

*Review Article***The Impact of Increasing Nickel Production on Forest and Environment in Indonesia: A Review**

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ABSTRACT

The history of nickel mining in Indonesia began in the Verbeek Mountains in Sulawesi in 1901. The finding of nickel and its extraction occurred in the Netherlands, making it the pioneering site for this ore. Also, the substantial rise in the extraction of natural resources like nickel through mining would inevitably profoundly influence forests, which serve as the core of the ecosystem for both flora and fauna. This study aims to determine the consequences of the growing nickel production on Indonesia's forests and environment. It involves examining the alterations in the forests due to the increased nickel production and evaluating the broader environmental effects. The research method used in this research is a literature review. This technique seeks to analyze, assess, and interpret diverse research findings to examine them within the investigated subject's framework. The research result of this investigation demonstrates that the escalating nickel production in Indonesia is detrimental to forests and the environment, leading to deforestation, degradation of habitats, and contamination of the air and soil. These alterations present immediate hazards to human well-being, such as respiratory problems and effects on agricultural output. It is crucial to evaluate and improve the methods used for nickel production and adopt sustainable management strategies to reduce the negative impacts on the environment and protect both the ecosystem and human welfare.

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1. Introduction

There is no doubt that in Indonesia, mining entails the extraction of natural resources for economic growth and societal development. Indonesia, known for its abundant natural resources, engages in this activity. Still, it also significantly impacts changes in terrestrial ecosystems, mainly forests. This raises questions about the history and process of mining development in Indonesia, especially nickel mining. The history of nickel mining in Indonesia began in the Verbeek Mountains in Sulawesi in 1901 (Khoirul 2023). Dutch mineralogists first discovered it, which immediately became the first location where nickel was extracted. This region was called Kolaka Regency to produce the nickel needed for export to other countries. Later, a Canadian mineralogist continued exploration in 1934 and planned to expand mining. This began INCO's operations in Indonesia, running a nickel mining block in Soroako, near Kolaka (Whitten and Henderson 2012).

Nickel mining in Indonesia started production in 1941 (McCarthy 2016). However, after Indonesia gained independence in 1945, Van Gorsel (2022) submitted more data, stating that in 1917 nickel ore was first discovered in Sulawesi by an exploration team from the Indonesian Mining Ministry. This nickel ore is used daily as a mixture of metals and non-metallic materials.

Nickel mining in Indonesia continues to grow due to attractive mining prospects. In addition, companies continue to explore enormous resources in Sulawesi to find new locations to expand their business. As a result, Indonesian nickel mining can continue to develop into one of the largest nickel reserves in the world. Recently, various smelters have been developed in Indonesian nickel mining. In addition to meeting the needs of nickel exports, several regulations govern it. Nickel production also aims to meet the needs of local industries in various businesses, such as electrical cables, machine parts, and many other products. In this way, the capacity of some large smelters in Indonesia can reach 90 thousand tons per year. Having more than 20 smelters in Indonesia makes this possible to fulfill. Moreover, the number of these smelters will continue to grow. By next year, 30 smelters are expected. This will make Indonesia a significant competitor worldwide in nickel production and supply (Konewka et al. 2021).

According to McCarthy (2016), PT. Vale was the first to manage nickel mines in Indonesia in 1920. Exploration of this nickel mine took place during the independence period under the leadership of President Ir. Soekarno. In 1968, PT. Vale was officially established as PT International Nickel Indonesia. By receiving a Contract of Work (CoW), a license from the Indonesian government was granted to the company to conduct the mining and processing of nickel ore. PT. Vale was first established in Sorowako, East Luwu Regency, South Sulawesi. This first nickel mining company had exclusive rights to exploit certain areas in Sulawesi. They use the agreements contained in the CoW to process, stockpile, and sell other nickel minerals. This multi-mining company, a global leader in nickel ore production, is based in Brazil. PT. Vale operates under an amended contract from 2014 to 2025.

As a developing country supporting national development, Indonesia utilizes its natural resources as a potential source of national income to enhance more sustainable growth. This opinion is also based on research results (Soelistijo 2013). Vertical and regional increases in mineral value added are necessary to increase national income and regional development. Developing advanced industries such as stainless steel, non-ferrous alloys, other steel legacies, electroplating, and chemicals can increase nickel's added value and regional value. In addition, if mining companies that usually operate in remote areas also contribute to regional development, they will directly develop underdeveloped areas through regional development programs such as their CSR programs (with a net gain coefficient of nickel mining of about 2.5–4.6% or higher) in the coming years, especially in developing countries such as Indonesia.

Data from 2021 explains that Indonesia is one of the countries with the largest nickel reserves in the world, with the country's nickel reserves of 21 million metric tons in 2021, which may make Indonesia the largest nickel-producing country in the world by one million metric tons. Indonesia also produces the world's best nickel type for electric car battery development. The International Energy Association (IEA) claims that the renewable energy trend will increase the demand for nickel in the global market, mainly due to the emergence of environmentally friendly electric vehicles. By 2040, 58% of vehicles worldwide will be electric (Li and Chen 2019). In addition, the electric car industry relies heavily on nickel as a raw material for electric car batteries, so that the government will increase the amount of nickel downstream in the country. This will be done by increasing the number of smelters, of which PT. Aneka Tambang Tbk is the owner. Presidential

Regulation Number 55 of 2019 on Accelerating the Battery-Based Electric Motor Vehicle Program for Road Transportation establishes the program (Agung and Adi 2022).

In line with the rapid development of nickel mining in Indonesia to meet ambitious national and international needs, it also aligns with the potential for environmental damage. According to Maisel et al. (2023), global nickel production is expected to increase by at least 65% by 2030 due to demand for electric vehicle battery components, and the International Energy Agency projects that Indonesia will be able to meet two-thirds of the world's nickel needs. In addition, Indonesia has also entered into multi-billion-dollar agreements with foreign companies wishing to invest in the nickel mining and processing sector. However, environmental issues in mining areas, including nickel mines, are still of concern to domestic observers. The Indonesian government is not unaware of this. The government has paid attention to environmental pollution caused by mines, according to the Ministry of Energy and Mineral Resources or *Kementerian Energi dan Sumber Daya Mineral* (ESDM).

In addition, the role of forests is also significant for the sustainability of living things, such as animals and humans, who may depend on their primary needs in the forest. Therefore, forest management as an essential ecosystem for living things is critical. Furthermore, forest utilization activities demonstrate the role of forest resources in the economy. The purpose of forest utilization, as stated in Forestry Law Number 41 of 1999, is to optimize the welfare of the entire community while maintaining its sustainability. Except for nature reserve forests, core zones, and jungle zones in national parks, forest area utilization can be carried out in all forest areas. Production forests can include the use of areas, the use of environmental services, the use of timber and non-timber forest products, and the collection of products (Alam and Hajawa 2007).

Forests also serve as the primary needs of living beings, such as water resources from river flows. In addition to being used for sanitation, agriculture, and household needs, river flows in Indonesia can be a renewable energy source that does not hurt the environment because no waste emissions are produced (Taufiqurrahman and Windarta 2020). Thanks to its topographical conditions, including mountains, hills, lakes, and reservoirs, Indonesia has great potential for using water energy sources. Indonesia's total water energy potential reaches 75,091 MW, but only about 7.2% of this potential has been utilized. Hydropower plants have proven effective and have contributed as much as 66% of the total capacity of 7 GW of new and renewable power plants. Therefore, with the diversity of new and renewable energy potential available in Indonesia, the government must design a comprehensive planning and policy strategy to optimize the utilization of clean energy that can be generated from river flow as one of the resources that have excellent potential for providing clean energy for the community.

The consequences may be temporary if deforestation can be rehabilitated, but deforestation and land conversion will reduce the quantity and quality of forests as a natural resource. Unfortunately, the impacts of deforestation and climate change make rainforests particularly vulnerable. Illegal logging and deforestation methods have caused the forest area to shrink dramatically. The loss of rainforests causes ecosystem damage, species extinction, and climate change. As forests are destroyed, carbon dioxide stored in trees is released back into the atmosphere, leading to the greenhouse effect and global warming. Incredible biodiversity: more than half of the world's flora and fauna live in rainforests. Many of these species are still undiscovered, and many more are threatened with extinction due to deforestation and loss of natural habitat. Rainforest biodiversity is essential for food, medicine, and new technological and scientific discoveries (Nobre and Nobre 2018).

The abundance of natural resources in the form of nickel and the construction of many nickel mines in deforested areas have significant adverse impacts on the environment. Moreover, this can have far-reaching negative implications in the context of excessive nickel mining. Mining activities often have adverse environmental impacts, such as deforestation, water and air pollution, soil erosion, and land degradation, and these effects can damage natural ecosystems and disrupt ecological balance. According to [Nurbaya et al. \(2022\)](#), massive mining expansion could lead to higher deforestation rates amid the government's efforts to reduce greenhouse gas emissions and lower carbon emissions through the Forestry and Other Land Use Net Sink (FOLU Net Sink) 2030 program. In contrast, mining expansion in forest areas is still permitted within production and protected forest areas. Protected areas are defined in Spatial Planning Law 26 of 2007 as areas designated to protect the preservation of the environment, including natural and man-made resources. In addition to conservation forest areas, protected forest areas fulfill the five criteria of the Spatial Planning Law. Protected forests, peat, and water catchment areas fall under protected areas with requirements that protect subordinate areas.

The direct impact caused by the massive expansion of nickel mining in Morowali, as a case example described by [Syarifuddin \(2022\)](#), is that the conversion of oil energy to electricity-based energy with the use of electric vehicles does minimize motor vehicle gas emissions that have an impact on climate change. However, it becomes a clean energy conversion that is not comparable due to violations by nickel mining activities, which are one of the critical components in making electric vehicle batteries. Mining sites have not been able to minimize the ecological impacts that occur. Coastal areas have been found to have a lot of mine residue silt containing dangerous metals and chemicals. The color of seawater becomes brownish. The mangrove forest area, used for crab cultivation, is also disturbed due to sediment waste from nickel mining activities. Fishery resources, one of the essential pillars of the Morowali community's economy, have been disrupted.

In addition, nickel mining has caused environmental damage to roads, pollution of river water and watersheds, air pollution, land degradation, damage to flora and fauna, and social impacts such as changes in community behavior and no empowerment of public health ([Agussalim et al. 2023](#)). However, behind these civilization and technological advancement projects, there are significant impacts on society and the ecosystem. Massive nickel mining in various parts of Indonesia, especially in Kolaka Regency, Southeast Sulawesi Province, has caused apparent environmental damage. For example, mining activities cause damage to coastal ecosystems and deforestation in forest areas no longer covered by the Borrow-to-Use Forest Area Permit (IPPKH) requirements. This occurred due to the anticipation of an inadequate environmental impact assessment (AMDAL) ([Agussalim et al. 2023](#)).

The results of environmental damage caused by nickel were also elaborated by [Irawati \(2020\)](#) that, as an example of North Sulawesi's Pomalaa District, locals in Hakatutobu Village have changed their way of life because mining activities have damaged its coastal environment. They now establish fishing in the middle of the sea to maintain the fish population in Hakatutobu Village. However, the locals' main reason for changing their lives is now also under threat. This is because the place where they grow seaweed and sea corn on the coast of Hakatutobu is also being damaged by the traffic of shipping mud containers from land acquisition. Hakatutobu village under Pomalaa is most affected by mining. So, as mentioned earlier, the Bajo community is constantly marginalized due to the destruction of the water environment.

A study by [Syarifuddin \(2022\)](#) also outlines the negative implications of nickel mining operations in Morowali, where the discharge of waste into the ocean has resulted in impacts that

continue up to three years after the project has been completed. These effects were even observed up to twenty kilometers from the center of the mine activity. Impacts include significant changes in the aquatic ecosystem, including the discoloration of the seawater to a more turbid color, increased fish mortality, elevated concentrations of heavy metals in the water, and the discovery of arsenic bacteria that were never found before. Notably, these negative impacts arising from violations in nickel mining operations result in an imbalance between environmental benefits and effects. The nickel mine site continues to have significant ecological consequences, including the deposition of toxic waste along the coast containing heavy metals and hazardous chemicals, discoloring seawater, and disrupting crab culture habitat in mangrove forests. As a result, the fishing industry, an integral part of the Morowali community's economic life, has been seriously disrupted (Syarifuddin 2022).

This research assesses the impact of increasing nickel production on Indonesia's forests and environment. This literature review research will focus on the changes occurring in forests due to intensified nickel production, including deforestation, changes in plant composition, and habitat degradation in Indonesia. In addition, this research also assesses broader environmental impacts, such as air quality, health-related air pollution, and soil affected by nickel production activities. Lastly, this research also examines to comprehensively understand how escalating nickel production influences forest ecosystems and overall environmental sustainability in Indonesia.

2. Materials and Methods

2.1. Approach

The research method applied in this research is a literature review. This literature review approach identifies, evaluates, and interprets various research results to deepen them in the context of the topic under study. This approach is designed so that the research report compiled through literature analysis can comprehensively fulfill the predetermined research objectives. The statement above is supported by Andriani (2022), who states that the literature review research method is used to obtain a systematic discussion. The research method applied in the context of this study is a literature review, which delivers datasets and elaborates on documented findings. This approach of methodology is a paradigmatic model that describes and examines the issue's intricacies at the study's center. The researcher searches and retrieves materials and data from various literature sources while referring to references in relevant books. This aims to create a substantial foundation to support the formation and analysis of the content and discussions contained in the framework of this research with the necessary level of rigor and depth.

2.2. Data Collection

The data acquisition method applied involved an in-depth literature review of relevant sources. The software used to collect literature from internet data, as well as various tools and platforms, could have been employed, such as academic databases (PubMed, Google Scholar, Web of Science, library catalogs, and digital repositories). In addition, reference management software like Zotero, Mendeley, or EndNote might have been utilized to organize and set up the collected literature effectively. These tools facilitate the retrieval, organization, and citation of scholarly sources, and they could increase the efficiency of the literature review process. Also, about 61 sources, including academic papers, reports, articles, and other relevant documents, were reviewed

to gather information on the research topic. In addition, various information related to forests and the environment resulting in the negative impacts of increased nickel mining in Indonesia was obtained. Another focus was to examine the potential of nickel in Indonesia and the effects of mining activities on the environment in Indonesia. To strengthen the analysis, the research relies on secondary data collected from various sources, such as publications in scientific journals, conference proceedings, research reports, and news articles that discuss the potential impacts of forest destruction associated with nickel mining activities. The collected information will be arranged and analyzed comprehensively to solve the research objective (Astro et al. 2020).

2.3. Data Analysis

Qualitative analysis is used in this research to explore more about the information so that the objectives can be presented with an accurate discussion. That statement is also supported by Moser and Korstjens (2018), stating that qualitative analysis is used to classify data based on the research problem and its collection. The qualitative analysis assesses the data collected from secondary data, namely through literature studies, and whether the implementation is by current theories and rules to measure how effective the implementation process is. Also, the stages of qualitative analysis employed in this study encompassed several vital steps. First, literature that was carefully reviewed and categorized based on relevance to the research objectives was collected. Thematic analysis was also utilized to identify recurring themes, patterns, and concepts within the literature. In Addition, content analysis was employed to scrutinize the content of the literature, identifying specific arguments, viewpoints, and evidence presented by various authors. This process identified and analyzed similarities, differences, and contradictions among different sources to comprehensively understand the research topic.

In line with this, the data were critically evaluated to assess the credibility, reliability, and validity of the information obtained from the literature. This involved evaluating the authority and expertise of the authors, the rigor of their research methods, and the consistency of their findings with established theories and principles. Overall, the qualitative analysis process involved rigorous scrutiny and interpretation of the secondary data collected from literature studies to evaluate the alignment with current theories and rules and examine the implementation process.

3. Results and Discussion

3.1. Data on Potential Nickel Reserve Areas in Indonesia

Indonesia's large resource deposits and exceptional nickel quality have established it as a prominent global supplier of nickel, granting it a crucial role in shaping the global nickel supply chain. Furthermore, the government mandates the practice of down streaming among domestic industry operators to enhance the value added to nickel commodities in the worldwide market and boost state revenue. The present circumstances significantly affect the expansion of the mining sector in the region, particularly in places rich in nickel deposits, such as Southeast Sulawesi (Agussalim et al. 2023). The data on mining locations scattered in Indonesia also has the potential for diverse damage to water sources, and water flows around the nickel mine, coupled with the ever-increasing demand for nickel. In addition, according to Laila and Simangunsong (2023), Indonesia is the country that produces the most nickel and has the largest nickel reserves in the world. This mineral has a diverse role in various industries, including as the primary raw material

for producing batteries, stainless metals, stainless steel, and other critical raw materials. A report discussing investment opportunities in the nickel sector in Indonesia, published by the Ministry of Energy and Mineral Resources (ESDM), emphasizes that most of the national nickel reserves are located in Central and Eastern Indonesia. Furthermore, the main focus areas are Central Sulawesi, South Sulawesi, Southeast Sulawesi, and North Maluku, with around 90% of Indonesia's total nickel reserves in these regions (Naryono 2023). Based on data provided by the Ministry of Energy and Mineral Resources, in 2020, the global demand for nickel reached 2.4 million tons, and about two-thirds of it was used in the stainless-steel manufacturing process. As such, nickel is a critical element in battery technology, significantly impacting the global steel and stainless steel industries. Future projections indicate that demand will continue to increase, especially for use in electric vehicle (EV) battery production. In addition, the data displayed in **Table 1** also shows that Sulawesi Island occupies the first position with the largest nickel reserves in Indonesia, followed by Maluku and Papua Island.

Table 1. The nickel reserve potential data in various regions in Indonesia for the year 2020

| No. | Islands | Value (ton of ore) |
|-----|----------|--------------------|
| 1 | Sulawesi | 2,600,000,000 |
| 2 | Maluku | 1,400,000,000 |
| 3 | Papua | 60,000,000 |

Source: Fauziyyah and Paksi (2023).

Also, the country's expansion of nickel ore mining has triggered an increase in nickel ore production, and according to data from the Ministry of Energy and Mineral Resources (*Kementerian Energi dan Sumber Daya Mineral* or ESDM), Indonesia's nickel ore production during the 2018–2022 period increased by an average of 20.21% per year. In 2018, nickel ore production was recorded at 38,329,146 tonnes, and then in 2019, it rose remarkably high to 60,948,143 tonnes, representing an increase of around 59.01%. In 2020, Indonesia's nickel ore production declined to 48,040,003 tons due to the COVID-19 outbreak. However, production activities resumed to normal in 2021, increasing nickel ore production to 65,509,854 tons. In 2022, nickel ore production is projected to reach 69,866,259 tons. **Table 2** and **Fig. 1** show the nickel ore production from 2018 to 2022.

Table 2. Nickel ore production of Indonesia in 2018–2022

| Year | Nickel ore production (ton) | Growth (%) |
|--------------------------------|-----------------------------|--------------|
| 2018 | 38,329,146 | 0 |
| 2019 | 60,948,143 | 59.01 |
| 2020 | 48,040,003 | -21.18 |
| 2021 | 65,509,854 | 36.37 |
| 2022* | 69,866,259 | 6.65 |
| Average growth (%/year) | | 20.21 |

Notes: *estimation. Reference: Ministry of Energy and Mineral Resources, processed by Bizteka (Bizteka Industry and Commodity 2023).

3.2. Countries with the Largest Nickel Producers in the World

The current demand trend and data from **Table 1** show that nickel reserves in Indonesia are very scarce. In addition, the current and future increase in nickel demand will continue to increase

in line with national and international ambitions to produce electric vehicles, where nickel is the primary raw material in the manufacture of electric vehicles. Based on data covering the period from 2021 to 2022, the outlook for nickel in the future looks very bright. As a critical commodity and the primary raw material in battery production for the rapidly growing EV industry, nickel has an increasingly strategic role. The United States Geological Survey (USGS) reported that worldwide nickel production would reach 3.3 million metric tons by 2022. This figure shows a significant increase of 20.88% compared to the previous year, with an output of around 2.73 million metric tons.

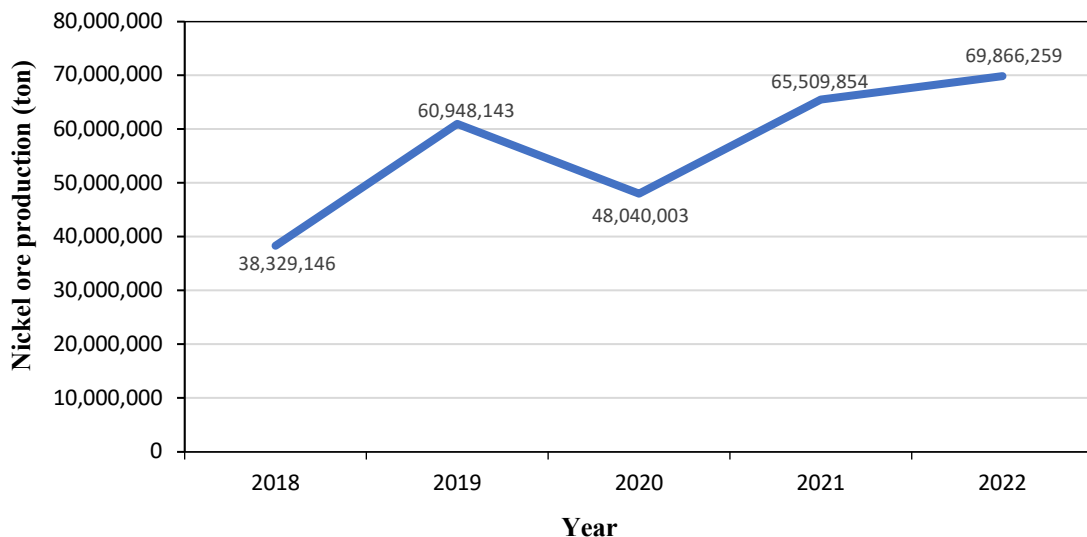


Fig. 1. Nickel ore production in Indonesia between 2018 and 2022 (Bizteka Industry and Commodity 2023).

Interestingly, the report also revealed that Indonesia will be the world’s largest nickel producer in 2022. Indonesia’s total nickel production is estimated to reach 1.6 million metric tons, or about 48.48% of the total global nickel production during that year. Meanwhile, the Philippines ranked second in nickel production, contributing about 330 thousand metric tons, while Russia contributed 220 thousand tons of nickel. These three countries play a central role in the global nickel supply chain, and with the growing demand for electric vehicle batteries, the future of nickel as a highly coveted commodity looks promising (USGS 2023). Countries with the largest nickel producers in the world are shown in **Table 3**.

Table 3. Countries with the largest nickel production

| No. | Country | Value (metric ton) |
|-----|---------------|--------------------|
| 1 | Indonesia | 1,600,000 |
| 2 | Philippines | 330,000 |
| 3 | Russia | 220,000 |
| 4 | New Caledonia | 190,000 |
| 5 | Australia | 160,000 |
| 6 | Canada | 130,000 |
| 7 | China | 110,000 |
| 8 | Brazil | 83,000 |

Source: USGS (2023).

3.3. Broad Distribution of Nickel Mines in Indonesia

As data published by the Ministry of Energy and Mineral Resources (ESDM) shows, the extension of nickel mining areas in Indonesia stretches over 520,877.07 ha. This area includes state forests, but other land uses may also exist. Therefore, the area may encompass state forests and other lands utilized for nickel mining activities. The presence of nickel mines is spread across seven provinces, which include Maluku, North Maluku, Papua, West Papua, South Sulawesi, Central Sulawesi, and Southeast Sulawesi. Among these provinces, Southeast Sulawesi stands out as the region that controls the most extensive nickel mining land in Indonesia, covering an area of 198,624.66 ha. This region includes Konawe District, which has nickel mines covering an area of 21,100 ha. Central Sulawesi also contributes to this sector with a nickel mining area of 115,397.37 ha, while South Sulawesi has nickel mines with an area of 198,624.66 ha. On the other hand, Papua has nickel mines covering an area of 16,470 ha, while West Papua has nickel mines covering an area of 22,636 ha. For additional information, this data was collected using nickel mining business licenses (*Ijin Usaha Pertambangan /IUP*) from all companies registered with the Ministry of Energy and Mineral Resources and only implemented in the state forest area. Furthermore, Data Indonesia.id collected information on the area of nickel mines from various companies in each province (Yoesgiantoro et al. 2022). Fig. 2 shows the distribution of nickel mining areas in Indonesia.

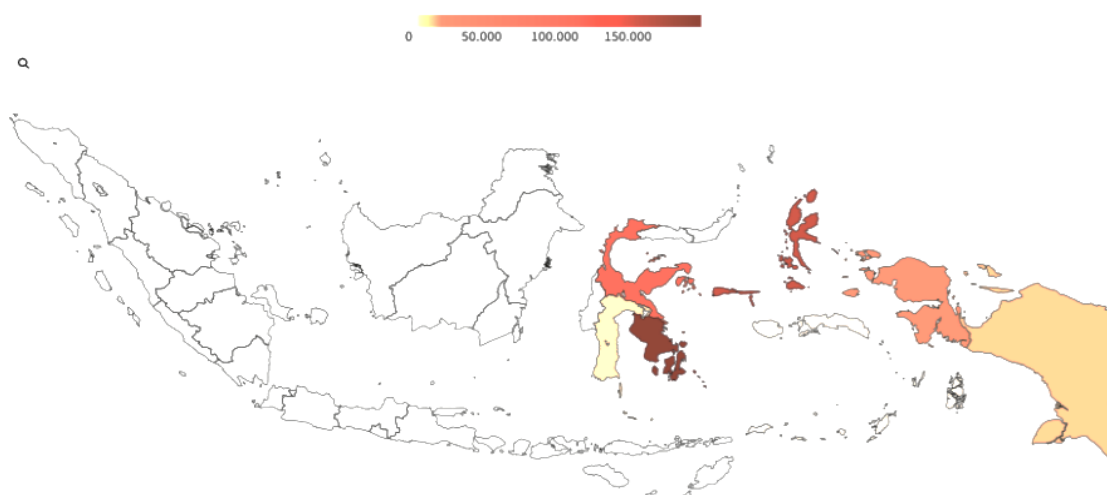


Fig. 2. Distribution of nickel mining land area in Indonesia in 2022 (Yoesgiantoro et al. 2022).

3.4. Indonesia's Nickel Export Destination

According to data collected by Rosada et al. (2023), Indonesia's nickel export volume to China reached an impressive amount of 581.66 million tons from January to November 2022, according to statistics released by the Central Statistics Agency (BPS). This represents a remarkable increase of 1,077.06% compared to the same period of the previous year. Indonesia not only serves as a major supplier of nickel to the global market but also plays a central role in nickel exports. In the first eleven months of the year, Indonesia's nickel exports to China accounted for 74.29% of Indonesia's total exports, reaching a value of USD 5.22 billion. This share was the largest compared to other export destinations. As one of the leading export destinations, Japan reached an export value of USD 1.1 billion (21.09%).

Meanwhile, South Korea received exports of around USD 106.94 million, Malaysia USD 70.67 million, and Norway USD 61.87 million. Singapore received around USD 1.08 million, India USD 579.87 million, and Hong Kong USD 78.87 million, while Brazil and the United States received exports worth USD 14.67 million and USD 5.6 thousand, respectively, for Indonesia's nickel exports to these countries. It should be noted that since January 2020, the Indonesian government has banned nickel ore exports through Minister of ESDM Regulation Number 11 of 2019. This step was taken as part of efforts to encourage industrial downstream and increase national economic value. With the implementation of downstream through the construction of nickel ore smelters in the country, the export value of Indonesia's flagship commodity recorded an increase of more than forty percent during the first eleven months of 2022. The following (Table 4) are Indonesia's nickel export destinations in 2022.

Table 4. Indonesia's nickel export destination countries in 2022

| No. | Country | Value (metric ton) |
|-----|---------------|--------------------|
| 1 | China | 3,877,202,958 |
| 2 | Japan | 1,100,605,094 |
| 3 | South Korea | 106,936,125 |
| 4 | Malaysia | 70,674,388 |
| 5 | Norway | 61,870,769 |
| 6 | Singapore | 1,080,901 |
| 7 | India | 579,867 |
| 8 | Hong Kong | 78,873 |
| 9 | Brazil | 14,677 |
| 10 | United States | 5,608 |

Source: [BPS \(2022\)](#).

The Indonesian government's decision to ban nickel ore exports, which started on January 1, 2020, was effectively implemented. According to data from the Central Statistics Agency (BPS), nickel ore exports plummeted to just 1,405 tons. Subsequently, in 2021 and 2022, nickel ore exports decreased significantly to 65 kg and 492 kg, respectively. In contrast, nickel ore export activities were substantial in 2018 and 2019. 2018, before the export ban was enforced, Indonesia exported 19,764,459 tonnes of nickel ore valued at USD 628,027 thousand. The following year, in 2019, nickel ore exports surged to 32,380,135 tonnes worth USD 1,097,013 thousand. Notable companies involved in nickel ore exports included PT Macika Mada Madana, PT Aneka Tambang (ANTAM) Tbk, PT Rohol Energi Indonesia, PT Sinar Jaya Ultra Utama, PT Wana Tiara Persada, PT Trimegah Bangun Persada, PT Gane Permai Sentosa, PT Tekindo Energi, and PT Gebe Sentra Nickel. However, the export ban sparked controversy as the European Union later challenged it at the World Trade Organization (WTO). The WTO ruled against Indonesia's defense, finding that the policy violated several provisions of the 1994 General Agreement on Tariffs and Trade (GATT). The WTO panel recommended that Indonesia promptly take corrective actions to align with its obligations under the 1994 GATT regarding nickel ore exports ([Bizteka Industry and Commodity 2023](#)). The following (Tables 5 and 6) show Indonesia's nickel exports in the specific country in 2019.

Table 5. Indonesia's nickel ore export in 2018–2022

| Year | Volume (ton) | Value (in thousand USD) |
|------|--------------|-------------------------|
| 2018 | 19,764,459 | 628,027 |
| 2019 | 32,380,135 | 1,097,013 |
| 2020 | 1,405 | 117 |
| 2021 | - | - |
| 2021 | - | - |

Source: Bizteka Industry and Commodity (2023).

Table 6. Indonesia's nickel ore export development in 2019

| Destination country | Volume (kg) | Share (%) | Value (USD) |
|---------------------|-----------------------|---------------|----------------------|
| China | 31,153,856,812 | 96.21 | 1,051,604,330 |
| Ukraine | 1,175,478,000 | 3.63 | 43,687,090 |
| Japan | 50,800,000 | 0.16 | 1,721,104 |
| Total | 32,380,134,812 | 100.00 | 1,097,012,524 |

Source: Bizteka Industry and Commodity (2023).

As mentioned, Indonesia exported substantial amounts of nickel ore in 2019 to various countries. The primary destination was China, receiving 31,153,857 tonnes valued at USD 1,051,604 thousand. Ukraine was the second-largest recipient, importing 1,175,478 tonnes worth USD 43,687 thousand, followed by Japan with 50,800 tonnes valued at USD 1,721 thousand.

3.5. Distribution of Indonesia's Tropical Rainforests and the Amount of Forest Loss in Indonesia

A report by BPS (2022) mentioned the extent of forest cover in Indonesia, which stretches from Sumatra to Papua, of 101.22 million ha. Forest cover accounted for 52.80 percent of Indonesia's land area, which reached 191.69 million ha. The most extensive forest cover was in Papua, with about 32.88 million ha in 2021, which accounted for 77.91 percent of the island's land area. Kalimantan has the next largest forest area, at 28.53 million ha (52.42%), followed by Sumatra with 16.05 million ha (33.38%) and Sulawesi with 11.60 million ha (61.54%). Furthermore, Maluku has a forest area of 6.78 million ha (85.99%), Bali-Nusa Tenggara 2.74 million ha (37.49%), and Java 2.64 million ha (20.4%). Overall, BPS said that the forest area in Indonesia has decreased from 2017 to 2021. In addition, according to the BPS report, Kalimantan Island experienced the most significant decrease in forest area, with a reduction of 654,663 ha and 610,405 ha, respectively. Although forests are a renewable natural resource, their utilization and management must maintain the balance and sustainability of the ecosystem. Forest resources can survive in the long term with environmentally sound management.

According to Aulia et al. (2023), Indonesian forests covered approximately 96,419,384.40 ha (about 51% of the total land area) in 2017 and 86,773,348.49 ha (about 46% of the total land area) in 2021 (Fig. 3). It was observed that Papua Province had the highest forest cover areas in both 2017 (approximately 22.9 million ha) and 2021 (approximately 20.7 million ha) compared to other provinces. Eastern Indonesia provinces generally maintained relatively high forest cover in recent years. Conversely, DKI Jakarta had the most minor forest cover, accounting for only 0.4% of the total area. The Java region exhibited the lowest forest cover percentage, around 20% of the total area.

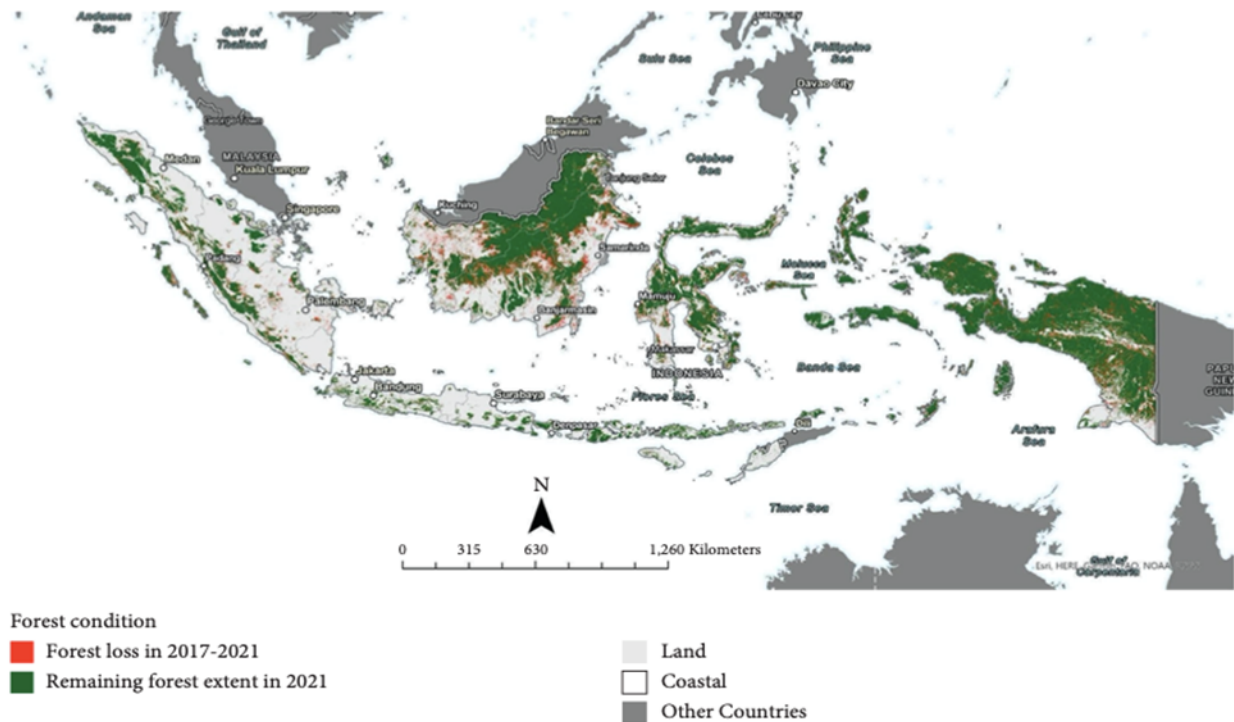


Fig. 3. Indonesia's forest cover conditions from 2017 to 2021 (Aulia et al. 2023).

Also, to correlate with the data above, the rainforest is vital in maintaining ecosystem balance. Because rainforests are rich and complex ecosystems, Rainforests are the world's lungs, absorbing carbon dioxide (CO₂) and producing oxygen through photosynthesis. By storing much carbon, they help reduce the concentration of CO₂ in the atmosphere and control climate change. In addition, they monitor the water system and ensure that people have clean water, reducing the chances of floods and landslides (Ali 2023).

According to data focusing on deforestation due to nickel mining (Pandu 2023), the massive development of electric vehicles, which are seen as environmentally friendly transportation, can threaten the conservation of natural forests. This is because the expansion of nickel mining for electric vehicle batteries has led to deforestation in various regions of Indonesia. Nickel mining permits until 2023 ranked second after gold, covering an area of almost 900,000 ha. However, nickel mining entities are the most numerous, with 319 permits. The latest data from the Coal and Geothermal Mineral Resources Center (PSDMBP) of the Ministry of Energy and Mineral Resources (ESDM) shows that Indonesia is one of the countries with the largest nickel reserves in the world. As of 2023, Indonesia's nickel resources amount to 17.33 billion tons with reserves of 5.03 billion tons.

Based on the mapping of mining coverage from 2000 to 2022 conducted by Auriga, the overall area of mining pits in Indonesia tends to increase. The area of mining pits for nickel has also risen significantly since 2011. Auriga's analysis also indicated that, cumulatively, over the past 20 years, 24,811 ha of forest land has been cleared for nickel mining. The most considerable deforestation due to nickel mining occurred in 2012, covering an area of nearly 4,000 ha. This deforestation has happened in various regions, including North Maluku, West Papua, South Sulawesi, Central Sulawesi, and Southeast Sulawesi. This expansion raises concerns regarding the condition of natural forests within the 560,000 ha nickel mining concessions. The largest natural

forest area within nickel concessions is located in Central Sulawesi, comprising more than 200,000 ha.

3.6. Impact of Increased Nickel Mining on Indonesia's Forest

Mining in Indonesia has existed since the country's inception, both legally and illegally. In terms of regulations, all legal mining activities must comply with forestry laws. Together with government regulations (PP) and Minister of Environment and Forestry regulations (Permen LHK) derived from it, Law (UU) Number 5 of 1967 concerning Job Creation in the Forestry Sector, which has been amended into Law Number 41 of 1999, Legal mining in production forests and protected forest areas is permitted within the regulatory framework. However, mining in protected forests must be done cautiously, and activities that can significantly damage the forest and eliminate its functions are prohibited. According to Article 38 Paragraph 1 of Law Number 41 of 1999, only production forests and protected forest areas can be used for development outside forestry activities. Development activities unrelated to forestry are intended for strategic purposes that cannot be avoided, such as mining, the construction of roads, electricity networks, telephones, and water installations, as well as religious, defense, and security interests. Mining, including nickel mining in forest areas, is regulated by forest area borrow-to-use permits (IPPKH) issued by the Ministry of Environment and Forestry (KLHK) by the terms and conditions stated in the derivative laws (Naryono 2023).

In addition to the legal regulation of nickel mining, mining activities are regulated by Law Number 4 of 2009 concerning Mineral and Coal Mining (Mining Law). To further detail the implementation of this law, it is elaborated in the form of Government Regulation (GR), one of which is GR Number 23 of 2010 concerning the Implementation of Mineral and Coal Mining Business Activities. According to the Ministry of Energy and Mineral Resources of the Republic of Indonesia or *Menteri Energi dan Sumber Daya Mineral* (EDSM Ministry of Indonesia), currently, mining activities, known more commonly, are mining for metal mineral commodities including gold, copper, nickel, bauxite, and coal commodities (Kementerian Energi dan Sumber Daya Mineral Republik Indonesia 2011).

Also, Sari (2021) explained that the management of mineral and coal mining in Indonesia is entering a new phase. The central government will take over the management of mineral and coal mining, which was previously managed by regional authorities, and this regulation will apply nationwide. The Indonesian government issued two laws in 2020 that sparked debate among various circles: Law Number 3 of 2020 concerning Amendments to Law Number 4 of 2009 concerning Mineral and Coal Mining, and Law Number 11 of 2020 concerning Job Creation.

The Omnibus Law regarding mining clusters consolidates regulations from several existing laws, including Law Number 4 of 2009 on Mineral and Coal Mining, Law Number 22 of 2001 on Oil and Gas, Law Number 21 of 2014 on Geothermal, and Law Number 30 2009 on electricity. This law grants the Central Government the authority to oversee minerals and coal, which can be delegated to local governments. It delineates responsibilities for mineral processing and refining between the Ministry of Energy and Mineral Resources and the Ministry of Industry, where mining to processing activities requires a mining business license or *izin usaha pertambangan* (IUP), and refining activities necessitate an industrial business permit or *izin usaha industri* (IUI). Furthermore, it clarifies the definitions of "processing" and "refining" in the Mineral and Coal Law. Additionally, the law provides incentives for downstream coal, such as gasification,

exempting it from Domestic Market Obligation (DMO) obligations, imposing 0% coal royalties, and granting permits for the duration of the mine's lifespan.

Setiawan and Horman (2019) also, since the enactment of Law Number 04 of 2009, particularly concerning mineral and coal mining business licenses, companies in the mining sector have been granted five years to establish smelters following the issuance of the law. This law also stipulates government regulations, namely Government Regulation Number 23 of 2010, which underwent four revisions and was eventually replaced by Government Regulation Number 08 of 2018. To enforce these regulations, ministerial regulations were established, including (1) Ministerial Regulation Number 7 of 2012 concerning the Increasing of Mineral Value Added through Mineral Processing and Purification Activities, (2) Ministerial Regulation Number 11 of 2012 about amendment to Ministerial Regulation Number 7 of 2012 on Adding Value to Minerals through Mineral Processing and Refining Activities, (3) Ministerial Regulation Number 20 of 2013 about the Second Amendment to Ministerial Regulation Number 7 of 2012 on Enhancing Mineral Value through Mineral Processing and Refining Activities, (4) Ministerial Regulation Number 1 of 2014 about Value-Added Minerals Increase through Domestic Mineral Processing and Refining Activities, (5) Ministerial Regulation Number 8 of 2015 about amendment to Ministerial Regulation Number 01 of 2014 on Enhancing Mineral Value through Domestic Mineral Processing and Refining Activities, (6) Ministerial Regulation Number 7 of 2017 about Procedure for Establishing Benchmark Prices for Metal Mineral and Coal Sales, and (7) Ministerial Regulation Number 25 of 2018, with Ministerial Regulation Number 25 of 2018 currently being the applicable regulation. For the downstream processing of nickel mining, the government issued Ministerial Regulation Number 1 of 2014, stating that certain minerals like nickel can be processed and purified domestically with a minimum grade of less than 1.7% nickel. However, domestic smelters can only process and purify nickel grades above 2%. Nickel exports experienced rapid growth from 2009 to 2013 but declined in 2014 due to the enactment of Government Regulation Number 1 of 2014, which imposed restrictions on the export of raw minerals. However, companies in the process of establishing smelters are granted government recommendations to continue exporting.

In addition, the loss of forest on a small island in Maluku due to nickel mining activities is an example of maladaptation. Maladaptation can be described as actions that can increase climate crisis-related risks, harm, increase vulnerability to climate crisis, or reduce people's well-being. Coastal communities, which rely heavily on coastal and marine resources, are losing their homes to the expansion of nickel mining. Maladaptation also threatens thousands of villages in eastern Indonesia due to the climate crisis. The most vulnerable areas are located in coastal Maluku, with 1,064 villages under threat, followed by East Nusa Tenggara or Nusa Tenggara Timur (NTT), villages, and Central Sulawesi, 1,011 Villages in other regions, such as West Nusa Tenggara or Nusa Tenggara Barat (NTB) with 297 villages, North Sulawesi with 783 villages, Southeast Sulawesi with 954 villages, Gorontalo with 201 villages, South Sulawesi with 527 villages, West Sulawesi with 152 villages, North Maluku with 934 villages, West Papua with 570 villages, and Papua with 662 villages, also face similar threats due to the climate crisis.

Furthermore, Kadir and Suaib (2020) also highlighted the impact of the nickel mining industry in four provinces, namely South Sulawesi, Central Sulawesi, Southeast Sulawesi, and North Sulawesi. The report exposes the consequences of the government's ambition to make Indonesia the world's largest battery producer, which has driven the expansion of nickel mining for batteries in Sulawesi. As a result, the environment is being damaged, human rights are being

violated, and territories managed by indigenous and local communities, including women, are being seized, particularly in nickel mining zones. In Central Sulawesi, nickel processing from the Indonesia Morowali Industrial Park (IMIP) has polluted marine ecosystems due to tailings disposal, damaged coral reefs, and disturbed coastal fishermen. The sedimentation factor brought by rain affects mangrove ecosystems that have long been used as crab breeding grounds. Indonesia now has 52% of the world's nickel reserves, driving increased nickel production for electric car batteries, especially in South Sulawesi, with seven nickel mining companies' licenses. The impacts include severe pollution and sedimentation of Lake Mahalona, rivers, coasts, seas, and Mori Island in East Luwu. A 74,253.4 ha forest area in South Sulawesi, once a habitat for flora and fauna and a source of livelihood for indigenous and local communities, has been turned into a nickel mining zone. Extensive deforestation reached 4,752.87 ha and grows as nickel mining activities intensify in the Verbeck mountains.

Also, the result of research by [Ambarwati et al. \(2020\)](#) that informants responded to the presence of nickel mining, noting significant changes in both the physical environment, encompassing the natural surroundings, and the positive social setting. Nickel mining has also allowed residents to establish kiosks and food stalls. However, there are negative impacts on various fronts, including the biotic environment involving plant damage and health issues, alongside effects on the physical environment such as polluted watersheds, disrupted rice fields, and reduced plantation areas. Additionally, the social change underscores the intricate relationship between mining activities and their broader repercussions on the community.

The extensive issuance of mining permits, particularly for nickel mining on Sulawesi Island, has resulted in significant ecological impacts, ranging from deforestation to pollution along the coasts, seas, and small islands. The Indonesian government has facilitated the acquisition of vast land areas by the nickel mining industry, which grants borrow-to-use permits for forest areas, including those in production and protected forest zones traditionally maintained by indigenous and local communities. According to a spatial study conducted by WALHI Sulawesi Region, there have been 74 forest area borrow-to-use permits or *izin pinjam pakai kawasan hutan* (IPPKH) permits issued by the Ministry of Environment and Forestry on Sulawesi Island, covering an extensive area of 48,621.98 ha ([Naryono 2023](#)). Furthermore, in East Luwu Regency, South Sulawesi, the Indonesian Ministry of Environment and Forestry has issued three borrow-to-use forest area permits (IPPKH) to three nickel mining companies, encompassing an area of 9,711.77 ha ([Naryono 2023](#)).

The collaborative efforts between Indonesia and China in the nickel industry also yielded three beneficial impacts that significantly bolstered Indonesia's economic development. However, specific issues, particularly environmental considerations, require urgent attention. The expansion of nickel mining activities in Indonesia has resulted in environmental degradation. As of 2022, Indonesia's total nickel mining area covered 1,037,435.22 ha, with 765,237.07 ha located within forested regions ([Wicaksono 2023](#)). Indonesia's nickel mining has been overgrown, leading to many trees being cut down and environmental pollution. For example, open-pit mining for nickel ore has worsened water quality in places like East Halmahera. This is mainly caused by the release of harmful nickel metal waste into rivers. The contamination harms fish populations, which poses hazards to their safety and fitness for consumption. Moreover, water bodies that are contaminated with harmful compounds can force fish habitats to move to places that are not affected, as stated by [Sariato et al. \(2016\)](#).

Increased nickel mining operations negatively affect soil fertility as well. A study on PT Bumi Konawe Abadi's post-mining land in Southeast Sulawesi was carried out by [Mustafa et al. \(2022\)](#). The study discovered that low pH, organic carbon content, and phosphorus levels indicate low fertility in the soil when mixed with mining products. Additionally, the soil lacks sufficient total nitrogen. In addition, PT Waja Inti Lestari, a separate firm, conducted mining exploration in the Lapapao block of Babarina village, leading to water pollution and the disturbance of the coastal ecosystem. This occurred due to the release of mining substances into the ocean, negatively affecting the second-largest seaweed-producing region in Southeast Sulawesi. The disturbance of the marine ecosystem in this area threatens potential resources ([Agussalim et al. 2023](#)). Furthermore, the coral reef habitat in Morowali Waterways is threatened by nickel waste, which harms the reefs. Lastly, the disposal of tailings waste, which includes rocks, chemicals, and elements, can become toxic upon exposure to water or air, quickly leading to damage to habitats and reefs ([Syarifuddin 2022](#)).

[Barus et al. \(2022\)](#) found that testing the land stability index in this study at the nickel mining site in North Konawe was going well. However, adding other parameters, such as soil depth, can still be improved and modified. The measure of land stability in this study can also be used as a new parameter in the assessment because it can quantify changes in the index over time. The analysis using the developed method shows that at the North Konawe nickel mining location, there are more unstable areas after additional activity. If no reclamation action is taken, there is a potential for further damage in the future.

3.7. Impact Nickle Mining in Forest and Environment in Indonesia

The preceding sub-topic is expected to examine the impact of nickel exploitation on the ecological equilibrium and long-term viability of forests in Indonesia and its connection to the broader concept of environmental carrying capacity. Within this context, “carrying capacity” pertains to the environment’s capability to sustain and facilitate the existence and endeavors of humans and other animals. This encompasses aspects such as forest management and the preservation of biodiversity. It is imperative to consider the ecological ramifications of nickel mining activities, including deforestation, biodiversity loss, land degradation, and harm to wildlife habitats. Mining activities have a detrimental impact on the air and water quality in surrounding areas. Air pollution arises from the release of dust and harmful gases, while water pollution results from mining waste disposal. These environmental issues have significant repercussions for forest ecosystems and human well-being. Recovery and rehabilitation endeavors are of utmost importance, encompassing the restoration of degraded land, reestablishing indigenous flora, and revitalizing impaired ecosystems. Ultimately, the extraction of nickel can harm the environment by releasing greenhouse gases and causing soil degradation. These effects can have lasting repercussions on the climate and weather patterns at both global and regional scales.

First, the amount of trees in Indonesia has declined since nickel mines were established there. The soil quality is impacted, and pollutants produced during and after nickel mining contaminate it. Investigating pollution in Kolaka, Southeast Sulawesi, by [Hartono et al. \(2017\)](#) also discovered that the Oko River has red water in Lamedai Village, which is in Tanggetada Subdistrict, Kolaka Regency, Southeast Sulawesi. For five kilometers, the water flows, and it is typically used for irrigation. The red color is likely caused by waste from nickel mining in the area that PT Vale Indonesia is in charge of. The environmental organization WALHI South East Sulawesi has

revealed its findings on environmental pollution, especially in rice fields, rivers, and coastal ecosystems in the nickel ore mining and refining area in Pomalaa District, which the Oko Oko River passes. The mine could result in the loss of the forest's function as a water sink and could even cause flooding and damage agriculture by dumping waste into the river. The river often overflows during the rainy season, causing flooding in Lamedai and inundating about 750 ha of land, including 450 ha of productive rice fields, resulting in crop failure. Sample testing showed that the Oko Oko River contained hexavalent chemicals or total chromium that allegedly exceeded the specified quality standard (0.021–0.124 mg/L). Similar pollution also occurred in several other rivers that are also used as a source of drinking water for the community and as the primary source of irrigation for Lamedai Village, adjacent to Pomalaa Sub-district.

It is also added by [Rosada et al. \(2023\)](#) that Indonesia has nickel mines covering 520,877.07 ha spread across seven provinces, including Maluku, North Maluku, Papua, West Papua, South Sulawesi, Central Sulawesi, and Southeast Sulawesi. The nickel mining area in North Maluku is the largest, reaching 156,197.04 ha. Even so, the question of whether the size of the mining area and the revenue generated each year can guarantee the absence of nickel mining exploitation in North Maluku remains a question mark. Nickel ore exploitation in Indonesia has been a source of conflict, criminalization of communities, and environmental damage. The impact has been widespread: farmers have lost production space due to land conversion, both legal and illegal.

In some cases, farmers who refuse to sell their land face intimidation and are forced to relinquish their land, such as in Central Halmahera District, North Maluku. The impacts of nickel exploitation in the region include environmental damage, notably seawater pollution. As a result, fishermen's catches in some villages are reduced, forcing them to fish in more distant waters, increasing production costs. Tailings or end-of-mine waste that pollute the sea, especially in the Tanjung Uli and Gemaf Bay fisheries areas in Central Halmahera, have destroyed water quality and marine ecosystems in Weda Bay.

In addition, pollution caused by nickel mining affects the soil's biological and chemical conditions. The results of research conducted by [Sittadewi \(2016\)](#) show that mining causes a decrease in physical, chemical, and biological land conditions, indicating the occurrence of post-mining land degradation. Rehabilitation activities must be done on post-mining land to prevent more severe degradation. Mining disturbs the soil profile from its normal state due to dredging, stockpiling, and compaction by heavy equipment. This affects the water system and aeration, affecting plant root growth and development. The texture and structure of the earth are also damaged, which makes it less able to hold water and nutrients. Because mining changes the shape of the earth's layers and the conditions that plants need to grow. The chemistry of the land is also altered by mining, which lowers the pH, makes the soil less fertile, and makes nutrients less available in the soil. At the same time, the solution of sulfide materials raises the levels of heavy metals. What goes wrong is that the earth is either too acidic or too basic, and there are not enough nutrients like nitrogen (N) and phosphorus (P). Low soil pH can have a detrimental effect on high soil temperatures by reducing the availability of essential nutrients such as phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca). Plants may encounter incredible difficulty in assimilating minerals such as phosphorus (P), calcium (Ca), magnesium (Mg), and potassium (K) in soil with high acidity. Consequently, there could be a decrease in the availability of P and an increase in the presence of Al, Mn, Fe, Cu, Zn, and Ni.

[Angelita et al. \(2020\)](#) and [Mustafa et al. \(2022\)](#) also show that the mined nickel laterite land has low nutrients. They discuss low pH, low C-organic levels, low total nitrogen, low phosphorus

availability, low ion exchange capacity, and low base saturation. Based on these results, it looks like the land is not very fertile. It is backed up by the soil structure study, which shows that the dusty clay fraction is more common than the silty soil fraction. Because clay makes up most of the soil, it is not porous or permeable. It was also found that the soil from the old nickel mine had less C-organic content and less P_2O_5 . This made it much harder for the soil to stay fertile and support production through the acts of soil microbes. The dusty clay fraction shows the slow formation of granulation in the soil, especially in forming stable soil aggregates. The low P_2O_5 content inhibits plant root growth, so plants will suffer, affecting overall soil fertility.

In addition to soil pollution, mining activities also contribute significantly to water pollution cases. The results of the report reported by [Bramer et al. \(2018\)](#) and the observations regarding changes in biotic components in the study area include changes in topography, namely from an initially hilly shape to flat and hollow. Excavation stripping overburdens cause this change. In addition to topographic changes, a decrease in surface water quality is also one type of damage to abiotic components analyzed in the study area. Water quality in the Bahodopi watershed can provide an overview of potential damage, which can be seen from the analysis of the physical and chemical parameters of the water. Physical parameters include temperature, turbidity, color, and TSS, while chemical parameters involve pH. Some of these water quality parameters show signs of degradation, such as changes in temperature, turbidity, color, TSS, and pH.

The founding research result from [Prematuri et al. \(2020\)](#) is that open-cast nickel mining has impacted soil fertility. The concentrations of Total N (Total Nitrogen), TC (Soil Organic Carbon), available P, and exchangeable Ca and Na in post-nickel mine soil were 98%, 93%, 11%, 85%, and 74% lower than those in natural forest soil, respectively. The diminished fertility of post-mining soil reduced the growth of fast-growing tropical tree species, namely *F. moluccana* and *A. saman*. However, the results indicate that *A. saman* demonstrated better adaptation to growth on post-nickel mining land. There was no significant difference in biomass between *A. saman* in post-nickel mining soil and natural forest soil. In future studies, a comparison between *F. moluccana* and *A. saman* could be investigated to have a more comprehensive impact on soil improvement on post-nickel mining land.

In addition, the comprehensive review emphasizes the toxicity and carcinogenicity of nickel in both human and plant environments. Being omnipresent in the environment, Nickel unavoidably exposes individuals to potentially harmful doses. While it is biologically essential for plants, debates persist regarding its significance to higher animals, particularly humans. The exponential increase in nickel consumption and the prevalence of nickel-containing products in contemporary times have rendered nickel and its derivatives inevitable sources of environmental pollution across all production, disposal, and recycling stages. Various geogenic processes continually distribute nickel between land, water, and air. In the atmosphere, nickel occurs at relatively low concentrations, mainly in particulate form, with diameters varying based on the source. Workers in nickel-producing or nickel-related industries, exposed to workplace air, may face heightened risks of acute nickel toxicity compared to the general population. Scientific reports derived from studies on occupationally exposed groups reveal that inhalation of nickel and its derivatives introduces various diseases, such as sinusitis, rhinitis, anosmia, and others. High exposure and ingestion of nickel derivatives can lead to symptoms such as breathing difficulties, headaches, coughing, nausea, vomiting, and diarrhea. These effects can be fatal in severe cases, impacting animals and humans ([Begum et al. 2022](#)).

This is not the first case of environmental damage caused by nickel mining. At the very least, there have been several threats and impacts of environmental damage caused by nickel mining over the years. The results of monitoring and research conducted by WALHI show significant ecological implications in the nickel industry supply chain. In addition, there are threats of criminalization against indigenous peoples, including environmental activists who are fighting to protect their land from the adverse impacts of nickel mining. Previous research conducted by Khairun University about Obi Island showed findings of heavy metals in the biota in Obi Island waters. It was found that 12 types of fish contained nickel-containing heavy metals. In addition, it is estimated that the area of nickel mining concessions in Indonesia has reached 999,587.66 ha, and about 653,759.16 ha of these concessions are suspected to be within forest areas. By 2022, the nickel mining area will further expand by granting additional concessions, reaching 1,037,435.22 ha, of which approximately 765,237.07 ha are within forest areas. The expansion of nickel mining, especially those located within forests, will expand deforestation in Indonesia and, worse, increase greenhouse gas emissions into the atmosphere, not reduce them (Agrawal et al. 2018).

The case of North Maluku, specifically Halmahera and the surrounding minor islands, compared to the larger islands, is that they have narrower and shorter characteristics. Anggi Putra, the Campaign and Policy Intervention Manager of Forest Watch Indonesia (FWI), said that the approach to using this area must be done with caution and cannot be generalized. However, nickel mining licenses covering 201,000 ha have been granted to 43 companies, putting enormous pressure on Halmahera and the surrounding small islands. Furthermore, approximately 180,587 ha of this area are in protected and production forest areas. The impact has led to worsening conditions in Halmahera and surrounding minor islands, with forest destruction in nickel mining concessions reaching 7,565 ha from 2017 to 2021. It is estimated that this damage will continue to increase to 157,000 ha in the future due to the nickel mine. The negative environmental impacts of mining and deforestation have also extended tens of kilometers to Sagea, which is about 10 km from IWIP (Palpacuer and Roussey 2023).

The rainforest ecosystem in the Lumereo Mountains, the location of the Tanamalia Block to be expanded by Vale, plays a vital role in the lives of the community and the surrounding environment. In addition, this forest is also home to a variety of Indonesian flora and fauna. All of these assets are under serious threat of damage or even loss due to the expansion of the mine, which companies from Brazil and Japan mostly own. According to provisional research conducted by the WALHI South Sulawesi, of the total area of the Tanamalia Block in the Lumereo Mountains, approximately 3,654 ha have been identified as pepper farms managed by farmers, mainly in several villages in the Towuti sub-district. These gardens have been planted and maintained for the past two decades (Rosadi et al. 2021).

Sedimentation from nickel ore at Mandiodo cannot be controlled, and the processing, loading, and unloading of nickel ore at the special docks or mining jetties cause marine pollution. As a result, nickel ore waste turns the color of the sea reddish, even reaching the waters of the open ocean. The mining management process is not by applicable regulations. The mine is located very close to the sea, facilitating marine pollution. During 2015–2016, water quality in the Mandiodo Block showed that heavy metals such as nickel and mercury and oil content in diesel and gasoline polluted the environment. These heavy metals are potentially harmful and toxic in large quantities or specific forms. The negative impact of these heavy metals is felt in the Mandiodo marine ecosystem, especially on two types of fish food sources, namely benthos and plankton, which are vulnerable to heavy metal contamination. As a result of benthic and plankton contamination, fish

tend to leave their original habitat, causing a decline in fish populations and migration to other places. Some fish even stay and consume food contaminated with heavy metals. Environmental pollution in the region is mainly related to submarine sedimentation from nickel ore, resulting in unstable fish concentrations and an unfavorable environment. These heavy metals threaten the vital organs of fish, such as their gills, liver, and reproductive capabilities. In particular, threats can threaten the viability of fish populations. In addition, the distribution of nickel potential in North Konawe covers an area of 82,626.03 ha, with nickel reserves of approximately 46,007,440.652 tons. This significant amount raises concerns about environmental impacts if mining management is not by applicable regulations (Mishra et al. 2023).

Konawe Islands district in Southeast Sulawesi experienced significant changes when nickel mining company PT Gema Kreasi Perdana (GKP) began operations. As a result, river and seawater were discolored, and the dust generated disturbed settlements and gardens. Biodiversity, such as birds and bees, which used to be an everyday part of life, is now hard to find. Wawonii Island, located in Konawe Islands Regency, Southeast Sulawesi, has an area of about 706 km². According to Indonesian law, small islands should be off-limits to mining activities. Researchers from the National Research and Innovation Agency (BRIN) are concerned that nickel mining will damage Wawonii Island's ecosystem, which has rich biodiversity. BRIN noted that there are around 1,000 species of plants on Wawonii Island. Wawonii Islanders depend on around 200 plant species for their daily lives as food sources, building materials, medicines, cosmetics, handicrafts, and energy. Around 80% of these plants grow naturally in forests, shrubs, and agricultural land (Upe et al. 2020).

Furthermore, nickel mining activities on Wawonii Island, located in Konawe Islands Regency, Southeast Sulawesi, are causing the little island's environment to degenerate. More than 1,000 plant species and scores of animals, including green turtles and rare birds, are threatened in their natural habitats. A taxonomist from BRIN's middle for Biosystematics and Evolution Research, Rugayah, stated that coconut plantations dominate Wawonii Island, which extends from the shore to the island's middle. Apart from coconut, the people of Wawonii rely on cacao, cloves, and cashews. The island is also home to flora, including ferns, monocots (gymnosperms), and dicots (angiosperms). This plant diversity plays a vital role in ensuring food availability for the local population of Wawonii Island so that they do not need to rely entirely on food supplies outside the island (Adidharma et al. 2023).

Supriatna et al. (2020) also reported a real threat in the Bahodopi District, Morowali Regency, and Central Sulawesi. There are endemic animals whose habitat is starting to be threatened due to the expansion of nickel mining in protected forest areas. The report explained that Boti, a primate found only in Central Sulawesi, is currently listed in CITES with a status in Appendix II. This primate is considered vulnerable because it has experienced a population decline of more than 30% in the last 40 years. Boti can be found exclusively in rainforests at certain altitudes, ranging from sea level to around 2,000 meters above sea level (masl). The population density of Boti ranges from one to five individuals per square kilometer. About 20 Boti live in a group in a narrow forest that covers about 12 ha and still has a status as an area for other purposes (APL). Unfortunately, in the last four years, the protected forest area in Bahodopi has been shrinking, from 10,820.43 ha in 2019 to only 10,378.73 ha in 2022. Mining, particularly nickel mining, is a natural and ongoing threat to Boti primates and their habitat. In Central Sulawesi, there are large nickel mining operations, such as IMIP, which was established with investment from China and has become the center of the nickel industry, covering the entire production chain,

from mining to smelting, as well as the generation of end products that are exported to China. Esti, a supervisor at the Tasikoki Animal Rescue Center (PPST) in North Sulawesi, believes that nickel mining or the nickel processing industry severely disrupts Boti's habitat in the remaining natural forests.

Also, the environmental carrying capacity or carrying capacity reflects the ecosystem's ability to support life and organism activities over a certain period without experiencing irreversible degradation. Climate change, which results from increased concentrations of greenhouse gases in the atmosphere, significantly impacts the environment. In this context, the environmental carrying capacity has the potential to influence climate change through several mechanisms. First, ecosystems such as forests act as natural carbon sinks, reducing atmospheric carbon dioxide concentrations. Disruptions to the environmental carrying capacity, such as deforestation, can reduce the forest's ability to sequester carbon, increasing CO₂ emissions and accelerating climate change.

Additionally, forest vegetation also influences patterns of water evaporation and plant transpiration, which can affect rainfall patterns and local and regional climate conditions. Healthy environments tend to create stable microclimate conditions, while instability in carrying capacity can result in unstable microclimatic conditions, exacerbating the impacts of local climate change. Therefore, maintaining and restoring the environmental carrying capacity, primarily through forest conservation and sustainable natural resource management, can play a role in reducing the impacts of climate change and increasing ecosystem resilience to ongoing climate change.

As the observed result from [Sedayu \(2024\)](#) supports the statement above, The development and operation of the PT Indonesia Weda Bay Industrial Park (IWIP) and surrounding nickel mining areas in Halmahera, North Maluku, have devastated the livelihoods of indigenous communities and other members of society, as well as caused environmental damage, approximately 5,331 ha of tropical forests have been cleared within the nickel mining concessions in Halmahera, resulting in the loss of about 2.04 metric tons of greenhouse gases previously stored there in the form of carbon. Another environmental impact is air pollution due to PT IWIP using steam power plants outside the grid or captive power plants. These plants are suspected of using low-quality coal, resulting in worse pollution. In addition, [Munikhah and Ardi \(2021\)](#) also stated that carbon emissions from mining and nickel processing could damage the environment if not handled properly.

Nickel mining has the potential to impact climate change by affecting the environmental carrying capacity and contributing to deforestation and greenhouse gas emissions. Indonesia is essential for preserving global ecosystem equilibrium and mitigating climate change, as it is home to some of the world's most remarkable tropical forests. Nevertheless, the development of nickel mines can disrupt the environmental carrying capacity by destroying forest ecosystems, reducing carbon sequestration capacity, and expediting land degradation. The ecological damage caused by nickel mining can lead to further climate change, including increased land surface temperatures and reduced rainfall, ultimately significantly impacting the environment and the Indonesian population. Therefore, protecting the environmental carrying capacity from the adverse effects of nickel mining is imperative to mitigate climate change in Indonesia.

Accordingly, in addition to the carbon emissions generated by the IWIP coal plants, the adjacent nickel mining operations also significantly contribute to deforestation, which is a factor in the climate emergency and the loss of biodiversity. Through geospatial analysis, Climate Rights International (CRI) and the University of California, Berkeley, AI Climate Initiative found that a

minimum of 5,331 ha of tropical forests have been cleared within the nickel mining concessions in Halmahera, resulting in the release of approximately 2.04 metric tons of greenhouse gases (CO₂e) previously stored as carbon in those forests (Shennum and Renaldi 2022).

Water pollution indicates a deviation from expected water properties due to introducing components that disrupt normal functions rather than a matter of purity. According to environmental researcher Arfah Durahman from AEER, a decline in water quality is evident from detecting hexavalent chromium metal ions at various surface water and coastal points. Downstream of the Wosea River, which passes through nickel industry areas, hexavalent chromium is found at a concentration of 0.017 mg/L, exceeding the Initiative for Responsible Mining Assurance (IRMA) standard of 0.011 mg/L. This toxic ion is also detected in several locations near industrial areas in the sea. River water pollution in the mining vicinity is attributed to mining activities causing alterations in surrounding villages and regions, impacting the quality of the river and seawater. Field and image analysis by the Save Sagea Coalition reveals that road construction toward mining areas destabilizes soil layers, leading to significant sediment runoff during rainfall that introduces disease agents into nearby river channels, posing risks to human consumption and impacting various species within the river ecosystem (Bidul and Zaid 2024; Puspitasari 2012).

Mining activities can lead to soil pollution, destroying vegetation and soil profiles in the surrounding environment and disrupting terrestrial animal habitats and ecosystems. The change in land use to mining areas and the creation of large mining pits that cannot be refilled can have significant negative impacts, potentially forming artificial lakes containing highly acidic and hazardous substances. Mining activities also produce methane gas, a potent greenhouse gas, which, if not properly managed, can contribute to global warming by releasing it into the atmosphere. Additionally, mining causes erosion, increases erosion rates at river estuaries, and damages local roads and land in mining areas (Wahanisa and Adiyatma 2021).

Environmental degradation remains a widely discussed topic across various segments of society, and appropriate solutions and mitigation strategies must be found while reviewing government policies related to environmental aspects. Environmental degradation occurs due to the actualization of natural environmental potentials caused by influencing factors. For instance, earthquakes result from the movement of tectonic plates, and stormy rains occur due to high sea surface temperatures. Elevated sea surface temperatures contrast sharply with temperatures below the ocean's surface or within the water. Landslides, including those caused by soil structure erosion, are another consequence of environmental degradation (Kutanegara 2014).

According to Myllyvirta et al. (2024), the projected health risks from exposure to elevated concentration levels indicate a concerning trend in air pollution dispersion modeling conducted by CREA. The number of deaths attributed to processing facilities and captive CFPPs (Coal-Fired Power Plants) meeting energy demand is expected to increase significantly by 2030, paralleling the anticipated rise in production capacity. Deaths could escalate from 215 in 2020 to 3,833 in 2025, an almost 18-fold increase over five years, with projections reaching 4,982 in 2030 and 8,325 in 2060 without intervention. Below are the air pollution-related deaths attributed to smelters and captive powers, grouped by emitting provinces: Central Sulawesi, Southeast Sulawesi, and North Maluku (Fig. 4).

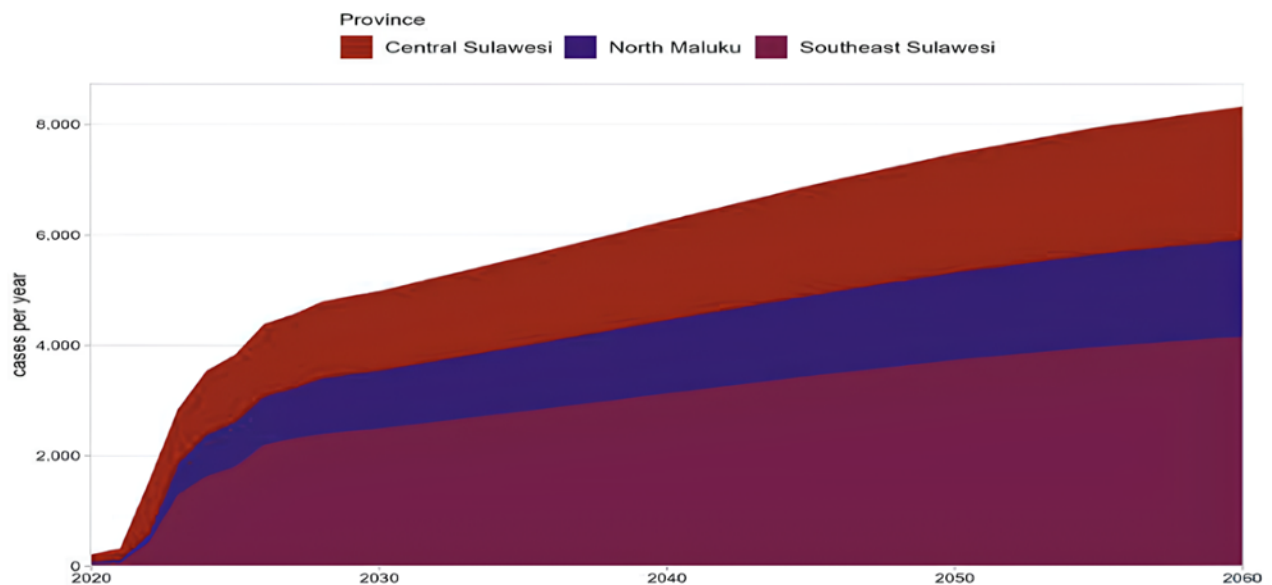


Fig. 4. Air pollution-related deaths attributed to smelters and captive powers, grouped by emitting province, namely Central Sulawesi, Southeast Sulawesi, and North Maluku (Myllyvirta et al. 2024).

Air pollution-related costs, calculated from associated health impacts, particularly impact adults with respiratory diseases like asthma and COPD, along with heightened risks of stroke and diabetes. Newborns and children are also affected, facing issues such as low birth weight, premature births, respiratory infections, asthma, and reduced lung function. At the same time, economic losses mount due to work absences from sick leave or caregiving, translating into direct GDP impacts (Myllyvirta et al. 2024).

The case of research brought by Ghorani-Azam et al. (2016) is that the village of Bondoala, located in Bondoala District, Morosi Regency, is impacted by mining activities conducted by PT. OSS and PT. VDNI, mainly due to air pollution resulting from the burning process of nickel ore processing. This process releases hazardous chemical elements that affect air quality. Air quality degradation occurs during the burning of nickel ore, releasing toxic compounds, including carbon monoxide, carbon dioxide, methane, benzene, toluene, xylene, sulfur, arsenic, mercury, and lead. Prolonged exposure to these pollutants can adversely affect public health. Lead exposure, for example, can pose risks of anemia and neurological and brain function disorders.

The use of nickel in industries can have adverse effects if dosage and handling are not carefully considered. According to the Agency for Toxic Substances and Disease Registry (ATSDR), nickel can be absorbed through inhalation, ingestion, and dermal contact. Health disorders resulting from nickel exposure include systemic disorders, immunological disorders, neurological disorders, reproductive disorders, developmental disorders, carcinogenic effects, and even death. These disorders can arise from acute (14 days or less), intermediate (15–364 days), or chronic (365 days or more) exposure. Inhalation exposure to nickel can lead to fatalities, with systemic effects causing respiratory disorders, cardiovascular disorders, gastrointestinal disorders, hematological disorders, kidney disorders, impacts on immunology and lymphatic glands, reproductive disorders, and cancer. Oral exposure to nickel can also result in fatalities, with systemic effects causing cardiovascular disorders, gastrointestinal disorders, hematological disorders, muscular pain, liver disorders, kidney disorders, skin health disorders such as dermatitis,

and neurological disorders. Dermal exposure through skin contact can cause allergic contact dermatitis (Miaratiska and Azizah 2015).

Air pollution resulting from mining activities, which have operated 30 Smelters using Rotary Kiln Electric Furnace (RKEF) technology with a total production of 300,000 tons of nickel per year, is believed by the author to deteriorate air quality significantly. For example, dust affects the surrounding communities' health and leads to respiratory infections. Logically, polluted air affects lung function, with pollutants triggering respiratory diseases such as flu, bronchitis, and pneumonia, as well as chronic conditions like asthma and chronic bronchitis. According to the World Health Organization (WHO), respiratory infections are contagious diseases affecting the upper or lower respiratory tract, ranging from asymptomatic to life-threatening, depending on the pathogen, environment, and host. Another source indicates that respiratory infections are among the health disorders caused by mining dust exposure and are relatively prevalent. Open mining activities release N₂O, CO, SO₂ gases, and coal dust particles into the air, which can contribute to respiratory infections. If inhaled by local communities, these particles can disrupt their respiratory systems. In China, cases of black lung disease correlate with the presence of pyrite in coal, affecting approximately 440,000 coal miners with black lung disease (Miaratiska and Azizah 2015).

4. Conclusions

According to the research findings, it can be inferred that the rising nickel production in Indonesia substantially influences forests and the environment. The increased nickel production is causing deforestation, changes in plant composition, and degradation of habitats, all contributing to the decline of forest ecosystems. In addition, the broader environmental consequences, such as the deterioration of air and soil quality caused by nickel production activities, worsen the issue even more. These ecological changes impact the ecosystem and have direct consequences for human health. In Addition, nickel production can result in air pollution that can cause respiratory and other health issues in nearby communities. Soil deterioration can result from mining activities, adversely affecting food safety and agricultural output. In light of these discoveries, it is imperative to reassess the current methods and regulations governing the extraction of nickel to safeguard the integrity of forests, the environment, and human well-being. To mitigate the adverse effects of the increasing nickel output and protect the general welfare of living organisms, including humans, who rely on these ecosystems, it is imperative to implement sustainable management techniques and enforce more stringent laws.

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