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GLOBAL RESEARCH TRENDS ON HEAVY METAL CONTAMINATION IN REFILL DRINKING WATER NEAR CEMENT FACTORIES: A BIBLIOMETRIC INSIGHT ALIGNED WITH SDG-6

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ABSTRACT

Ensuring access to safe drinking water remains a major challenge in the context of rapid urbanization and industrial growth. Refill Drinking Water Depots (DAMIU) have emerged as a widely used alternative to conventional water supply systems, especially in low- and middle-income nations. Nevertheless, the safety of DAMIU water is increasingly at risk due to contamination by heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg), which largely stem from surrounding industrial operations like cement production. Inadequately controlled emissions—whether dust, gases, or liquid waste-can seep into soils and surface waters, polluting raw water sources. Exposure to these heavy metals in humans may lead to serious health conditions such as neurological disorders, kidney damage, and cancer. Therefore, the adoption of efficient water purification techniques—particularly adsorption-should be prioritized to ensure DAMIU water complies with safety standards and supports the realization of Sustainable Development Goal 6 (Clean Water and Sanitation).

Keywords: Heavy Metals, Refill Drinking Water, Health Risk, Industrial Pollution, SDG-6.

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INTRODUCTION

The safety of drinking water continues to be a pressing issue in global health, especially as rapid urbanization and industrialization advance. Refillable Drinking Water Depots (DAMIU) have emerged as an alternative solution to meet increasing demand for clean water. However, the safety of these depots has come under scrutiny due to the risk of heavy metal contamination, often stemming from industrial waste, including emissions from cement factories.[1-8] Improperly managed industrial effluents can introduce pollutants into the environment through soil infiltration, surface runoff, and atmospheric deposition.[7] Commonly detected in industrial discharges, heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) pose serious risks due to their high toxicity and ability to accumulate in human tissues. Chronic exposure to these elements has been associated with neurological impairments, renal dysfunction, and increased cancer risk.[3-5] In the case of DAMIU, contamination from heavy metals poses a serious threat, as many depots rely on groundwater or surface water sources that are vulnerable to industrial pollution. Numerous studies have reported that the water quality in several DAMIUs fails to consistently meet national and international safety standards, particularly in regions adjacent to industrial zones.[4] Accordingly, continuous monitoring of water quality and the implementation of effective treatment

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technologies such as adsorption using activated carbon or natural zeolites are vital to mitigate the health risks posed by these contaminants.[1] This study aims to analyze global trends related to the impact of industrial heavy metals on the quality of refillable drinking water using a bibliometric approach. By reviewing publications over the past decade, this research offers insights into dominant research topics, contributing countries, and the development of mitigation technologies to manage health risks associated with heavy metal contamination.

EXPERIMENTAL

Material and Methods

This review investigates the global research landscape on heavy metals and their impact on community drinking water by conducting a bibliometric analysis based on international publications. Data were obtained through a systematic search on the ScienceDirect platform, using the Scopus database as the primary source. Keywords such as heavy metals, health risks, drinking water, and exposure were applied to article titles, abstracts, and author keywords to extract relevant publications from the period 2014 to 2024. The dataset included 448 total publications, comprising 402 research articles and 30 review papers, all selected based on their direct relevance to the quality of refillable drinking water. The filtering and organization of data were carried out using Microsoft Excel to tabulate publication trends, subject areas, contributing journals, and research categories. For bibliometric mapping and visualization, VOS viewer software was employed to generate co-occurrence networks, keyword clustering, and citation linkages. This analytical approach provided a comprehensive graphical overview of current research trends, dominant topics, and international collaboration patterns related to heavy metal contamination in drinking water.

General Procedure

This research utilized bibliometric methods to explore worldwide publication trends related to the influence of industrial heavy metals on refillable drinking water quality. The methodology was conducted in several systematic stages, as outlined below.

Database Selection

The study employed the Scopus database as the principal reference source, given its broad indexing of peer-reviewed research across environmental science, engineering, and public health.

Keyword Identification and Search Query

A structured search strategy was developed using keywords such as “heavy metals”, “refill drinking water”, “industrial pollution”, and “water contamination”. Boolean operators (AND, OR) were applied to refine search sensitivity and specificity. The search was restricted to publications published between 2013 and 2023.

Screening and Inclusion Criteria

The collected documents were filtered using specific inclusion criteria: only articles written in English, published in peer-reviewed journals, and directly addressing heavy metal contamination in refillable drinking water or comparable settings were considered, while reviews, editorials, and conference papers were excluded. Duplicate entries were removed during the screening process.

Data Extraction and Preprocessing

Information, including article titles, authors, journal names, keywords, publication dates, and citation numbers, was extracted in either BibTeX or CSV format. Data preprocessing involved standardization of author names, keywords, and institutional affiliations to ensure consistency and accuracy during analysis.

Bibliometric Analysis Tools

The processed dataset was analyzed using VOSviewer and Bibliometrix (an R-based package). These tools were employed to construct visual maps and generate bibliometric indicators, including co-authorship networks, keyword co-occurrence maps, citation analyses, and country or institutional contribution metrics.

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Detection Method

Bibliometric analysis is a quantitative approach employed to explore the progression of scientific fields by analyzing their social, intellectual, and conceptual frameworks. It is widely applied across academic fields and focuses on the statistical evaluation of scholarly outputs such as journal articles, books, and other forms of scientific communication.[2] This method enables researchers to identify emerging research areas, track influential authors or institutions, and uncover collaboration networks. Following the bibliometric mapping, A focused literature review was carried out to gain deeper insights into the main themes, research methods, and findings presented in the chosen studies.

RESULTS AND DISCUSSION

Trends in Document Types with the Highest Publications on Heavy Metals in Community Drinking Water

The graph above shows the trend in the number of document publications based on their type, namely articles and reviews. The graph shows data from 2014 to 2024. Based on the graph above, in 2024, the number of articles is very high, reaching 56 documents, while the number of reviews is only 5. While in 2014 the number of articles was only 7 and has increased from year to year, the review graph has only increased slightly. In 2018, the number of articles began to increase rapidly compared to the previous year, to 26 documents, while reviews remained at 1. The growth of articles continued with a significant increase in 2020, reaching 41 documents. On the other hand, reviews began to show a small increase, increasing to 2 documents. In 2022, the number of articles increased to 52 documents, while reviews continued to increase slowly to 3 documents. This trend continued until 2024, when the number of articles peaked at 56, and reviews increased to 5.

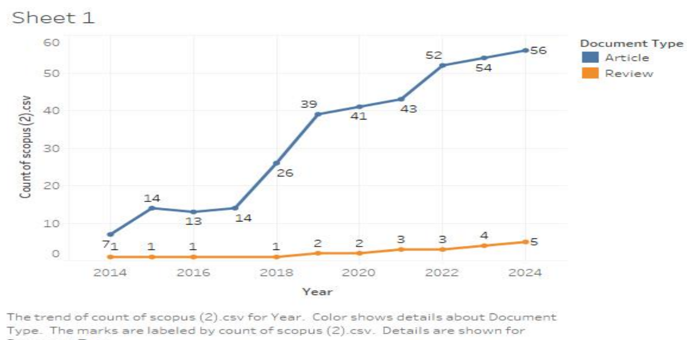

Fig.-1: Trends in Journal Publications per year within the Field Heavy Metals in Drinking water

Contributions from Different Countries

The quantity of publications contributing to the map is data that represents the number of publications originating from various countries in the world. Each country in Fig.-3 is labeled with a number that shows the amount of publication contribution to the entire database. Countries with higher numbers depict a more significant amount of contribution; the United States and India occupy the top positions with 49 publications each, indicating that these two countries have a dominant role in the context of publications. Nigeria follows with 36 publications, becoming one of the countries with the highest contributions on the African continent. Other contributions came from countries such as Saudi Arabia with 13 publications, South Africa with 18 publications, and Australia with 17 publications, reflecting active participation in the regional scope. Several countries had smaller contributions, such as Canada (8 publications), Brazil (7 publications), Sweden (7 publications), Russia (7 publications), and Egypt (7 publications). In addition, countries in South and Southeast Asia, such as Bangladesh and Sri Lanka, each contributed 6 publications, while Indonesia contributed 5 publications. Japan, with 9 publications, and the United Kingdom, with 10 publications, also made significant contributions. This data depicts the global distribution of publications across continents, revealing patterns that can be further analyzed to understand trends, priorities, or research and publication capacities of individual countries. With total contributions spanning many countries, this map provides insight into how publication activity is distributed geographically across the world.

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Author Keyword Shared Network Analysis

The network above illustrates the relationship between keywords used by authors in their publications, based on their degree of relatedness and co-occurrence in the documents. Each node represents a keyword, while the lines connecting the nodes indicate the relatedness between the keywords. The frequency of a keyword is illustrated by the node's size, where bigger nodes correspond to more frequent occurrences.

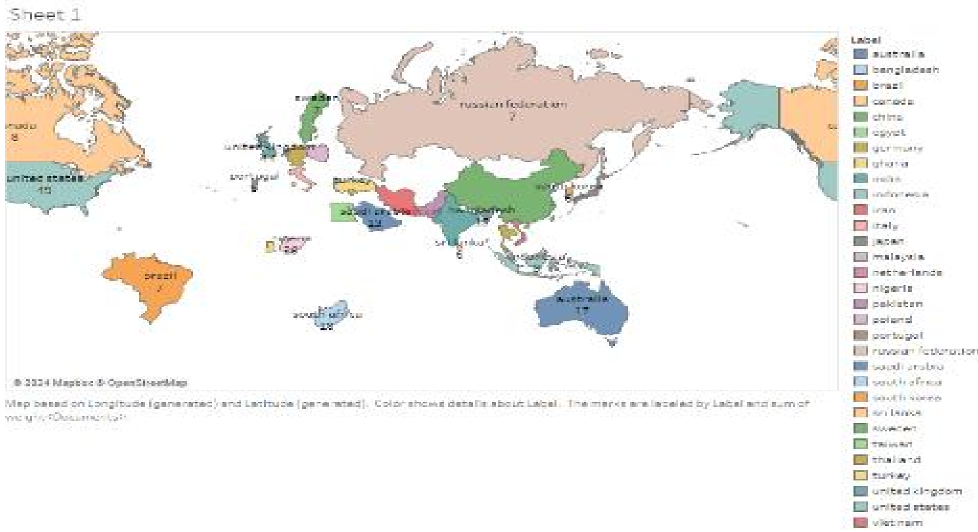

Fig.-2: Contributions from Different Countries

The color of the node indicates the clustering of the keywords, which means that keywords in a cluster often appear together and have a close thematic relationship. The figure above explains that keywords such as "drinking water", "health risk", and "humans" are at the center of the network with large node sizes, indicating that themes related to human health and drinking water quality are the main focus in the publications. The red cluster, which includes keywords such as "lead", "pollution exposure", and "risk factors", shows a close relationship between pollution, exposure to hazardous substances, and risk factors for humans. The green cluster focuses on keywords such as "groundwater pollution", "water quality", and "human health", indicating the main theme related to groundwater pollution and its impact on human health.

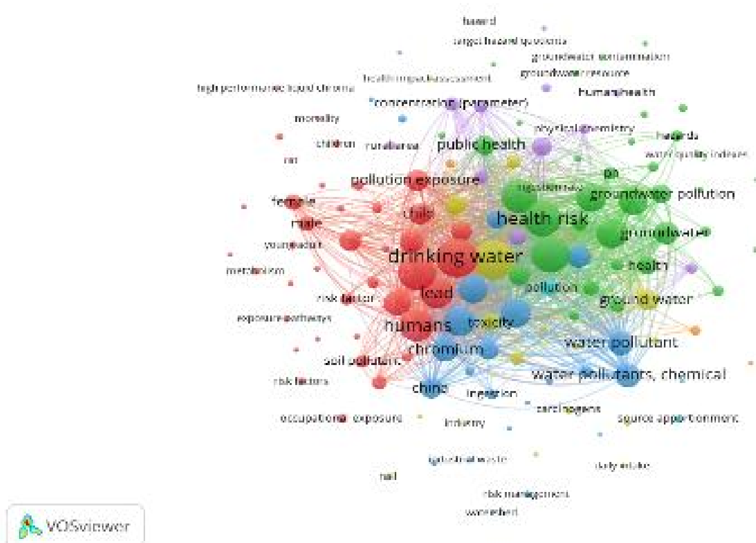

Fig.-3: Network Analysis with Author Keywords

On the other hand, the blue cluster includes keywords such as "water pollutant", "toxicity", and "industrial waste", which describe the relationship between water pollutants, industrial waste, and their toxicity to the environment and humans. The yellow and purple clusters include more specific keywords such as "risk management", "health impact assessment", or "source apportionment", which focus on evaluating the impact and managing risks related to water quality issues.

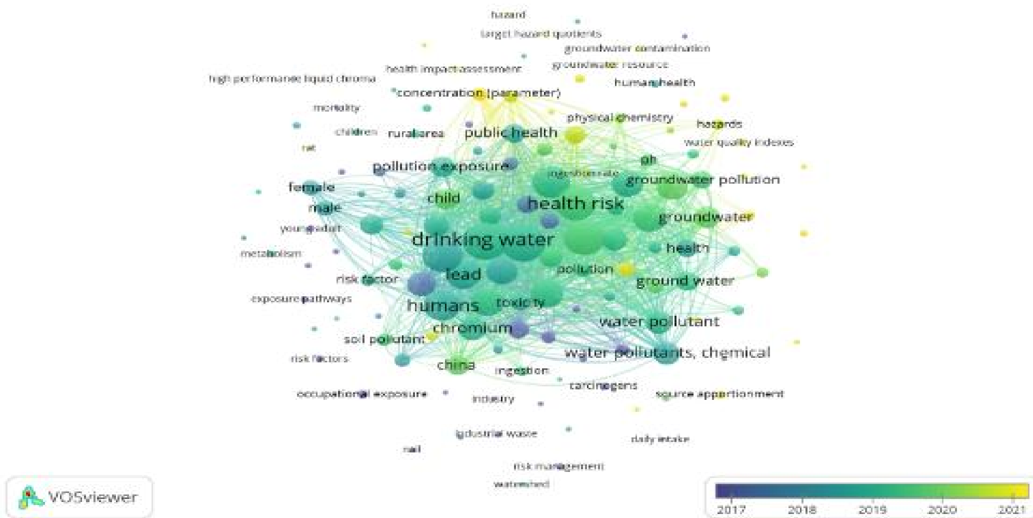

Fig.-4: Co-occurrence Network by Author Keywords 2017-2021

The graph illustrates keywords as nodes, where node size denotes the frequency of occurrence. A bigger node indicates a higher usage of that keyword. The colors of the nodes reflect the time period when the keyword was dominant, based on the time legend in the bottom right. Blue indicates keywords that were popular in earlier years (2017-2018), while yellow indicates keywords that are more recent or relevant in recent publications (2020-2021). Green nodes fall somewhere in between these two time spectrums. The main nodes seen are "drinking water", "health risk", "humans", "lead", and "pollution", indicating that these topics are closely related and dominate in this analysis. The nodes are connected by lines (edges), which illustrate the relationship or co-occurrence between keywords in the publication. The thickness and density of the lines indicate the strength of the relationship between keywords. The network is also clustered into several thematic groups based on secondary colors. For example, the clusters related to “health risk” and “groundwater pollution” include keywords such as “toxicity,” “water pollutants,” and “public health,” highlighting the relationship between health risks and water contamination. On the other hand, keywords such as “lead,” “chromium,” and “soil pollutant” focus more on specific types of contaminants. In the data image, it can be concluded that the latest research (marked in yellow) emphasizes aspects such as "water quality indexes" and "health management", while previous research discussed more general issues such as "pollution" and "drinking water". This shows the development of research focus over time.

Our bibliometric study provides the first global review of heavy metals on the quality of refilled drinking water. Figure-1: Presenting the flow of data processing mechanisms in bibliometric studies. Data processing goes through several stages, such as identification, screening, and final evaluation of 448 selected publications. In this process, it is ensured that only relevant studies to the topic of heavy metals on the quality of refill drinking water are included in the analysis, so that it reflects something that is structured in the bibliometric methodology to ensure the validity of the results of this research. Figure-2: This graph shows the increasing trend in the number of scientific publications in the form of articles and reviews from 2014 to 2024. Articles dominate with a much higher number, starting from 71 publications in 2014, although it decreased to 14 in 2016, but continued to increase until it was projected to reach 56 in 2024. Meanwhile, the number of reviews experienced a slower increase, from 1 publication in 2014 to an estimated 5 in 2024. This trend reflects an increase in research activity and academic productivity, with the contribution of articles being much more significant than reviews. Figure-3: Distribution map of publications showing contributions from different countries, with the United States and India being the highest, contributing 49 publications each, followed by Nigeria with 36 publications. Other significant contributions came from South Africa (18), Australia (17), and Saudi Arabia (13), while countries such as Canada, Brazil, Sweden, Russia, and Egypt contributed 7–8 publications each. Several South and Southeast Asian countries, such as Bangladesh, Sri Lanka (6 publications), and Indonesia (5 publications), also contributed. These data depict the global distribution of publications, indicating the dominant role of certain countries and the active participation of different regions in research, reflecting global research trends and capacities. Figure4: This keyword network shows the relationships between keywords based on their co-occurrence in publications, with larger nodes representing more frequently used keywords. Node colors indicate thematic clusters, with the red cluster focusing on pollution, exposure to hazardous substances, and human health risks, while the green cluster highlights groundwater pollution and its impacts on health. The blue cluster deals with water pollutants, industrial waste, and toxicity, while the yellow and purple clusters cover specific topics such as risk management and health impact assessment. Keywords such as "drinking water," "health risk," and "humans" are central to the network, reflecting the research focus on drinking water quality and human health. Figure-5: Based on the graph, the trend in the number of publications shows the dominance of article-type documents compared to reviews from 2014 to 2024. The number of articles has increased consistently and significantly, starting from 71 documents in 2014 to 56 documents in 2024. In contrast, reviews show much slower growth, increasing from 1 document in 2014 to only 5 documents in 2024. This shows that the Article type of publication is more in demand or published more often than Reviews during that period.

CONCLUSION

This study presents the first bibliometric analysis of global research trends regarding heavy metal contamination in refill drinking water, emphasizing the urgency of health risk assessments and policy-driven solutions. The increasing volume of publications highlights growing global concern and academic engagement in this field. Aligned with the goals of SDG-6 (Clean Water and Sanitation), additional research is needed on technological solutions for mitigation, along with expanded international partnerships in environmental health.

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CONFLICT OF INTERESTS

No potential conflicts of interest have been reported by the authors.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-6: Clean Water and Sanitation*. 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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