South American Publishing

SAP Environmental Research and Ecotoxicity. 2025; 4:172
doi: 10.56294/ere2025172

REVIEW

Impact of Mercury Poisoning in Rivers: A Bibliometric Review of Human Health Effects

Impacto del envenenamiento por mercurio en ríos: una revisión bibliométrica de las afectaciones a la salud humana

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Cite as
Chaves Cano AM. Impact of Mercury Poisoning in Rivers: A Bibliometric Review of Human Health Effects. SAP Environmental Research and Ecotoxicity. 2025; 4:172. https://doi.org/10.56294/ere2025172

Publication History
Submitted: 17-05-2024
Revised: 28-11-2024
Accepted: 03-04-2025
Published: 04-04-2025

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ABSTRACT

Mercury poisoning in rivers poses a serious threat to aquatic ecosystems and human health, particularly for communities reliant on these resources. This article presents a bibliometric review of scientific literature (2015–2025) to analyze the impact of mercury in rivers and its health effects, identifying research trends and gaps. The methodology involved a Scopus search using key terms such as "mercury poisoning," "rivers," and "human health," selecting 1,194 articles analyzed through bibliometric indicators and content analysis with Bibliometrix. Results revealed a progressive increase in publications, peaking in 2023–2024, reflecting growing global concern. Four main thematic areas were identified: (1) toxicity mechanisms and bioaccumulation of methylmercury, (2) health effects, particularly in vulnerable groups, (3) risk assessment and monitoring methodologies, and (4) mitigation and remediation strategies. Key findings highlighted disparities in artisanal mining regions, advances in detection technologies, and challenges in implementing policies like the Minamata Convention. The study concludes that while robust evidence exists on mercury risks, gaps persist in harmonizing methods and applying sustainable solutions.

Keywords: Mercury; Rivers; Human Health; Bibliometrics; Methylmercury; Pollution.

RESUMEN

El envenenamiento por mercurio en ríos representa una grave amenaza para los ecosistemas acuáticos y la salud humana, especialmente en comunidades que dependen de estos recursos. Este artículo presenta una revisión bibliométrica de la literatura científica (2015-2025) para analizar el impacto del mercurio en ríos y sus afectaciones a la salud, identificando tendencias y vacíos de investigación. La metodología se basó en una búsqueda en Scopus utilizando términos clave como "mercury poisoning", "rivers" y "human health", seleccionando 1,194 artículos que fueron analizados mediante indicadores bibliométricos y análisis de contenido con Bibliometrix. Los resultados mostraron un aumento progresivo de publicaciones, con un pico en 2023-2024, reflejando la creciente preocupación global. Se identificaron cuatro ejes temáticos principales: (1) mecanismos de toxicidad y bioacumulación del metilmercurio, (2) efectos en la salud, particularmente en grupos vulnerables, (3) metodologías de monitoreo y evaluación de riesgo, y (4) estrategias de mitigación y remediación. Destacaron las disparidades en regiones con minería artesanal, los avances en tecnologías de detección y los desafíos en la implementación de políticas como el Convenio de Minamata. El estudio concluye que, aunque existe un sólido cuerpo de evidencia sobre los riesgos del mercurio, persisten brechas en la armonización de métodos y la aplicación de soluciones sostenibles.

Palabras clave: Mercurio; Ríos; Salud Humana; Bibliometría; Metilmercurio; Contaminación.

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INTRODUCTION

Mercury poisoning has become a major environmental and public health problem in recent decades.[1,2] Mercury is a heavy metal that poses a significant environmental and health risk in aquatic ecosystems, particularly in its methylated form.[3] As noted by Teng et al.[4], the primary source of soil contamination comes from natural release, but human activities also contribute to the problem, especially near mercury mining sites.

Rivers, as key water systems, are particularly exposed to mercury contamination.[5] This metal enters water bodies through sediments, macrophytes, and fish, as indicated by Gutierrez-Mosquera et al.[6], with higher bioavailability in fish and possible health risks for carnivores. Methylation of mercury in aquatic environments leads to the formation of methylmercury; this compound, warns Jeong et al.[7], poses significant toxicity risks to aquatic organisms through bioaccumulation and biomagnification, which produces adverse effects even at low concentrations.

Exposure to methylmercury has been associated with various health conditions, including neurological disorders,[8] effects on cognitive development in children,[9] and motor dysfunction.[10] The most vulnerable populations, such as Indigenous communities that depend on fishing as a primary food source, are at high risk, according to Martoredjo and colleagues.[11] Given the complexity of the problem and its impact on public health, it is essential to carry out an exhaustive analysis of the existing literature that addresses the relationship between mercury contamination in rivers and its effects on human health.[12,13]

Despite advances in research on mercury's impacts, important gaps in knowledge persist, particularly regarding regional differences in exposure, synergistic effects with other pollutants, and the most effective strategies for its mitigation.[14] This article aims to present a bibliometric review that synthesizes the available information on the impact of mercury poisoning in rivers, focusing on human health effects.

METHOD

Research Design

This study is based on a bibliometric approach[15,16] to analyze the scientific production related to the impact of mercury poisoning in rivers and its effects on human health. Bibliometrics allows for quantifying and evaluating trends in the academic literature through indicators of productivity, impact, and collaboration.[17,18,19] To guarantee a systematic and reproducible review, the steps proposed by standardized methodologies were followed.[20]

Data Source and Search Strategy

Data collection was performed in Scopus, one of the most exhaustive bibliographic databases used in scientific reviews due to its wide coverage of indexed journals. The search formula was constructed using Boolean operators and key terms in English since this is the predominant language in scientific literature. The query applied was:

(TITLE-ABS-KEY ("mercury poisoning" OR "mercury contamination" OR "methylmercury") AND TITLE-ABS-KEY ("rivers" OR "aquatic ecosystems" OR "freshwater") AND TITLE-ABS-KEY ("human health" OR "public health" OR "neurotoxicity" OR "health effects")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re"))

This equation ensured the retrieval of original articles and reviews, excluding other types of documents such as conferences or editorials. In addition, temporal filters were applied to cover studies published between 2015 and 2025 to analyze the recent evolution of knowledge in this field.

Selection Criteria and Data Processing

The records obtained were purified through a two-stage selection process: first, duplicates and non-relevant papers were eliminated by reviewing titles and abstracts; subsequently, the relevance of the remaining articles was assessed by critical reading of the full text. Only research addressing the relationship between mercury contamination in rivers and its impact on human health was included. The extracted data were organized in a matrix that included variables such as year of publication, country of origin, and network of co-occurrence of keywords. This information was processed using Bibliometrix (in R).

Bibliometric Analysis

The study combined performance and scientific impact metrics with qualitative analysis. Among the quantitative indicators, the following were considered:

- Annual productivity: temporal evolution of the number of publications.
- Collaboration networks: Analysis of co-authorships to identify influential research groups.
- Co-Word Maps: Grouping key terms to detect dominant lines of research.

A content analysis was also performed to categorize the findings into thematic axes. This mixed approach allowed us to quantify the academic production and interpret its meaning in the context of environmental health.

Limitations

Although this method guarantees a systematic review, certain limitations are recognized, such as the possible exclusion of relevant studies indexed in other databases (Web of Science, PubMed) or published in languages other than English. Also, the bias inherent in the Scopus retrieval algorithms could affect the completeness of the results. However, the rigorous search strategy and validated tools minimize these risks, ensuring a robust approach to the state of the art.

https://doi.org/10.56294/ere2025172

RESULTS AND DISCUSSION

The information search formula employed yielded 1194 documents distributed by year of publication in figure 1. The largest peak of publications per year was observed in 2023, with 156 studies, very close to that obtained in 2024 (155 studies). In 2025, 50 studies were published, almost 1/3 of the previous year

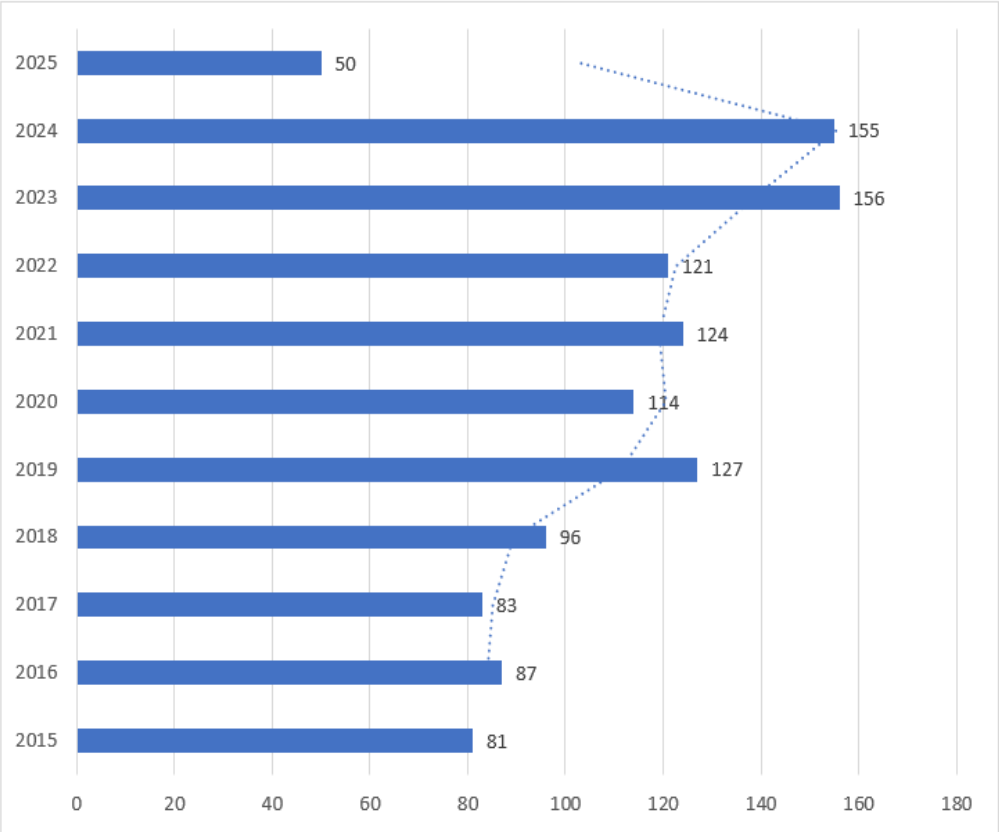


Figure 1. Documents distributed by publication year

The collaborative network analysis identified that the most prominent authors focus mainly on analyzing the effects and consequences of mercury and methylmercury. Other collaborations are observed in studying their effects on plant and animal life and health risks (figure 2).

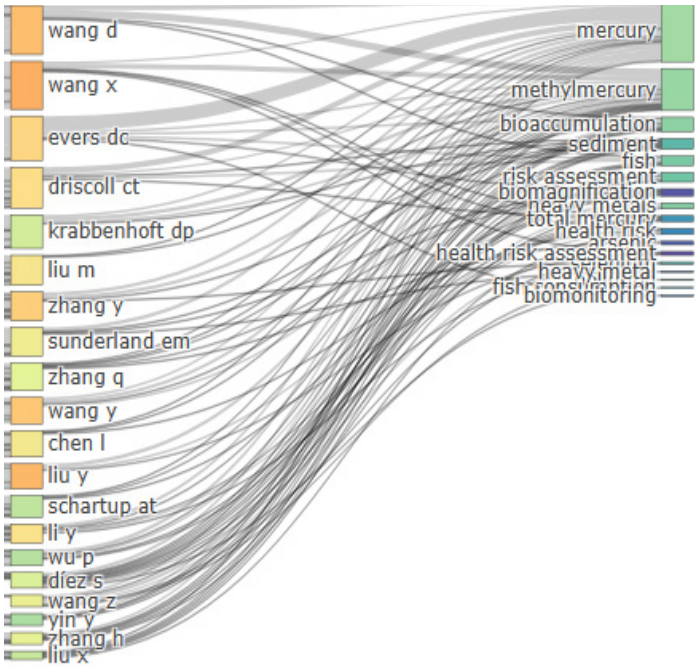


Figure 2. Collaboration networks among authors

The thematic analysis presented in figure 3 can be grouped into four emerging thematic axes: (1) mechanisms of toxicity and bioaccumulation of methylmercury, (2) effects on population health, especially in vulnerable groups, (3) monitoring and risk assessment methodologies, and (4) environmental mitigation and remediation strategies.

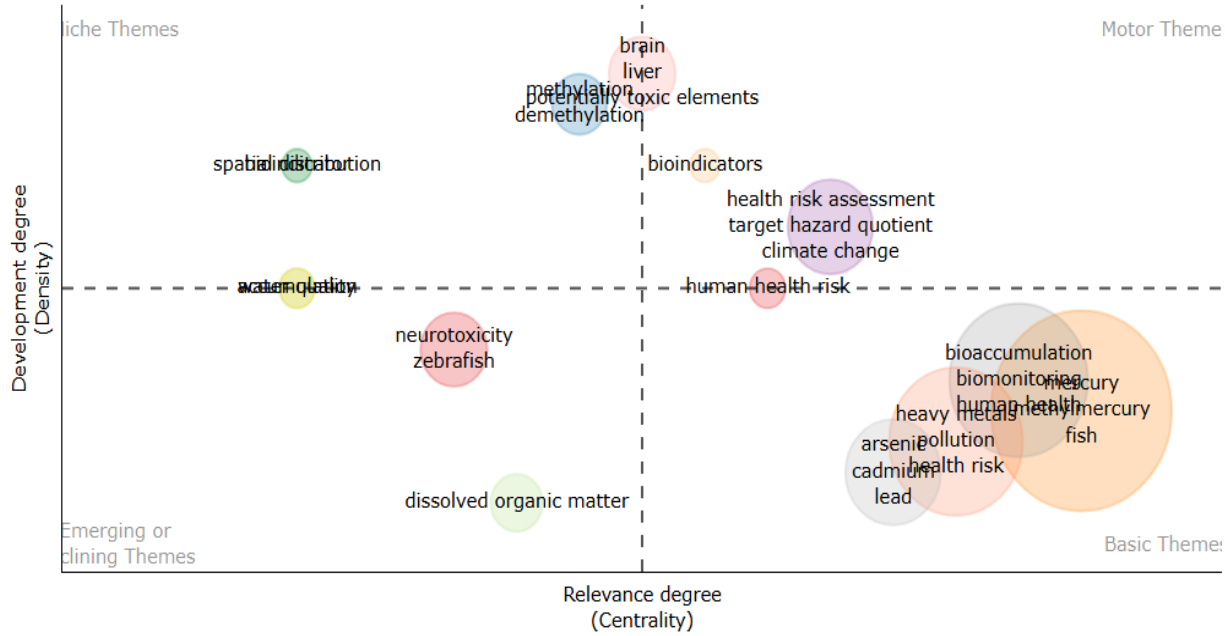


Figure 3. Analysis of the thematic axes identified in the literature

From this bibliometric analysis, key patterns were identified in the scientific production on the impact of mercury on rivers and human health, which made it possible to delimit the four central thematic axes that structure the knowledge in this field. These axes synthesize the research priorities identified in the literature while highlighting the interdisciplinary nature of the subject, linking toxicology, epidemiology, and environmental management.

Mechanisms of Toxicity and Bioaccumulation of Methylmercury

The first thematic axis addresses the biogeochemical processes determining mercury's transformation, dispersion, and bioaccumulation in aquatic ecosystems. Once deposited in rivers, inorganic mercury (Hg^{2+}) is methylated by anaerobic microorganisms, becoming methylmercury (MeHg), its most toxic and bioavailable form.[21] In this regard, De Moura Meneses et al.[22] point out that Hg exposure is higher in the riverside population (90 %) than in urban areas (57,1 %).

In addition, MeHg biomagnifies along the food chain, from soil to organisms, which, according to Du and colleagues[23], poses a potentially greater risk to residents who consume aquifer products. Research has shown that high mercury concentrations in fish in the Amazon floodplains, 70 % above the recommended guidelines for human consumption, pose health risks to human populations in the region.[24] This phenomenon is evidence of the contaminant's persistence and its ability to affect populations distant from the original emission sources. In this regard, Eissa & Younes[25] point out that the most frequently reported fishery products are tuna, swordfish, salmon, mackerel, and sharks, with heavy metals, pathogenic microorganisms, poor controls, and parasitic infestation being the main hazards.

At the toxicological level, MeHg interferes with fundamental cellular processes. In vitro and in vivo experiments have corroborated that this interaction causes neuronal oxidative stress and synaptic glutamate dyshomeostasis, leading to neuronal apoptosis.[26] Furthermore, its exposure during pregnancy can produce adverse outcomes, such as spontaneous abortion and intrauterine growth retardation, by inhibiting cell viability, altering cellular sub-microstructure, and inducing apoptosis and the capacity for cell migration and invasion.[27] Taken together, this axis underscores the need to delve deeper into the environmental and molecular factors that modulate mercury toxicity, as their understanding is essential for predicting risks and designing intervention strategies.

Population Health Effects and Vulnerable Groups

The second axis explores the health consequences of mercury exposure, emphasizing the disparities affecting vulnerable populations. Epidemiological evidence indicates that prolonged consumption of MeHg-contaminated fish is associated with neurological, renal, and cardiovascular disorders.[28,29,30] These effects are particularly severe in indigenous and coastal communities, where fish constitutes up to 70 % of the basic diet.[24]

Pregnant women and fetuses represent the highest risk group since, according to Go et al.[31], exposure to low levels of methylmercury significantly suppresses neurite outgrowth during embryonic development, which affects neuronal migration and myelination. Studies have shown that prenatal mercury exposure is associated with developmental delays, neurocognitive deficits, and conditions such as autism spectrum disorder.[32] The author believes this should lead to re-evaluating acceptable exposure limits,

especially in endemic areas where dietary alternatives are limited.[33,34,35]

In addition to neurological impacts, recent research has associated mercury with immunological and endocrine alterations, such as thyroid dysfunction and insulin resistance.[36,37] However, gaps remain in understanding long-term effects and synergistic interactions with other contaminants, such as lead or arsenic, common in mining areas.

Monitoring and Risk Assessment Methodologies

The third axis focuses on the scientific and technological tools used to quantify the presence of mercury in rivers and estimate its impact on human health. Traditionally, the analysis of water, sediment, and biological tissue samples by mass spectrometry (ICP-MS) has been the reference method for determining Hg and MeHg concentrations.[38] However, recent advances such as the automatic ethylation-purge and trap-GC-ICP-MS system developed by Liu et al.[39] and the method developed by Kulomäki et al.[40] with 3D printing based on a metal scavenger for the preconcentration and speciation of Hg are observed in the literature.

In parallel, risk assessment models have evolved to integrate socio-environmental variables[41,42], such as local food habits and risk perception in affected communities.[43] According to Lim and co-workers,[44] these methodologies are crucial to overcoming the limitations of traditional approaches.

On a global scale, the Minamata Convention on Mercury initiative is a multidisciplinary policy framework that aims to reduce mercury pollution, human exposure, and environmental health.[45] However, challenges such as lack of harmonization between countries and poor data representativeness in underdeveloped regions still limit the effectiveness of these tools.[46,47] Future research should integrate emerging technologies like artificial intelligence to predict pollution hotspots or satellite remote sensing to map emission sources in real time.[48]

Environmental Mitigation and Remediation Strategies

The fourth axis looks at interventions designed to reduce mercury release into the environment and remediate already contaminated ecosystems. Although mercury levels in soils from abandoned gold mine tailings in the Peruvian Amazon are low, Ramirez et al.[49] warn that reducing mercury use in mining operations is crucial to reducing human and environmental risks.

As for remediation, phytoremediation-use of aquatic plants such as P. miliaceum and S. oppositiofilia-can effectively reduce metal contamination in mine soils.[50] In addition, the phytoplankton Chlorella vulgaris has been shown to inhibit mercury methylation by iron-reducing bacteria but enhance it by sulfate-reducing bacteria, potentially modulating MeHg production and bioaccumulation in aquatic environments.[51]

Finally, public policy plays a key role in articulating these strategies.[52] The Minamata Convention requires comprehensive bottom-up formalization approaches and significant external funding from consumers, large mining corporations, and governments to reduce mercury emissions effectively.[53] Thus, its success depends on transnational cooperation, continued funding, and the inclusion of local communities in decision-making. This axis highlights the urgency of adopting comprehensive approaches that combine technological innovation, effective governance, and environmental education, as the solution to the mercury problem requires both scientific advances and socio-political commitment.

CONCLUSIONS

This bibliometric review evidences that river mercury poisoning constitutes a global challenge with profound implications for human health and aquatic ecosystems. The analysis of scientific production between 2015 and 2025 revealed a sustained growth in research, with a notable peak in 2023-2024, reflecting the growing concern about the effects of this pollutant. The four thematic axes identified - toxicity and bioaccumulation mechanisms, effects on population health, monitoring methodologies, and mitigation strategies - highlight the interdisciplinary complexity of the problem, as well as the need to address it from complementary perspectives. Future studies should delve deeper into synergistic interactions with other contaminants, as well as long-term health effects and remediation strategies adapted to local contexts. It is the author's opinion that only through coordinated actions - based on evidence and with an equitable commitment - will it be possible to mitigate the impact of this toxic metal and protect both river ecosystems and the health of present and future generations.

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FINANCING

None.

CONFLICT OF INTEREST

None.

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https://doi.org/10.56294/ere2025172