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The Impact of Pollution Caused by Microplastics in Rivers

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Abstract. Microplastics, as a new type of water environment pollutant, have been widely detected in river ecosystems worldwide, and their environmental behavior and ecological risks have attracted significant attention. Based on existing research findings, this paper systematically reviews the basic characteristics and main sources of river microplastics, summarizes the current status of pollution occurrence and ecotoxicological effects in typical watersheds, focuses on analyzing the research progress and application limitations of two mainstream treatment technologies, and explores the key factors affecting treatment effectiveness. Research shows significant regional differences in microplastic pollution in rivers, with terrestrial imports being the main contributing pathway, which can exert multiple toxic effects on aquatic organisms through feeding and other pathways; Existing treatment technologies each have their advantages, but their engineering application still has limitations. Finally, this paper looks ahead to future research directions, aiming to provide theoretical references for the prevention and control of microplastic pollution in rivers.

Keywords: River pollution, Microplastics, Influencing factors, Ecotoxicological effects, Processing technology

1. Introduction

Rivers are the core carriers of terrestrial freshwater ecosystems and key routes for transporting land-based plastic pollutants into the ocean. With the large-scale production and widespread application of plastic products, plastic waste enters river environments through various routes, gradually breaking down into microplastic particles under physical, chemical, and biological processes [1]. Microplastics have tiny particle size, strong migration ability, long environmental retention periods, and can serve as adsorption carriers for various pollutants, making them a new type of pollutant affecting river water environment safety [2]. Existing monitoring data show that microplastic pollution has been detected in rivers in different regions, and its potential risks to aquatic ecosystems are gradually emerging [3, 4], Conducting related research holds significant practical value for safeguarding the health of the watershed water environment.

Extensive research on river microplastics has been conducted both domestically and internationally, achieving phased results in occurrence surveys, source analysis, and risk assessment. Global-scale studies have preliminarily clarified the overall distribution pattern of microplastics in rivers, confirming that population density and land use types are the core drivers of pollution levels [4, 5]; special domestic surveys targeting key river basins such as the Yangtze, Yellow, and Pearl

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Rivers have basically clarified the characteristics and main sources of microplastic occurrence in different regions [6-8]. At the same time, toxicological studies have confirmed that microplastics have multidimensional damaging effects on aquatic organisms [9, 10]. Laboratory research on some treatment technologies has also made positive progress [11]. However, existing research still has shortcomings: First, pollution survey areas are uneven, mostly concentrated in large river basins, with a lack of data on small and medium-sized rivers [3, 12]; Second, toxicology research is mostly based on laboratory exposure to a single species, with insufficient understanding of the actual risks under complex pollution in natural rivers [9, 13]; Third, treatment technologies mostly remain at the laboratory stage, with engineering plans adapted to the actual watershed lacking in scope [1, 11].

To address these shortcomings, this paper focuses on river microplastics, integrates existing research findings, and reviews them from five dimensions: basic characteristics, current pollution status, risk effects, treatment technologies, and influencing factors. This paper reviews the environmental behavior and risk mechanisms of river microplastics and improves the theoretical understanding system in this field; On the other hand, it summarizes the progress and limitations of mainstream treatment technologies, clarifies the key factors affecting treatment effectiveness, provides a theoretical basis for subsequent technical optimization and watershed control plans, and offers practical references for environmental management of river microplastic pollution.

2. Basic characteristics and sources of riverine microplastics

The authors are strongly encouraged to use this document for the preparation of your paper. Please Microplastics in river environments usually refer to plastic particles smaller than 5 mm in diameter, which can be divided into primary and secondary categories based on their formation pathways [1, 2] Primary microplastics refer to plastic products that are micron-sized during production, such as daily chemical microbeads and industrial plastic pellets; Secondary microplastics are formed by the breakdown of large plastic waste pieces through environmental fragmentation and are the main components of river microplastics [11]. From the perspective of physical and chemical properties, common materials include polyethylene, polypropylene, polyethylene terephthalate, and polyvinyl chloride. The density difference directly determines the state of occurrence. Particles with density less than water tend to suspend on the water surface, while denser particles tend to settle in sediments [2, 14]. Microplastics have a large specific surface area and strong hydrophobicity, can adsorb heavy metals and persistent organic pollutants, and their own additives can be gradually released, forming a compound pollution effect [1, 10].

The main source of microplastics in rivers is land-sourced, which can be divided into three categories: domestic sources, agricultural sources, and industrial sources [6, 14]. The main sources of domestic life come from domestic sewage discharge and surface runoff erosion. Among these, synthetic fibers produced from textile washing are the core source of fibrous microplastics, and household waste can also enter rivers after being washed by rainwater [15, 16]. In terms of agricultural sources, the main contributing sources are the fragmentation of agricultural plastic mulch film residues, irrigation water transport, and the discharge of livestock and poultry farming waste. Agricultural non-point source pollution has become an important source of microplastics input into rivers in rural areas [17]. Industrial sources mainly include wastewater discharge from plastic processing enterprises and losses from industrial raw material transportation [6]. Besides land-based input, plastic waste inside rivers continues to break apart under hydraulic shearing, ultraviolet irradiation, and biological processes, serving as the in-situ generation pathway for secondary microplastics and resulting in persistent pollution input [2, 14].

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3. Current pollution status and risk effects of river microplastics

Microplastic pollution has been widely detected in global river ecosystems, and there is significant spatial heterogeneity in pollution levels across different watersheds [4, 18]. Watersheds with dense populations and high levels of industrialization generally have higher microplastic concentrations, while remote watersheds have relatively lower concentrations; Within the same watershed, concentrations in urban sections are significantly higher than in rural sections, and pollutant accumulation is likely to occur in areas where main and tributary streams converge [5, 18]. Relevant surveys have been conducted in major river basins in China, and the detection rates of microplastics in water bodies and sediments in the Yangtze, Yellow, Pearl, and Chishui rivers are at relatively high levels [6, 7, 19, 20]. Among them, microplastics in the upper Yellow River basin are mainly fibrous and have high sediment accumulation [6, 15]; Microplastics in the Pearl River Delta network area have high transmission efficiency and large output [7]; Surveys in the Taihu Lake and Huangshui River basins confirm that agricultural non-point sources and domestic sources are the main drivers of regional pollution [16, 7]; Microplastic pollution from surface rivers in typical mining cities also shows a strong correlation with industrial activities [21]. Overall, microplastic pollution in China's rivers shows significant regional differences and is mainly driven by human activities.

The harm microplastics cause to river ecosystems spans multiple levels, including individuals, populations, and ecosystems, and their toxicological effects have been confirmed by multiple studies [9, 10]. At the individual level, microplastics can enter fish, benthic organisms, and plankton through feeding, causing damage to the intestinal mucosa, digestive disorders, and triggering oxidative stress responses that affect growth and reproductive functions; Small-sized microplastics can penetrate tissue barriers and enter the circulatory system and internal organs, producing stronger toxic effects [9, 13]. At the ecosystem level, the synergistic effect of microplastics and sediment further amplifies risks. In high-sediment rivers, microplastics and sediment settle together, increasing the feeding probability of benthic organisms and exacerbating pollution transmission in benthic food chains [13]. Additionally, microplastics act as pollutant carriers, transferring adsorbed heavy metals and organic pollutants into organisms, causing complex toxicity [1, 10]; Microplastics can also accumulate step by step along the food chain, causing long-term disruption to the community structure and material cycles of river ecosystems, threatening the stability of watershed ecosystems [4, 10].

4. Technologies and research progress for river microplastic pollution control

4.1. Modified biochar adsorption and removal technology

Adsorption is an important technical approach for removing microplastics in water. Among them, biochar has become a research hotspot in microplastics treatment due to its wide raw material availability and good environmental compatibility [11]. Ordinary biochar has limited adsorption capacity for microplastics. Existing research mostly enhances adsorption performance through raw material screening, process modification, and surface modification. The core is to regulate biochar's pore structure, surface functional groups, and charge characteristics, and to strengthen mechanisms such as electrostatic adsorption, hydrophobicity, and pore interception [11, 20].

Some studies have used filamentous algae as raw material to prepare modified biochar, systematically exploring its removal effect and mechanism on microplastics in water [22]. The core innovation of this study lies in the resource utilization of discarded algae from algal blooms, and by combining oxygen-limited pyrolysis with surface modification to prepare hierarchical porous algae-

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based biochar, it overcomes the limitations of traditional straw-based biochar with single pore structures and insufficient capture capacity. The results show that under optimized conditions, the modified biochar can remove microplastics from simulated water bodies by over 85%, and still maintain high capture efficiency for microplastics with particle sizes smaller than 100 μm. This case demonstrates that raw material screening and process optimization can significantly improve biochar's adsorption performance, and algae-based biochar offers dual environmental benefits from waste resource utilization, meeting the collaborative management needs of eutrophic rivers. The limitation of this technology is that existing research mostly focuses on pure water or simulated wastewater, where sediment and dissolved organic matter in actual river bodies compete for adsorption sites, significantly reducing treatment efficiency; At the same time, the regeneration process for biochar after adsorption saturation and the final disposal pathway for loaded microplastics are still immature, limiting engineering applications [11, 20].

4.2. Watershed source control and process interception technology

Microplastic pollution sources are dispersed and transport routes are complex, making it difficult for a single end-point treatment technology to achieve effective control across the entire watershed. Therefore, a systematic control scheme combining source reduction with process interception has become an important direction for large-scale river microplastic pollution control [1, 6]. The core of this technical approach is to reduce input volume from the entire plastic chain, while installing interception facilities at key points of river transmission to reduce the output of microplastics downstream and to river estuaries [1, 5].

Some studies have established a three-tier prevention and control system based on the characteristics of microplastic pollution in the Yellow River Basin: "source reduction - process interception - end-point treatment" [6]. The core innovation of this study lies in combining the regional characteristics of the Yellow River Basin—high sediment content, long-distance transmission, and prominent agricultural non-point source contributions—to systematically integrate agricultural mulch film recycling, sewage treatment plant upgrades, and river interception facility construction, forming differentiated management and control schemes. Model evaluation results show that if the recycling rate of farmland mulch film across the entire basin is increased to 80%, and county-level and above sewage treatment plants add advanced treatment units, the annual microplastic output in the main stream of the Yellow River can be reduced by more than 40%. This case confirms that systematic control solutions at the watershed scale offer higher cost-effectiveness, can coordinate solutions to microplastic pollution from multiple sources and media, and are suitable for large-scale watershed management needs. Its limitations lie in the high dependence on policy enforcement and cross-regional collaboration mechanisms, with long governance effectiveness cycles and a lack of long-term project operation data to support these [6, 15].

Another study focused on the Pearl River Delta river network area, coupled hydrological models with microplastic migration models, and combined them with field monitoring data to identify key transmission nodes and interception blind spots in the river network area [7]. The core innovation of this study is to incorporate hydrodynamic conditions into the interception efficiency evaluation system, overcoming the limitations of traditional empirical interception site setup. The study found that interception facilities installed at the intersection of the main river channel and primary tributaries can intercept about 30% of floating microplastics, making it the most cost-effective site setup in the river network area. This study verifies the application value of process interception technology in areas with dense river networks, but also reveals common limitations of physical interception technology: it can only effectively remove large-particle floating microplastics, with

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extremely low removal efficiency for suspended and small-sized microplastics, making it impossible to achieve full-particle size effective treatment [7, 11].

5. Technologies and research progress for river microplastic pollution control

The physical and chemical properties of microplastics themselves are the core intrinsic factors determining treatment efficiency [11, 14]. In terms of particle size, the difficulty of microplastic removal increases significantly as particle size decreases. Conventional filtration and interception technologies can effectively remove millimeter-scale microplastics, but their efficiency for submicron-scale microplastics drops significantly; Small-particle microplastics have stronger penetration and are more likely to break through the physical barriers of treatment facilities [11, 18]. In terms of materials, different plastics have differences in density, surface polarity, and hydrophobicity, directly affecting the effectiveness of adsorption and settling technologies. For example, hydrophobic materials like polyethylene and polypropylene are more easily adsorbed by biochar through hydrophobicity, while the adsorption efficiency of hydrophilic plastics is significantly reduced [14, 22]. In terms of form, fibrous microplastics tend to wrap around filter materials and have good physical interception effects; Fragmentary and spherical microplastics are more easily lost with water flow, making interception relatively more difficult [2, 11].

Water environment medium conditions are important external factors affecting treatment effectiveness [13, 14]. Sediment particles in rivers interact with microplastics in complex ways. On one hand, sediment can co-settle with microplastics through flocculation, improving the removal efficiency of sedimentation separation technology; On the other hand, sediment occupies the pores and active sites of adsorbent materials, competing for adsorption with microplastics and significantly reducing the treatment effectiveness of adsorption technology [13]. Dissolved organic compounds also interfere with the treatment process, forming organic envelopes on microplastic surfaces, altering their surface properties and thereby affecting the efficiency of adsorption and flocculation technologies [10, 14]. In addition, river hydrodynamic conditions also have a significant impact. Excessively fast flow speeds shorten hydraulic retention time and reduce the duration of adsorption and interception technologies, leading to decreased treatment efficiency; Water temperature affects the metabolic activity of microorganisms in biodegradation technology, altering the rate of microplastic degradation [14, 18].

The characteristics of watershed pollution emissions also indirectly affect the effectiveness of microplastic treatment [6, 21]. In agriculture-dominated watersheds, microplastics are mostly imported with non-point source runoff, and pollution concentrations fluctuate significantly with rainfall, increasing the difficulty of operating continuous treatment facilities [17]. Microplastics are concentrated in urban-dominated watersheds and can be treated centrally by sewage treatment plants, but the water contains more types of compound pollutants, which can easily cause multiple disruptions to the treatment process [6, 16]. In rivers in special areas such as mining cities, microplastics often coexist with pollutants like heavy metals. Compound pollution not only increases ecological risks but also increases the complexity of treatment technologies [21].

6. Technologies and research progress for river microplastic pollution control

In summary, microplastics have become a new type of pollutant widely distributed in global river ecosystems, with their input mainly via terrestrial routes, showing significant spatial differences across different basins. Human activity intensity is the core driving factor in pollution distribution. Microplastics can cause multiple toxic damages to aquatic organisms through feeding and other

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means, and under the synergistic action of environmental media such as sediment, they further amplify ecological risks, posing long-term potential threats to the structure and function of river ecosystems. Currently, the main control technologies for river microplastics include modified biochar adsorption and watershed system control. The former is highly efficient in point-source pollution treatment, while the latter is suitable for comprehensive control in large-scale watersheds. However, both technologies have certain application limitations and are still far from large-scale engineering application. Moreover, treatment effectiveness is generally influenced by multiple factors such as the physical and chemical properties of microplastics, water environment and media conditions, and watershed pollution discharge characteristics. Future research needs to further supplement pollution survey data for different types of watersheds, deepen research on ecological toxicology mechanisms under composite pollution scenarios in natural water bodies, and promote the engineering adaptation and system integration of treatment technologies, building a full-chain collaborative watershed prevention and control system to provide more comprehensive theoretical and technical support for river aquatic ecological environment protection.

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