

Environmental Behavior, Ecological Effects and Health Risks of Pollutants in Aquatic Ecosystems

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1. Introduction to the Special Issue

Aquatic ecosystems are fundamental to sustaining global biodiversity and providing essential ecosystem services, yet they face unprecedented threats from anthropogenic pollution. Rapid industrialization, urbanization, and agricultural intensification have led to the continuous discharge of complex contaminants into water, ranging from traditional pollutants like heavy metals to emerging contaminants (ECs) such as pharmaceuticals, personal care products, per- and polyfluoroalkyl substances (PFASs) and microplastics [1,2]. These pollutants are characterized by widespread occurrence, complex sources (including industrial effluents, agricultural runoff and wastewater treatment plant discharges) and long-term persistence, posing significant threats to the integrity of the natural water environment and the safety of drinking water resources [3,4]. Consequently, understanding the fate, transport, and impacts of these pollutants is critical for developing effective mitigation strategies and safeguarding water resources [5].

The environmental behavior of pollutants in aquatic systems is governed by a complex interplay of physical, chemical and biological processes, including adsorption, dissolution, degradation and migration [1]. These processes determine the fate, transport and bioavailability of contaminants, which are strongly influenced by environmental factors such as pH, temperature, dissolved organic matter, and redox conditions [6,7]. For instance, heavy metals exhibit notable mobility in aquatic environments, readily adsorbing onto suspended particles and sediment matrices, thereby affecting their bioavailability and long-term persistence [8]. In addition, ECs such as microplastics can act as vectors for hydrophobic organic pollutants, facilitating their transport and enhancing their accumulation in sediment and biota [9]. The varying environmental behaviors of pollutants exert distinct and significant impacts on aquatic ecosystems. Pollutants such as mercury, polychlorinated biphenyls (PCBs) and organochlorine pesticides can accumulate in the tissues of aquatic organisms, leading to organ toxicity, reproductive impairment, developmental abnormalities and behavioral disruptions [10]. Moreover, the co-occurrence of multiple contaminants can exert synergistic toxic effects, altering metal-binding proteins, generating oxidative stress, and disrupting endocrine functions, thereby magnifying their individual deleterious consequences [11]. At the ecosystem level, pollutant-induced stressors can impair essential ecological functions, including nutrient cycling, primary production, organic matter decomposition and biodiversity maintenance [12]. Furthermore, bioaccumulation and biomagnification through food webs further exacerbate these impacts, potentially posing a threat to human health [13]. Thus, integrating toxicological data with exposure assessments



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through advanced modeling approaches is urgent for establishing water quality criteria, and the assessment of health risks associated with aquatic pollutants is crucial for public health protection and environmental management [14,15].

This Special Issue, entitled “Environmental Behavior, Ecological Effects and Health Risks of Pollutants in Aquatic Ecosystems,” aimed to compile the latest research on the environmental behavior of pollutants in aquatic ecosystems, their interactions with aquatic organisms, and their environmental health risks. This collection provides an in-depth and systematic interdisciplinary study and analysis of the ecological impacts of water pollutants (including aspects of environmental science and engineering, ecology, Earth science, and environmental chemistry), with a particular focus on the assessment of their potential ecological risks, covering the following topics (among others): (1) assessment of nutrient elements such as carbon, nitrogen, and phosphorus; (2) assessment of emerging contaminants, heavy metals, and toxic and hazardous substances; (3) environmental behaviors, such as the transport and transformation of pollutants in water ecosystems; (4) the relationship between pollutant stress and aquatic ecological conditions, particularly the effects of algal blooms. This Special Issue will serve as a valuable platform for exchanging knowledge, fostering interdisciplinary collaboration, and providing a scientific basis and theoretical support for the evaluation of the ecological risks of pollutants in aquatic ecosystems.

2. The Main Contributions of This Special Issue

Following a rigorous peer-review process, eight manuscripts have been accepted for publication in this collection. Below is a summary of the key findings from these contributions, which span toxicological assessments, hydrological impacts and advanced monitoring technologies.

Regarding heavy metals and source apportionment, Wang et al. (Contribution 1) investigated the health risks of heavy metals in the drinking water sources of water-carrying lakes, focusing on Luoma Lake as a case study affected by retreating polder projects. The authors modeled the exposure pathways, revealing that these pollutants pose substantial risks to human populations, and established a vital foundation for managing drinking water safety in areas experiencing intense hydrological alterations. Similarly, Shi et al. (Contribution 2) conducted a comprehensive bibliometric analysis exploring how the source apportionment of heavy metals in soil and water has evolved over the past 20 years. They mapped a methodological shift from basic statistical tracing to advanced spatial analyses, providing a clear roadmap for future policy strategies aimed at mitigating heavy metal pollution.

Regarding emerging contaminants and combined toxicity, Yao et al. (Contribution 3) investigated the single and combined toxic effects of BDE3 (a polybrominated diphenyl ether) and copper (Cu) on the photosynthesis and antioxidant enzyme system of the aquatic plant *Salvinia natans* (L.). Due to the unregulated handling of e-waste, the co-existence of PBDEs and heavy metals is increasingly common. The plant experienced significant oxidative stress, leading to the heavy activation of antioxidant defense enzymes (SOD and CAT). This study highlighted that the co-existence of copper exacerbates the cellular damage caused by BDE3, emphasizing the hidden dangers of combined pollution in aquatic environments.

In terms of nutrient dynamics and hydrological stressors, Lyu et al. (Contribution 4) explored the multi-decade variations in sediment and nutrient export in cascading developmental rivers in Southwest China. Their research assessed the long-term impacts of land-use changes and the construction of dams on riverine ecosystems, revealing how human-induced structural modifications alter the transport and transformation of essential nutrients. Focusing on agricultural impacts, Fang et al. (Contribution 5) examined

the mechanisms by which irrigation water levels influence nitrogen transformation and microbial activity in paddy fields. The authors demonstrated that dynamic shifts in field water levels directly impact microbial community composition, thereby influencing the final form and fate of nitrogen. Their findings provide actionable strategies for optimizing irrigation to control non-point source nitrogen pollution.

In terms of physical stressors, ecological responses, and advanced monitoring, Kang et al. (Contribution 6) shifted the focus to physical stressors, conducting an experimental study on the behavioral responses of Korean fishes to changes in water turbidity. Using a specialized mixing unit and video monitoring, the study showed that high turbidity and suspended solids act as critical physical pollutants, disrupting visual cues, foraging behavior, and habitat suitability. Addressing the severe ecological consequences of eutrophication, Cui et al. (Contribution 7) applied machine learning and remote sensing to identify harmful algae in Ulansuhai Lake. By integrating advanced algorithms with remote sensing data, they developed a highly accurate and timely monitoring tool for early bloom warning. Furthermore, Wang et al. (Contribution 8) explored another extreme eutrophication phenomenon known as “black bloom” (blackwater events) in Chaohu Lake. By employing machine learning methods such as Random Forest and Bayesian Networks, the authors unraveled the complex interactions among limiting factors like ferrous iron (Fe(II)) and sulfide (S(-II)), and successfully established critical threshold values for these factors, offering crucial data for developing precise oxygenation strategies to rapidly eliminate black blooms.

3. Conclusions and Future Prospects

This Special Issue presents a collection of multidisciplinary research works that advance our understanding of the environmental behavior, ecological effects and health risks of pollutants in aquatic ecosystems. The eight contributions collectively highlight the need for a comprehensive perspective when assessing the ecological effects of pollutants. The studies demonstrate the need for evaluating the synergistic toxicological effects of mixed pollutants [3], understanding how anthropogenic practices and structures govern nutrient transport [4,5], determining physical parameters affecting aquatic life behaviors [6], and mitigating heavy metal bioaccumulation [2,8]. Furthermore, the application of advanced analytical tools and machine learning highlights the critical role of modern technology in unraveling complex ecological phenomena like harmful algal and black blooms [7,8].

In aquatic ecosystems, research on the environmental behavior, ecological effects and health risks of pollutants is rapidly growing. However, further studies are required to fill the knowledge gap in the following aspects: (1) long-term field studies are needed to monitor the chronic exposure and cumulative health risks of multiple pollutants; (2) the integration of emerging analytical technologies and computational modeling should be advanced to enable real-time pollutant monitoring and predictive risk assessment; (3) the quantitative linkage between ecological risk assessment and human health risk evaluation should be strengthened through multi-pathway exposure analysis.

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