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Environmental Nano- and Micro-Particulates as Conveyors of Hydrophobic Organic Contaminants in Potable Water

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Abstract
Vegetable water systems are contaminated by hydrophobic organic pollutants (HOCs) carried by nano- and micro-particulates, such as microplastics and artificial nanomaterials. Particulate matter with a high surface-to-volume ratio and chemical affinity may enhance the bioavailability and environmental persistence of chemical contaminants, such as endocrine-disrupting chemicals (EDCs), polycyclic aromatic hydrocarbons (PAHs), and persistent organic pollutants (POPs). Investigating adsorption processes, ecological and health hazards, and possible technical solutions, this article summarises current research on microplastic transportation and interactions with organic contaminants. It also delves into ways to filter and oxidise water using nanotechnology to lessen the impact of contaminants.

Keywords: *Microplastics, nanomaterials, potable water contamination, hydrophobic organic contaminants, polycyclic aromatic hydrocarbons, persistent organic pollutants, adsorption mechanisms*

1. Introduction

Microplastic and nanomaterial pollution of drinkable water is a growing problem that threatens ecosystems and human health. These particles come from a variety of places, including wastewater treatment plants, factories, and the breakdown of more significant pieces of plastic. Because they do not biodegrade, microplastics and nanomaterials remain in aquatic ecosystems after release and transport hydrophobic organic contaminants (HOCs) like pesticides, long-lived organic pollutants (POPs), and polycyclic aromatic hydrocarbons (PAHs) (Verla et al., 2019). Their ability to absorb harmful chemicals is enhanced by their large surface area and diminutive size, which raises the risk of pollution transmission in water systems.

Microplastics are present at every stage of the water distribution system, from primary water sources to the taps in people's homes, according to recent research (Sun et al., 2024). This has led to heightened worries about the potential health effects of human exposure, such as endocrine disruption and carcinogenicity. Yin et al. (2024) found that many physicochemical factors, such as the polymer composition, surface charge, and the impacts of environmental ageing, influence these particles' propensity to interact with pollutants. Microplastics undergo surface modifications due to oxidation, ultraviolet radiation, and microbial colonisation, which change their ability to adsorb and bind pollutants over time.

Beyond human health risks, the interaction between microplastics and organic contaminants poses serious threats to aquatic ecosystems. These pollutants can bioaccumulate in marine and freshwater organisms, leading to food chain contamination. The long-range transport of microplastic-bound pollutants further exacerbates their environmental impact, making remediation efforts increasingly challenging.

This paper aims to explore the role of micro- and nano-particulates in transporting hydrophobic contaminants within potable water systems. It will examine the mechanisms of contaminant adsorption, assess the environmental and human health risks, and discuss potential mitigation strategies, including advanced water treatment technologies and policy interventions. Understanding these dynamics is essential for developing practical solutions to minimise microplastic pollution and safeguard drinking water quality.

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2. Sources and Characteristics of Environmental Nano- and Micro-Particulates

2.1 Sources of Micro- and Nano-Particulates

Nano- and micro-scale particulates originate from various sources, including:

- **Industrial Discharges:** Plastic processing, textile manufacturing, and chemical industries release microplastics into aquatic environments (Albaseer et al., 2024).
- **Plastic Degradation:** Environmental weathering fragments larger plastics into micro- and nanoparticles (Morales-Cano et al., 2023).
- **Household Waste and Cosmetics:** Personal care products and detergents contribute to microplastic pollution in wastewater.

2.2 Physical and Chemical Properties

The ability of microplastics to adsorb and transport contaminants is influenced by:

- **Hydrophobicity**: Polymers like polyethylene and polystyrene readily attract hydrophobic pollutants (Reichel et al., 2021).
- **Surface Area**: The high surface-to-volume ratio of nano-sized particles makes them very effective adsorbents. (Gehrke et al., 2015).
- **Aging and Photodegradation**: Environmental exposure alters plastic surfaces, increasing their capacity to bind contaminants (Yin et al., 2024).

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3. Mechanisms of Contaminant Adsorption and Transport

The adsorption of hydrophobic organic contaminants onto nano- and micro-particulates is primarily driven by:

3.1 Hydrophobic Interactions

Nanomaterials and microplastics have a high affinity for hydrophobic surfaces, which hydrophobic organic contaminants (HOCs) like polycyclic aromatic hydrocarbons (PAHs) do as well. Synthetic polymer surfaces are ideal for HOC adsorption since they do not include any polar functional groups. These surfaces are also non-polar. To put it another way, this mechanism makes contaminants more bioaccumulable by making them more environmentally persistent. Aged plastics, which have been exposed to the elements, are more likely to have accumulated HOCs, according to the research. Yin et al. (2024) found that benzo(a)anthracene (BaA), a PAH known to cause cancer, can easily attach to microplastics that are already in their old age, which increases the likelihood that it may be transported over long distances in water courses.

3.2 Surface Chemical Modifications

The surface characteristics of microplastics are changed by ageing processes such as oxidation, hydrolysis, and extended UV exposure, which results in the development of functional groups like hydroxyl (-OH) and carbonyl (-C=O) groups. By raising surface roughness and chemical affinity, these changes improve HOC adsorption (Reichel et al., 2021). Furthermore, by providing microbial metabolic byproducts that function as additional binding sites, biofilm growth on microplastics might further affect contaminant adsorption. These changes improve microplastics' ability to carry and hold onto organic contaminants for long periods.

3.3 Transport in Water Systems

Microplastics and nanoparticles serve as mobile carriers of contaminants within aquatic environments, particularly in drinking water systems. Several key factors govern their mobility:

- **Density and Buoyancy:** Lighter plastics such as polyethylene and polypropylene tend to remain suspended in water, whereas denser materials like polyvinyl chloride (PVC) sink to sediment layers. This differential transport influences pollutant distribution across water bodies.
- **Water Flow and Turbulence:** Hydrodynamic conditions in treatment plants and distribution networks affect the movement of microplastics. High flow rates and turbulence enhance their ability to remain suspended, facilitating the widespread dissemination of adsorbed contaminants (Sun et al., 2024).

Given their persistence and transport mechanisms, microplastic-bound contaminants pose a significant challenge for drinking water safety, necessitating improved removal strategies and regulatory measures to minimise exposure risks.

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4. Environmental and Human Health Implications

4.1 Bioavailability and Toxicity

Ingesting microplastics can release hydrophobic organic contaminants (HOCs) into the digestive tract. These contaminants include persistent organic pollutants (POPs), polycyclic aromatic hydrocarbon (PAHs), and endocrine-disrupting chemicals (EDCs). These substances provide severe health risks, such as disruption of hormones, carcinogenicity, and organ toxicity (Morales-Cano et al., 2023). Microplastics' high surface area enhances the adsorption of toxic substances, which increases their bioavailability and persistence in biological systems.

4.2 Ecotoxicological Concerns

Fish, shellfish, and other creatures bioaccumulate microplastic–contaminant complexes, which are common in aquatic environments. Aquatic animals' reproductive health is impacted, metabolic processes are disturbed, and oxidative stress is brought on by ingesting microplastic-bound contaminants. Furthermore, when these pollutants ascend the food chain, they experience biomagnification, which eventually endangers human health (Albaseer et al., 2024). Environmental pollution is made worse by the long-distance movement of microplastic contaminants, which affects freshwater and marine ecosystems worldwide.

4.3 Microplastic Contamination in Potable Water

From raw water sources to residential taps, studies have shown that microplastics are found at every point of the drinking water supply chain (Sun et al., 2024). As HOC vectors, these particles can contaminate human drinking water with dangerous substances. Advanced purification techniques like nanofiltration and electrochemical oxidation must be developed since traditional water treatment procedures including coagulation, sedimentation, and filtration may not wholly remove microplastic particles. To protect public health, immediate technical and legislative actions are required in light of the growing incidence of microplastic pollution.

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5. Mitigation Strategies and Technological Innovations

5.1 Nanotechnology-Based Water Treatment

Nanotechnology has emerged as a promising approach to removing microplastics and associated contaminants. Effective techniques include:

- **Graphene Oxide and Carbon Nanotubes:** These materials exhibit high adsorption efficiency for organic pollutants (Gehrke et al., 2015).
- **Membrane Filtration:** Nanofiltration and reverse osmosis are highly effective at removing microplastics from drinking water (Nagar & Pradeep, 2020).
- **Photocatalysis and Electrochemical Degradation:** Advanced oxidation processes break down both plastic particles and adsorbed contaminants (Nagar & Pradeep, 2020).

5.2 Policy and Regulatory Approaches

Regulatory frameworks must be strengthened to control microplastic pollution in drinking water. Proposed measures include:

- **Stricter Industrial Regulations**: Enforcing limits on microplastic discharge into water bodies (Albaseer et al., 2024).
- **Microplastic Monitoring Programs**: Implementing routine surveillance of drinking water sources (Sun et al., 2024).
- **Development of Biodegradable Alternatives**: Encouraging industries to adopt sustainable plastic substitutes (Morales-Cano et al., 2023).

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6. Conclusion

Nano- and micro-particulates play a critical role in transporting hydrophobic organic contaminants in potable water. Their interactions with pollutants raise significant environmental and health concerns, necessitating urgent action. Advanced nanotechnology-based treatment solutions and strengthened regulatory policies can help mitigate these risks. Future research should focus on cost-effective remediation strategies and biodegradable material alternatives to reduce microplastic pollution.

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