Progress in the Treatment of Heavy Metal Pollution of Water Sediment

Ruqi YI[1], Yongfeng FAN[2], Chenhao LIANG[3], Lidan CAI[3]

1. College of Culture and Media, Jiangxi University of Technology, Nanchang 330022, China; 2. Party Committee Organization Department, Jiangxi University of Technology, Nanchang 330022, China; 3. College of Urban Construction, Jiangxi University of Technology, Nanchang 330022, China

Abstract In recent years, as China's industrialization process and urban-rural integration strategy have continued to deepen, some industrial and domestic wastewater has been discharged directly into rivers without effective treatment. This has resulted in the continuous accumulation and enrichment of pollutants in water bodies. This phenomenon results in a significant accumulation of heavy metals in the sediment of water bodies, which not only represents a significant threat to the ecological environment but also ultimately poses a risk to human health. The objective of this study is to provide a comprehensive review of the current status of heavy metal pollution in water sediment in China. In addition, this paper analyzes the advantages and limitations of existing techniques for the harmless treatment of heavy metal pollution and forecasts the development direction of this field.

Key words Sediment, Heavy metal pollution, Treatment technology, Ecological civilization

1 Introduction

The report of the 20th National Congress of the Communist Party of China placed significant emphasis on the comprehensive and coordinated advancement of water resource management, water environmental protection, and water ecological restoration. The report highlighted the necessity for strengthening ecological protection and governance of crucial waterways, including rivers, lakes, and reservoirs. Additionally, it underscored the importance of eliminating the phenomenon of black and odorous water bodies in urban areas. Furthermore, the report underscored the significance of source prevention and control of soil pollution, and presented management strategies for new pollutants[1].

In recent years, as China's industrialization process continues to accelerate and urban-rural integration deepens, some industrial and domestic wastewater has been discharged directly into rivers as a result of improper treatment. This has led to the gathering of a variety of toxic substances in the water body and the emergence of serious water pollution problems. These pollutants continue to accumulate, enrich, and precipitate in the river's sediment, which in turn leads to a significant excess of heavy metals in the sediment. Heavy metals present a significant risk to the ecological environment and human health due to their teratogenic, carcinogenic, and mutagenic properties. As a consequence of external conditions, alterations in the sediment will occur, which will in turn result in changes to the heavy metals present. This will lead to the onset of secondary pollution of the water body. These deleterious substances will ultimately enter the human body via the food chain, resulting in significant adverse effects on human health.

2 Review of the current status of heavy metal pollution of sediments in major lake and river basins in China

In recent years, scholars in China have conducted comprehensive research and analysis on the pollution status of the sediment of major river and lake basins. The results of the study indicate that the concentration of heavy metals in the sediment of these lake and river basins is generally higher than the background concentration, and that anthropogenic contamination is a significant factor. The pollution of the rural water environment in North China serves as an illustrative case. Relevant studies have demonstrated that the average concentrations of heavy metals, including Cu, Zn, and Hg, in the sedimentary deposits within the study area have exceeded the background values typically observed in the soil of Tianjin. Notably, the degree of pollution by Hg has already reached a relatively mild level, which may potentially pose a certain degree of threat to the ecological environment[2]. The study by Rong Nan *et al.*[3] revealed the existence of exceedances of heavy metals, including As, Cu, and Zn, in the middle reaches of the Yangtze River in the Net Lake Basin. These findings indicate that heavy metal pollution in this basin is significantly influenced by anthropogenic factors. The study conducted by Fang Zheng *et al.*[4] further concentrated on the Xinjiang River within the Poyang Lake water system. As one of the five major rivers in the water system, the Cd pollution in the Xinjiang River is particularly severe, with a concentration that is 52.76 times higher than the background concentration. This is closely related to local agricultural activities, industrial development, and domestic sewage discharge.

The preceding studies demonstrate that the sediments at the

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base of major river basins in China are frequently subjected to significant anthropogenic pollution. In order to reduce the ecological risk, it is of particular importance to implement harmless treatment of sediment. Concurrently, the relevant authorities must reinforce the regulation of sewage discharge in order to resolve this issue in a comprehensive manner.

3 Research progress on harmless treatment of heavy metal pollution in sediment

The improvement in water quality and the ecological environment is contingent upon the implementation of harmless treatment and restoration techniques for heavy metal pollution in sediment. Currently, two primary strategies are employed to address heavy metal pollution in sedimentary environments within China: *in-situ* remediation and ectopic remediation. *In-situ* remediation has gained greater popularity than ectopic remediation due to its relatively low cost and straightforward operational process.

In particular, *in-situ* remediation technique can be subdivided into three categories: physical remediation, chemical remediation, and bioremediation. Each of these techniques possesses distinctive advantages and operational scenarios, offering a range of solutions for the non-toxic remediation of heavy metal pollution in the sediment.

3.1 *In-situ* physical remediation technique

3.1.1 Sediment covering technique. The sediment covering technique, a traditional method, relies primarily on uncontaminated gravels, zeolites, and specially designed artificial covering materials. The strategic placement of these materials effectively covers the upper portion of the sediment, forming a physical barrier that prevents the release of heavy metal elements, including Cu, Zn, and Hg, from the sediment into the water body[5]. Although this technique is relatively simple to operate and inexpensive, its long-term application can result in the thickening of the riverbed sediment layer, which in turn affects the river's depth and capacity. Of greater concern is the potential for the release of heavy metals from the originally sequestered sediment into the water body when the cover material is damaged for various reasons. This could result in secondary pollution.

In order to overcome the limitations of traditional covering technique, researchers have developed active covering technique. This technique introduces active materials, such as activated carbon, lanthanum-modified clay, and aluminum-modified zeolite, on top of the original physical blocking. These materials are capable of not only effectively covering the sediment, but also controlling the release of the majority of pollutants through adsorption and immobilization. In comparison to traditional covering techniques, the active covering method exhibits superior performance, with a generally favorable outlook for its application[6].

3.1.2 Electrokinetic remediation. Electrokinetic remediation represents a novel approach to remediation that employs the action of an electric field to activate heavy metals present in the sediment, subsequently directing them into a specific electrolyzer. Through intricate physical processes, including electromigration, electroosmosis, and electrophoresis, heavy metal ions exhibit directional movement within an electric field, ultimately accumulating in the vicinity of the electrode. By implementing a regular cleaning and treatment regimen for the sediment in these areas, it is possible to significantly reduce the overall heavy metal content in the sediment. This technique is not only highly targeted and efficient, but also can be combined with other repair techniques to form a diversified repair program, demonstrating strong compatibility and adaptability[7].

3.2 *In-situ* chemical remediation technique

Chemical remediation technology represents a significant approach to environmental treatment. Its fundamental objective is to initiate specific chemical reactions by meticulously introducing chemical reagents into the sediment. These reactions can markedly alter the chemical form of heavy metals in the sediment, thereby effectively reducing the dissolution and migration potential, and toxicity of heavy metals. The principal branches of chemical remediation technique include chemical leaching technique, chemical fixation technique, precipitation remediation technique, *etc.* In practice, these methods demonstrate notable advantages, including high efficiency, convenient operation, and relatively low cost[8].

It is important to acknowledge that, while chemical remediation technique offers numerous benefits, the precise control of chemical reagents is essential in real-world applications. The delivery of an excessive quantity of reagent may result in alterations to the structure of the water, which could potentially lead to the generation of secondary pollution and the emergence of other potential hazards. Consequently, in the operational phase, it is imperative to meticulously regulate the dosage of drugs to guarantee that the anticipated remediation outcome is attained, while simultaneously preventing detrimental effects on the surrounding environment due to excessive reagent delivery.

3.3 *In-situ* bioremediation technique

3.3.1 Microbial remediation technique. Microbial remediation technique represents an environmental treatment method that is meticulously designed in accordance with the specific conditions of the water body in question. The method is based on the introduction of specific microorganisms that are capable of effectively degrading pollutants in polluted water bodies. These microorganisms utilize pollutants as a nutrient source, employing a distinctive metabolic mechanism to effectively alter the chemical form of heavy metals. This process reduces the concentration and toxicity of heavy metals in the sediment, thereby significantly enhancing the quality of the surrounding aquatic environment. The microbial sediment remediation technique, which is currently the most widely used in this field, encompasses a wide range of methods, including sediment bio-oxidation, the application of bio-stimulants, and bioaugmentation technique. These techniques are typically accompanied by phytoremediation technique, collectively forming an effective and environmentally responsible system for the remediation of water bodies.

3.3.2 Phytoremediation technique. Phytoremediation is a technique that involves the planting of specific aquatic plants with the objective of removing heavy metal pollutants from the sediment in water bodies. The principal mechanism of action of this technique involves the processes of extraction, volatilization, stabilization, and degradation of heavy metals by plants. In comparison to other remediation techniques, phytoremediation exhibits a number of advantages, including a relatively low cost, the ease of large-scale planting, and the formation of mutually beneficial symbiotic relationships with microorganisms. Nevertheless, this technology is not without limitations. The remediation process is relatively slow and inefficient, and there is a potential for secondary pollution due to improper treatment of plants at the conclusion of the remediation process. Given the extensive scope of phytoremediation technology and its inherent complexity, it is clear that theoretical research plays a pivotal role in providing the necessary support. Nevertheless, the theoretical research of this technique has not yet been sufficiently developed, which, to a certain extent, constrains its widespread dissemination in practical applications[9].

3.4 Co-remediation technique As a comprehensive treatment strategy, the core of co-remediation technique is the construction of an efficient and environmentally friendly treatment system based on the specific situation of water pollution. This is achieved by cleverly combining physical, chemical, biological, and other remediation techniques in order to achieve comprehensive remediation of water bodies. The rapid development of industry and mining has led to an increase in the prevalence of water pollution, with pollution sources becoming increasingly diverse and complex. In light of the intricate nature of the pollution issue, the conventional *in-situ* remediation approach has proven inadequate, exhibiting shortcomings that have become increasingly evident.

In this context, the co-remediation technique, which is characterized by high efficiency, low pollution, environmental protection, and numerous other advantages, has gradually emerged as the primary research focus in the field of heavy metal pollution treatment. This technique is not only effective in addressing complex and variable water pollution problems, but also has a broad application prospect, high practical value and promotion potential[10].

4 Conclusions and suggestions

Heavy metal pollution of water sediment not only damages the ecological environment but also poses a serious threat to the health of neighboring residents and animals. Consequently, there is an immediate requirement to enhance the comprehensive remediation of heavy metal contamination of water sediment. To address this problem, the relevant departments and organizations have primarily employed three remediation strategies: physical remediation, chemical remediation, and bioremediation. These strategies have yielded significant outcomes. Nevertheless, it is imperative to acknowledge the limitations of this approach. In light of the aforementioned considerations, it is recommended that the pertinent departments and enterprises intensify their endeavors in the following domains.

(i) It is recommended that Xi Jinping's thought on ecological civilization should be followed as a guiding principle and that in-depth source control strategies for sewage discharge should be implemented. It is imperative that relevant government departments implement rigorous enforcement of the law, enhance their oversight and management of all types of sewage discharge, and guarantee that all sewage discharge adheres to the relevant standards. Concurrently, a comprehensive mapping of regulatory blind zones should be conducted with the objective of definitively eliminating any form of illegal emissions.

(ii) It would be beneficial for local governments to implement a more proactive talent policy, informed by relevant policy, with the aim of attracting and retaining a greater number of exceptional talents who are dedicated to environmental protection. The optimization of talent structures can facilitate the construction of innovative talent teams, thereby stimulating the vitality of scientific and technological innovation.

(iii) It is recommended that investment in scientific research should be increased and that technological innovation should be promoted. The government, enterprises, universities and research institutions, and other relevant parties should enhance communication and collaboration, exploit the full potential of diverse treatment and restoration techniques, and integrate a range of techniques for graded treatment. Concurrently, treatment plans should be formulated on the basis of the differing levels of pollution, with a view to ensuring the realization of efficient, low-cost, scientific, and reasonable engineering effects.

(iv) In the process of scientific and technological innovation, scientific research institutions should give full consideration to the feasibility and practicality of the technique under consideration. It is imperative to facilitate the transition from laboratory pilot studies to large-scale industrialization of the heavy metal pollution remediation technique. This entails ensuring that theoretical research can be effectively transformed into practical applications.

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