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MERCURY-CONTAMINATED SOIL: BIBLIOMETRIC MAPPING AND FUTURE NEEDS

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ABSTRACT

This study utilized bibliometric and content analysis methods to investigate research trends, identify key contributors, dominant themes, and future directions regarding mercury contamination in soil. Data were collected from the Scopus database from January 2015 to August 2024 using targeted search terms and analyzed using VOSviewer and Bibliometrix. Mercury research activities from 2015 to 2024 steadily increased, with an R-squared value of 0.7916. Five main research clusters were identified: Environmental Remediation Techniques, Risk Assessment and Pollution Analysis, Health Risks and Environmental Management, Pollution Monitoring and Environmental Impact, and Ecotoxicology and Environmental Health. These clusters highlight diverse focus areas and the interconnected global efforts to address mercury contamination. China, the United States, and Spain lead research output. Future studies should focus on mercury-contaminated agricultural soil for human risk assessment, particularly in areas heavily affected by ASGM.

Keywords: ASGM, Bibliometric Analysis, Contamination, Mercury, Soils.

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INTRODUCTION

Mercury (Hg) is a global pollutant[1] because of its high biotoxicity, persistent bioaccumulation, and extensive contamination.[2] It exists in elemental, inorganic, and organic forms, each with varying levels of toxicity and environmental impact.[3] Mercury contamination affects air, water, and soil, entering the food chain and human bodies through various exposure routes, with notable impacts on wildlife and public health.[4] Human activities, particularly artisanal and small-scale gold mining (ASGM), industrial emissions, and coal burning, account for the majority of global mercury emissions, with ASGM contributing approximately 37% of releases.[5] Natural sources, such as volcanic eruptions and rock weathering, also contribute to mercury pollution.[6,7] Mercury's transformation into methylmercury, a neurotoxic compound, further exacerbates its ecological impact by bioaccumulation through food chains, posing threats to biodiversity, food security, and human health.[8] Bibliometric analysis is an effective tool for mapping research trends, identifying gaps, and guiding future priorities in environmental studies.[9] Unlike systematic reviews, bibliometric methods analyze large datasets to uncover collaboration networks, influential studies, and emerging themes, providing a comprehensive overview of the intellectual landscape.[10] Despite its relevance, no bibliometric study has focused specifically on mercury contamination in soils, underscoring the necessity of this research. This study aims to conduct an in-depth bibliometric and content analysis of mercury contamination in soils to answer critical questions, including research trends, key contributors,

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dominant themes, and future research directions. The findings will provide valuable insights for shaping research agendas and policy strategies to mitigate mercury's impact on the environment and public health.

EXPERIMENTAL

The bibliometric analysis employed the Scopus database as its methodological approach, which is critical for mapping the scientific landscape with coverage across diverse academic disciplines and evaluating research impact, including identifying trends, collaborations, citation information, author details, publication metrics, and research patterns.[11] In this study, the data gathering process consisted of three steps, as described in Fig.-1.

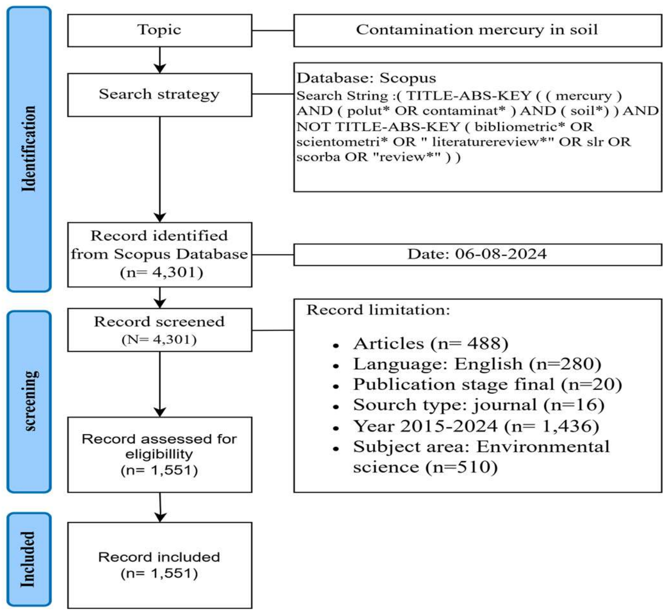

Fig.-1 Data Collection from the Scopus Database Between January 2015 to August 2024

The data collection steps in this study were based on and modified from the PRISMA flow diagram.[12] The data retrieved from Scopus on August 06, 2024, involved search terms organized into three blocks: one focused on contamination, another focused-on mercury, and soil. The refined dataset was then analyzed using VOS viewer 1.6.20 and Bibliometrix.[13] The research employs three interconnected analytical components: descriptive, bibliometric, and content analyses to address the research questions.

RESULTS AND DISCUSSION

The annual publication trends of mercury contamination in soils are shown in Fig.-2 highlighting the growth and increasing focus of research activity in this area over time.

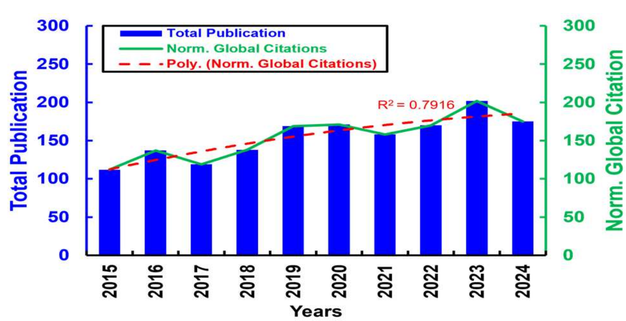

Fig.-2 Annual Total Publication and Normal Global Citation from 2015 to 2024

Fig.-2 Showed the annual trends in publications and normalized global citations on mercury contamination in soils, showing a steady increase from 2015 to 2024, with an *R*-squared value of 0.7916. This reflects growing global attention to mercury-related ecological and health risks, particularly linked to artisanal and small-scale gold mining (ASGM) as a major source of emissions.[5,14]

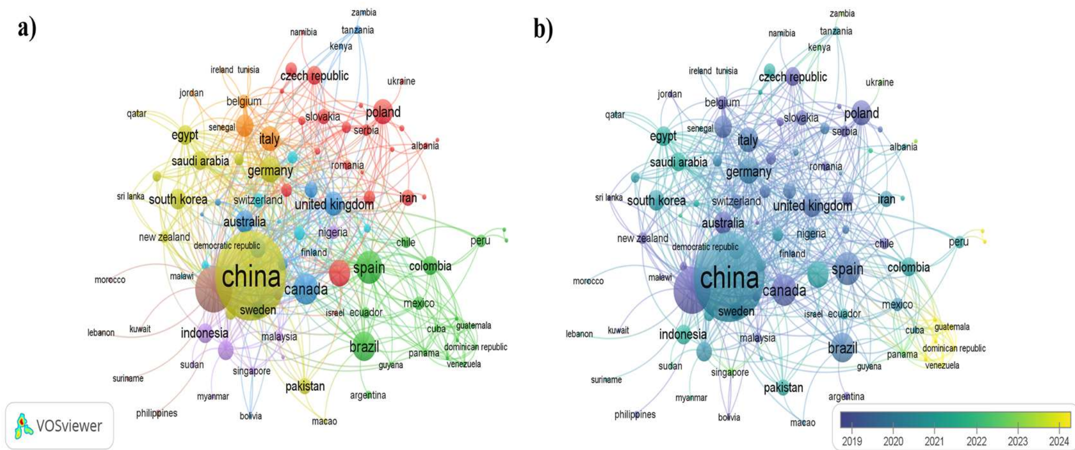

Fig.-3 Visualization of the Most Productive and Collaborative Countries (a) Network Visualization, (b) Overlay Visualization

Using VOS viewer, Fig.-3(a) visualizes the global research network across 112 countries, with 108 meeting the citation threshold. Among these, 100 countries formed interconnected networks, highlighting key contributors and collaborative efforts. Larger nodes indicate higher research output, while thicker lines represent stronger collaborative ties. Fig.-3(b) presents an overlay visualization of international collaboration in mercury contamination research. The color gradient indicates the mean year of publication. The darker blue color represents countries with longer research histories, whereas the yellow color highlights newer contributors. Central countries, such as China, United States, and Spain, demonstrate strong, extensive connections, highlighting their pivotal role in global research networks. Indonesia is ranked 16th in Southeast Asia.

Table-1 Top Countries with Mercury Contamination in Soil Research

Rank	Country	Number of docs
1	China	674
2	United States	184
3	Spain	94
4	Canada	83
5	Brazil	76

Table-1 Highlights the leading contributors to research on mercury contamination in soils Globally. China, the United States, and Spain lead in research output, underscoring their prominent roles in environmental research.

Table-2 Characteristics of the Top Five Most Prolific Journals

Rank	Sources	Articles	Cited score	Percentil	Quartile
1	Science of The Total Environment	197	17.6	95%	Q1
2	Chemosphere	102	15.8	98%	Q1
3	Environmental Monitoring and Assessment	101	4.7	67%	Q2
4	Environmental Pollution	96	16.0	98%	Q1
5	Environmental Science and Pollution Research	90	8.7	83%	Q1

The five most prolific journals publishing research on mercury contamination in soils, sourced from the Scopus database, are presented in Table-2. The Science of the Total Environment achieved the highest number of articles and citation scores with 197 articles and a citation score of 17.6. This overview highlights the impact and relevance of these journals to the academic community and their significant contributions to advancing research in this field. To identify the most influential studies on mercury contamination in soil, the top 5 studies with the highest average annual citation frequency are presented in Table-3. The most-cited article, "Contamination features and health risk of soil heavy metals in China" by Haiyang Chen (2015), has received 1174 citations, reflecting its significant contribution to understanding mercury contamination and associated risks. Other highly cited works include studies on heavy metal contamination patterns, ecological risks, and mitigation strategies, all of which serve as key references for advancing research and policy in this field. These articles underscore the foundational role of highly cited research in shaping trends, informing policies, and guiding future studies on mercury contamination in soils.

Table-3 The Most Frequently Cited 5 Articles on Mercury Contamination in Soil

First Author	Tittle	Year	Global Citations
Chen H	Contamination features and health risk of soil heavy metals in China	2015	1174
Tóth G	Heavy metals in agricultural soils of the European Union with implications for food safety	2016	1118
Lu Y	Impacts of soil and water pollution on food safety and health risks in China	2015	864
Liang J	Spatial distribution and source identification of heavy metals in surface soils in a typical coal mine city, Lianyuan, China	2017	463
Men C	Pollution characteristics, risk assessment, and source apportionment of heavy metals in road dust in Beijing, China	2018	453

The co-authorship network in mercury contamination research includes 7226 authors, of which 361 meet the threshold of at least three documents and three citations. Among them, 214 authors formed a substantial interconnected network, as shown in Fig.-4.

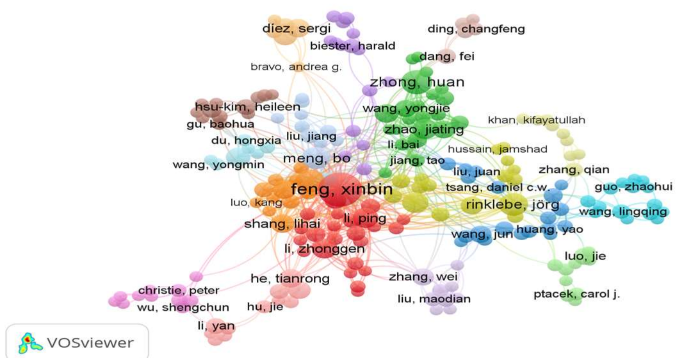

Fig.-4 Visualization Co-Authorship–Author Collaboration

This analysis highlights central contributors and collaborative groups that significantly influence the field. Strong co-authorship networks correlate with higher research productivity and impact, facilitating the sharing of resources and expertise to address mercury contamination challenges.[15] The co-occurrence analysis identified five primary research themes within the field of mercury contamination in soil Fig.-5(a). Based on 3654 author keywords, 211 met the threshold of at least five occurrences, forming five distinct clusters with 2165 links and a cumulative link strength of 4171. The five clusters represent distinct research themes: environmental contamination and remediation (red), risk assessment and pollution analysis (green), health risks and environmental management (blue), pollution monitoring and environmental impact (yellow), and ecotoxicology and environmental health (purple). The overlay visualization of author keyword co-occurrences in mercury contamination in soil research, as depicted in Fig.-5(b) reveals the distribution of research topics over time. The color gradient in this visualization indicates the average publication year for each keyword, with lighter colors representing more recent research areas and potential future research. Emerging topics, including "Agriculture soil", "ASGM", and "geo accumulation index" are shown in lighter hues, reflecting new trends and evolving interests. In contrast, more established themes like "Mercury," "Heavy Metals," and "Soil" are central to the network and appear in darker shades, signifying their enduring significance in the field.

CONCLUSION

This study provides a comprehensive analysis of mercury contamination research, highlighting its critical environmental and public health implications while addressing key knowledge gaps. The steady rise in publications and citations over the past decade reflects growing global recognition of mercury's persistence and toxicity, with major contributions from China, the United States, and Spain, and Indonesia's emerging role in Southeast Asia due to its extensive artisanal and small-scale gold mining (ASGM) activities.

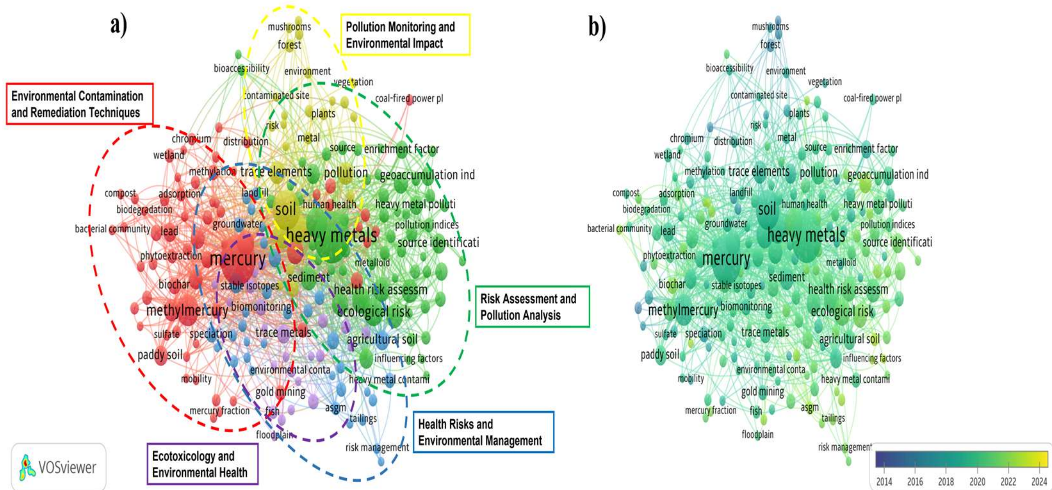

Fig.-5 Visualization Author Keyword Co-Occurrences (a) Network Visualization That Results in 5 Clusters (b) Overlay Visualization

Thematic analysis identifies core research areas, including environmental contamination, risk assessment, remediation technologies, and ecotoxicology, while emphasizing the urgent need to address mercury contamination in agricultural soils, particularly in ASGM-intensive regions.

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CONFLICT OF INTERESTS

The author declares no conflict of interest.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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