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Recent trends in polycyclic aromatic hydrocarbons pollution distribution and counteracting bio-remediation strategies

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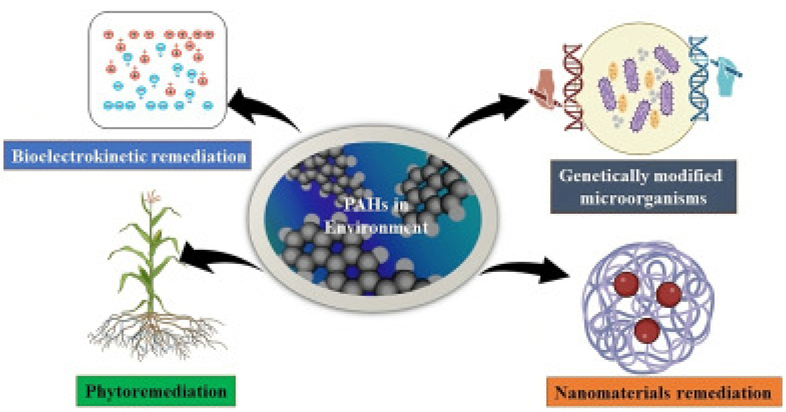
Highlights

- The overall toxicity of PAHs from environmental sources was reviewed.
- The toxicity effect of PAHs on soil, plants, waterbodies, and human health was debated.
- Various approaches and methods are explained for removing PAHs from the environment.
- Suggested techniques to clean up the PAHs polluted sites and improve quality.

Abstract

Polycyclic aromatic hydrocarbons (PAHs) are distributed worldwide due to long-term anthropogenic pollution sources. PAHs are recalcitrant and highly persistent in the environment due to their inherent properties, such as heterocyclic aromatic ring structures, thermostability, and hydrophobicity. They are highly toxic, carcinogenic, immunotoxic, teratogenic, and mutagenic to various life systems. This review focuses on the unique data of PAH sources, exposure routes, detection techniques, and harmful effects on the environment and human health. This review provides a comprehensive and systematic compilation of eco-friendly biological treatment solutions for PAH remediation, such as microbial remediation approaches utilizing microbial cultures. I*n situ* and *Ex situ* bioremediation of PAH methods, including composting land farming, biopiles, bioreactors bioaugmentation, and phytoremediation processes, are discussed in detail, as is a summary of the factors affecting and limiting PAH bioremediation. This review provides an overview of emerging technologies that use multi-process combinatorial treatment approaches and answers to generating value-added by-products during PAH remediation.

Graphical abstract



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Introduction

Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds with multiple aromatic rings (cyclic structures containing carbon and hydrogen atoms) bonded together. PAHs can be found in natural and artificial sources, such as coal, oil, and gas, as well as in car exhaust and tobacco smoke (Faboya et al., 2020). They can also be formed while burning organic matter, such as wood or food. The constant PAH inflow due to rapid urbanization and rising energy demand seriously threatens the lake ecosystem. Compared with any other class of non-halogenated compounds in the ecosphere and biosphere, PAHs have the broadest range of structural variations in nature.

Additionally, the concentrations of these hydrocarbons in water and sediment will keep rising with continued oil production and motor vehicle emissions. PAHs perish in the environment by evaporation, photo-oxidation, advanced oxidation processes, adsorption on soil particles, and leaching (Bhalla et al., 2022). They are difficult to break down in natural matrices, and as their molecular weight increases, so does their persistence. Some PAHs are considered potentially carcinogenic to humans, toxic to aquatic life, and can negatively affect the environment by bio-accumulation in the food chain (He et al., 2021).

Numerous case studies demonstrated that anthracene, a type of PAH, is not carcinogenic but becomes toxic when combined with other PAHs (Marzuki et al., 2021). Due to its hydrophobicity, it can accumulate in the environment swiftly. Anthracene causes nose and eye irritation, lung inflammation, and, in some cases, cause cancer when it is crushed. When anthracene enters the body, it damages the stomach, lymphatic system, skin, and intestines, initiating burning, edema, and itching. However, it can be biodegraded rapidly in soil with light (Bibi et al., 2018). This property may be of importance while developing novel techniques of bioremediation.

Nonetheless, only a few studies have shown that it can biologically remove PAHs from aqueous media (Muralidharan et al., 2023). Notably, a lot of naphthalene, the simplest compound, is made from heavy petroleum in a petroleum refinery. It is perilous and only slightly soluble in water. Red blood cells exposed to high naphthalene concentrations could lead to hemolysis, eventually leading to hemolytic anemia. The signs of this illness include weakness, anorexia, restlessness, and pale skin. Importantly, exposure to naphthalene in high amounts develops tumors in animals and humans (F. Wang et al., 2022).

It is vital to minimalize the adverse effects of PAHs on the environment, and several approaches are available to reduce polycyclic aromatic hydrocarbon. Microbial degradation is the primary method for eliminating PAHs and xenobiotics (Dai et al., 2022). Microbial degradation can efficiently remove PAHs by metabolizing and removing PAHs from the environment using microorganisms such as bacteria and fungi from water and soil (Sharma, 2022a). The process of microbial degradation of PAHs is mediated by microbial hydroxylases, which convert PAHs into more water-soluble and less toxic compounds that can be further degraded by other microorganisms (Ghosal et al., 2016). The utilization of coastal ecosystems bacteria for the biodegradation of PAHs has been studied by several scientists (Vijayanand et al., 2023). Several variables can influence how effectively PAHs are degraded, including the number of bacteria present, pH, temperature, salinity, nutrients, and others; they may be optimized to produce a more effective process (Cui et al., 2023). Importantly, PAHs can be persistent compounds, and the microbial degradation process may be slow and incomplete. Additionally, the degradation process can also generate by-products that are also toxic (Tufail et al., 2021). Therefore, monitoring the degradation process and the products developed are essential to ensure the method is effective and does not create a new problem.

Many microorganisms are used in the broad field of biodegradation to dissolve chemical bonds. Microbial degradation of PAHs includes a variety of mechanisms, including the use of enzymes, production of organic acids, and consumption of electrons from the PAH molecules. Bioremediation can be performed *in situ* or ex-situ modes. In situ, remediation involves applying the bacteria directly to the contaminated area, while ex-situ remediation removes the contaminated soil or water and treats it in a different place. The key players in bioremediation are ubiquitous microorganisms perfectly adapted for pollutant destruction by producing extracellular hydrolytic enzymes, enabling them to utilize toxic pollutants to lead and essential functions (Sharma, 2022b). For example, *Mycobacteria* can break down heavy metals, polychlorophenols, and various PAHs, whereas *Nocardia* can break down alkanes, polychlorinated biphenyls, chlorophenols, *Gordoniae,* and sulfonated azo dyes can break down alkanes (Sharma, 2022a). Accordingly, the strains mentioned above can successfully compete with growing fast bacteria like *Pseudomonas* and similar genera due to their capacity to break down harmful contaminants like aromatics. This review covers the essential sources, identification and detection methods of PAHs, a summary of the PAHs toxicological effects on soil, waterbodies, plants, animals and human health. Here we highlight the beneficial designs from Eco-friendly techniques for PAHs and their toxic derivative bioremediation as well as difficulties that were faced with PAHs bioremediation.

Section snippets

Environmental sources of polyaromatic hydrocarbons

Numerous industrial, agricultural, and medical processes release harmful hydrocarbon compounds into the environment as toxic pollutants (Sharma et al., 2021). PAHs are produced when an organic substance is partially damaged at a high temperature and then allowed to cool to a low temperature for an extended period (Stogiannidis and Laane, 2015). They are hazardous chemicals that exist naturally and are generated as a result of a variety of natural processes. The following are the examples of…

Effects of PAHs toxicity

PAHs are solid substances with two or more fused aromatic rings of carbon and hydrogen atoms. They appear white, frequently colourless, or pale yellow (Suman et al., 2016). Aromatic are arranged in linear, angular, or clustered molecular arrangements. Atmospheric PAHs (in the gas state as aerosols) are placed in the particulate phase in water, soil, and plants via dry/wet deposition processes (Abdel-Shafy and Mansour, 2016). Because of their low vapor pressure and high hydrophobicity, PAHs with …

Polyaromatic hydrocarbons detection techniques

PAH detection by various physical and chemical methods is crucial to monitor and manage pollution and its harmful environmental effects. Spectroscopy, GC-MS, Fluorescence spectroscopy, Electrochemical sensors, Enzyme-linked immunosorbent assay (ELISA), and LC with UV–visible and fluorescence methods are commonly used in PAHs detection. The distribution of energy held by a particle at any given time serves as the foundation for the characteristics of spectroscopy. The class of conjugated…

Eco-technologies for decontaminating the PAHs polluted sites

For a sustainable environment and the growth of industries, the treatment of industrial effluents must be practical and affordable (Mahmood and Earley, 2019). Various treatment options are available with multiple degradation mechanisms that fall under biological, physical, chemical, phytoremediation, thermal desorption, and electrokinetic remediation (Ossai et al., 2020). Each treatment has advantages and disadvantages, so selecting the best option for a contaminated environment requires…

Role of bacteria, fungi, or algae in bioremediation of EDCs

Using living organisms to break down or eliminate environmental toxins is a method known as bioremediation. Bacteria, fungi, and algae have demonstrated remarkable promise in the remediation of endocrine-disrupting substances (EDCs), such as pharmaceuticals, insecticides, and industrial chemicals (Roccuzzo et al., 2021).

- **Bacteria:** Numerous EDCs are biodegraded in large part by bacteria. They can generate enzymes that can break down or change EDCs into less hazardous forms, which is only one of…

…

Toxicity of PAHs on animals and aquatic lives

Polycyclic aromatic hydrocarbons (PAHs) encompass a group of chemicals distinguished by possessing two or more condensed aromatic rings. These compounds are extensively found in the air, water, and soil and are recognized as pervasive pollutants (Cong et al., 2021)that harm the environment. PAHs are prominent in aquatic ecosystems, as they are noticed in various organisms such as water, sediment, fish, benthic invertebrates, sea birds, and sea mammals (Sørhus et al., 2021). Based on their…

Nanoremediation approaches

Nanoremediation approaches have gained considerable attention for remediating contaminated sites due to their promising potential (Hussain et al., 2022). Nanoparticles and related technologies offer advantages such as extensive dispersion, large surface areas, and specific reactivity, making them highly suitable for in-situ decontamination processes. Functionalized nanoparticles, modified with enzymes, biosurfactants, proteins, humic acids, and DNA, have been developed to enhance their…

Conclusion and future perspectives

The pollution of toxic PAHs from the various sources discussed above has severely impacted pristine environments and human health. As discussed in this review, significant strides have been made in developing PAH pollution environmental remediation methods and techniques. However, many issues remain unresolved, and PAH site remediation remains daunting. The evidence accumulated over several years of research suggests that reproductions of lab-scale results into the potential application are…

Credit author statement

Selvaraj Barathi: Writing - Original Draft & Conceptualization. **Gitanjali J:** Writing - Review & Editing. **Gandhimathi Rathinasamy:** Writing - Review & Editing. **Nadana Sabapathi:** Writing - Review & Editing. **K.N. Aruljothi:** Writing - Review & Editing. **Jintae Lee:** Writing - Review & Editing. **Sabariswaran Kandasamy:** Supervision, Methodology, Visualization & Validation.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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