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Editorial: Recent advances in volatile organic compounds, heavy metals, microplastics, and solid wastes in ecosystems

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Editorial on the Research Topic

Recent advances in volatile organic compounds, heavy metals, microplastics, and solid wastes in ecosystems

Introduction

The accelerating pace of industrialization and urbanization has led to widespread pollution of air, water, and soil. Key pollutants, including volatile organic compounds (VOCs), heavy metals, microplastics, and solid wastes, pose significant risks to ecosystems and human health. Despite their chemical differences, these pollutants share traits like persistence, bioaccumulation, and complex transformation, threatening both natural and human-made environments (Zhou et al., 2023; Lou et al., 2024; Xu et al., 2024; Zhang et al., 2024; Boisseaux et al., 2025; Hu et al., 2025; Jomova et al., 2025; Peng et al., 2025; Xiao et al., 2025; Yan et al., 2025). To address these challenges, *Frontiers in Environmental Science* presents a Research Topic entitled “Recent Advances in Volatile Organic Compounds, Heavy Metals, Microplastics, and Solid Wastes in Ecosystems.” This Research Topic consists of nine peer-reviewed papers, including original research articles and bibliometric analyses, which collectively investigate the distribution patterns, transformation mechanisms, ecological impacts, and sustainable remediation strategies of pollutants across various environmental interfaces.

Key elements in this Research Topic

VOCs are a crucial class of air pollutants and precursors of ground-level ozone and secondary organic aerosols. Zhu et al. conducted a bibliometric analysis of 2,493 studies on photocatalytic oxidation of VOCs between 1998 and 2023, revealing China as the most active contributor. The research focus has transitioned from TiO₂-based ultraviolet

photocatalytic systems to visible-light-responsive and hybrid nanostructured catalysts, with increased emphasis on charge carrier separation, adsorption regulation, and optimization of reaction kinetics. These advancements reflect a paradigm shift from empirical catalyst development toward mechanism-driven design strategies.

Complementary insights emerge from the study by [Chen et al.](#), who investigated the photodegradation processes of the representative pharmaceutical contaminant clofibric acid in urban, suburban and rural water bodies. They demonstrated that the composition of dissolved organic matter (DOM) regulates the balance between direct and indirect photolysis. However, the resulting by-products demonstrated higher eco-toxicity compared to the parent compound. Collectively, these findings underscore both the potential and complexity of photocatalytic and photochemical pathways for the control of VOCs and organic contaminants, necessitating further investigation into reaction intermediates and the environmental safety of degradation processes.

Heavy metals continue to represent one of the most persistent threats to terrestrial and aquatic ecosystems due to their inherent toxicity, environmental mobility, and resistance to degradation. [Jiang et al.](#) examined soil heavy-metal variations in Guizhou's karst region, finding lower concentrations of Hg, Cd, and Pb in natural forest soils compared with cultivated lands. Vegetation cover effectively reduced atmospheric deposition, whereas fertilizer application enhanced Cd accumulation, highlighting the link between land-use change and heavy metal enrichment. Similarly, [Qian et al.](#) evaluated five key metals (Cd, As, Pb, Hg, Cu) in *Gastrodia elata* cultivation areas in Yunnan. Although elevated levels of Hg, Cd, and Cu were observed, health risk indices indicated no immediate threat to human health. Collectively, these studies demonstrate how ecological functions, agricultural practices, and geological backgrounds jointly govern the behavior of heavy metals. At broader scales, [Jia et al.](#) conducted a knowledge-map analysis of heavy-metal source apportionment (1994–2022), revealing global research hotspots in positive matrix factorization (PMF) modeling, health-risk assessment, and sediment-based tracing. Meanwhile, [Lu et al.](#) investigated the distribution of pollutants and microbial responses in the Qaidam Basin, revealing that gradients of heavy metals and organic pollutants are closely associated with microbial community restructuring. Their findings indicate that microbial adaptation mechanisms play crucial roles in pollutant cycling within extreme saline environments. Future research should integrate cross-media transport models with microbial ecology to improve the quantification of heavy metal bioavailability and long-term ecological feedbacks.

Beyond chemical pollutants, solid waste management and resource recovery have become pivotal to environmental sustainability. [Liu et al.](#) developed a phosphogypsum-based ecological concrete using electrolytic manganese slag as a cementitious binder and clay ceramics as aggregate. The optimized mixture exhibited higher compressive strength and improved water retention, while simultaneously supporting grass growth and immobilizing heavy metals such as As, Cu, and Pb. This study presents a practical pathway for transforming hazardous

industrial by-products into functional green construction materials. Similarly, [Dai et al.](#) utilized *rosa roxburghii* residue to synthesize FeOOH-modified biochar, achieving a maximum adsorption capacity of 5.7 mg g⁻¹ for Sb(V) at pH 2. The process not only enabled efficient removal of toxic antimony but also facilitated the valorization of agricultural waste. These studies mark a shift from traditional end-of-pipe treatment toward a circular economy approach that unites pollutant control with material reuse and ecosystem restoration, advancing the “waste-to-resource” concept essential for low-carbon, sustainable development.

Among the innovative approaches highlighted in this Research Topic, [Chen et al.](#) provided a comprehensive review of micro-nano-bubble (MNB) technologies and their expanding role in environmental remediation. MNBs exhibit exceptional physicochemical properties, including high interfacial potential, large specific surface area, and prolonged stability, which enhance oxygen transfer and promote the *in situ* generation of reactive oxygen species. When integrated with photocatalytic or biochar-based systems, MNBs produce synergistic effects that accelerate pollutant transformation and increase overall treatment efficiency. This study demonstrates how advanced interfacial engineering and cross-disciplinary innovation can transform pollution control by integrating physical, chemical, and biological mechanisms to support sustainable ecosystem restoration.

Conclusion

This Research Topic brings together interdisciplinary studies on the behavior and control of VOCs, heavy metals, and solid wastes in various ecosystems. The papers provide insights into pollutant distribution, transformation, and ecological effects, linking air, water, and soil processes. Covering both fundamental mechanisms and applied remediation, they highlight advances in catalytic oxidation, microbial adaptation, biochar adsorption, and resource recycling. Future research should integrate multi-pollutant models, assess long-term ecological risks, and develop low-carbon technologies. Together, these studies support evidence-based environmental policies and promote the goal of resilient, sustainable ecosystems.

Author contributions

YG: Writing – review and editing, Writing – original draft. YS: Writing – original draft, Writing – review and editing. ZZ: Writing – original draft, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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