and heavy alkyl phenols constitute organic components present in generated water and contribute to the formation of dispersed oil (Kong et al. 2023).

Coking and Steel Industry Wastewater

Worldwide, the industrial expansion is significantly rising, particularly in the critical industries of steel, coal gasification, textiles, and coke, which together generate millions of tons of industrial effluent. Industrial effluent is very hazardous and can cause cancer and genetic disorder, including PAHs like C_5H_5N and phenolic compounds. Over the previous ten years, considerable efforts have been devoted to research for the coking waste. The use of membrane bioreactors (MBR), moving bed biofilm reactors (MBBR) has been optimized to improve the extraction efficiency of conventional activated sludge methodology (Lamichhane et al. 2016). Despite an improved eradicate around 25%, significant costs and vary biofouling remain critical problems that must be addressed for the commercialization of these methods (Man et al. 2017).

Aluminum Smelting Wastewater

Numerous sectors release waste containing toxic metals into the atmosphere, comprising aquatic ecosystems. These substances may include acids and very poisonous Metallic compounds and mineral substances, such as aluminum. This contamination may render water inhospitable for aquatic creatures, unfit for residential use or irrigation, and may allow wastes to re-enter the food chain, adversely affecting people (Mortazavi et al. 2019). This pollution mostly results from atmospheric deposition from several sources, with industrial and vehicular emissions being the most significant contributors. Urbanized landscapes and industrial locations exhibited much more metal pollution than rural regions (Omolola et al. 2025). Although aluminum is one of the most prevalent metals, it is neither required nor biologically significant in living beings. Currently, there is no evidence demonstrating its biological significance in living organisms (Nasrollahzadeh et al. 2021).

Wood Treatment and Preservation Effluents

Solid wood is a naturally occurring polymer composite formed by the combination of cellulose, hemicelluloses, and lignin, which are structured into tubular structures that create a cylindrically layered composite (Mannina et al. 2020). Wood is regarded as a renewable resource since it may be organically replaced. Global wood preservative producers, such as KMG compounds, Koppers, Borax, Kop-Coat, BASF Wolman GmbH, and Arxada, are formulating new compounds in compliance with environmental agency standards (Pathak et al. 2022).

Pulp and Paper Industry Wastewater

The pulp and paper sector produces diverse waste during the paper manufacturing process at various operating phases. A significant amount of wastewater is produced during preparation of wood chips, pulping, bleaching, and paper manufacturing operations (Mahmoud 2020). Lignins were extracted from wood chips using Na_2S alkaline therapy circumstances throughout the wood chip preparation, washing, and pulping procedures. At this step, the produced lignin-rich effluent is referred to in the form of black liquor. The bleaching method involves the treatment of pulp with toxic chemicals, including H_2O_2 and CaO hence increasing the toxicity of the resultant effluents (Pulleyblank et al. 2019).

Dye, Paint, and Plastic Manufacturing Effluents

The fabric, printing, paper, processing of food, and leather industries mostly produce dye wastewater, with worldwide annual production of 800,000 tons of dyes, of which about 200,000 tons are textile dyes. Dye effluent contains many pollutants, including adhesives, salts, acids, toxic, and cancerous. These attributes contribute to ocular burns, dermal irritations, allergy, and asthma in the human body (Safo-Adu et al. 2023). The dye business produces many contaminants at different concentrations. Consequently, dye wastewater constitutes a threat to both human health and the ecosystem. Furthermore, it is exceedingly detrimental to use dye effluent in routine tasks such as showering, laundering and cooking. Despite being aware of the detrimental effects and existing national restrictions, after dyes have served their usefulness, they are discarded into the environment without treatment (Rayaroth et al. 2023).

Sources of PAHs in Industrial Wastewaters

Polycyclic aromatic hydrocarbons (PAHs) enter industrial wastewaters via many processes related to raw material use, combustion, high-temperature activities, and waste disposal. The composition and concentration of PAHs in industrial effluents are contingent upon the particular industrial activity and its related chemical or thermal processes (Sayara and Sánchez 2020). Comprehending these sources is essential for formulating targeted treatment and pollution mitigation methods. Table 6.2 represents different sources of PAHs in Industrial Wastewater.

The origins of PAHs in industrial wastewater are varied and mostly associated with combustion, chemical processing, and inadequate waste management. Comprehending these sources is essential for recognizing high-risk sectors, informing environmental policies, and developing efficient wastewater treatment systems. Figure 6.1 represents the different sources of PAHs in wastewater (Akinpelumi et al. 2023). Mitigating PAH emissions at their origin is a fundamental approach to

Table 6.2 Sources of PAHs in industrial wastewater

Source	Industries	Common PAH
Incomplete combustion	Steel, power plants, cement, incineration	Benzo[a]pyrene, Fluoranthene, Pyrene
PAH-containing chemicals	Wood treatment, asphalt, dyes, plastic manufacturing	Phenanthrene, Chrysene, Naphthalene
Waste and by-product disposal	Coke plants, smelters, incinerators, landfill sites	High-MW PAHs
Atmospheric deposition	Any high-temperature industry	Depends on local activity
Spills and leakages	Petroleum refining, chemical plants	Anthracene, Benzo[b]fluoranthene
Fuel/lubricant contamination	Heavy industries using diesel or furnace oil	Fluorene, Acenaphthene
Thermal decomposition and pyrolysis	Carbon black, aluminum, coke production	Pyrene, Benzo[a]anthracene
Runoff from contaminated surfaces	Mixed industrial zones	Depends on source

limiting environmental mitigating pollution and protecting environment and human well-being (Satouh et al. 2021).

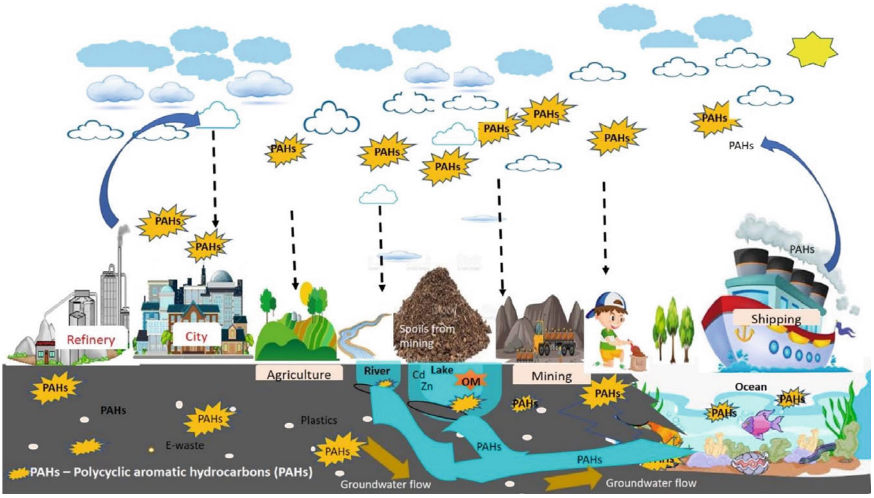


Fig. 6.1 Sources of PAHs in wastewater. Reproduced with permission from Akinpelumi et al., Journal of Hazardous Materials Advances, ©2023, Elsevier

Impact of Industrial Wastewater Containing PAH on Human Health and Environment

The general community is primarily exposed by inhalation of PAHs of indoor and outdoor air, consumption of polluted food, cigarette smoking, and contact with smoke from open fires. Common roots of PAHs encompass fossil fuels utilized in transportation, cooking, residential heating, and diverse industrial processes (Borji et al. 2020). Numerous studies on wild fish have established a connection between PAH exposure and the development of hepatic neoplasms or toxicopathic liver lesions linked to neoplasia. Such exposure is commonly identified through the presence of SPAHs in sediments, PAH metabolites or fluorescent aromatic compounds (FACs) in fish bile, PAH-DNA adducts in liver tissue, or through contaminated dietary intake (Zhao et al. 2021). Similar to mammals, fish possess immune defense systems that include both cell-mediated and humoral responses (Mukwevho et al. 2020). Research on innate immune responses indicates that fish macrophage activities are significantly influenced by PAH exposure, particularly with regard to the sensitivity of macrophage respiratory bursts. Lymphocyte proliferation is significantly affected by exposure to PAH in the context of acquired immune responses. Humans may be exposed to PAHs and their derivatives via many routes: inhalation of airborne PAHs, ingestion of PAHs in water, and dermal contact with PAHs in diverse surroundings. Moreover, eating represents another potential exposure pathway, since PAHs may readily infiltrate the food chain and bioaccumulate; moreover, food may get contaminated with PAHs during high-temperature cooking. The severity of the impacts of PAH exposure on human life is significantly influenced by the duration and method of exposure, the concentration and type of PAH, and the health status of the affected persons (Ma et al. 2017). However, outliers exist, such as naphthalene, which exhibits more carcinogenicity than other high molecular weight polycyclic aromatic hydrocarbons, such as benzo(ghi)perylene. Due to their varying carcinogenic potential, several global organizations have categorized PAHs into groups based on this criterion, including the International Agency for Research on Cancer (IARC), the US Environmental Protection Agency (EPA), and the European Union (EU) (Montano et al. 2025). Among the prioritized PAHs, benzo(a)pyrene (BaP) has attracted significant interest from the scientific community because to its elevated carcinogenic potential. Consequently, BaP is often used as an indicator of PAH carcinogenicity and is regarded as representative of PAHs. Chronic exposure to PAHs may result in long-term consequences such as cataracts, renal and hepatic damage, respiratory issues, and diminished immune system function. Reports indicate that PAHs may induce short-term effects after acute exposure to high concentrations of PAHs. The adverse effects including irritation and inflammation. Moreover, several PAHs, including anthracene, benzo(a)pyrene, and naphthalene, are recognized as skin irritants, with anthracene and benzo(a)pyrene also acting as skin sensitizers (Kouras et al. 2025). Figure 6.2 represents the effect of industrial waste water containing PAHs on human health.

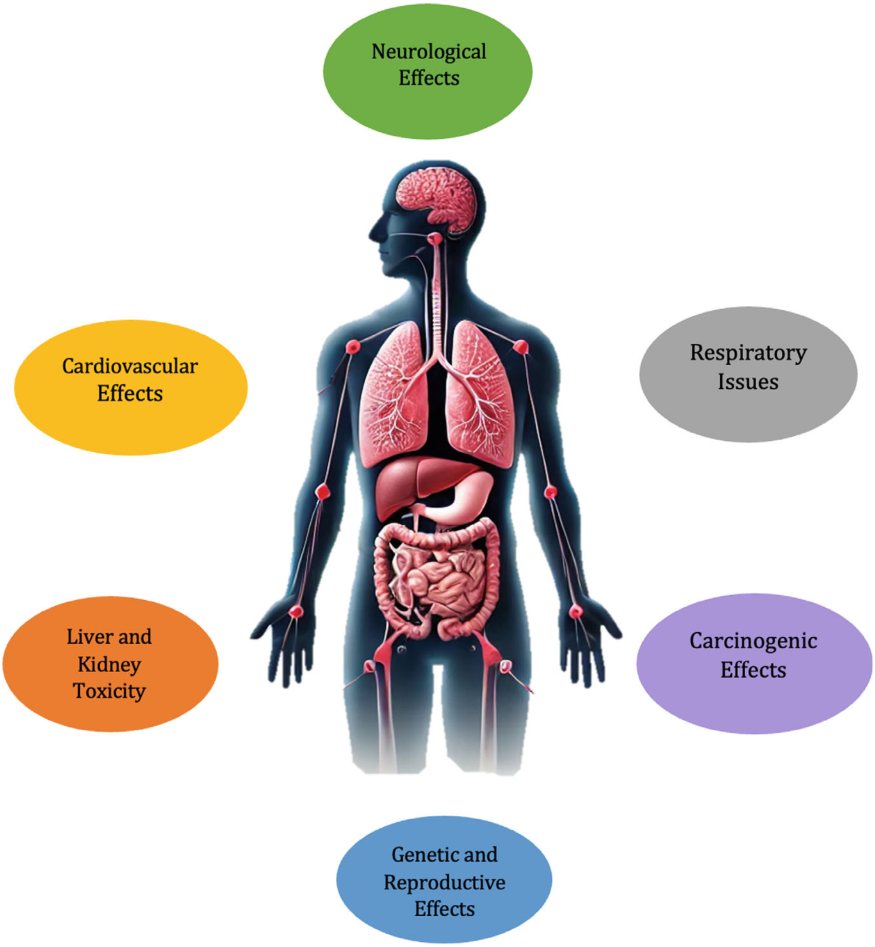


Fig. 6.2 Effect of industrial waste water containing PAHs on human health

Remediation of PAHs in Industrial Wastewaters

The isolation and accumulation of PAHs from industrial wastewater test material are critical for their precise determination. Remediation strategies seek to lower environmental pollutants to acceptable levels via Environmental degradation and transformation in atmospheric and aquatic media (Shen et al. 2020). Pollution from PAHs is a major worldwide issue, given their harmful impacts on human well-being and ecosystems. Multiple mitigation measures have been utilized to address PAH pollution involving physical and chemical components, and biological methods. PAHs, owing to their hydrophobic characteristics, demonstrate

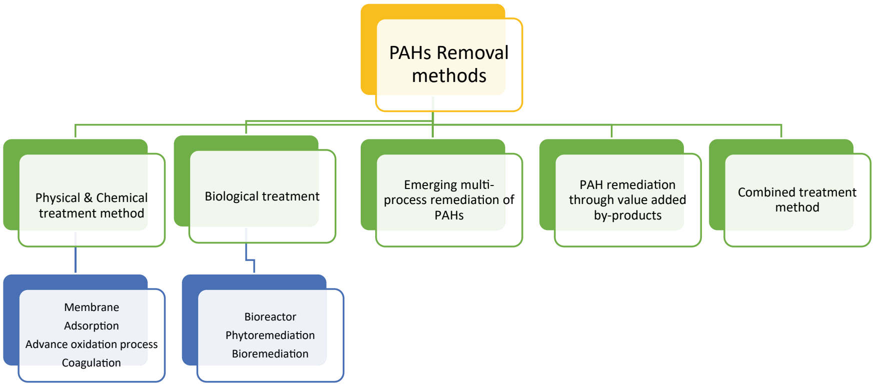


Fig. 6.3 Different methods of removal of PAHs from industrial waste water

significant solubility in organic solvents (Pandey et al. 2020). Figure 6.3 presents the different techniques employed for the elimination of PAHs.

Physical and Chemical Methods

Physical and chemical treatment methods are utilized to eliminate large particles along with pollutants from wastewater. Physical therapy is often utilized as a first phase prior to the implementation of advanced technologies (Fouda et al. 2021). Physical treatment methods include membrane filtration and adsorption. Most physical methods primarily transfer PAHs from water to another medium without modifying their chemical structure. Consequently, physical methods alone are insufficient for the complete removal of PAHs. Chemical procedures have garnered increased attention due to the inefficiency and time-consuming nature of physical methods for PAH removal. Chemical treatments encompass processes that can decompose or convert PAHs into less harmful or more manageable forms (Muthukumar et al. 2020). Table 6.3 provides an outline of the diverse methods employed for the recovery of PAHs.

Membrane

Membrane filtration treats water and wastewater by holding pollutants in a porous filter material. Sand is a filtered material and popular because to its accessibility, efficacy, and affordability (Bis et al. 2019). Advanced membrane-based pretreatment technologies remove PAHs from generated water. Ultrafiltration, microfiltration, nanofiltration, and reverse osmosis are popular. Integrating membrane-based techniques has also improved PAH removal efficiency. Nanofiltration technology has acquired interest due of its capability to remove organic micropollutants from water and wastewater (Han et al. 2022a). This method rejects monovalent salts little while maximizing organic micropollutant rejection. Ultrafiltration membrane

Table 6.3 Different method used in removal of PAHs

PAHs	Method	Removal effectiveness (%)	References
Naphthalene	Ultraviolet light exposure	62	Qiao et al. (2018)
Pyrene	Adsorption	40	Zhao et al. (2021)
16 PAHs	Anaerobic anoxicoxic biological treatment	99–100	Alao and Adebayo (2022)
Benzo (a) pyrene	Adsorption	48	Qiao et al. (2018)
16 PAHs	Photocatalyst ozonation	57	Dhara and Dutta (2025)
Naphthalene	Bioremediation	100	Qiao et al. (2018)
Anthracene	Bioremediation	73	Qiao et al. (2018)
Naphthalene	Green-derived sorbent material	76.20–105.60	Zhao et al. (2021)
16 PAHs	Bioremediation	42–77	Qiao et al. (2019)
Phenanthrene	Green-derived sorbent material	76.20–105.60	Zhao et al. (2021)
Acenaphthene	Green-derived sorbent material	76.20–105.60	Zhao et al. (2021)
Fluoranthene	Green-derived sorbent material	76.20–105.60	Zhao et al. (2021)
Pyrene	Green-derived sorbent material	76.20–105.60	Zhao et al. (2021)
Phenanthrene	Bioremediation	95	Alao and Adebayo (2022)
Pyrene	Bioremediation	54	Alao and Adebayo (2022)
Fluoranthene	Fenton method	62.95	Haneef et al. (2020)
Phenanthrene	Fenton method	63.16	Haneef et al. (2020)
Anthracene	Fenton method	85.47	Haneef et al. (2020)
Phenanthrene	Absorption and degradation	80	Gupta and Gupta (2016)
Pyrene	Absorption and degradation	65	Gupta and Gupta (2016)
Benzo (a) pyrene	Absorption and degradation	65	Gupta and Gupta (2016)
16 PAHs	Phytoremediation	89	Bhatti et al. (2024)
16 PAHs	Biodegradation	67.27	Ismail et al. (2022)
Pyrene,	Magnetic floatation	89.9	Mirzaee and Sartaj (2022)

(continued)

Table 6.3 (continued)

PAHs	Method	Removal effectiveness (%)	References
Benzo (a) pyrene	Magnetic floatation	66.9	Mirzaee and Sartaj (2022)
Indenopyrene	Magnetic floatation	78.2	Mirzaee and Sartaj (2022)
16 PAHs	Biodegradation	77.38	Ismail et al. (2022)
Phenanthrene	Oxidation	90.1	Wei et al. (2015)
Naphthalene	Oxidation	97.5	Wei et al. (2015)
Anthracene	Oxidation	55.4	Wei et al. (2015)
Benzo (a) pyrene	Oxidation	26.7	Wei et al. (2015)
Naphthalene	Air-assisted microextraction	82	Patel et al. (2020)
Phenanthrene	Adsorption	90	Gupta and Gupta (2016)
Naphthalene	Oxidation adsorption	92	Wei et al. (2015)
Fluorene	Oxidation adsorption	100	Wei et al. (2015)
Pyrene	Precipitation method	99	Sakshi et al. (2019)
Fluoranthene	Precipitation method	98	Sakshi et al. (2019)
Chrysene	Precipitation method	87	Sakshi et al. (2019)
Phenanthrene	Precipitation method	97	Sakshi et al. (2019)
Naphthalene	Oxidations	97	Wei et al. (2015)
Anthracene	Oxidations	95	Cao et al. (2018)
Fluorene	Oxidations	87	Jalili et al. (2020)
Benzo (b) fluoranthene	Adsorption	59–91	Ren et al. (2019)
15 PAHs	Dispersive liquid–liquid microextraction	90	Krishnan et al. (2017)
PAHs	Electrochemical advanced oxidation	99.9	He et al. (2020)
PAHs with low and high molecular weights	Biodegradation	86	Ghasemi et al. (2017)

bioreactors were used to test the efficacy of removal for three low-concentration polycyclic aromatic hydrocarbons phenanthrene, fluoranthene, and pyrene from wastewater. The removal efficiencies were 91%, 82%, and 92% (Yemele et al. 2024).

Adsorption

Adsorption processes are classified as physical (physisorption) or chemical (chemisorption) based on their interactions (Gupta and Gupta 2016). Adsorption is a proven method for removing PAHs from generated water. Petroleum, wastewater, and agricultural leftovers are used to make carbon-rich biochar (Mukwevho et al. 2020). Figure 6.4 represents different types of adsorbents used in removal of PAHs from Industrial waste water. Pyrolysis biochar absorbs PAHs and other organic contaminants due to its aromatic carbon structure, similar to graphene. The porous carbon substance activated carbon, made from agricultural waste is an excellent adsorbent (de Andrade et al. 2020). Graphene, a hexagonal honeycomb of carbon atoms, removes pollutants well. Adsorption systems operate in batch and continuous modes. Small-scale applications like lab pilot studies use batch adsorption. Combine a specific amount of adsorbent and adsorbate in a reactor until equilibrium is reached. To improve adsorption effectiveness, temperature, adsorbate concentration, adsorbent amount, agitation speed, and particle size are considered (Yang et al. 2019). Continuous flow adsorption systems suit large-scale industrial applications.

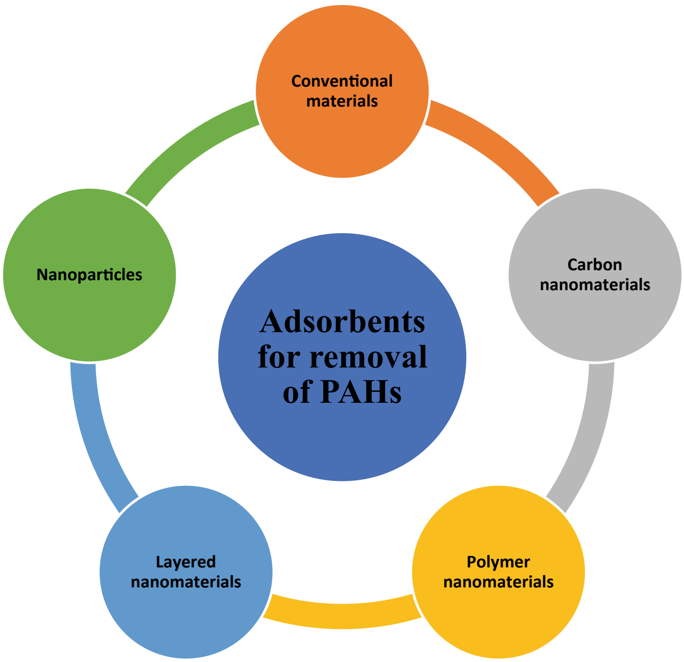


Fig. 6.4 Systematic presentation of different types of adsorbents used in removal of PAHs from Industrial waste water

Advance Oxidation Process (AOPs)

AOPs were created in the Twentieth century methods for the treatment of oil and gas wastewater, eliminating contaminants and reducing color and odor. Advanced oxidation processes (AOPs) often include O_3, Cl_2, H_2O_2, and Fenton reagents, such as UV/H2O/Fe^{3+} systems. The efficacy of AOPs ranges from 32 to 99%. This diversity underpins its dependability, especially with catalysts. PAH degradation uses molecular ozone, hydroxyl radicals, and reactive species (Jackulin et al. 2024). Ozone interacts with PAH aromatic rings due to its electrophilicity, whereas hydroxyl radicals enable non-selective oxidation. Hydrogen peroxide and ferrous salt decompose organic wastewater pollutants efficiently in the Fenton reaction. This method is commonly used to decompose complex organic contaminants (Gaurav et al. 2021). Table 6.4 summarizes various oxidation methods utilized for the elimination of PAHs from industrial wastewater.

Coagulation

Coagulation is a typical way to reduce colloidal suspensions and organic contaminants like PAHs in aqueous solutions. Coagulation and chemical precipitation are efficient methods for water and wastewater treatment, often used in advanced purification technologies (Nowacka and Włodarczyk-Makuła 2015). Alum, aluminum chloride, ferric chloride, and ferric sulfate have been studied as coagulants. Various polymeric coagulants, such as polyaluminium chloride, polyferric chloride, and polyferric sulfate, as well as organic polyelectrolytes such polydiallyldimethyl ammonium chloride and anionic polyacrylamides, have shown efficient in treatment operations (Rosińska and Dąbrowska 2021). Composite inorganic-organic coagulants have been tested. Coagulation is effective yet has several downsides. The procedure produces a lot of putrescible sludge, making handling difficult. Chemical dosing operations are expensive and constraining. Nowacka and Włodarczyk-Makuła (2015) found that coagulation-precipitation procedures had varying PAH removal efficiency. Pyrene, fluoranthene, anthracene, and phenanthrene had elimination efficiencies of 75%, 57%, 40%, and 30%.

Biological Methods

Biological methods have emerged as environmentally friendly alternatives for the remediation of polycyclic aromatic hydrocarbons (PAHs), garnering significant interest due to the limitations of physical and chemical approaches. Traditional approaches frequently encounter issues associated with elevated costs, intricate procedures, strict regulatory standards, and insufficient degradation of pollutants. Biological techniques have been recognized for their potential to achieve efficient and sustainable remediation of PAHs (Sakshi et al. 2019). Table 6.5 presents a comparative overview of the benefits and drawbacks linked to different methods for the removal of PAH from industrial wastewater.

Table 6.4 Different methods of removal of PAHs from industrial waste water

PAHs	Water sample	Method of oxidation	Removal efficacy (%)	Industry	Source
Point source PAHs	Coking wastewater treatment plant	Ozone and ultraviolent	75	Coking industry wastewater	Sun et al. (2019)
8PAHs	Coagulant water	Hydrogen peroxide and ultraviolent	76	Steel industry wastewater	Martínez-Álvarez et al. (2021)
8PAHs	Electro coagulated water	Hydrogen peroxide and ultraviolent	70	Petrochemical and oil refining industries	Ramesh et al. (2022)
8PAHs	Groundwater	Hydrogen peroxide and ultraviolent	76	Textile and dyeing industries	Ijah et al. (2022)
Fluorene	Treated water produced water synthetic wastewater	Hydrogen peroxide and ultraviolent	98	Phosphate fertilizer industry	Ramezanzadeh et al. (2020)
Dibenzofuran	Treated water produced water synthetic wastewater	Hydrogen peroxide and ultraviolent	99	Pulp and paper industry	Han et al. (2022b)
Dibenzothiophene	Treated water produced water synthetic wastewater	Hydrogen peroxide and ultraviolent	99	Coal processing/ combustion	Shen et al. (2020)
15 PAHs hydrocarbons	Water treatment landfill leachate	Fenton reaction	100	Wood preservation plants	Jinadasa et al. (2020)
6 PAHs	Cooking wastewater treatment plant	Hydrogen peroxide and ultraviolent	70	Aluminum smelting and metal foundries	Ansari et al. (2023)

Table 6.5 Summary of advantages and disadvantages all methods of PAHs removal from industrial waste water

Treatment method	Advantages	Disadvantages	Source
Adsorption	Minimal initial expenditure, compact modules, environmentally sustainable, adaptable method, and recyclable and recoverable adsorbent	Regular regeneration is required, influenced by salinity, elevated temperature, maximum retention duration, costly adsorbent restoration, and detrimental excess adsorbent	Sher et al. (2023)
Advanced oxidation process	Effortless operation, significant degradation and solubilize oil minerals	Proficient labour necessary, optimisation, oversight, and preparation processes needed	Wang et al. (2018)
Bioremediation	Access to inexpensive microorganisms, a straightforward method, and complete mineralisation result in the generation of CO_2, H_2O, and biomass	Prolonged deterioration Time and task optimisation is an excessive undertaking	Sher et al. (2023)
Chemical oxidation	Brief treatment duration and environmentally sustainable	Maximum operational and maintenance costs	Wang et al. (2018)
Chemical precipitation	Energy-efficient procedure, user-friendly, economical, and optimal recovery	Demand for chemicals, production of sludge, and ancillary waste	Sher et al. (2023)
Electrochemical technologies	Advantageous byproduct, environmentally sustainable, and devoid of chemical requirements	Essential skilled labour and challenges in scaling	Riley et al. (2018)
Flotation	The operation is straightforward, the integration enhances process efficiency, it is sturdy and durable, and has no moving components	Retention period of 4–5 min, maximum air production, and skim volume	Wang et al. (2018)
Membrane filtration	Cost-effective, reduced likelihood of membrane fouling, compact modules, appropriate for saline water	Mineral scaling, membrane pore wetting, and membrane fouling	Sher et al. (2023)

PAHs undergo degradation via aerobic and anaerobic biological processes. Research indicates that mixed microbial cultures typically exhibit superior performance compared to pure cultures in the biological degradation of less water-soluble PAHs. Comprehensive assessments of wastewater treatment plants utilizing biological treatment methods have demonstrated their effectiveness in eliminating organic compounds. PAH removal in these systems occurs through several mechanisms, including volatilization during aeration, microbial degradation, and adsorption onto sludge. In conventional wastewater treatment plants, volatilization generally accounts for less than 2% of the overall contribution. Effective biodegradation typically necessitates the introduction of specialized microorganisms to improve PAH removal, whereas adsorption is the primary removal mechanism owing to the strong affinity of PAHs for particulate matter (Dai et al. 2022).

Bioreactor

Municipal wastewater treatment plants (MWTPs) treat industrial sewage using biological, physical, and chemical methods to effectively reduce contaminants such as solids, nutrients, and organic pollutants. The objective of these treatments is to reduce ecotoxicity and safeguard the quality of surface and groundwater (Bao et al. 2023). PAHs can undergo biodegradation in both aerobic and anaerobic environments. Baniasadi et al. (2018) demonstrate that lower molecular weight organic pollutants undergo more effective degradation during biological treatment due to their greater biodegradability and transformability relative to higher molecular weight compounds.

Research indicates differing removal efficiencies for PAHs in municipal biological wastewater treatment facilities. Zhao et al. (2021) found that the total removal efficiency of PAHs in summer varied between 63.22 and 63.58%. A separate study indicated that aerobic activated sludge treatment attained a phenanthrene (PHE) removal efficiency ranging from 83 to 97%. Sequencing batch reactors (SBRs) have shown the capacity to eliminate around 55% of PAHs. PAHs such as benzo(ghi)perylene (BghiP), naphthalene (NAP), and pyrene (PYR) showed varying removal rates (Kuyukina et al. 2020).

Phytoremediation

Phytoremediation and bioremediation are effective strategies that employ plants, microorganisms, and enzymes to detoxify contaminated environments, facilitating their restoration to a natural condition without leading to additional harm to nature (Dhara and Dutta 2025). Phytoremediation is an innovative environmental technique that makes use of growing plants in polluted soils, waters to facilitate the removal or degradation pollutants. Some plant species exhibit notable effectiveness, indicating greater efficiency and appropriateness for phytoremediation processes. Bioremediation utilizes biological mechanisms to degrade environmental contaminants via metabolic processes, leading to the production of innocuous byproducts including cell biomass, carbon dioxide, and water. Microbial-based bioremediation for the elimination of PAHs in contaminated with oil areas was initially documented in the mid-twentieth century (Bhatti et al. 2024).

Bioremediation

Microbial Remediation

Bacteria exhibit significant metabolic versatility, enabling them to efficiently degrade PAH pollutants. Anaerobic PAH degradation operates through distinct mechanisms alternative electron acceptors to decompose and cleave aromatic rings

(Sui et al. 2021). Degradation by aerobic mechanisms of PAHs by bacteria primarily entails oxygenase-mediated metabolic pathways, encompassing the functions of monooxygenase and dioxygenase enzymes. The degradation process initiates with dioxygenase enzymes facilitating the hydroxylation of aromatic rings, resulting in the production of cis-dihydrodiol intermediates. The intermediates undergo further oxidation to form diol compounds via the action of dehydrogenase enzymes (Ismail et al. 2022).

Bacteria

Bacteria degrade PAH contaminants via different metabolic pathways due to their metabolic flexibility. When PAHs degrade aerobically, bacteria use O_2 as the ultimate acceptor of electrons to hydroxylate and cleave aromatic rings. Anaerobic PAH degradation decomposes aromatic structures via reductive processes and other electron acceptors (Liu et al. 2017). PAHs degrade aerobically via oxygenase-mediated mechanisms, including monooxygenases and dioxygenases. Dioxygenase enzymes hydroxylate aromatic rings to create cis-dihydrodiol intermediates, starting the degradation process. These intermediates are metabolized to diols by dehydrogenases. Mixed bacterial cultures and consortia, which collaborate on catabolic activities and have many degradation routes, often degrade PAH completely. Recent research has focused on PAH breakdown using mixed bacterial cultures and consortia (Wang et al. 2017). PAH breakdown is successful with immobilized and genetically engineered bacteria. Dispersion of bacterial inocula is a major issue in soil or sediment degradation. In subterranean soils, microbial mobility is limited and cells adhere strongly to soil organic materials, making dispersion difficult (Ismail et al. 2022).

Archaea

Saline environments, especially those linked to oil industries, are particularly vulnerable to petroleum pollution resulting from regular discharges of pollutants, such as PAHs. Extreme conditions frequently require the use of extremophiles, particularly archaea, for efficient bioremediation, given that standard microorganisms may fail to endure or operate effectively in high salinity environments (Patel et al. 2020). Current research has emphasized the crucial function of archaea in the bioremediation of PAHs. Nonetheless, research on their degradation mechanisms and pathways is comparatively sparse when contrasted with bacterial systems (Gou et al. 2022). The archaeon exhibited the ability to break down PAH in environments with elevated salinity (Banerjee et al. 2024).

Emerging Multi-process Remediation Of PAHs

Bioremediation with nanoparticle-based eco-engineering techniques are developing to remove contaminants including PAHs from atmosphere. Refinement is needed to develop functionalized nanoparticles by changing surface characteristics.

Functionalized nanoparticles improve bioremediation effectiveness and applicability by performing many activities. Enzymes, proteins, DNA, humic acids, and biosurfactants are used as functionalizing agents in bionanoremediation to remove petroleum hydrocarbons, including PAHs (Fouda et al. 2021). Nanoscale nanoparticles (NPs) have high reactivity and surface area, which are their principal benefits. Biofunctionalized nanoparticles efficiently remove PAH from polluted settings by nano-adsorption and catalytic degradation (Sam et al. 2023). After treatment, FeHCF NPs converted all PAHs into light weighted, non-hazardous metabolites, proving their photocatalytic and adsorbent properties. Physical, chemical, and biological strategies for PAH removal are successful, but combining them may boost effectiveness, especially for HMW PAHs (Barathi et al. 2023). Integrated remediation technologies overcome the limits of standalone procedures by tackling dead-end product creation, enabling faster environmental cleaning. Physical–biological coupling, chemical–biological coupling, multi-biological remediation, and complete physical–chemical–biological remediation systems have been studied for PAH cleanup (Gou et al. 2022). In the first and second cycles, alkaline precipitation and *Sphingobium* sp. PHE9 inoculation removed of PAHs from washing solvents. This shows how integrated techniques degrade PAHs and restore the ecosystem (Sharma et al. 2024).

PAH Remediation Through Value Added By-products

PAH biodegradation byproducts such biogas, bioelectricity, biosurfactant, and EPS have been studied for practical uses (Sam et al. 2023). Gitipour et al. (2018) used biostimulation to anaerobically degrade PAHs in polluted marine sediments. The study employed biostimulants such fresh organic byproducts from Solid waste from urban areas, digestate, and nutrients to degrade PAH by 55% in 120 days. Biohydrogen production peaked at 80 ml gVS^{-1} on days 3–30 under acidogenic settings, whereas biomethane production peaked at 140 ml gVS^{-1} on days 50–120 under methanogenic conditions. Biomethane production increased beyond 120 days, suggesting biostimulation might increase yields. Biohydrogen is a greener, sustainable fuel cell energy source. Vehicles, home electronics, and portable batteries might utilize it. Biogas, mostly methane, is a sustainable source of energy that may be utilized for heating, electrical production, and engine and turbine fuel. PAH degradation and bioelectricity production have been studied in microbial bioelectrochemical systems with one or more chambers that promote microorganism-mediated anode- and cathode-mediated redox reactions (Kumar et al. 2022). Microorganisms transmit electrons from organic materials to the anode, generating an electric current during deterioration. At the cathode, electrons reduce biotic or abiotic substances to generate electricity. This approach destroys PAHs and generates power, which may address energy needs (Lai et al. 2020). With alternate electron acceptors, biocatalytic mechanisms degrade PAHs better. Scientists created aerobic and anaerobic sediment microbial fuel cells. Anaerobic conditions resulted in degradation rates of 77%, 53%, and 37%, with a power production reduction of 3.6 mW m^{-2}. Biosurfactants and EPSs are produced during PAH decomposition. Amphiphilic biosurfactants produced by various PAH-degrading microorganisms increase PAH bioavailability and degradation efficiency (Sher et al. 2023). Biosurfactants from PAH degraders include rhamnolipids, lipopeptides, glycoproteins, and surfactins. Environmentally friendly biosurfactants are used in food, agriculture, oil, cosmetics, and medicines. They are suitable dispersion agents, emulsifiers, and chemically produced surfactant alternatives due to their excellent foaming ability, low critical micelle concentration, and robust surface activity (Wang et al. 2018).

Combine Treatment Method

High-molecular-weight PAHs may be degraded, solubilized, and removed from water via physical, chemical, and biological techniques. Biodegradation and Fenton oxidation remove PAHs, especially naphthalene and phenanthrene from water. The biodegradation method uses a Bacillus fusiformis (BFN) Fenton oxidation process, whereas strain from activated sludge synthesizes ferrous nanoparticles from tea extract in oxygen, nitrogen, and air (Gitipour et al. 2018). Biologically active filtration using biological and physical processes to remediate oil and gas effluent appears promising. This approach uses river ecosystem microorganisms and nutrients to produce biofilms that can survive high total dissolved solids. Granular activated carbon (GAC) removes organic contaminants and suspended particles well in this method. Integrated physical, chemical, and biological treatments may improve PAH solubilization and degradation. Strong oxidants, adsorption, and membrane technologies remove high-molecular-weight PAHs well (Chen et al. 2016). PAH removal rates in membrane bioreactors for wastewater treatment range from 50 to 100%, with low-molecular-weight PAHs being more efficient (Dai et al. 2022).

Future Outlook

Surface runoff and atmospheric deposition may transport combustion-derived PAHs to wastewater treatment plants. The destiny and behavior of PAHs and their derivatives in wastewater treatment plants are contingent upon physicochemical and environmental factors (Ziyaei et al. 2024). Water has a higher concentration of low molecular weight PAHs (LMW PAHs) than silt. Research indicates that wastewater treatment plant influent mostly contains LMW PAHs with two or three aromatic rings, whereas the effluent primarily consists of compounds with two rings. High Molecular Weight PAHs (HMW PAHs) adhere to sediment more effectively than to water. Sewage discharges LMW PAHs into Rivers, whereas municipal silt used as fertilizer emits HMW PAHs. SPAHs with higher molecular weight accumulate more in sediment (Li et al. 2025). Wastewater treatment plants exhibit insufficient biodegradation of PAHs. Hydrophobic and persistent PAHs adsorb onto soil. Full-scale membrane bioreactor wastewater treatment plants using activated sludge detected PAHs and their derivatives in the influent, effluent, and sludge. These devices degrade PAHs with 90% efficacy, despite their design and operation lacking optimization. To improve the detection of PAH and its derivatives, researchers should investigate trace nitro-PAH detection in complex matrices (Xie et al. 2025). Microbial activity requires investigation since PAHs may impede wastewater treatment plant (WWTP) efficacy. Certain wastewater treatment plants contravene regulations. The European Commission restricts sediment PAHs to 6000 ng/g prior to cropping. Improving pulmonary arterial hypertension treatment systems is essential research. PAH remediation strategies are chosen based on economic viability and ecological sustainability (Smetanová et al. 2025). Biotherapies are advantageous since they exhibit prolonged efficacy compared to physical and chemical treatments. Temperature, nutrient availability, aeration, and organic input rates influence microbial activity, hence affecting these processes. Wastewater treatment plants use biological techniques to eliminate PAHs, including anaerobic and anoxic treatments, albeit their effectiveness is limited (He et al. 2025). Research indicates that these circumstances reduce LMW PAHs by 35–52.9%. Seasonal and deleterious compounds in wastewater treatment plants may impair biological treatment efficacy, resulting in consistency challenges. Organic constituents, fungal immobilization, and substrate preparation enhance the deterioration of PAHs in soil. Ligninolytic fungi enhance biodegradation and microbial activity. Soil pH, temperature, and moisture influence biodegradation. Microbial activities operate most effectively in a pH range of 6.5–7.5. Beer grains and organic soil have the ability to decompose PAHs (Wu et al. 2025). Unidentified variables generate these outcomes. In sorption studies, lignin has superior binding affinity for pyrene compared to cellulose or hemicellulose. Phenol increases lignin pyrene sorption while decreasing cellulose and hemicellulose levels. Immobilization of lignocellulosic and PAH-degrading enzymes enhances PAH degradation. It is necessary to test these therapies in intricate hydrocarbon-contaminated environments (Zhao et al. 2025). This study should expand and evaluate the use of these approaches. The use of mushroom compost, charcoal, and distillery grains may facilitate the degradation of PAH. Laboratory investigations are promising; yet, empirical field studies are requisite. The bioavailability and degradation of PAH are enhanced by the water solubility of surfactants and the lowering of interfacial tension. Prolonged contact between soil and PAHs reduces enzyme activity, suggesting that surfactants may maintain enzyme functionality. Investigate white-rot fungi that decompose polycyclic aromatic hydrocarbons and lignocellulose in contaminated soils (Sayed et al. 2025).

Conclusion

This chapter examines PAHs and their alterations in extensive treatment of wastewater facilities. Their behavior, destiny, methods of analysis, biological therapies, viability evaluations approaches are discussed. The conversion of PAHs in WWTP has been hardly researched. Prior studies have shown that PAHs in industrial effluents may vary in concentration and often exceed permissible environmental threshold values. In a case study, concentrations of naphthalene, phenanthrene, and pyrene are documented in effluent from coke oven facilities, where levels of 50–300 μg/L of these compounds have been achieved by production processes and treatment methods. Petroleum refinery effluents may have benzo[a]pyrene concentrations reaching 15 mg/L, far above the WHO value of regulations of 0.7 mg/L for drinking water use. Furthermore, the concentrations of cumulative PAHs in surface waters receiving untreated or partly treated wastewater often exceed 500 μg/L, resulting in environmental contamination and bioaccumulation of PAHs in aquatic organisms. Many developing countries, although having regulatory frameworks and environmental standards like to those of the US EPA and EU, do not implement rigorous procedures and lack adequate technology for the removal of PAH. Conventional techniques for treatment like sedimentation and filtering are not always enough; thus, sophisticated procedures like adsorption, advanced oxidation processes, and bioremediation must be used to progressively eradicate them. In summary, the existence of PAHs in industrial wastewater is a critical issue that needs both immediate and long-term remedies. Addressing the issue not only safeguards ecological integrity but also improves public health and aligns industrial growth with principles of effective environmental management.

References

Abdel-Shafy, H.I., Mansour, M.S.: A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation. Egypt. J. Pet. **25**(1), 107–123 (2016)

Abdullah, S.R.S., Al-Baldawi, I.A., Almansoory, A.F., Purwanti, I.F., Al-Sbani, N.H., Sharuddin, S.S.N.: Plant-assisted remediation of hydrocarbons in water and soil: application, mechanisms, challenges and opportunities. Chemosphere **247**, 125932 (2020)

Adeniji, A.O., Okaiyeto, K., George, M.J., Tanor, E.B., Semerjian, L., Okoh, A.I.: A systematic assessment of research trends on polycyclic aromatic hydrocarbons in different environmental compartments using bibliometric parameters. Environ. Geochem. Health **45**(5), 1289–1309 (2023)

Akinpelumi, V.K., Kumi, K.G., Onyena, A.P., Sam, K., Ezejiofor, A.N., Frazzoli, C., Ekhator, O.C., Udom, G.J., Orisakwe, O.E.: A comparative study of the impacts of polycyclic aromatic hydrocarbons in water and soils in Nigeria and Ghana: towards a framework for public health protection. J. Hazard. Mater. Adv. **11**, 100336 (2023)

Al Farraj, D.A., Hadibarata, T., Yuniarto, A., Syafiuddin, A., Surtikanti, H.K., Elshikh, M.S., Al Khulaifi, M.M., Al-Kufaidy, R.: Characterization of pyrene and chrysene degradation by halophilic Hortaea sp. B15. Bioprocess Biosyst. Eng. **42**, 963–969 (2019)

Alao, M.B., Adebayo, E.A.: Fungi as veritable tool in bioremediation of polycyclic aromatic hydrocarbons-polluted wastewater. J. Basic Microbiol. **62**(3–4), 223–244 (2022)

Ansari, F., Ahmad, A., Rafatullah, M.: Review on bioremediation technologies of polycyclic aromatic hydrocarbons (PAHs) from soil: mechanisms and future perspective. Int. Biodeterior. Biodegrad. **179**, 105582 (2023)

Banerjee, S., Gupta, N., Pramanik, K., Gope, M., GhoshThakur, R., Karmakar, A., Gogoi, N., Hoque, R.R., Mandal, N.C., Balachandran, S.: Microbes and microbial strategies in carcinogenic polycyclic aromatic hydrocarbons remediation: a systematic review. Environ. Sci. Pollut. Res. **31**(2), 1811–1840 (2024)

Baniasadi, M., Mousavi, S.M., Zilouei, H., Shojaosadati, S.A., Rastegar, S.O.: Statistical evaluation and process optimization of biotreatment of polycyclic aromatic hydrocarbons in a bioreactor. Environ. Eng. Manag. J. **17**(8), 1869–1877 (2018)

Bao, S., Zhao, L., Liu, Y., Yang, L., Liu, P., Chen, C., Mao, X.: Influencing factors of bioaugmentation treatment of PAH-contaminated soils in slurry bioreactors. J. Environ. Chem. Eng. **11**(3), 109893 (2023)

Barathi, S., Gitanjali, J., Rathinasamy, G., Sabapathi, N., Aruljothi, K.N., Lee, J., Kandasamy, S.: Recent trends in polycyclic aromatic hydrocarbons pollution distribution and counteracting bioremediation strategies. Chemosphere **337**, 139396 (2023)

Berardi, C., Fibbi, D., Coppini, E., Renai, L., Caprini, C., Scordo, C.V.A., Checchini, L., Orlandini, S., Bruzzoniti, M.C., Del Bubba, M.: Removal efficiency and mass balance of polycyclic aromatic hydrocarbons, phthalates, ethoxylated alkylphenols and alkylphenols in a mixed textile-domestic wastewater treatment plant. Sci. Total. Environ. **674**, 36–48 (2019)

Bhatti, S.S., Bhatia, A., Bhagat, G., Singh, S., Dhaliwal, S.S., Sharma, V., Verma, V., Yin, R., Singh, J.: PAHs in terrestrial environment and their phytoremediation. In: Bioremediation for Sustainable Environmental Cleanup, pp. 67–85. CRC Press (2024)

Bis, M., Montusiewicz, A., Piotrowicz, A., Łagód, G.: Modeling of wastewater treatment processes in membrane bioreactors compared to conventional activated sludge systems. Processes **7**(5), 285 (2019)

Bokade, P., Bajaj, A.: Molecular advances in mycoremediation of polycyclic aromatic hydrocarbons: exploring fungal bacterial interactions. J. Basic Microbiol. **63**(3–4), 239–256 (2023)

Borji, H., Ayoub, G.M., Al-Hindi, M., Malaeb, L., Hamdan, H.Z.: Nanotechnology to remove polychlorinated biphenyls and polycyclic aromatic hydrocarbons from water: a review. Environ. Chem. Lett. **18**, 729–746 (2020)

Cao, W., Qiao, M., Liu, B., Zhao, X.: Occurrence of parent and substituted polycyclic aromatic hydrocarbons in typical wastewater treatment plants and effluent receiving rivers of Beijing, and risk assessment. J. Environ. Sci. Health Part A **53**(11), 992–999 (2018)

Chen, F., Tan, M., Ma, J., Zhang, S., Li, G., Qu, J.: Efficient remediation of PAH-metal co-contaminated soil using microbial-plant combination: a greenhouse study. J. Hazard. Mater. **302**, 250–261 (2016)

Chen, C.F., Ju, Y.R., Lim, Y.C., Hsieh, S.L., Tsai, M.L., Sun, P.P., Katiyar, R., Chen, C.W., Dong, C.D.: Determination of polycyclic aromatic hydrocarbons in sludge from water and wastewater treatment plants by GC-MS. Int. J. Environ. Res. Public Health **16**(14), 2604 (2019)

Dai, C., Han, Y., Duan, Y., Lai, X., Fu, R., Liu, S., Leong, K.H., Tu, Y., Zhou, L.: Review on the contamination and remediation of polycyclic aromatic hydrocarbons (PAHs) in coastal soil and sediments. Environ. Res. **205**, 112423 (2022)

de Andrade, J.R., Oliveira, M.F., Canevesi, R.L.S., Landers, R., da Silva, M.G.C., Vieira, M.G.A.: Comparative adsorption of diclofenac sodium and losartan potassium in organophilic clay-packed fixed-bed: X-ray photoelectron spectroscopy characterization, experimental tests and theoretical study on DFT-based chemical descriptors. J. Mol. Liq. **312**, 113427 (2020)

Dhara, A., Dutta, R.: A review on sources and distribution of polycyclic aromatic hydrocarbons (PAHs) in wetland ecosystem: focusing on plant-biomonitoring and phytoremediation. Environ. Sci. Pollut. Res. 1–23 (2025)

Fouda, A., Hassan, S.E.D., Saied, E., Azab, M.S.: An eco-friendly approach to textile and tannery wastewater treatment using maghemite nanoparticles (γ-Fe2O3-NPs) fabricated by Penicillium expansum strain (Kw). J. Environ. Chem. Eng. **9**(1), 104693 (2021)

García, J., García-Galán, M.J., Day, J.W., Boopathy, R., White, J.R., Wallace, S., Hunter, R.G.: A review of emerging organic contaminants (EOCs), antibiotic resistant bacteria (ARB), and antibiotic resistance genes (ARGs) in the environment: Increasing removal with wetlands and reducing environmental impacts. Bioresour. Technol. **307**, 123228 (2020)

Gaurav, G.K., Mehmood, T., Kumar, M., Cheng, L., Sathishkumar, K., Kumar, A., Yadav, D.: Review on polycyclic aromatic hydrocarbons (PAHs) migration from wastewater. J. Contam. Hydrol. **236**, 103715 (2021)

Gbeddy, G., Goonetilleke, A., Ayoko, G.A., Egodawatta, P.: Transformation and degradation of polycyclic aromatic hydrocarbons (PAHs) in urban road surfaces: influential factors, implications and recommendations. Environ. Pollut. **257**, 113510 (2020)

Ghasemi, N., Zare, F., Davari, P., Vilathgamuwa, M., Ghosh, A., Langton, C., Weber, P.: Dissimilar trend of nonlinearity in ultrasound transducers and systems at resonance and non-resonance frequencies. Ultrasonics **74**, 21–29 (2017)

Ghosal, D., Ghosh, S., Dutta, T.K., Ahn, Y.: Current state of knowledge in microbial degradation of polycyclic aromatic hydrocarbons (PAHs): a review. Front. Microbiol. **7**, 1369 (2016)

Gitipour, S., Sorial, G.A., Ghasemi, S., Bazyari, M.: Treatment technologies for PAH-contaminated sites: a critical review. Environ. Monit. Assess. **190**, 1–17 (2018)

Gou, Y., Song, Y., Yang, S., Yang, Y., Cheng, Y., Li, J., Zhang, T., Cheng, Y., Wang, H.: Polycyclic aromatic hydrocarbon removal from subsurface soil mediated by bacteria and archaea under methanogenic conditions: performance and mechanisms. Environ. Pollut. **313**, 120023 (2022)

Gupta, H.: PAH determination in effluent and sludge samples of paper industry. Environ. Technol. Innov. **9**, 115–121 (2018)

Gupta, H., Gupta, B.: Photocatalytic degradation of polycyclic aromatic hydrocarbon benzo[a]pyrene by iron oxides and identification of degradation products. Chemosphere **138**, 924–931 (2015)

Gupta, H., Gupta, B.: Adsorption of polycyclic aromatic hydrocarbons on banana peel activated carbon. Desalination Water Treat. **57**(20), 9498–9509 (2016)

Han, N., Wang, S., Rana, A.K., Asif, S., Klemeš, J.J., Bokhari, A., Long, J., Thakur, V.K., Zhao, X.: Rational design of boron nitride with different dimensionalities for sustainable applications. Renew. Sustain. Energy Rev. **170**, 112910 (2022a)

Han, N., Feng, S., Guo, W., Mora, O.M., Zhao, X., Zhang, W., Xie, S., Zhou, Z., Liu, Z., Liu, Q., Wan, K.: Rational design of Ruddlesden–Popper perovskite electrocatalyst for oxygen reduction to hydrogen peroxide. SusMat **2**(4), 456–465 (2022b)

Haneef, T., Ul Mustafa, M.R., Rasool, K., Ho, Y.C., Mohamed Kutty, S.R.: Removal of polycyclic aromatic hydrocarbons in a heterogeneous Fenton like oxidation system using nanoscale zero-valent iron as a catalyst. Water **12**(9), 2430 (2020)

He, Y., Yang, C., He, W., Xu, F.: Nationwide health risk assessment of juvenile exposure to polycyclic aromatic hydrocarbons (PAHs) in the water body of Chinese lakes. Sci. Total. Environ. **723**, 138099 (2020)

He, H., Ren, R., Jin, Q., Gong, L., Zhang, L., Xue, M., Fan, J., Wang, S.: Occurrence of EU-priority polycyclic aromatic hydrocarbons in edible oils and associated with human health risks in Hangzhou city of China. J. Food Compos. Anal. 107834 (2025)

Ijah, U.J.J., Musa, I.O., Amao, F., Maude, A.M., Victor-Ekwebelem, M.O.: Wastewater quality and unhygienic practices in Minna abattoir, North Central Nigeria. Sci. World J. **17**(2), 332–337 (2022)

Ismail, N.A., Kasmuri, N., Hamzah, N.: Microbial bioremediation techniques for polycyclic aromatic hydrocarbon (PAHs)—a review. Water Air Soil Pollut. **233**(4), 124 (2022)

Jackulin, F., Chitra, B., Karthick, S., Rangasamy, G.: A review on recent advancements in the treatment of polyaromatic hydrocarbons (PAHs) using sulfate radicals based advanced oxidation process. Environ. Res. 119124 (2024)

Jalili, V., Barkhordari, A., Ghiasvand, A.: Solid-phase microextraction technique for sampling and preconcentration of polycyclic aromatic hydrocarbons: a review. Microchem. J. **157**, 104967 (2020)

Jinadasa, B.K.K.K., Monteau, F., Fowler, S.W.: Review of polycyclic aromatic hydrocarbons (PAHs) in fish and fisheries products; a Sri Lankan perspective. Environ. Sci. Pollut. Res. **27**, 20663–20674 (2020)

Kong, X., Zhang, J., Ji, Q., Li, C., Chen, X., Cao, X., Zhu, F., Yang, S., Li, S., He, H.: Insights into adsorption mechanisms of nitro polycyclic aromatic hydrocarbons on common microplastic particles: experimental studies and modeling. Chemosphere **320**, 138050 (2023)

Kouras, A., Manoli, E., Avgenikou, A., Paraschaki, A., Voutsa, D., Samara, C., Foska, E.: Inhalation health risk assessment in the port of Volos, Greece, based on multiannual evolution of PM10-bound polycyclic aromatic hydrocarbons and metals/metalloids: implications for EU-regulated PM10 pollutants. Atmos. Environ. 121348 (2025)

Krishnan, S., Rawindran, H., Sinnathambi, C.M., Lim, J.W.: Comparison of various advanced oxidation processes used in remediation of industrial wastewater laden with recalcitrant pollutants. In: IOP Conference Series: Materials Science and Engineering, vol. 206, no. 1, p. 012089. IOP Publishing (2017)

Kumar, V.V., Venkataraman, S., Kumar, P.S., George, J., Rajendran, D.S., Shaji, A., Lawrence, N., Saikia, K., Rathankumar, A.K.: Laccase production by Pleurotus ostreatus using cassava waste and its application in remediation of phenolic and polycyclic aromatic hydrocarbon-contaminated lignocellulosic biorefinery wastewater. Environ. Pollut. **309**, 119729 (2022)

Kuppusamy, S., Thavamani, P., Venkateswarlu, K., Lee, Y.B., Naidu, R., Megharaj, M.: Remediation approaches for polycyclic aromatic hydrocarbons (PAHs) contaminated soils: technological constraints, emerging trends and future directions. Chemosphere **168**, 944–968 (2017)

Kuyukina, M.S., Krivoruchko, A.V., Ivshina, I.B.: Advanced bioreactor treatments of hydrocarbon-containing wastewater. Appl. Sci. **10**(3), 831 (2020)

Lai, X., Ning, X.A., Chen, J., Li, Y., Zhang, Y., Yuan, Y.: Comparison of the Fe2+/H2O2 and Fe2+/PMS systems in simulated sludge: removal of PAHs, migration of elements and formation of chlorination by-products. J. Hazard. Mater. **398**, 122826 (2020)

Lamichhane, S., Krishna, K.B., Sarukkalige, R.: Polycyclic aromatic hydrocarbons (PAHs) removal by sorption: a review. Chemosphere **148**, 336–353 (2016)

Li, R., Shen, Y., Shao, Y., Gao, Y., Yao, Z., Liu, Q., Liu, X., Shi, G.: Measurement Report: Polycyclic Aromatic Hydrocarbons (PAHs) and Their Alkylated (RPAHs), Nitrated (NPAHs) and Oxygenated (OPAHs) Derivatives in the Global Marine Atmosphere: Occurrence, Spatial Variations, and Source Apportionment, pp. 1–22. EGUsphere (2025)

Liu, S.H., Zeng, G.M., Niu, Q.Y., Liu, Y., Zhou, L., Jiang, L.H., Tan, X.F., Xu, P., Zhang, C., Cheng, M.: Bioremediation mechanisms of combined pollution of PAHs and heavy metals by bacteria and fungi: a mini review. Bioresour. Technol. **224**, 25–33 (2017)

Ma, Y., Liu, A., Egodawatta, P., McGree, J., Goonetilleke, A.: Quantitative assessment of human health risk posed by polycyclic aromatic hydrocarbons in urban road dust. Sci. Total. Environ. **575**, 895–904 (2017)

Mahmoud, A.E.D.: Nanomaterials: green synthesis for water applications. In: Handbook of Nanomaterials and Nanocomposites for Energy and Environmental Applications, pp. 1–21 (2020)

Man, Y.B., Chow, K.L., Cheng, Z., Mo, W.Y., Chan, Y.H., Lam, J.C.W., Lau, F.T.K., Fung, W.C., Wong, M.H.: Profiles and removal efficiency of polycyclic aromatic hydrocarbons by two different types of sewage treatment plants in Hong Kong. J. Environ. Sci. **53**, 196–206 (2017)

Mannina, G., Cosenza, A., Rebouças, T.F.: A plant-wide modelling comparison between membrane bioreactors and conventional activated sludge. Bioresour. Technol. **297**, 122401 (2020)

Martínez-Álvarez, I., Le Menach, K., Devier, M.H., Barbarin, I., Tomovska, R., Cajaraville, M.P., Budzinski, H., Orbea, A.: Uptake and effects of graphene oxide nanomaterials alone and in combination with polycyclic aromatic hydrocarbons in zebrafish. Sci. Total. Environ. **775**, 145669 (2021)

Mirzaee, E., Sartaj, M.: Activated carbon-based magnetic composite as an adsorbent for removal of polycyclic aromatic hydrocarbons from aqueous phase: characterization, adsorption kinetics and isotherm studies. J. Hazard. Mater. Adv. **6**, 100083 (2022)

Montano, L., Baldini, G.M., Piscopo, M., Liguori, G., Lombardi, R., Ricciardi, M., Esposito, G., Pinto, G., Fontanarosa, C., Spinelli, M., Palmieri, I.: Polycyclic aromatic hydrocarbons (PAHs) in the environment: occupational exposure, health risks and fertility implications. Toxics **13**(3), 151 (2025)

Mortazavi, M., Baghdadi, M., Javadi, N.H.S., Torabian, A.: The black beads produced by simultaneous thermal reducing and chemical bonding of graphene oxide on the surface of amino-functionalized sand particles: application for PAHs removal from contaminated waters. J. Water Process. Eng. **31**, 100798 (2019)
Mukwevho, N., Gusain, R., Fosso-Kankeu, E., Kumar, N., Waanders, F., Ray, S.S.: Removal of naphthalene from simulated wastewater through adsorption-photodegradation by ZnO/Ag/GO nanocomposite. J. Ind. Eng. Chem. **81**, 393–404 (2020)
Muthukumar, H., Shanmugam, M.K., Gummadi, S.N.: Caffeine degradation in synthetic coffee wastewater using silverferrite nanoparticles fabricated via green route using Amaranthus blitum leaf aqueous extract. J. Water Process. Eng. **36**, 101382 (2020)
Nasrollahzadeh, M., Sajjadi, M., Iravani, S., Varma, R.S.: Green-synthesized nanocatalysts and nanomaterials for water treatment: current challenges and future perspectives. J. Hazard. Mater. **401**, 123401 (2021)
Nowacka, A., Włodarczyk-Makuła, M.: Effectiveness of priority PAH removal in a water coagulation process. Water Sci. Technol. Water Supply **15**(4), 683–692 (2015)
Omolola, A.H., Ogunmoroti, E.A., Ayoola, P.B., Adedosu, T.A.: Assessment of physicochemical properties and polycyclic aromatic hydrocarbons (PAHs) in wastewater from New Atenda Abattoir, Ogbomoso and its environmental impacts. Int. J. Sci. Res. Technol. **3**(01) (2025)
Pandey, N., Gusain, R., Suthar, S.: Exploring the efficacy of powered guar gum (Cyamopsis tetragonoloba) seeds, duckweed (Spirodela polyrhiza), and Indian plum (Ziziphus mauritiana) leaves in urban wastewater treatment. J. Clean. Prod. **264**, 121680 (2020)
Patel, A.B., Shaikh, S., Jain, K.R., Desai, C., Madamwar, D.: Polycyclic aromatic hydrocarbons: sources, toxicity, and remediation approaches. Front. Microbiol. **11**, 562813 (2020)
Pathak, S., Sakhiya, A.K., Anand, A., Pant, K.K., Kaushal, P.: A state-of-the-art review of various adsorption media employed for the removal of toxic polycyclic aromatic hydrocarbons (PAHs): an approach towards a cleaner environment. J. Water Process. Eng. **47**, 102674 (2022)
Pulleyblank, C., Cipullo, S., Campo, P., Kelleher, B., Coulon, F.: Analytical progress and challenges for the detection of oxygenated polycyclic aromatic hydrocarbon transformation products in aqueous and soil environmental matrices: a review. Crit. Rev. Environ. Sci. Technol. **49**(5), 357–409 (2019)
Qiao, M., Bai, Y., Cao, W., Huo, Y., Zhao, X., Liu, D., Li, Z.: Impact of secondary effluent from wastewater treatment plants on urban rivers: polycyclic aromatic hydrocarbons and derivatives. Chemosphere **211**, 185–191 (2018)
Qiao, M., Fu, L., Cao, W., Bai, Y., Huang, Q., Zhao, X.: Occurrence and removal of polycyclic aromatic hydrocarbons and their derivatives in an ecological wastewater treatment plant in South China and effluent impact to the receiving river. Environ. Sci. Pollut. Res. **26**, 5638–5644 (2019)
Ramesh, A., Harris, K.J., Archibong, A.E.: Reproductive toxicity of polycyclic aromatic hydrocarbons. In: Reproductive and Developmental Toxicology, pp. 759–778. Academic Press (2022)
Ramezanzadeh, M., Bahlakeh, G., Ramezanzadeh, B.: Green synthesis of reduced graphene oxide nanosheets decorated with zinc-centered metal-organic film for epoxy-ester composite coating reinforcement: DFT-D modeling and experimental explorations. J. Taiwan Inst. Chem. Eng. **114**, 311–330 (2020)
Rayaroth, M.P., Marchel, M., Boczkaj, G.: Advanced oxidation processes for the removal of mono and polycyclic aromatic hydrocarbons—a review. Sci. Total. Environ. **857**, 159043 (2023)
Ren, J., Li, J., Li, J., Chen, Z., Cheng, F.: Tracking multiple aromatic compounds in a full-scale coking wastewater reclamation plant: interaction with biological and advanced treatments. Chemosphere **222**, 431–439 (2019)
Riley, S.M., Ahoor, D.C., Regnery, J., Cath, T.Y.: Tracking oil and gas wastewater-derived organic matter in a hybrid biofilter membrane treatment system: a multi-analytical approach. Sci. Total. Environ. **613**, 208–217 (2018)
Rosińska, A., Dąbrowska, L.: Influence of type and dose of coagulants on effectiveness of PAH removal in coagulation water treatment. Water Sci. Eng. **14**(3), 193–200 (2021)

Safo-Adu, G., Attiogbe, F., Emahi, I., Ofosu, F.G.: A review of the sources, distribution sequences, and health risks associated with exposure to atmospheric polycyclic aromatic hydrocarbons. Cogent Eng. **10**(1), 2199511 (2023)

Sakshi, Singh, S.K., Haritash, A.K.: Polycyclic aromatic hydrocarbons: soil pollution and remediation. Int. J. Environ. Sci. Technol. **16**, 6489–6512 (2019)

Sam, K., Onyena, A.P., Zabbey, N., Odoh, C.K., Nwipie, G.N., Nkeeh, D.K., Osuji, L.C., Little, D.I.: Prospects of emerging PAH sources and remediation technologies: insights from Africa. Environ. Sci. Pollut. Res. **30**(14), 39451–39473 (2023)

Satouh, S., Martín, J., Orta, M.D.M., Medina-Carrasco, S., Messikh, N., Bougdah, N., Santos, J.L., Aparicio, I., Alonso, E.: Adsorption of polycyclic aromatic hydrocarbons by natural, synthetic and modified clays. Environments **8**(11), 124 (2021)

Sayara, T., Sánchez, A.: Bioremediation of PAH-contaminated soils: process enhancement through composting/compost. Appl. Sci. **10**(11), 3684 (2020)

Sayed, F.A., Eid, M.H., El-Sherbeeny, A.M., Abdel-Gawad, G.I., Mohamed, E.A., Abukhadra, M.R.: Environmental and health risk assessment of polycyclic aromatic hydrocarbons and toxic elements in the Red Sea using Monte Carlo simulation. Sci. Rep. **15**(1), 4122 (2025)

Sharma, S., Shaikh, S., Mohana, S., Desai, C., Madamwar, D.: Current trends in bioremediation and bio-integrated treatment of petroleum hydrocarbons. Environ. Sci. Pollut. Res. **31**(46), 57397–57416 (2024)

Shen, X., Zhang, J., Xie, H., Hu, Z., Liang, S., Ngo, H.H., Guo, W., Chen, X., Fan, J., Zhao, C.: Intensive removal of PAHs in constructed wetland filled with copper biochar. Ecotoxicol. Environ. Saf. **205**, 111028 (2020)

Sher, S., Waseem, M., Leta, M.K.: Review of techniques for the removal of polycyclic aromatic hydrocarbons from produced water. Environments **10**(3), 40 (2023)

Singh, S., Parveen, N., Gupta, H.: Adsorptive decontamination of rhodamine-B from water using banana peel powder: a biosorbent. Environ. Technol. Innov. **12**, 189–195 (2018)

Singh, S., Kumar, A., Gupta, H.: Activated banana peel carbon: a potential adsorbent for Rhodamine B decontamination from aqueous system. Appl. Water Sci. **10**, 185 (2020)

Smetanová, S., Jbebli, A., Kohoutek, J., Puklová, V., Černá, M., Krsková, A., Zvonař, M., Reguli, Z., Andrýsková, L., Piler, P., Přibylová, P.: Changing pattern of exposure to polycyclic aromatic hydrocarbons over time in the Central European population. J. Expo. Sci. Environ. Epidemiol. 1–15 (2025)

Sui, X., Wang, X., Li, Y., Ji, H.: Remediation of petroleum-contaminated soils with microbial and microbial combined methods: advances, mechanisms, and challenges. Sustainability **13**(16), 9267 (2021)

Sun, S.J., Zhao, Z.B., Li, B., Ma, L.X., Fu, D.L., Sun, X.Z., Thapa, S., Shen, J.M., Qi, H., Wu, Y.N.: Occurrence, composition profiles and risk assessment of polycyclic aromatic hydrocarbons in municipal sewage sludge in China. Environ. Pollut. **245**, 764–770 (2019)

Wang, J., Liu, J., Ling, W., Huang, Q., Gao, Y.: Composite of PAH-degrading endophytic bacteria reduces contamination and health risks caused by PAHs in vegetables. Sci. Total. Environ. **598**, 471–478 (2017)

Wang, L., Chen, L., Tsang, D.C., Li, J.S., Yeung, T.L., Ding, S., Poon, C.S.: Green remediation of contaminated sediment by stabilization/solidification with industrial by-products and CO2 utilization. Sci. Total. Environ. **631**, 1321–1327 (2018)

Wei, C., Bandowe, B.A.M., Han, Y., Cao, J., Zhan, C., Wilcke, W.: Polycyclic aromatic hydrocarbons (PAHs) and their derivatives (alkyl-PAHs, oxygenated-PAHs, nitrated-PAHs and azaarenes) in urban road dusts from Xi'an, Central China. Chemosphere **134**, 512–520 (2015)

Wu, D.D., Wei, N.N., Zhang, C.G., Yue, X.Z., Li, H., Zhang, W.Y., Jia, X.R., Zhu, J.K., Zhang, W.Q., Fan, Y.C., Yang, S.M.: Long-term atmosphere surveillance (2017–2022) of PM2. 5-bound polycyclic aromatic hydrocarbons and health risk assessment in a typical city in Northern China. BMC Public Health **25**(1), 1888 (2025)

Xie, J., Lan, R., Zhang, L., Yu, J., Liu, X., You, Z., Yang, F., Lin, T.: Global occurrence, food web transfer, and human health risks of polycyclic aromatic hydrocarbons in biota. Sci. Total. Environ. **958**, 177969 (2025)

Yang, X., Li, Z., Liu, Y., Xing, Y., Wei, J., Yang, B., Zhang, C., Yang, R.T., Tsai, C.J.: Research progress of gaseous polycyclic aromatic hydrocarbons purification by adsorption. Aerosol Air Qual. Res. **19**(4), 911–924 (2019)

Yemele, O.M., Zhao, Z., Nkoh, J.N., Ymele, E., Usman, M.: A systematic review of polycyclic aromatic hydrocarbon pollution: a combined bibliometric and mechanistic analysis of research trend toward an environmentally friendly solution. Sci. Total. Environ. **926**, 171577 (2024)

Zhao, C., Xu, J., Shang, D., Zhang, Y., Zhang, J., Xie, H., Kong, Q., Wang, Q.: Application of constructed wetlands in the PAH remediation of surface water: a review. Sci. Total. Environ. **780**, 146605 (2021)

Zhao, J.Y., Liu, Y., Shang, N.: Analysis of the potential disease burden of occupational polycyclic aromatic hydrocarbons exposure-associated lung cancer in China from 1990 to 2021. Chin. J. Ind. Hyg. Occup. Dis. **43**(6), 430–434 (2025)

Ziyaei, K., Mokhtari, M., Hashemi, M., Rezaei, K., Abdi, F.: Association between exposure to water sources contaminated with polycyclic aromatic hydrocarbons and cancer risk: a systematic review. Sci. Total. Environ. 171261 (2024)