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Original Paper

Mercury Menace: Unraveling Accumulation and Impact in China's Southern Lakes: A Mini Review

Yang Wang[1] & Yang Ma[1]

[1] School of Municipal and Geomatics Engineering, Hunan City University, Hunan Province Engineering & Technology Research Center for Rural Water Quality Safety, Yiyang, Hunan 413000, China

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Abstract

This review explores mercury pollution in China's southern lake region, focusing on its accumulation in aquatic plants and the resulting ecological and human health impacts. Mercury's transformation within ecosystems disrupts biodiversity and food webs, posing significant environmental threats. Human exposure, primarily through contaminated fish, leads to serious health risks. The review highlights future research directions, including advanced detection technologies, phytoremediation strategies, and the influence of climate change on mercury dynamics. Emphasizing the need for improved risk assessments and effective policy frameworks, the article advocates for interdisciplinary approaches to mitigate mercury pollution. By integrating scientific innovation and community engagement, sustainable management and protection of both ecosystems and human health can be achieved.

Keywords

Mercury Accumulation, Aquatic Plants, Ecological Impact, Human Health Risk

1. Introduction

Mercury (Hg) is a naturally occurring heavy metal renowned for its high toxicity and persistence in the environment. As a global pollutant, mercury poses significant environmental and health risks due to its ability to bioaccumulate and biomagnify within food chains (Clarkson & Magos, 2006). The adverse effects of mercury contamination have been extensively documented across various ecosystems worldwide. However, the mechanisms underlying its accumulation and transformation in the aquatic ecosystems of China's southern lake region remain complex and intriguing areas of study.The southern lake region of China, characterized by abundant water resources and diverse aquatic vegetation, serves as a critical area for studying mercury dynamics. This region includes notable water bodies such as

Dongting Lake, the second-largest freshwater lake in China (Figure 1), which plays a vital role in regional biodiversity and ecological balance (Jiang et al., 2012). Aquatic plants in these ecosystems are integral to nutrient cycling, water purification, and providing habitats for numerous organisms. However, they also act as potential sinks for heavy metals like mercury, making it essential to understand the extent and impact of this accumulation.The mercury accumulation potential of aquatic plants varies significantly among species and is influenced by multiple factors. These include the mercury concentration in surrounding water and sediment, plant growth stages, and specific physiological characteristics (Zhang et al., 2019). For instance, fast-growing species with extensive root systems, such as *Eichhornia crassipes* (water hyacinth), often exhibit higher mercury accumulation potential due to their ability to absorb and translocate mercury efficiently (Wang et al., 2020).

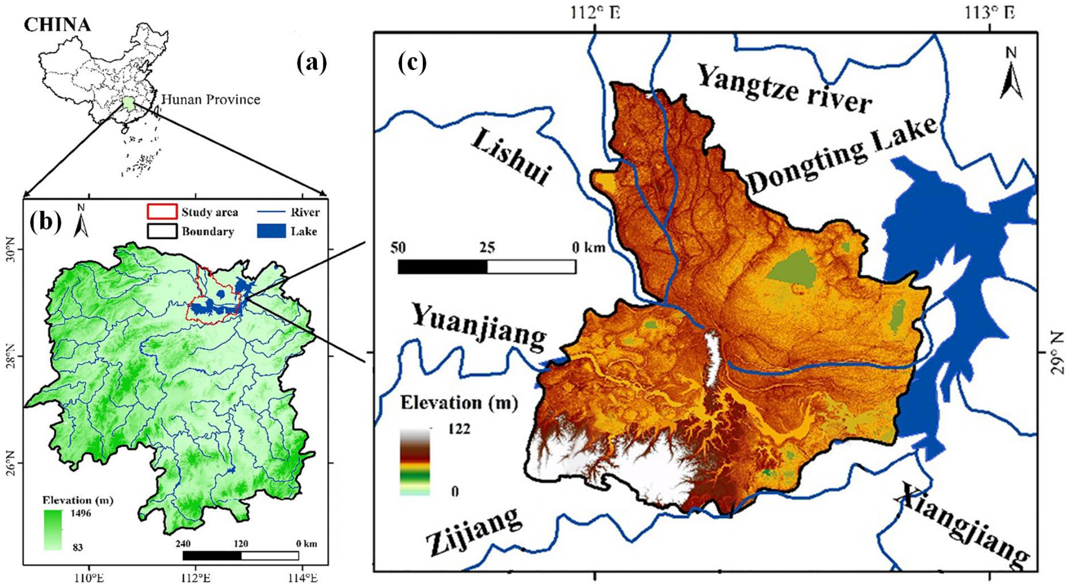

Figure 1. Location and Water System of the Dongting Lake Basin in China (Zhang et al., 2021)

Recent studies have quantified mercury concentrations in various aquatic plants, revealing levels ranging from 0.1 to 1.5 mg/kg in plant tissues, depending on environmental conditions and plant species (Lee et al., 2020). These findings underscore the variability and complexity of mercury uptake in aquatic ecosystems.

Once mercury enters aquatic plants, it can undergo various transformations, including methylation, which increases its toxicity. Methylmercury (MeHg), the most toxic form, can be transferred to higher trophic levels, posing significant health risks to humans and wildlife (Mason et al., 2000). The transformation mechanisms involve complex biochemical processes, including the role of specific transport proteins and chelating agents that facilitate mercury uptake and sequestration within plant tissues (Shi et al., 2021).

The methylation of mercury in plants is influenced by environmental factors such as pH, temperature, and the presence of other ions, which can affect the rate and extent of mercury conversion (Qian et al., 2019). Understanding these processes is crucial for assessing the ecological risks associated with mercury pollution.

Human activities significantly exacerbate mercury pollution in these regions. Industrial processes, such as coal combustion and metal refining, release substantial mercury amounts into the atmosphere, which subsequently deposit into aquatic systems (Streets et al., 2005). Additionally, agricultural practices contribute to mercury contamination through fertilizers and pesticides containing trace mercury amounts (Li et al., 2017).

In recent years, there has been growing concern over increasing mercury levels in China's southern lake region. Both natural processes, such as volcanic activities and forest fires, and anthropogenic activities contribute to this rise. Despite increasing awareness, there remains a significant knowledge gap regarding the specific mechanisms of mercury accumulation and transformation in the region's aquatic plants.

This review aims to synthesize current knowledge on the mercury accumulation potential of aquatic plant species in China's southern lake region, focusing on West Dongting Lake. It will explore factors influencing mercury accumulation, mechanisms of mercury transformation within plants, and potential implications for the local ecosystem and public health. By providing valuable insights, this review will inform future research and policy-making aimed at mitigating mercury contamination impacts in this critical region.

2. Mercury Pollution in the Southern Lake Region of China

The southern lake region of China, home to numerous freshwater bodies such as Dongting Lake and Poyang Lake, is a critical area for biodiversity and ecological health. However, this region faces significant environmental challenges due to mercury pollution, which poses threats to both ecosystems and human health (Zhang et al., 2012).

2.1 Sources of Mercury Pollution

Mercury pollution in this region arises from both natural and anthropogenic sources. Natural sources include volcanic activity and weathering of mercury-containing rocks, but these are relatively minor compared to human-induced contributions. The primary anthropogenic sources include:

2.1.1 Industrial Emissions

The rapid industrialization of China has led to increased mercury emissions from coal-fired power plants, cement production, and metal smelting industries. These activities release mercury into the atmosphere, which is then deposited into aquatic systems through precipitation (Streets et al., 2005).

2.1.2 Agricultural Practices

The use of fertilizers and pesticides containing trace amounts of mercury contributes to soil and water contamination. Runoff from agricultural lands can introduce mercury into nearby lakes and rivers, exacerbating pollution levels (Li et al., 2017).

2.1.3 Waste Disposal

Improper disposal of industrial and municipal waste, including electronic waste, can lead to mercury leaching into the environment. Landfills and waste incineration facilities are significant point sources of mercury emissions (Chen et al., 2019).

2.2 Environmental Impact

The impact of mercury pollution on the southern lake region is profound. Mercury can exist in various forms, with methylmercury being the most toxic and readily bioavailable. In aquatic environments, mercury undergoes methylation, a process facilitated by microbial activity, which converts inorganic mercury into methylmercury (Compeau & Bartha, 1985).

Methylmercury accumulates in the tissues of aquatic organisms, leading to biomagnification up the food chain. Top predators, such as fish and birds, often exhibit high mercury concentrations, posing risks to wildlife and humans who consume them (Wang et al., 2012).

2.3 Human Health Concerns

Communities around the southern lake region are particularly vulnerable to mercury exposure due to their reliance on fish and other aquatic resources as dietary staples. Chronic exposure to mercury can lead to severe health issues, including neurological and developmental disorders, particularly in children and pregnant women (Clarkson & Magos, 2006).

2.4 Regulatory and Mitigation Efforts

Recognizing the severity of mercury pollution, China has implemented several regulatory measures to curb emissions. The Minamata Convention on Mercury, a global treaty to protect human health and the environment from anthropogenic mercury emissions, has been a significant step forward (UNEP, 2013). China has committed to reducing mercury emissions through stricter controls on industrial processes and promoting cleaner technologies (Wu et al., 2016).

Local governments have also initiated efforts to monitor mercury levels in water bodies and implement remediation projects. These include phytoremediation strategies using aquatic plants to absorb and sequester mercury from contaminated waters (Zhang et al., 2019).

2.5 Future Challenges and Research Directions

Despite these efforts, challenges remain in effectively managing mercury pollution in the southern lake region. Continued industrial growth, coupled with insufficient enforcement of regulations, poses ongoing risks. Future research should focus on developing more efficient mercury monitoring techniques and exploring innovative remediation technologies.

Additionally, public awareness campaigns are crucial to educate communities about the risks of mercury exposure and promote safer practices. Collaborative efforts between government agencies, researchers, and local communities are essential to safeguard the ecological and human health of this vital region.

3. Mercury Accumulation in Aquatic Plants

Aquatic plants play a pivotal role in the biogeochemical cycling of mercury in freshwater ecosystems. Their ability to accumulate mercury from water and sediments makes them essential bioindicators of environmental health and potential agents for bioremediation (Zhang et al., 2019). Understanding the mechanisms and factors influencing mercury accumulation in these plants is crucial for assessing ecological risks and developing mitigation strategies.

3.1 Mechanisms of Mercury Uptake

Mercury uptake in aquatic plants occurs primarily through roots, although leaves can also absorb atmospheric mercury. Once absorbed, mercury is translocated to various plant parts, where it can be sequestered or transformed. The uptake process is influenced by several factors, including the form of mercury present, environmental conditions, and plant-specific characteristics (Wang et al., 2020).

Mercury exists in different forms, including elemental mercury (Hg^0), ionic mercury (Hg^2+), and organic mercury, such as methylmercury (MeHg). Ionic mercury is the most common form absorbed by plants, facilitated by transport proteins that also transport essential ions like calcium and potassium (Shi et al., 2021). The efficiency of mercury uptake is influenced by the plant's root morphology and the presence of root exudates that can alter mercury speciation and availability.

3.2 Factors Influencing Accumulation

The extent of mercury accumulation in aquatic plants is determined by a complex interplay of environmental and biological factors:

3.2.1 Mercury Concentration in Water and Sediments

High mercury levels in the environment generally lead to increased accumulation in plant tissues. Studies have shown that plants in contaminated areas can have mercury concentrations up to 1.5 mg/kg, significantly higher than those in uncontaminated sites (Lee et al., 2020).

3.2.2 Species-Specific Characteristics

Different aquatic plant species exhibit varying capacities for mercury accumulation. For instance, *Eichhornia crassipes* (water hyacinth) and *Phragmites australis* (common reed) are known for their high accumulation potential due to their rapid growth rates and extensive root systems (Wang et al., 2020).

3.2.3 Environmental Conditions

Factors such as pH, temperature, and the presence of competing ions can significantly affect mercury uptake. Acidic conditions often enhance mercury solubility, increasing its availability for plant uptake (Qian et al., 2019).

3.2.4 Plant Growth Stage

Younger plants tend to accumulate more mercury due to higher metabolic rates and nutrient uptake demands. As plants mature, the rate of mercury accumulation may decrease (Zhang et al., 2019).

3.3 Implications for Ecosystem Health

The accumulation of mercury in aquatic plants has significant implications for ecosystem health and food web dynamics. Mercury sequestered in plant tissues can be transferred to herbivores and subsequently to higher trophic levels, leading to biomagnification (Mason et al., 2000). This process poses risks to wildlife and humans, particularly in communities relying on fish and other aquatic organisms as dietary staples.

3.4 Potential for Phytoremediation

Despite the risks, the ability of aquatic plants to accumulate mercury presents opportunities for phytoremediation. By selecting and cultivating species with high mercury uptake capacities, contaminated water bodies can be effectively managed. Research into genetic and biotechnological enhancements could further improve the efficiency of mercury removal by aquatic plants (Shi et al., 2021).

Understanding the dynamics of mercury accumulation in aquatic plants is essential for assessing ecological risks and developing effective remediation strategies. Future research should focus on elucidating the molecular mechanisms of mercury uptake and exploring the potential of genetically engineered plants for enhanced phytoremediation capabilities. By harnessing the natural abilities of aquatic plants, it is possible to mitigate the impacts of mercury contamination in vulnerable ecosystems like China's southern lake region.

4. **Migration and Transformation of Mercury in Plants**

Understanding the migration and transformation of mercury within plants is crucial for assessing its ecological impact and potential for phytoremediation. Once mercury is absorbed by plants, it undergoes complex processes of translocation and transformation, affecting its bioavailability and toxicity (Liang et al., 2020).

4.1 Uptake and Initial Transformation

Mercury enters plants primarily through the roots, although foliar absorption of atmospheric mercury can also occur. The form of mercury—elemental (Hg^0), ionic (Hg^2+), or methylmercury (MeHg)—influences its uptake and subsequent transformation. Ionic mercury is most readily absorbed by roots, where it can bind to thiol groups in root cell walls, reducing its mobility (Zhang et al., 2019).

Once inside, mercury can be transformed through various biochemical processes. For instance, mercury can bind with glutathione and phytochelatins, forming complexes that sequester it in vacuoles, thereby reducing its toxicity (Emamverdian et al., 2015).

4.2 Translocation to Aerial Parts

The movement of mercury from roots to shoots and leaves involves the plant's vascular system. This translocation is influenced by several factors, including plant species, mercury concentration, and environmental conditions (Wang et al., 2020). Studies have shown that certain plants exhibit limited mercury translocation, with most of the metal remaining in the roots. However, some species, such as *Eichhornia crassipes*, can efficiently transport mercury to aerial parts, which is beneficial for phytoremediation purposes (Shi et al., 2021).

4.3 Transformation Processes

Within the plant, mercury undergoes several transformation processes:

4.3.1 Reduction and Volatilization

Some plants can reduce ionic mercury to elemental mercury, which is less toxic and can be volatilized back into the atmosphere. This process is mediated by enzymes such as mercuric reductase and is considered a detoxification mechanism (Heaton et al., 2005).

4.3.2 Methylation

Although less common in plants compared to microbial environments, methylation can occur, leading to the formation of methylmercury. This transformation is significant because methylmercury is highly toxic and mobile. The extent of methylation varies among plant species and environmental conditions (Qian et al., 2019).

4.3.3 Demethylation

Conversely, some plants can demethylate methylmercury, converting it back to less toxic forms. This ability varies widely among species and is an area of active research (Liang et al., 2020).

4.4 Impact on Ecosystem and Phytoremediation Potential

The migration and transformation of mercury in plants have significant ecological implications. By sequestering mercury in less mobile forms, plants can reduce its bioavailability in the environment, thereby mitigating its impact on the food chain (Mason et al., 2000).

For phytoremediation, understanding these processes is critical for selecting appropriate plant species and optimizing conditions for mercury removal. Plants that can efficiently translocate and volatilize mercury are particularly valuable for cleaning contaminated sites (Wang et al., 2020).

Further research is needed to elucidate the genetic and molecular mechanisms underlying mercury transformation in plants. Advances in genetic engineering could enhance the phytoremediation capabilities of plants, making them more effective at detoxifying mercury-contaminated environments. Additionally, exploring the interactions between plants and soil microbes could provide insights into synergistic approaches for mercury remediation (Shi et al., 2021).

5. Implications for Ecosystem and Human Health

Mercury pollution in the southern lake region of China poses significant risks to both ecosystem integrity and human health. Understanding these implications is crucial for developing effective management and remediation strategies.

5.1 Ecosystem Impacts

5.1.1 Biodiversity and Food Web Dynamics

Mercury contamination affects biodiversity by altering food web dynamics. Aquatic organisms, particularly fish, accumulate mercury through their diet. This bioaccumulation leads to biomagnification, where top predators, including birds and mammals, exhibit higher mercury concentrations (Wang et al., 2012). High mercury levels can impair reproduction and survival rates, threatening species diversity and ecosystem stability (Scheuhammer et al., 2007).

5.1.2 Habitat Degradation

Mercury pollution contributes to habitat degradation, impacting aquatic vegetation and soil quality. Contaminated sediments can inhibit plant growth, reducing habitat complexity and the availability of resources for aquatic life (Zhang et al., 2019). This degradation affects not only individual species but also the entire ecosystem’s functionality.

5.1.3 Microbial Communities

Mercury affects microbial communities in soil and water, altering nutrient cycling and ecosystem processes. Mercury-resistant bacteria can dominate these communities, potentially disrupting normal microbial functions and impacting nutrient availability for plants and other organisms (Frossard et al., 2017).

5.2 Human Health Concerns

5.2.1 Dietary Exposure

Humans are primarily exposed to mercury through the consumption of contaminated fish and shellfish. Methylmercury, the most toxic form, accumulates in fish muscle tissue, posing risks to communities reliant on fish as a dietary staple (Clarkson & Magos, 2006). Chronic exposure can lead to neurological and developmental disorders, particularly affecting children and pregnant women (Rice et al., 2014).

5.2.2 Vulnerable Populations

Populations in the southern lake region are particularly vulnerable due to their proximity to contaminated water bodies and reliance on local resources. Subsistence fishers and indigenous communities face higher exposure risks, necessitating targeted public health interventions (Zhang et al., 2012).

5.2.3 Health Effects

Mercury exposure is linked to a range of health effects, including cognitive deficits, cardiovascular problems, and immune system suppression. The neurotoxic effects of methylmercury are well-documented, with long-term exposure leading to significant cognitive impairments (Grandjean & Landrigan, 2006).

5.3 Mitigation and Management Strategies

5.3.1 Regulatory Measures

Effective regulatory measures are essential to mitigate mercury pollution. The implementation of the Minamata Convention on Mercury represents a global commitment to reducing mercury emissions (UNEP, 2013). China has taken steps to limit industrial emissions and promote cleaner technologies, although enforcement remains a challenge (Wu et al., 2016).

5.3.2 Public Health Initiatives

Public health initiatives should focus on raising awareness about mercury risks and promoting safe dietary practices. Educational campaigns can inform communities about the dangers of consuming contaminated fish and encourage alternative food sources (Li et al., 2017).

5.2.3 Ecosystem Restoration

Restoration efforts should aim to rehabilitate contaminated habitats and restore ecological balance. Phytoremediation using mercury-accumulating plants offers a promising approach to removing mercury from affected areas (Zhang et al., 2019). Additionally, enhancing habitat complexity can support biodiversity and improve ecosystem resilience.

Further research is needed to understand the long-term impacts of mercury pollution on ecosystem and human health. Studies should focus on developing more accurate risk assessment models and exploring innovative remediation technologies. Collaborative efforts between scientists, policymakers, and local communities will be crucial in addressing the multifaceted challenges posed by mercury pollution (Mason et al., 2000).

6. Future Research Directions

As mercury pollution continues to pose significant ecological and health challenges, future research must focus on innovative strategies and comprehensive understanding to mitigate its impact. This section outlines key areas for future investigation.

6.1 Advanced Detection and Monitoring Techniques

Developing more sensitive and accurate methods for detecting mercury in environmental matrices is crucial. Current technologies, such as atomic fluorescence spectrometry and mass spectrometry, can be enhanced through the integration of nanotechnology and biosensors. These innovations could provide real-time monitoring capabilities, allowing for more precise tracking of mercury pollution sources and pathways (Li et al., 2021).

6.2 Mechanisms of Mercury Transformation

Further research is needed to elucidate the biochemical and molecular mechanisms underlying mercury transformation in plants and microbes. Understanding these processes can lead to the development of genetically engineered organisms with enhanced mercury detoxification capabilities. Studies should focus on identifying key genes and enzymes involved in mercury methylation and demethylation (Qian et al., 2019).

6.3 Phytoremediation and Bioremediation Strategies

Phytoremediation remains a promising approach for mercury remediation. Future research should explore the use of transgenic plants engineered to express mercury-resistant genes. Additionally, combining phytoremediation with microbial bioremediation could enhance mercury removal efficiency. Investigating plant-microbe interactions and their synergistic effects on mercury uptake and transformation will be crucial (Wang et al., 2020).

6.4 Impact of Climate Change

Climate change may influence mercury cycling in the environment. Rising temperatures and changing precipitation patterns can alter mercury deposition and bioavailability. Research should focus on modeling these impacts to predict future mercury dynamics under different climate scenarios. Understanding these interactions will help in developing adaptive management strategies (Zhang et al., 2019).

6.5 Human Health Risk Assessment

Improving risk assessment models for human exposure to mercury is essential. Current models often lack precision due to variability in individual susceptibility and exposure pathways. Future research should incorporate genetic, dietary, and lifestyle factors to create more personalized risk assessments. Longitudinal studies tracking health outcomes in populations exposed to mercury will provide valuable data (Rice et al., 2014).

6.6 Policy and Management Frameworks

Effective policy frameworks are needed to manage mercury pollution at local, national, and global levels. Research should evaluate the effectiveness of existing regulations, such as the Minamata Convention, and propose improvements based on scientific findings. Collaborative efforts between policymakers, scientists, and communities are essential to address mercury pollution comprehensively (UNEP, 2013).

6.7 Socioeconomic and Cultural Dimensions

Understanding the socioeconomic and cultural factors influencing mercury exposure and management is crucial. Research should explore how cultural practices, such as fishing and traditional medicine, contribute to mercury exposure. Engaging with local communities to incorporate traditional knowledge into management strategies can enhance their effectiveness and acceptance (Li et al., 2017).

6.8 Interdisciplinary Approaches

Addressing mercury pollution requires interdisciplinary collaboration. Integrating insights from ecology, toxicology, chemistry, and social sciences will lead to more holistic solutions. Collaborative research networks and data-sharing platforms can facilitate the exchange of knowledge and resources, accelerating progress in mercury research (Frossard et al., 2017).

Future research on mercury pollution should prioritize innovation and collaboration to develop effective solutions. By advancing detection technologies, understanding transformation mechanisms, and integrating interdisciplinary approaches, we can mitigate the ecological and health impacts of mercury pollution. These efforts will contribute to sustainable environmental management and the protection of human health.

7. Conclusion

Mercury pollution in China's southern lake region presents significant challenges to both ecosystems and human health. Our review highlights the critical pathways of mercury accumulation in aquatic plants and the broader environmental impacts. Mercury's transformation and migration through ecosystems disrupt biodiversity, alter food webs, and degrade habitats, posing severe ecological threats. Human health is at risk, primarily through dietary exposure to contaminated fish, leading to neurological and developmental disorders. Vulnerable populations, particularly those reliant on local resources, face heightened exposure risks.

Future research should focus on advancing detection technologies, understanding mercury transformation mechanisms, and developing effective phytoremediation strategies. Additionally, the impacts of climate change on mercury dynamics and the need for improved human health risk assessments are crucial areas for investigation.

Effective policy frameworks and interdisciplinary approaches are essential for comprehensive mercury management. By integrating scientific innovation with community engagement, we can mitigate the adverse effects of mercury pollution, ensuring sustainable ecosystem management and protecting public health.

Declaration of Competing Interest

The authors declare that they have no known competing interests.

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