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Ecological and Human Health Risks of Nickel Mining: A Systematic Review

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ABSTRACT

Introduction: The growing global demand for Nickel has sparked major concerns regarding environmental and health impacts, which require a comprehensive understanding. However, there have been gaps in the mapping of study focus and research trends so far, especially in the last ten years.
Method: This study aims to address these gaps through a systematic literature review and thematic analysis of 303 articles obtained from Scopus, PubMed, and Springer Open using PoP, Vos Viewer, and Watase Uake. The analysis was conducted by considering trends based on the year of publication, geographical distribution (especially in developing countries such as Indonesia, China, and others), research methodology, and identification of key themes such as heavy metal contamination, land use change, and public health impacts related to mining activities.
Results: The study show significant progress in understanding the impacts of nickel mining, but also identify areas that are still underexplored, especially in terms of theoretical development, methodological innovation, and contextual frameworks. The study also found that only 15% of the studies adopted an interdisciplinary approach, indicating the need for more intensive collaboration. These findings highlight the importance of strengthening policy frameworks, especially in areas with intensive mining activities, such as Indonesia.
Conclusion: This research proposes a future research agenda to address the emerging challenges and provides important insights for the development of more effective mitigation strategies. The results of this study are expected to contribute to the international policy framework, supporting the design of stronger and region-specific interventions to reduce the environmental and health impacts of nickel mining.

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INTRODUCTION

Nickel mining is a significant contributor to environmental pollution, with adverse effects on ecological and human health (1,2). The world's nickel reserves are; 139,419,000 Tons Ni, of which 72 tons of Ni (52%) are in Indonesia, the rest are spread across Australia 15%, Brazil 8%, Russia 5%, and other countries 20% (3–5), this data shows that most of the Nickel resources are in Indonesia and have the potential to affect in environmental changes to a higher degree. The mining and smelting process releases Nickel into the air, water, and soil, leading to widespread environmental pollution (6,7). This pollution is further exacerbated by industrial activities such as electrical coating, battery production, and waste incineration (8–10). The literature synthesis provides a comprehensive analysis of established and emerging sources, underscoring the multifaceted impact of nickel contamination.

Several studies highlight that health risks from nickel mining include respiratory problems, especially among workers in mining areas who often experience coughing, chest pain, and shortness of breath (1,2,6). Nickel exposure has been related to skin conditions such as contact dermatitis and respiratory cancer due to inhalation of nickel compounds (7,8). Other common health problems, such as headaches, body weakness, and digestive problems, are prevalent among those who live near nickel mining sites (9,10). The ecological risks of nickel mining include Contamination of soil and water, with increased levels of Nickel in the environment that can exceed safe limits and threaten local ecosystems. Mining activities also increase exposure to nickel sediments, which can lead to coral bleaching and toxicity in marine ecosystems, posing a significant threat to biodiversity. The bioavailability and toxicity of Nickel, especially in suspended sediments, play an important role in its ecological impact (11–13).

Given these risks, assessing and managing environmental and health hazards is essential, with strategies such as Hazard Quotient (HQ) assessments offering useful metrics for risk management (12,14,15). Effective mitigation strategies include phytoremediation, better waste management, and regular monitoring to reduce nickel pollution and its associated risks (14). A comprehensive literature review is essential to understand the specific health risks associated with nickel mining and pollution and to evaluate the potential long-term impacts on human health. This review highlights the mechanisms of toxicity, such as oxidative stress, mitochondrial dysfunction, and inhibition of DNA repair, that contribute to the carcinogenic effects of nickel exposure. Reactive Oxygen Species (ROS) are the main drivers of nickel-induced toxicity, causing cell and tissue damage. In addition, workers in the mining and refining industries face a higher risk of exposure, with direct contact with nickel dust and fumes causing occupational health problems. Environmental pollution from nickel mining can affect the surrounding community through consumption, inhalation, and skin contact with contaminated air, water, and soil (16–18).

Mitigation strategies to reduce ecological and health risks can be implemented by strengthening the regulatory framework. Enforcing strict occupational safety standards and environmental protection measures will help minimise the health risks associated with nickel mining (19–21). Periodic health risk assessments and ongoing monitoring of nickel levels in the environment are essential for early detection and prevention of adverse health impacts. This study aims to provide an in-depth understanding of the ecological and health risks associated with nickel mining pollution and suggest strategies to mitigate these risks.

METHODS

The approach used in this article is the Systematic Literature Review (SLR) with several tools. Public or Pherish (PoP) for searching the references, Vos Viewer for finding the topic idea, and Watase UAKE for identification, retrieval, conclusion, and generating the PRISMA Protocol, which aims to identify, evaluate, and synthesise relevant literature regarding the ecological and health impacts of nickel mining activities. The PRISMA protocol remains a valid and reliable method for systematic review. Although not a new method, PRISMA is still relevant and effective in conducting thorough searches and selecting suitable articles for review, thus meeting the objectives of this research. The systematic review process is carried out with the following steps: first, identifying keywords, inclusion and exclusion criteria, and research limitations; second, filtering relevant articles; third, search for selected works and identify exceptions if any; fourth, reading the title, abstract, and keywords of the selected articles; fifth, documenting the paths and important items of each article in the data extraction process; and finally, analyse the classification, conduct network analysis, develop network hypotheses, and make visualisations (22). The stage of SLR can be seen in Figure 1.

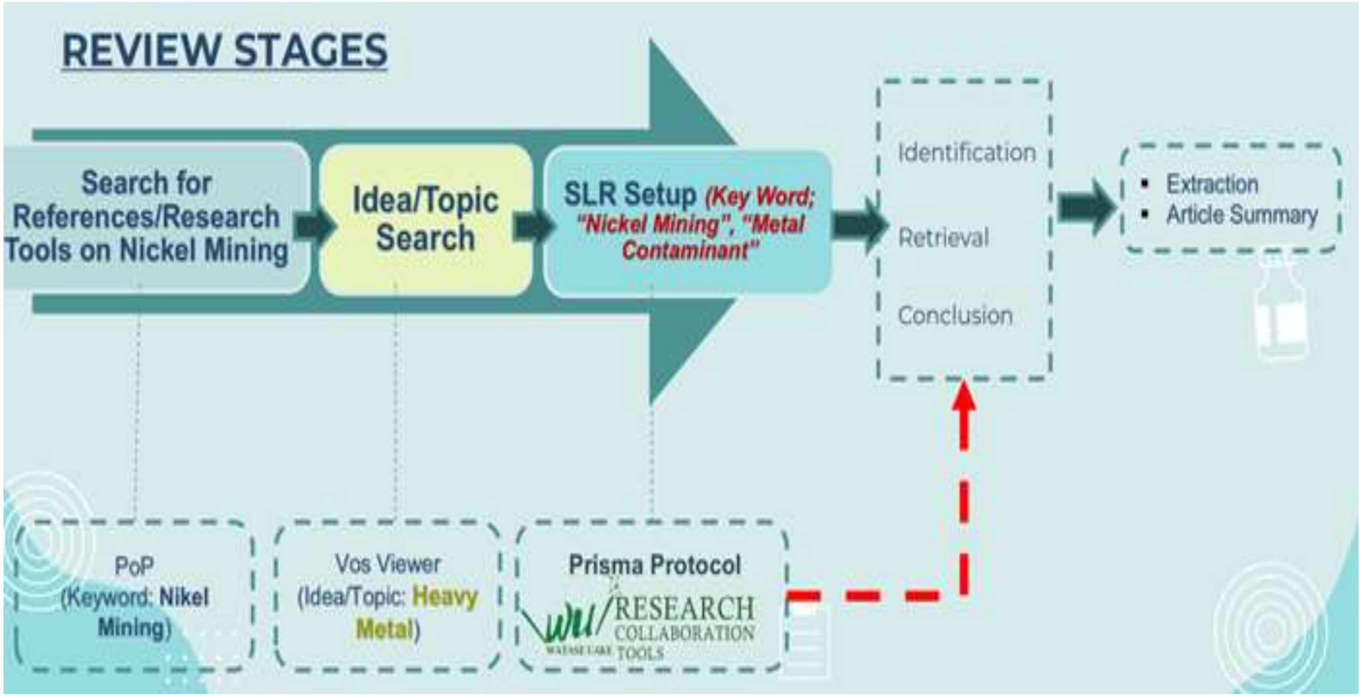

Figure 1. The Stage of SLR

Literature data collection was carried out through systematic searches in several academic databases, such as Scopus, PubMed, and Springer Open. Keywords used include terms such as "nickel mining," "ecological impact," "health risk," and "human health." The search is focused on using predetermined inclusion and exclusion criteria, namely articles published in the last ten years, in English, and based on empirical studies. The Scopus database was selected in this study because it has a strict and widely cited indexation system, where Scopus guarantees high data quality through a rigorous content selection process and re-evaluation by an independent Content Selection and Advisory Board. Scopus is a bibliographic database that provides access to scientific literature with journals that have gone through a peer-review process. Scopus is considered a reliable source for literature searches and has a strict selection process for including journals in its database.

The research keywords were chosen to include articles that discuss the impact of nickel mining. A total of 303 documents were initially found related to this topic before applying the filter. The criteria used to narrow the scope of articles include publications in scientific journals, publication periods between 2014 and 2024, and articles in the Scopus Q1–Q4 category. After the search process, all relevant articles are evaluated through a screening procedure. The first stage involves an abstract review to assess the relevance of the topic, followed by a full review of the article text that passes the initial stage. Data from the selected studies were then extracted using a standard form that included information such as research methods, study locations, types of impacts reported, and affected populations. In the final stage, 40 relevant articles were obtained and synthesised in the form of tables, images, graphs, and narratives to provide a holistic understanding of the issues raised and evidence-based policy recommendations. The PRISMA procedure carried out can be seen in Figure 2.

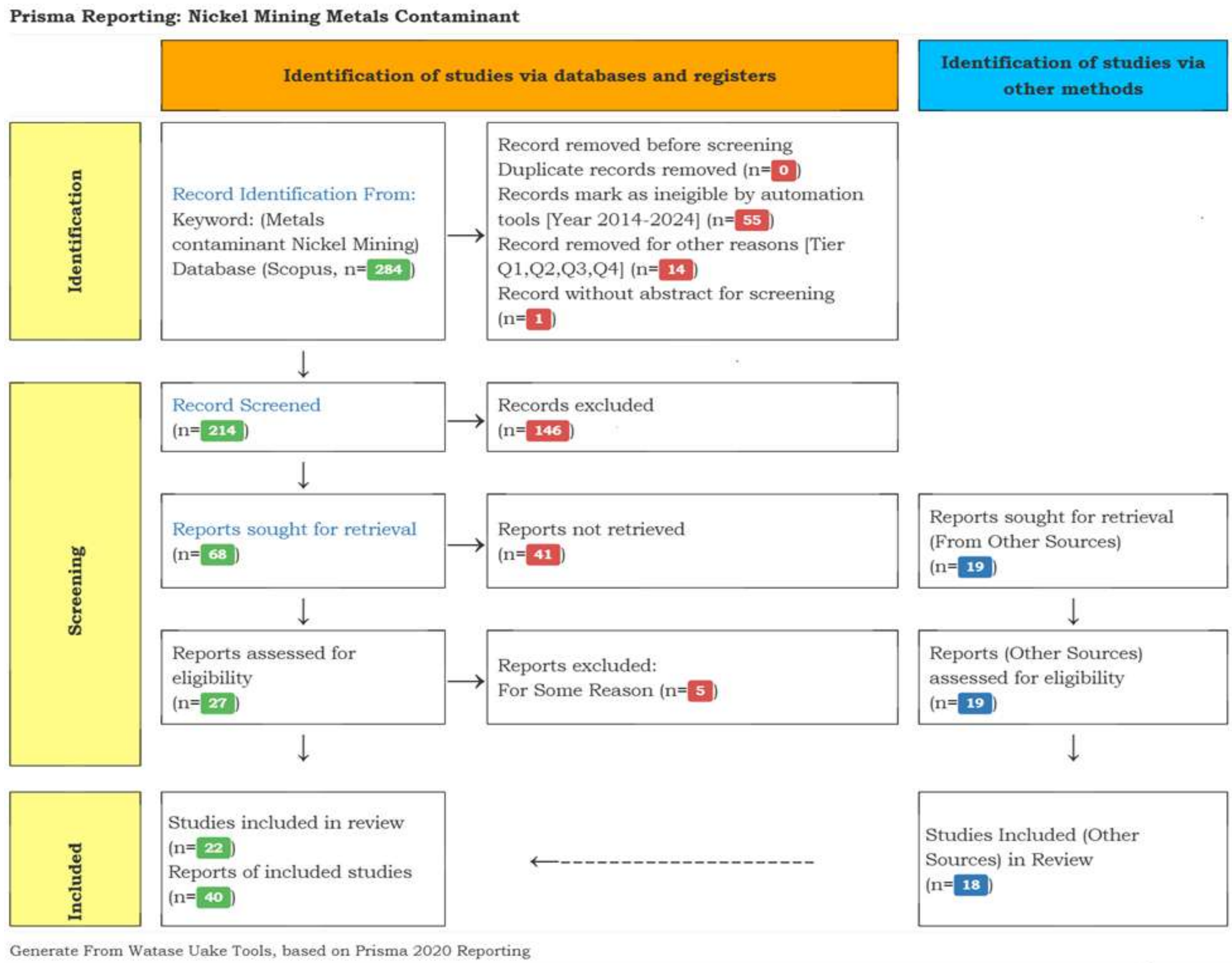

Figure 2. Identification, Screening, and Inclusion Steps with PRISMA Protocol

RESULT

This review of literature aims to summarise and categorise research developments related to the impact of nickel mining activities on health and the environment, identified based on the year of publication, study country, type of method used, type of pollutant, and resulting impact.

Years of Publication

The trend of scientific publications examining the impact of nickel mining on the environment and human health from 1985 to 2024. The data were collected from Scopus, PubMed, and SpringerOpen databases, taking into account peer-reviewed articles that explicitly discussed the ecological or human health impacts of nickel mining. Between 1985 and 2009, the number of publications remained relatively low and stagnant, averaging less than five articles per year. Starting in 2010, the level of publication increased substantially, reflecting increasing scientific and public attention to nickel-related environmental and health issues. The trend peaked in 2023 with 36 publications, followed by a slight decline to 34 articles in 2024. This pattern is in line with the expansion of nickel mining activities and growing global concerns about heavy metal pollution and associated risks. The trend of publication by year can be seen in Figure 3, which is generated directly from the Watase UAKE application.

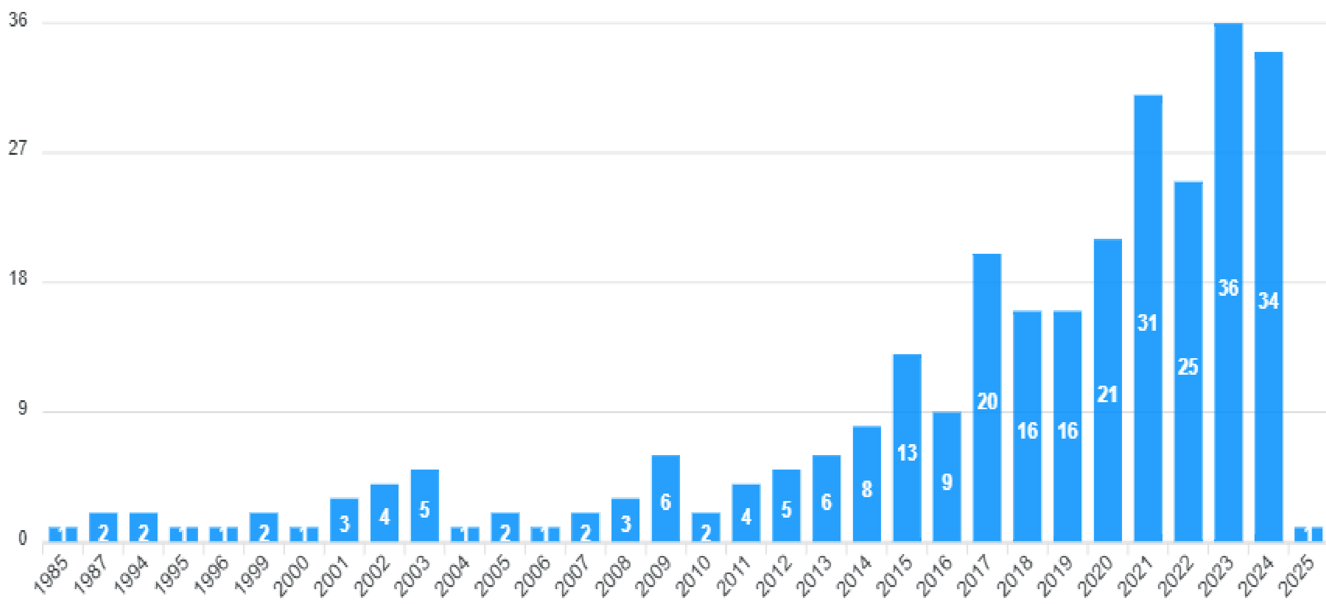

Figure 3. Year of publication

Figure 3 shows the temporal distribution, which underscores the evolution of research focus and the increasing recognition of the ecological and public health implications of nickel mining.

Country of Study

The results of the review show that developing countries dominate research contributions in the broader area than developed countries. This shows that the impact of nickel mining on the environment and health is more studied in developing countries, which is most likely due to the high mining activity in the region. In contrast, developed countries, although contributing less, remained involved in these studies, likely through international collaboration and contributions to the analysis of technologies and research methods. Countries that focus on research on the impact of Heavy Metals due to peer mining, especially Nickel, can be seen in Figure 4, which is generated from the Watase UAKE application.

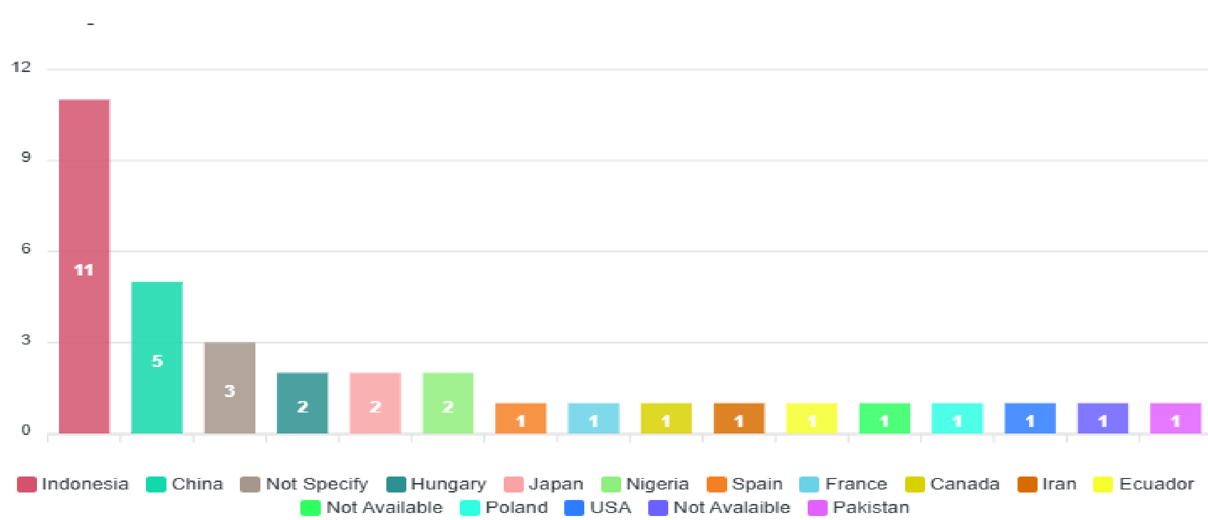

Figure 4. Country of Study

Figure 4 shows the geographic distribution of article publications discussing the impact of nickel mining on the environment and human health by the author's country of origin or institutional affiliation. Indonesia dominated with 11 publications, followed by China with five publications. Several other countries, such as Japan, Nigeria, and Spain, each contributed 2-3 publications. Meanwhile, countries such as France, Canada, Iran, and the United States have only one publication. Indonesia's dominance in this study reflects the significance of the nickel mining issue in the country, considering that Indonesia is one of the largest nickel producers in the world.

Context of Study

In the review article studied, the dominant focus is on the problem of heavy metals, particularly those related to their impact on the environment and human health. This in-depth research on heavy metals shows that there is a very high level of interest from experts in nickel mining activities, which are increasingly carried out in various parts of the world (1,7,8,10,16,23–29). The context of the research can be seen in Figure 5, which is generated from the Watase UAKE application.

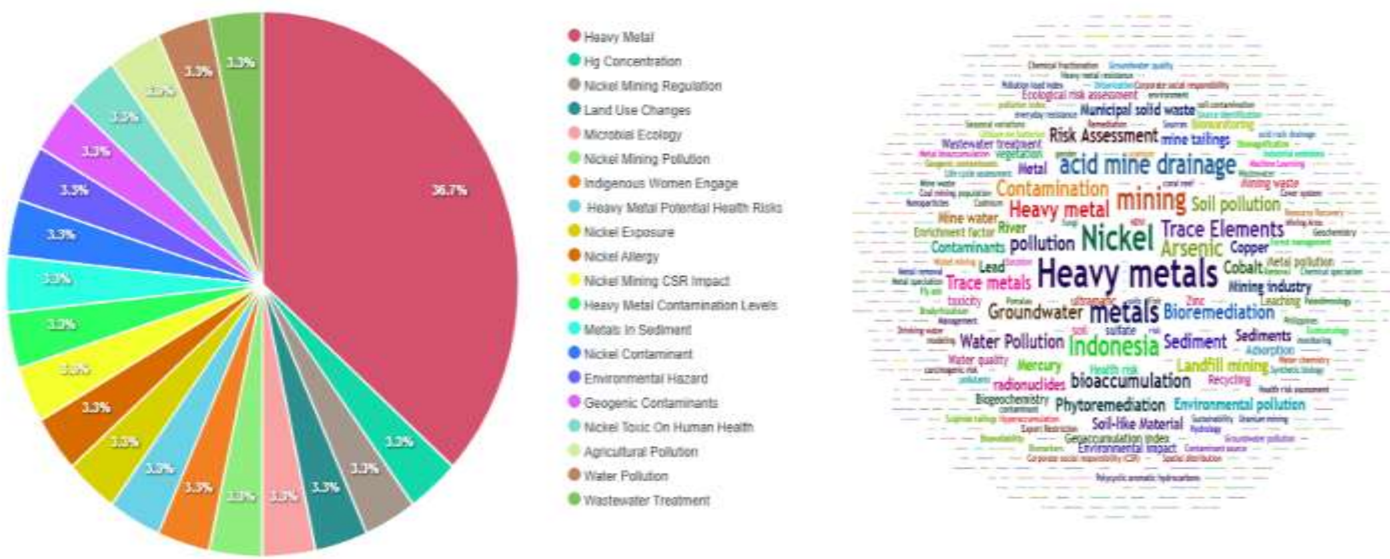

Figure 5. Context and Key Word of Study

Figure 5 illustrates the distribution of research topics related to the impact of nickel mining on the environment and human health. The topic of Heavy Metal dominated with a proportion of 36.7%, indicating the researchers' primary concern for heavy metal contamination resulting from nickel mining activities. Meanwhile, other topics such as Hg Concentration, Nickel Mining Regulation, Land Use Changes, Microbial Ecology, and various health and environmental issues each contributed 3.3%. This reflects the broad scope of research in this area, covering regulatory, social, and biological aspects, as well as health and ecological impacts.

Research Design

Research on nickel mining is carried out using various designs, including risk assessment, observational, quantitative, Monte Carlo, and others. The research design can be seen in Figure 6, which was generated from the UAKE Watase Application.

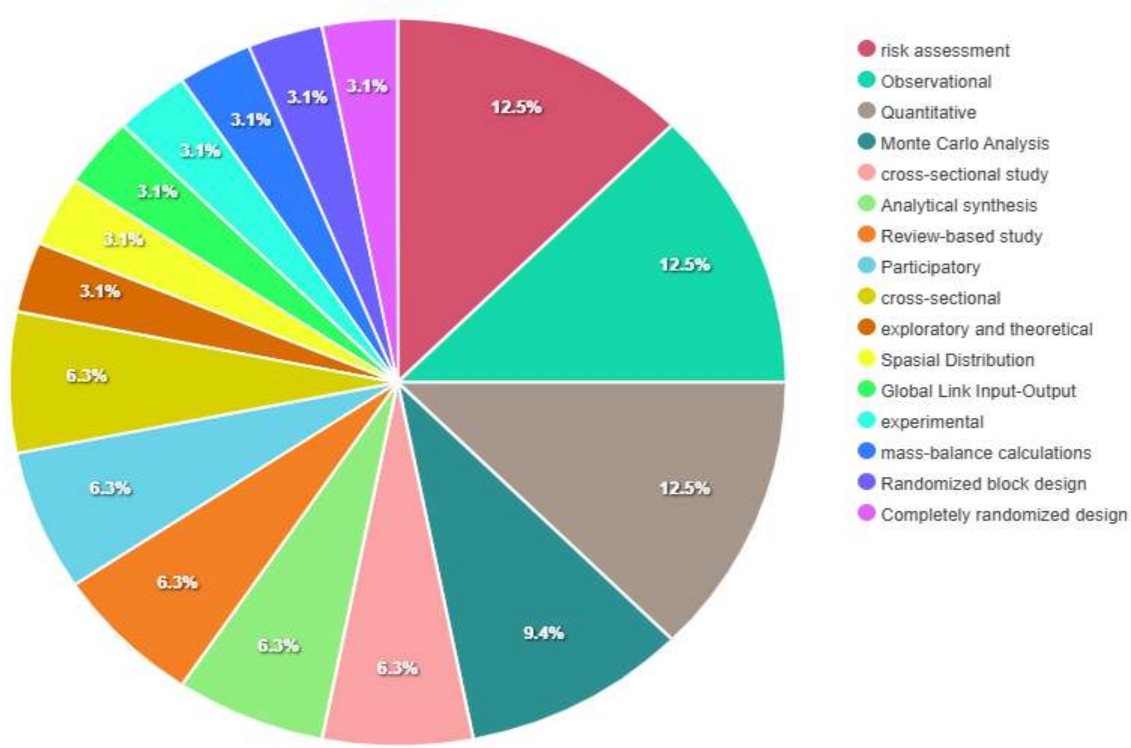

Figure 6. Research Design

Figure 6 shows the distribution of research methods used in studies related to the impact of nickel mining on the environment and human health. The most commonly used methods are Risk Assessment, Observational, and Quantitative, each with a proportion of 12.5%. This shows that risk evaluation and quantitative analysis are the main approaches to measuring the environmental and health impacts of mining activities. Other methods, such as Monte Carlo Analysis (9.4%), as well as various experimental designs, including Cross-Sectional Studies, Analytical Synthesis, and Review-Based Studies (6.3% each), also show an important role in providing analytical and theoretical perspectives. A small number of studies use special methods such as Mass-Balance Calculations or Completely Randomised Design (3.1%), which shows the diversity of methodologies in overcoming the complexity of nickel mining problems. This combination of methods reflects the multidisciplinary approach needed to assess the impacts of the mining sector holistically.

The results of the review based on Author, Year, Country, Context, and Study Focus are described in the following table:

Table 1. Article Extraction Results by Author, Year, Country, Context, and Focus Area of Study

NO	AUTTHOR	COUNTRY	COUNTRY STATUS	CONTEXT	FOCUS AREA
1	Brearley (2024)	Indonesia	Developing	Heavy Metal	Ecological Risk (30)
2	Chen et al. (2024)	Canada	Developed	Microbial Ecolgy	Ecological and Human Risk (31)
3	Erickson et al. (2024)	USA	Developed	Geogenic Contaminants	Ecological Risk (32)
4	Heijlen and Duhayon (2024)	Indonesia	Developing	Land Footprint	Ecological Risk (33)
5	Malik and Muzaffar (2024)	Iran	Developing	Heavy Metal	Ecological Risk (34)

6	Wahyono et al. (2024)	Indonesia	Developing	Heavy Metal	Ecological Risk (35)
7	Atta et al. (2023)	Pakistan	Developing	Heavy Metal Potential on Health Risks	Ecological and Human Risk (36)
8	Bondu et al. (2023)	France	Developed	Heavy Metal	Ecological and Human Risk (37)
9	Gunjyal et al. (2023)	N/A	Developing	Environmental Hazard	Human Risk (38)
10	Han et al. (2023)	China	Developing	Heavy Metal Contamination Levels	Ecological Risk (39)
11	Kerl et al. (2023)	Spain	Developed	Heavy Metal	Ecological Risk (40)
12	Maskuroh et al. (2023)	Indonesia	Developing	Resources Management	Others (20)
13	Mestanza-RamÃ³n (2023)	Ecuador	Developing	Hg Concentration	Ecological Risk (41)
14	Naha et al. (2023)	N/A	Developing	Wastewater Treatment	Ecological Risk (42)
15	Owhoeke et al. (2023)	Nigeria	Developing	Environmental Pollution	Ecological Risk (43)
16	Saeed et al. (2023)	Hungary	Developed	Heavy Metal	Ecological Risk (44)
17	Somani et al. (2023)	Hungary	Developed	Heavy Metal	Ecological and Human Risk (25)
18	Urama et al. (2023)	Nigeria	Developing	Toxic Metal	Ecological Risk (45)
19	Yu et al. (2023)	China	Developing	Metals In Sediment	Ecological Risk (46)
20	Wolkersdorfer and Mugova (2022)	N/A	Developed	Environmental Impacts	Ecological Risk (47)
21	Camba (2021)	Indonesia	Developing	Nickel Mining Regulation	Others (19)
22	El-Naggar et al. (2021)	N/A	Developing	Nickel Contaminant	Ecological Risk (48)
23	Glynn and Maimunah (2021)	Indonesia	Developing	Indigenous Women Engage	Others (49)
24	Ito et al. (2021)	Indonesia	Developing	Heavy Metal	Ecological Risk (50)
25	Jatnika et al. (2021)	Indonesia	Developing	Water Pollution	Ecological Risk (51)
26	Jiménez-Oyola et al. (2021)	China	Developing	Heavy Metal	Ecological Risk (52)
27	Leomo et al. (2021)	Indonesia	Developing	Heavy Metal	Ecological Risk (53)
28	Zamora-Ledezma et al. (2021)	N/A	Developing	Heavy Metal	Ecological Risk (54)
29	Dudek-Adamska et al. (2020)	Poland	Developed	Nickel Toxic to Human Health	Human Risk (55)
30	Genchi et al. (2020)	N/A	Developed	Nickel Exposure	Ecological Risk (56)
31	Hudayana et al. (2020)	Indonesia	Developing	Local Mining Communities	Others (57)
32	Prematuri et al. (2020)	Indonesia	Developing	Nickel Mining Pollution	Ecological Risk (58)
33	Zainuddin et al. (2020)	Indonesia	Developing	Nickel Mining CSR Impact	Others (59)
34	Nakajima et al. (2017)	Japan	Developed	Land Use Changes	Others (60)
35	Saito et al. (2016)	Japan	Developed	Nickel Allergy	Human Risk (61)

36	Wang and Yang (2016)	China	Developing	Water Pollution	Ecological and Human Risk (62)
37	Lu et al. (2015)	China	Developing	Agricultural Pollution	Ecological Risk (63)
38	Bernhoft (2015)	N/A	Developed	Cadmium Toxicity	Ecological and Human Risk (64)
39	Ning et al. (2015)	China	Developing	Heavy Metal	Ecological Risk (65)
40	Mudd (2010)	Canada	Developed	Nickel Mining Environmental	Ecological Risk (66)

Nickel Mining Impact on the Ecological

Nickel mining activities can have an impact on the environment, which can be in the form of Hazards, Water Pollution, and Land Use Changes. Nickel mining activities contribute significantly to environmental pollution, particularly through the release of heavy metals into water and soil (7,26,37,50) Research-based on spatial analysis and pollutant distribution models shows that heavy metals such asNickel and mercury can accumulate in sediments, affecting water quality and biodiversity (67–71) Water pollution due to mining activities also has an impact on aquatic ecosystems, disrupting the balance of the ecosystem and threatening the survival of aquatic organisms. Studies based on Risk Assessment indicate that ecosystems around mining areas face high risks, especially in developing countries where environmental monitoring and regulatory enforcement are often less than optimal (72–75).

Nickel production and its impact on the environment are greatly influenced by the intensity of the resources derived from the types of nickel ore mined, namely, laterite ore and nickel sulfide. Laterite ores, which are commonly found in the tropics, generally require a more intensive extraction process and can result in greater environmental impacts, such as deforestation, soil pollution, and changes in water flow patterns.

Nickel Mining Impact on Health

Nickel mining can generate a range of chemical pollutants that pose significant risks to human health and the environment. Among these pollutants are various types of heavy metals, which can accumulate in sediments and enter the food chain, leading to serious health issues for both wildlife and humans (38,55,61). The mining process itself often produces waste materials that contain toxic substances, which can leach into nearby water sources and soil, further exacerbating Contamination. The following table shows the impact of heavy metals due to mining on humans (1,38,55,61,76,77).

Table 2. Human Risks of Heavy Metal Exposure

Contaminant Type	Maximum Allowable Rate	Unit	Testing Method	Impact
Mercury (Hg)	0.001	Mg/L	SNI/APHA	Neurological disorders, tremors, decreased cognitive function, and visual impairment.
Lead (Pb)	0.01	Mg/L	SNI/APHA	Kidney damage, anaemia, impaired child development, and hypertension
Arsenic (As)	0.01	Mg/L	SNI/APHA	Skin Cancer, Lung Cancer, Bladder Cancer, Neurological Disorders
Sianida (CN)	0.07	Mg/L	SNI/APHA	Respiratory Distress, Heart Damage, Death
Cadmium (Cd)	0.003	Mg/L	SNI/APHA	Lung damage, bone damage, and kidney failure
Nickel (Ni)	0.07	Mg/L	SNI/APHA	Pneumonia, Inflammation, and Impaired Lung Function
Cuprum (Cu)	2	Mg/L	SNI/APHA	Kidney Tissue Inflammation
Ferrum (Fe)	0.01	Mg/L	SNI/APHA	Gestational Diabetes

DISCUSSION

Ecological Impact

Nickel production contributes significantly to environmental degradation, including land degradation, water pollution, and greenhouse gas emissions (67,78). The resource intensity of the ore extraction and refining process varies, depending on the type of ore being processed. Laterite ores generally require more energy and water compared to sulfide ores, leading to a larger environmental footprint. Additionally, laterite ore produces more waste, such as tailings, which can contaminate soil and water. On the other hand, although sulfide ore has a lower resource intensity, its processing still produces sulfur dioxide emissions, contributing to acid rain (31,79,80). Laterites require intensive hydrometallurgical processes such as High Pressure Acid Leaching (HPA) or Rotary Kiln-Electric Furnace (RKEF). This process consumes between 230 and 570 GJ per ton of Nickel and produces CO2 emissions of about 45 tons per ton of Nickel. Meanwhile, sulfide ore is processed through conventional pyrometallurgy, such as smelting, with lower energy consumption, which is around 114 GJ per ton of Nickel, with CO2 emissions equivalent to around 6 tons per ton of Nickel (81,82).

Land-use changes from mining activities, including vegetation clearing, contribute to biodiversity loss and accelerate soil erosion and degradation (60,83). Participatory and review-based study methods underscore the importance of local community involvement in natural resource management to mitigate these impacts (84,85). Research in Durban proves the success of community involvement in tackling environmental impacts, such as the reforestation project that began in 2008 in Buffelsdraai, Durban, which involved local communities in the planting of more than 500,000 trees. The project not only reduces the impact of climate change but also creates more than 600 jobs and provides livelihood benefits for local communities. The project was recognised as one of the top 10 global projects by the United Nations Framework Convention on Climate Change, highlighting the effectiveness of community engagement in environmental conservation (86). Ecosystem-based approaches, such as post-mining environmental restoration, should be prioritised. Effective collaboration between government, industry, and local community stakeholders is essential to ensure that the exploitation of nickel resources is economically beneficial and ecologically responsible.

Human Health Risk

The impact of nickel mining on human health is a growing concern, with many studies focusing on heavy metal exposure (87,88). Nickel exposure has been linked to a variety of health disorders, including allergic skin reactions such as contact dermatitis, as well as respiratory and cardiovascular diseases. The mechanism behind nickel allergy, which involves a complex immune response, highlights the potential health risks of long-term exposure (56,61). In addition, mercury (Hg) concentrations, which are often found in nickel mining activities, exacerbate toxicological risks to communities in mining areas (89). Risk assessments and quantitative analyses show that populations in developing countries, which are central to mining activities, are particularly vulnerable to this exposure.

Beyond the immediate health risks, environmental changes such as water and soil pollution significantly affect the quality of life of local communities. Spatial distribution methods are used to predict the spread of pollutants and assess their impact on public health (90,91). These findings emphasise the need for a holistic approach to address health impacts, combining clinical evaluation with environmental mitigation and stringent regulatory measures. International collaboration, especially from developed countries, is essential to provide technology- and policy-based solutions to reduce the adverse impacts of mining in developing regions.

Governance Policy

The surge in publications regarding the impacts of nickel mining in the last decade is likely reflecting the academic response to evolving environmental policies, increasing societal demands, and advances in health risk detection technology. The distribution of research, especially in developing countries, highlights the local urgency and global concern about the environmental and health risks associated with the exploitation of mineral resources. This trend also points to an increasing scientific focus on the problems caused by the nickel mining industry.

The dominance of studies on heavy metal pollution further underscores the significant threat nickel mining poses to ecosystems and human health. This thematic concentration is consistent with the priorities of international environmental agreements, such as the Minamata Convention on Mercury, which addresses the dangers of mercury pollution, and the Basel Convention, which regulates the transboundary movement of hazardous wastes (92,93). The increasing diversity of research topics demonstrates the importance of a multidisciplinary approach to understanding and managing the impacts of nickel mining holistically, both locally and globally.

CONCLUSSION

Based on a literature review, nickel mining activities have a significant impact on human health and environmental ecology. From a health perspective, exposure to heavy metals such as Nickel can trigger allergic reactions, respiratory disorders, and cardiovascular disease, especially in communities living around mining areas. Complex immunological mechanisms, such as activation of key signalling molecules, highlight the health risks associated with long-term nickel exposure. Ecologically, nickel mining contributes to water and soil pollution, habitat degradation, and biodiversity decline. The production process of Nickel, from laterite and sulfide ores, is resource-intensive, resulting in substantial carbon footprints and large amounts of waste.

The high volume of publications from developing countries underscores global concerns about the impacts of nickel mining, especially in relation to heavy metal contamination. The study emphasises the need for a multidisciplinary and collaborative approach to mitigate these impacts. Concrete recommendations include the implementation of a biological monitoring framework to track heavy metal exposure in human populations and ecosystems, the adoption of green extraction technologies to reduce environmental damage, and the development of integrated policy evaluation metrics to assess the effectiveness of regulatory measures. In addition, stricter regulations and the active involvement of local communities in environmental restoration efforts are essential to ensure that nickel exploitation is balanced with sustainable management strategies. This approach will help minimise risks to public health and the environment, ensuring a more sustainable future for mining areas.

AUTHOR'S CONTRIBUTION STATEMENTS

Herawati H. contributed to conceptualizing, methodology, writing the original draft, and editing the manuscript. Mallongi A., Daud A., Syam A., Amiruddin R., Erniyasih, and Tryanda S.V.P.T contributed to conceptualizing and methodology study and data analysis.

CONFLICTS OF INTEREST

The authors have stated that they do not have any conflicts of interest, including personal relationships or financial matters.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

In writing this article, the author uses Chat GPT and Grammarly to support language improvement.

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