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Heavy Metal Exposure in Pregnancy and the Impact on Fetal Development: Five Decades of Global Research Through Bibliometric Analysis

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Abstract: Exposure to heavy metals during pregnancy poses significant health risks to both pregnant women and the developing fetus. This study aimed to conduct a comprehensive bibliometric analysis of global research on heavy metal exposure during pregnancy and its impact on fetal development over the past five decades (1974–2024). Data were retrieved from the Scopus database, yielding 173 English-language publications for analysis. Bibliometric mapping was performed using VOSviewer, while trend visualization and geographical analysis were conducted using Tableau to identify publication trends, research hotspots, and knowledge gaps. The results revealed a marked increase in research output beginning in 2010, with lead (Pb) and mercury (Hg) emerging as the most extensively investigated metals, followed by growing attention to arsenic (As), cadmium (Cd), and manganese (Mn). Prominent research themes focused on associations between prenatal heavy metal exposure and adverse birth outcomes, including low birth weight, preterm birth, and impaired neurodevelopment. Geographically, research output was dominated by the United States, China, and European countries, whereas contributions from low-income and high-exposure regions remained limited. Frequently occurring author keywords included heavy metals, pregnancy, and fetal development. These findings highlight the need for more targeted research in underrepresented regions and on emerging heavy metals, in alignment with global public health priorities and the Sustainable Development Goals (SDGs). Overall, this analysis provides strategic insights to inform future research directions and policy initiatives aimed at reducing prenatal heavy metal exposure and improving maternal and fetal health outcomes.

Keywords: Metal; Heavy; Pregnancy; Fetal development; Bibliometrics

1 Introduction

Heavy metals are metallic elements characterized by relatively high atomic mass and density, typically exceeding 5 g/cm^3. While certain heavy metals are essential micronutrients at trace levels, many exhibit toxic properties that pose serious risks to human health when exposure exceeds physiological thresholds [1]. Adverse pregnancy outcomes are influenced by multiple factors, including poor maternal nutrition, smoking, alcohol consumption, and exposure to toxic environmental agents, particularly heavy metals. Elevated levels of heavy metal exposure have been consistently associated with unfavorable health outcomes in both mothers and infants [2–4]. Excessive maternal and fetal exposure during pregnancy has been linked to preterm birth and low birth weight, underscoring the vulnerability of this population [5].

Heavy metal exposure represents a global public health concern due to its widespread environmental occurrence and persistence. Metals such as cadmium (Cd), lead (Pb), mercury (Hg), and arsenic (As) are pervasive environmental pollutants that can accumulate in biological systems and exert toxic effects over time [6, 7]. Pregnancy and early developmental stages constitute critical periods marked by heightened susceptibility to environmental insults, owing to hormonal changes, rapid cellular differentiation, and immature immune function. Several heavy metals, including lead, mercury, and manganese (Mn), are capable of crossing the placental barrier and directly affecting fetal development [8]. Empirical evidence highlights the magnitude of this risk; for example, studies in Indonesia have reported blood lead levels in pregnant women residing in industrial areas that exceed the World Health Organization (WHO) recommended limit of 5 μg/dL [9]. Similarly, cord blood mercury concentrations in high-risk regions of China have been reported at levels more than twice the WHO safety threshold.

The relationship between environmental exposure and human health, particularly in relation to heavy metals, has been a subject of increasing concern for several decades. Heavy metals such as lead, cadmium, mercury, and arsenic are well recognized for their long-term toxic effects on multiple organ systems [10, 11]. These metals can contaminate food, drinking water, and consumer products, thereby increasing population-level exposure risks [12–14]. Although their adverse health effects have been extensively documented, pregnant women and fetuses are disproportionately vulnerable due to physiological adaptations during pregnancy that may enhance metal absorption and toxicity [15, 16].

Prenatal exposure to heavy metals has been shown to adversely affect maternal health and fetal development, contributing to complications such as preterm birth, low birth weight, and impaired cognitive development in offspring [17–19]. While previous studies have established the detrimental effects of prenatal heavy metal exposure, evidence remains fragmented across populations, exposure pathways, and geographical contexts [20, 21]. Consequently, the broader global patterns and research trajectories in this field remain insufficiently characterized.

Given growing concerns regarding the impact of heavy metal exposure on pregnancy and fetal development, a comprehensive assessment of the existing literature is warranted [22, 23]. Many studies are constrained by limited sample sizes or narrow geographical coverage, which hampers the ability to draw robust conclusions regarding global trends [13, 24–28]. Moreover, while mercury and lead have been extensively investigated, other metals, notably cadmium and arsenic, require further systematic evaluation to elucidate their long-term effects on pregnancy outcomes.

To strengthen the analytical foundation of this study, heavy metal exposure during pregnancy is examined through the lens of environmental toxicology and public health theory. The conceptual framework is grounded in the principles of bioaccumulation and metal toxicity, which emphasize the capacity of heavy metals to accumulate in biological tissues and disrupt physiological processes during critical developmental periods. Mechanistically, exposure to metals such as lead, mercury, arsenic, and cadmium during pregnancy can induce oxidative stress, endocrine disruption, and immune dysregulation, thereby impairing both maternal and fetal health. These processes align with established environmental health principles and are closely linked to the objectives of the Sustainable Development Goals (SDGs), particularly those related to maternal and child health.

Accordingly, this systematic review and bibliometric analysis aims to address existing knowledge gaps by synthesizing the global literature on heavy metal exposure in pregnant women and fetuses. Through a structured examination of scientific publications spanning multiple decades, this study identifies key research trends, thematic focuses, and areas requiring further investigation. The findings are intended to inform public health policymakers and support the development of targeted interventions to reduce heavy metal exposure among vulnerable populations, ultimately contributing to improved maternal and child health outcomes.

Despite compiling studies from diverse regions, the existing literature is characterized by several limitations, including small sample sizes, restricted geographical representation, and inadequate control for confounding variables. These constraints may affect the generalizability of reported findings. Furthermore, bibliometric evidence indicates pronounced geographical and socio-economic disparities in research output, with a concentration of studies originating from high-income countries such as the United States and China, while high-exposure regions including Southeast Asia and Sub-Saharan Africa remain underrepresented. Addressing these disparities is essential to achieving a more comprehensive and equitable global understanding of heavy metal exposure during pregnancy.

2 Methods

2.1 Types and Design of Research

A total of 173 publications were selected for inclusion in this bibliometric analysis. This corpus was considered sufficient to capture global research trends over five decades concerning heavy metal exposure during pregnancy and its impact on fetal development. The publications were retrieved from the Scopus database using the predefined search terms *heavy metals, pregnancy*, and *fetal development*. The search was restricted to peer-reviewed articles and review papers published in English between 1974 and 2024.

Article selection was conducted through a multi-stage screening process based on explicit inclusion and exclusion criteria. Studies were included if they (1) were published as peer-reviewed research articles or review papers, (2) were written in English, and (3) addressed heavy metal exposure during pregnancy and associated pregnancy or fetal outcomes. Publications were excluded if they were non-English, conference proceedings, dissertations, technical reports, or other forms of grey literature. The overall screening and selection process was documented using a PRISMA flow diagram to ensure transparency and reproducibility.

Although this selection strategy ensured consistency in data extraction and analysis, limiting the dataset to English-language publications may have introduced language bias. As a result, relevant studies from regions with high exposure risks—such as Southeast Asia, Sub-Saharan Africa, and Latin America—may have been underrepresented. Consequently, the findings of this study primarily reflect English-language literature indexed in Scopus. Future bibliometric analyses may reduce this limitation by incorporating multilingual databases or translation-assisted screening approaches to improve geographical and linguistic coverage.

Furthermore, reliance on a single database may have introduced representational bias, particularly with respect to publications from low- and middle-income countries that are not comprehensively indexed in Scopus. To generate a more inclusive and representative overview of global research activity, future studies are encouraged to integrate additional data sources, including Web of Science, PubMed, and relevant regional databases.

2.2 Bibliometric Analysis

Bibliometric analysis is a quantitative research approach used to systematically evaluate and map scientific literature in order to identify publication trends, assess research impact, visualize collaboration patterns, and detect emerging research themes and knowledge gaps. In this study, bibliometric analysis was employed to examine the global research landscape on heavy metal exposure during pregnancy over a five-decade period. Two complementary analytical tools—VOSviewer (version 1.6.20; Centre for Science and Technology Studies, Leiden University) and Tableau Desktop (version 2025.3; Tableau Software, Seattle, WA, USA)—were utilized based on their capability to process large-scale bibliographic datasets and generate interpretable visual outputs.

VOSviewer was used as the primary software for constructing and visualizing bibliometric networks. Specifically, it was applied to generate author keyword co-occurrence networks, citation networks, and co-authorship networks. Network clustering was performed using the Visualization of Similarities (VOS) mapping technique, which groups items according to the strength of their co-occurrence relationships. This modularity-based clustering approach enabled the identification of thematically coherent clusters representing dominant research topics and research hotspots within the literature. Bibliometric maps were visualized using color-coded clusters and density overlays to enhance the interpretability of relationships within the dataset.

To complement the network-based analysis, Tableau Desktop was employed to perform descriptive, temporal, and geographical analyses. The software was used to visualize annual publication trends, document types, and the geographical distribution of research output by country. Its interactive dashboard features enabled flexible exploration of temporal and spatial patterns that are difficult to capture through static bibliometric maps alone.

The integrated use of VOSviewer and Tableau Desktop was designed to provide both analytical depth and contextual breadth. While VOSviewer facilitated a detailed examination of intellectual structures and collaboration patterns, Tableau Desktop supported macroscopic visualization of publication dynamics across time and geography. This multi-tool analytical strategy enhanced the transparency, reproducibility, and interpretability of the bibliometric analysis.

2.3 Systematic Review Analysis

Systematic review analysis was conducted to systematically identify, evaluate, and synthesize relevant studies addressing heavy metal exposure during pregnancy and its associated maternal and fetal outcomes. This approach followed a structured and transparent process that included literature searching, study selection based on predefined inclusion and exclusion criteria, and critical appraisal of the selected publications. The purpose of the systematic review component was to provide an organized synthesis of empirical evidence to support interpretation of bibliometric findings and to contextualize research trends within public health and environmental health domains.

The literature search involved screening publications retrieved from the Scopus database. Studies were selected according to predetermined eligibility criteria, including relevance to heavy metal exposure during pregnancy, study design, and clarity of reported outcomes. Quality considerations focused on study scope, methodological rigor, and relevance to maternal and fetal health outcomes. The synthesized evidence was used to summarize reported exposure pathways, measured health effects, and recurring outcome patterns rather than to perform statistical aggregation. Consequently, no meta-analysis was conducted, as the heterogeneity of study designs, populations, exposure metrics, and outcome measures precluded meaningful quantitative pooling.

Several selection criteria and methodological limitations were acknowledged. First, the review was restricted to English-language publications to ensure consistency in data extraction and interpretation. This restriction may have introduced language bias by excluding relevant studies published in non-English languages, particularly from regions with high exposure risks. Second, data sourcing was limited to the Scopus database, which may underrepresent journals from low- and middle-income countries. Although Scopus is a widely recognized and reputable database, its coverage of regional and local journals is not comprehensive. Third, the reviewed time frame spanned publications from 1974 to 2024 in order to capture long-term research trends; however, older studies may lack contemporary analytical approaches, while more recent publications may be underrepresented due to indexing delays.

In terms of publication type, only peer-reviewed research articles and review papers were included to maintain methodological quality. Grey literature, including reports, theses, and non–peer-reviewed documents, was excluded, which may have limited the inclusion of context-specific or locally relevant findings. To enhance transparency, the study selection process, including exclusion reasons, was documented using the PRISMA flow diagram (Figure 1). In addition, a sensitivity check was performed by re-examining a subset of studies to assess whether the exclusion criteria substantially influenced the overall interpretation of findings.

Finally, geographical representation was evaluated as part of the systematic review synthesis. The disproportionate concentration of studies from high-income countries was explicitly recognized as a limitation, and the need for future research focusing on underrepresented regions—particularly low- and middle-income countries with elevated environmental exposure risks—was emphasized. This systematic review component therefore complements the bibliometric analysis by providing contextual depth and supporting a balanced interpretation of global research patterns.

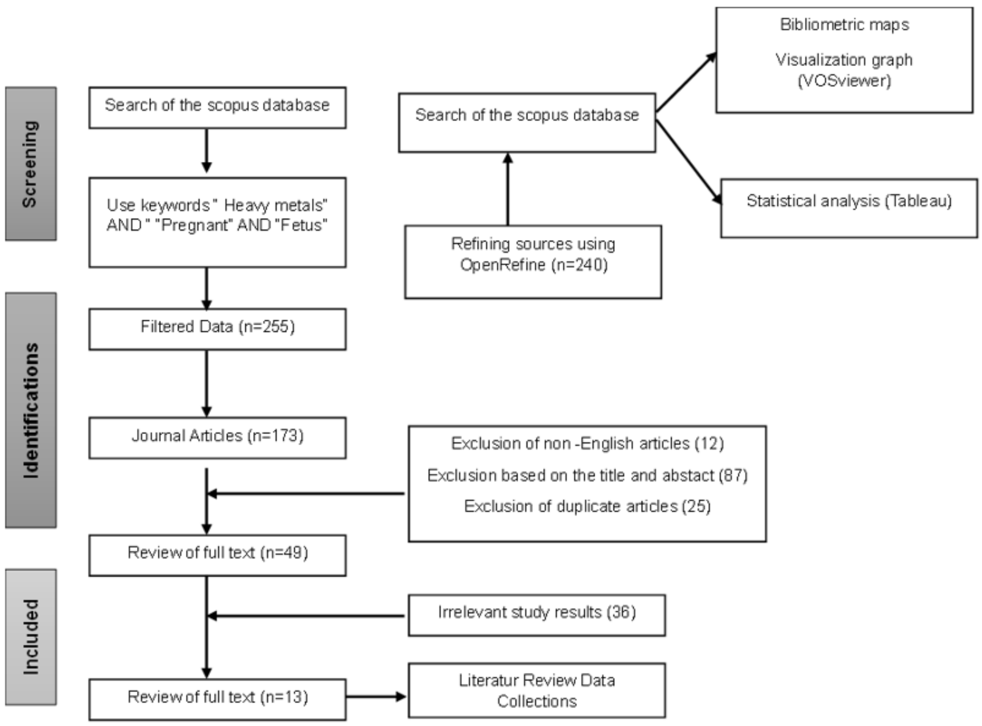

Figure 1. The PRISMA flowchart

3 Results

3.1 Trends in Publications by Document Type

The trends in publications addressing heavy metal exposure in pregnant women and fetuses by document type are illustrated in Figure 2. The bibliometric analysis showed a clear long-term increase in research activity over the study period, reflecting the growing scientific attention to this topic.

Between 1974 and 2024, a total of 173 publications were identified, comprising 146 research articles and 27 review papers. Overall, publication output exhibited substantial temporal variability. From 1975 to approximately 2000, research activity was limited, with only one to two articles or reviews published sporadically every few years. A modest increase was observed between 2000 and 2010, although annual publication numbers remained relatively low during this period.

A pronounced rise in publication volume occurred after 2010, marking a period of accelerated research growth. The number of publications reached its peak in 2019, with 27 articles, before showing a subsequent decline. Despite this decrease, scholarly output on the topic remained consistently active through 2024. Compared with original research articles, review papers were fewer in number but displayed a relatively stable publication pattern throughout the study period.

The substantial increase in publications beginning around 2010 indicates heightened scientific interest and awareness regarding heavy metal exposure during pregnancy, likely reflecting broader concerns related to environmental pollution and its health implications. The peak observed in 2019 may be associated with intensified research activity during that period. The more recent decline in publication numbers may reflect a combination of external influences, including shifts in research priorities, funding availability, and global disruptions such as the COVID-19 pandemic.

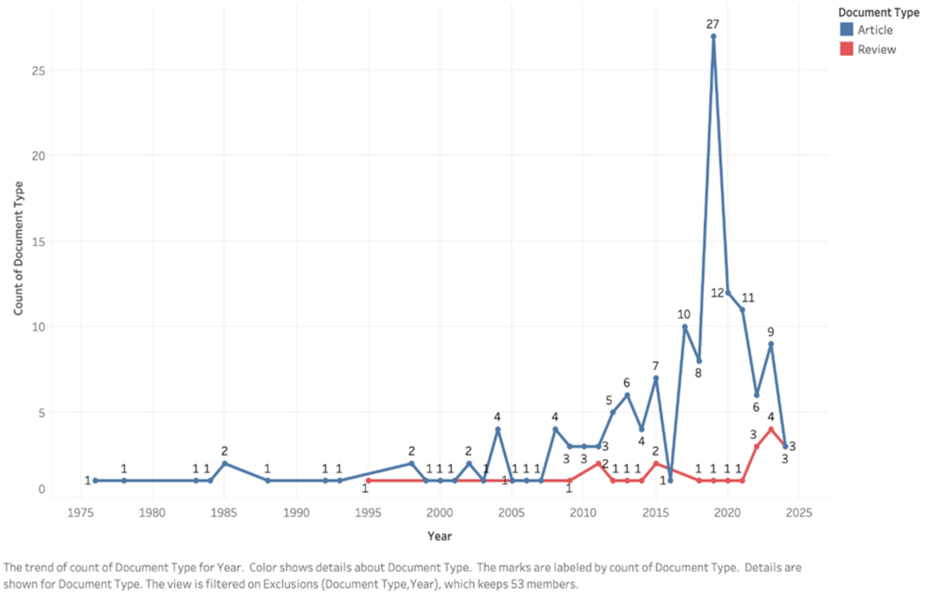

Figure 2. Trends in journal publications per year in heavy metal research

3.2 Contributions by Country

The distribution of publications by country is presented in Figure 3, illustrating the geographical contribution to research on heavy metal exposure in pregnant women. The analysis showed that the United States contributed the highest number of publications (n = 38), followed by China (n = 34). Together, these two countries accounted for a substantial proportion of the global research output in this field.

Overall, research activity was highly concentrated in North America, primarily driven by contributions from the United States (and, to a lesser extent, Canada), and in East Asia, with China emerging as the dominant contributor. In contrast, other large and industrialized countries, including Brazil and India, exhibited comparatively lower publication counts, suggesting potential gaps in research output despite their environmental exposure profiles.

Notably, regions characterized by substantial industrial activity and environmental pollution—such as South America, Africa, and Southeast Asia—were underrepresented in the publication landscape. This uneven geographical distribution highlights disparities in research capacity and output and indicates the need for increased scientific attention to populations in high-exposure but low-representation regions.

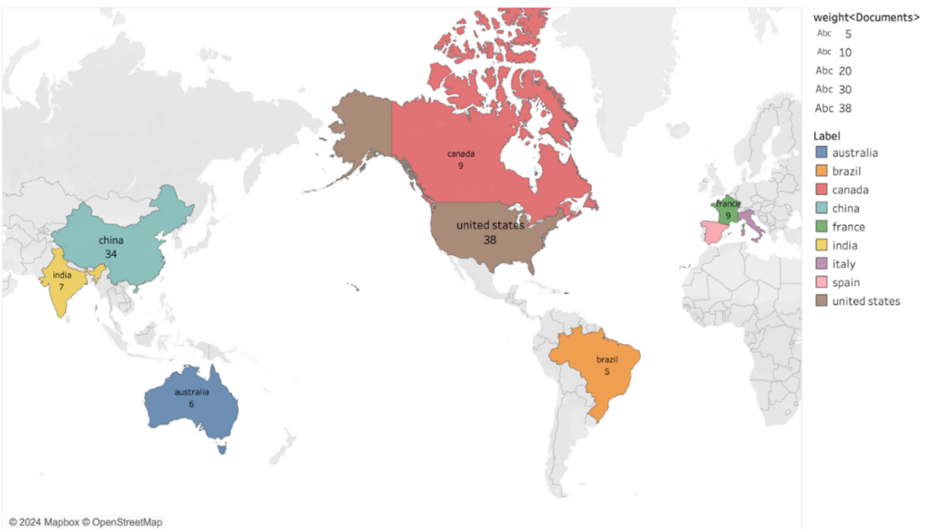

Figure 3. Number of publications by country

3.3 Author Keyword Co-Occurrence Network Analysis

The author keyword co-occurrence network analysis identified a total of 232 keywords, which were organized into five distinct clusters based on co-occurrence strength and thematic similarity, as shown in Figure 4. Each cluster was represented by a unique color: cluster 1 (red), cluster 2 (green), cluster 3 (blue), cluster 4 (yellow), and cluster 5 (dark purple).

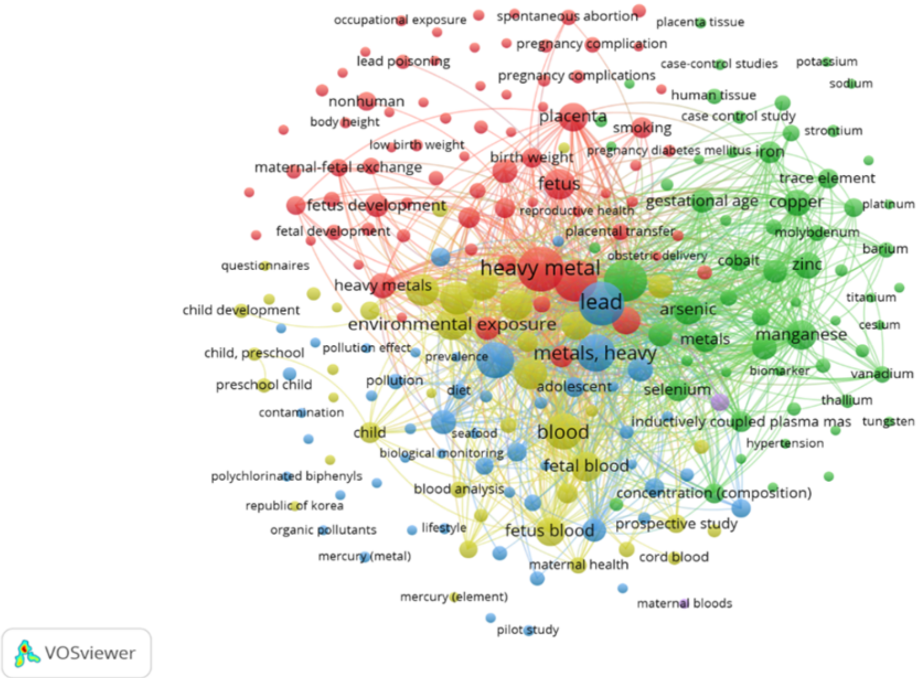

Figure 4. Network of author keywords, categorized into clusters

Cluster 1 (red) was the most dominant, comprising 76 keywords primarily centered on *heavy metals*, indicating that this term represents the core concept of the research field. Prominent associated keywords included *fetal development, placenta, pregnancy complications*, and *lead poisoning*, reflecting a strong emphasis on the effects of heavy metal exposure on maternal conditions and fetal health outcomes.

Cluster 2 (green) consisted of 62 keywords and was characterized by the frequent occurrence of *lead*, suggesting that lead remains the most extensively investigated metal. This cluster was closely linked to biological measurement terms such as *blood, maternal blood*, and *fetal blood*, highlighting the central role of biomonitoring approaches in assessing prenatal exposure.

Cluster 3 (blue) included 51 keywords related primarily to exposure assessment and analytical approaches, including *environmental exposure, biological monitoring*, and *blood analysis*. This cluster indicates a methodological focus on exposure characterization and measurement strategies within environmental health research.

Cluster 4 (yellow) emphasized exposure pathways and monitoring contexts, incorporating keywords related to *environmental* and *dietary exposure*, as well as the assessment of heavy metals in biological matrices such as maternal and fetal blood.

Cluster 5 (dark purple) was the smallest, containing two keywords associated with *maternal blood* and *mass spectrometry*, reflecting a specialized analytical focus within the literature.

The temporal evolution of research themes was examined using the VOSviewer overlay visualization covering the period 1974–2024, as presented in Figure 5. The color gradient, ranging from blue to yellow, indicates the relative emergence of keywords over time. During the earlier phase of intensified research activity (2010–2014), keywords such as *lead, fetus, fetal development, environmental exposure*, and *blood* were most prominent, demonstrating a sustained focus on lead exposure and its effects on fetal development using blood-based biomarkers. Keywords related to *mercury* and *pollution* effects also appeared during this period, reflecting long-standing concerns regarding the health impacts of environmental contamination.

In more recent years (2016–2020), increased attention was observed for keywords such as m*anganese, selenium, zinc, arsenic*, and *thallium*, indicating an expansion of research beyond traditionally studied metals such as lead and mercury. Concurrently, outcome-oriented keywords—including *gestational age, pregnancy complications, placenta, spontaneous abortion*, and *birth weight*—became more prominent, suggesting a growing emphasis on adverse pregnancy outcomes associated with prenatal heavy metal exposure. The emergence of terms such as *trace elements,* *biomarkers*, and *biological monitoring* further highlights increased interest in refining exposure assessment through biological indicators in pregnant women and fetuses.

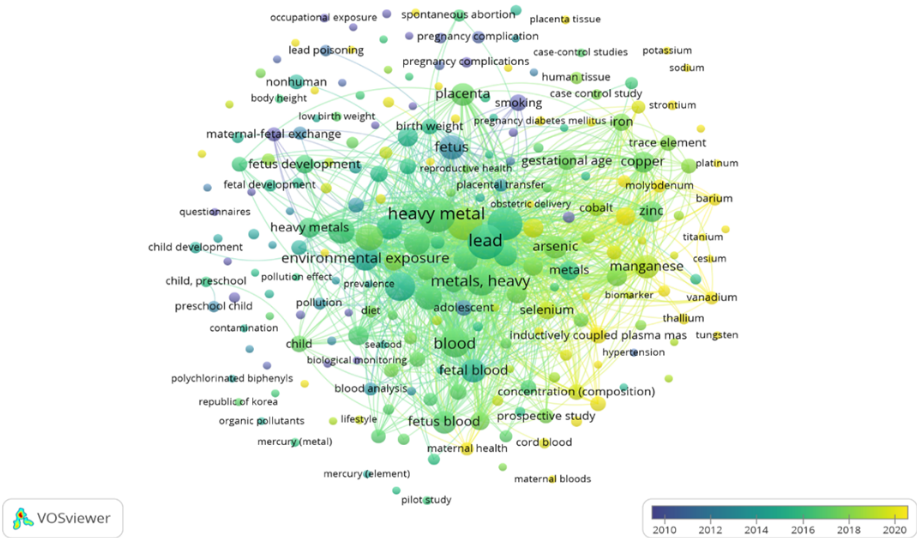

Figure 5. Author keyword co-occurrence network, 1974–2024

The integration of keyword network analysis with a targeted literature review informed the synthesis of empirical evidence summarized in Table 1, which presents representative studies on heavy metal exposure in pregnant women and fetuses across different geographical regions and research designs.

Table 1. Heavy metal in pregnant women and fetus

Ref.	Country	Study Design	Sample/ Population	Metals and Levels	Variables Measured	Effects on Pregnant Women	Effects on Fetuses	Key Findings	Analytical Method
[25]	China	Case-control	51 preeclamptic, 51 normotensive women	Cd in blood (1.21 μg/L in PE; 1.09 μg/L in controls)	Preeclampsia, fetal biometrics	Increased risk of preeclampsia	Reduced birth weight in PE group	Maternal cadmium was associated with higher preeclampsia risk and fetal growth restriction	ICP-MS
[18]	Mongolia	Observational	374 pregnant women	Cd (median 0.20 μg/L)	Birth weight, length, head circumference	Not specified	Reduced birth weight	Elevated cadmium exposure, linked to coal smoke, was associated with lower birth weight	ICP-MS
[19]	USA	Prospective cohort	381 pregnant women	Pb, tin, tungsten	Vitamin D status, metal concentrations	Lower vitamin D levels associated with higher metal exposure	Potential fetal exposure to toxic metals	Low vitamin D levels were associated with increased lead, tin, and tungsten concentrations	Chemilumin-escence immunoassay, ICP-MS
[26]	China	Cohort	314 exposed, 320 controls	Pb, Cd, Cr, Mn	Head circumference, BMI, ponderal index	Not specified	Reduced head circumference, BMI, and PI	Exposure to e-waste was associated with impaired fetal growth indicators	GFAAS
[8]	China	Observational	156 maternal–cord blood pairs	Pb, Ti, Mn, Ni, Cd, Cr	Birth weight, placental transfer	No significant effect	No significant effect on birth size	Placental transfer efficiency varied by metal; cadmium showed limited transfer	ICP-MS

Continued

Ref.	Country	Study Design	Sample/ Population	Metals and Levels	Variables Measured	Effects on Pregnant Women	Effects on Fetuses	Key Findings	Analytical Method
[27]	Brazil	Cohort	117 mother–child pairs	As, Cd, Pb, Hg	Maternal and fetal blood metals	Elevated maternal blood metals	Increased fetal exposure	Strong correlations between maternal and fetal metal levels indicate high fetal exposure risk	ICP-MS
[28]	Spain	Observational	100 maternal and 100 cord blood samples	Al, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, Zn	Blood metal levels, maternal–fetal correlation	No specific effect reported	Potential neurodevelopmental risks	Strong maternal–cord blood correlations, especially for Hg; elevated Pb and Cd levels observed	ICP-MS
[29]	Poland	Observational	134 women	Pb, Zn, Cu, Mn, Cr (varied concentrations)	Anthropometric outcomes	No significant adverse effects	Head circumference associated with Cr levels	Elevated Zn and Cu were positively associated with birth measures; Cr was inversely related to head circumference	ICP-OES
[30]	Ghana	Risk assessment	Pregnant women in Volta Region	As, Mn, Pb, Ni (mg/kg)	Clay consumption, metal exposure	Potential toxic and microbial risk	Possible neurodevelop-mental effects	Clay consumption posed high health risks (HQ > 1) due to As, Pb, and Ni	Flame AAS
[31]	USA	Cohort	1,159 mother–infant pairs	Cd, As, Hg, Pb; Zn and Se	Placental weight, efficiency, birth weight	Not specified	Birth weight affected	Cadmium adversely affected placental efficiency and birth weight; Zn and Se moderated toxicity	ICP-MS
[11]	Spain	Longitudinal observational	1,346 pregnant women	Zn (highest), Tl (lowest), As, Cd, Cu, Pb	Urinary metals, sociodemographic factors	Associations with occupation and social class	Potential neurodevelopmental risk	Metal exposure varied with dietary and environmental factors	ICP-MS-MS
[13]	USA	Prospective cohort	1,040 pregnant women	Multiple metals (Pb, Cd, Hg, As, Zn, Ni, etc.)	Blood and urine metals; diet and water use	Dietary and water-related exposure risk	Possible developmental effects	Metal exposure was strongly associated with diet and drinking water sources	ICP-MS
[32]	USA	Longitudinal cohort	100 mother–newborn pairs	Hg, Pb, Cd, As, Rb, Cu, Mn	Maternal blood metals across pregnancy	Elevated late-pregnancy transfer	Neurodevelop-mental risk	High maternal–fetal transfer ratios, particularly for Hg and Pb	ICP-MS, DMA-80

4 Discussions

This study provides a comprehensive overview of global research trends on heavy metal exposure during pregnancy and its implications for maternal and fetal health. Through a combined bibliometric and systematic synthesis, the findings demonstrate a substantial and sustained increase in scientific attention over the past five decades, with particularly rapid growth since 2010. This trend reflects heightened awareness of environmental pollution as a major public health concern and the increasing recognition of pregnancy as a critical window of vulnerability [33, 34].

4.1 Dominant Research Focus and Health Implications

The bibliometric results indicate that research in this field has been predominantly centered on exposure to Pb and Hg, followed by emerging attention to Cd, As, and Mn. Consistent with previous epidemiological evidence, these metals have been extensively linked to adverse pregnancy outcomes, including preterm birth, low birth weight, and impaired neurodevelopment. The frequent appearance of keywords such as birth weight, neurodevelopment, and placenta underscores the central role of fetal growth and developmental endpoints in current research agendas [32, 35].

Findings synthesized from empirical studies further confirm that maternal exposure to heavy metals is strongly associated with fetal exposure, primarily through transplacental transfer. Numerous studies report significant correlations between maternal and cord blood metal concentrations, indicating that fetal development is directly influenced by maternal body burden. Such exposure has been associated with increased risks of preeclampsia, vitamin D deficiency, altered placental efficiency, and restricted fetal growth, highlighting the broad spectrum of maternal–fetal health effects [36].

4.2 Methodological Trends and Geographical Disparities

Across the reviewed literature, biomonitoring approaches particularly the use of inductively coupled plasma mass spectrometry (ICP-MS) have been widely adopted due to their high sensitivity and analytical precision. Blood, urine, and placental tissues represent the most commonly analyzed biological matrices, reflecting an emphasis on direct exposure assessment. While methodological rigor has improved over time, substantial geographical disparities in research output remain evident [37, 38].

The United States, China, and several European countries dominate the publication landscape, whereas regions with high environmental exposure risks-including Southeast Asia and Sub-Saharan Africa-remain markedly underrepresented. This imbalance suggests that global evidence on prenatal heavy metal exposure is disproportionately derived from high-income settings, potentially limiting the generalizability of conclusions to populations experiencing the greatest environmental burdens [28].

4.3 Theoretical Interpretation of Findings

The observed research patterns and reported health effects can be interpreted through established theoretical frameworks in environmental health and toxicology. Bioaccumulation theory explains how heavy metals persist in biological tissues and progressively increase internal exposure levels. Combined with endocrine disruption and oxidative stress mechanisms, this framework accounts for the observed associations between prenatal metal exposure and adverse maternal and fetal outcomes [39].

Additionally, the predominance of fetal growth and neurodevelopmental outcomes aligns closely with the Developmental Origins of Health and Disease (DOHaD) theory. This paradigm emphasizes that environmental exposures during critical periods of intrauterine development can influence disease risk across the life course, including neurocognitive impairment and metabolic disorders in later life. The bibliometric prominence of placental and biomarker-related keywords further supports this life-course perspective [40, 41].

4.4 Research Gaps and Implications for Public Health Policy

Despite increasing scientific attention, this analysis reveals persistent knowledge gaps, particularly regarding low- and middle-income countries. From the perspective of the social determinants of health and environmental justice frameworks, unequal research capacity and limited monitoring infrastructure contribute to the underrepresentation of vulnerable populations. These disparities may exacerbate health inequities by constraining the evidence base needed to inform policy interventions in high-exposure regions [42].

From a policy standpoint, the findings underscore the necessity of integrating environmental exposure assessments into maternal and child health programs. Evidence-based strategies such as routine screening of pregnant women in high-risk areas, strengthened monitoring of food and water sources, and regulation of industrial emissions—are essential to reduce prenatal exposure. These measures are directly aligned with the objectives of the SDGs, particularly those addressing maternal health, environmental protection, and health equity [43, 44].

4.5 Future Directions

This bibliometric and systematic synthesis highlights the need for future studies to move beyond descriptive assessments toward theory-driven and longitudinal research designs. Expanding research coverage in underrepresented regions, investigating metal mixture effects, and integrating behavioral and policy perspectives will be crucial for advancing the field. As interest in this topic continues to grow, interdisciplinary and globally inclusive research efforts are essential to effectively mitigate the impacts of heavy metal exposure on pregnant women and fetuses.

5 Conclusions

This study provides a comprehensive bibliometric and systematic synthesis of global research on heavy metal exposure during pregnancy and its implications for maternal and fetal health over the past five decades. The analysis demonstrates a sustained and accelerating growth of scientific interest, particularly since 2010, reflecting the increasing recognition of environmental contamination as a critical determinant of reproductive and developmental health.

Overall, the literature consistently indicates that prenatal exposure to heavy metals most notably lead, mercury, cadmium, and arsenic is associated with adverse pregnancy and fetal outcomes. These effects extend beyond immediate birth outcomes to encompass broader developmental risks, underscoring pregnancy as a critical window of susceptibility to environmental exposures. At the same time, the bibliometric patterns reveal pronounced geographical imbalances, with research output concentrated in high-income countries, while regions facing elevated exposure risks remain underrepresented.

From a public health perspective, these findings highlight the urgent need to strengthen environmental risk assessment and surveillance within maternal and child health frameworks, particularly in low- and middle-income countries. Integrating exposure monitoring, preventive screening, and evidence-based regulatory measures into prenatal care systems is essential to mitigate health risks and reduce inequalities. Such actions are directly aligned with the objectives of the SDGs, especially those related to maternal health, environmental sustainability, and health equity.

Future research should prioritize longitudinal and theory-driven approaches, expand geographical coverage, and address the combined effects of metal mixtures to support more effective policy development. By consolidating the existing evidence base and identifying critical knowledge gaps, this study offers strategic insights to guide research agendas and inform interventions aimed at protecting maternal and fetal health in the context of growing environmental challenges.

Author Contributions

Conceptualization, H.A. and I.I.; methodology, H.A.; software, H.A., I.I., and A.B.B.; validation, H.A., M.M., S.W., R.I., and I.S.; formal analysis, H.A. and I.I.; investigation, I.I. and H.A.; resources, I.I.; data curation, I.I and H.A.; writing—original draft preparation, I.I.; writing—review and editing, I.I., H.A., A.B.B., R.I., M.M., S.W., and I.S.; visualization, I.I.; supervision, H.A.; project administration, I.I.; funding acquisition, H.A. and I.I. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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