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Rehabilitation and Conservation of Aquatic Resources on Former Nickel Mining Lands

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Abstract

Nickel mining plays a strategic role in supporting the national economy, particularly for the metal and renewable energy industries. However, mining activities also generate significant environmental impacts, especially land degradation and the decline of aquatic resource quality due to increased sedimentation, alterations in the physical and chemical properties of soil and water, and the introduction of heavy metals into aquatic systems. These conditions directly disrupt aquatic ecosystems and reduce biodiversity. This article aims to review rehabilitation and conservation strategies for aquatic resources in post-nickel mining areas through a literature review approach. The study employed a descriptive qualitative method by analyzing relevant national and international scientific publications focusing on land reclamation, revegetation, water quality management, and post-mining aquatic ecosystem restoration. The review results indicate that effective rehabilitation of aquatic resources requires an integrated approach, including land reclamation to stabilize soil conditions, revegetation using adaptive plant species to improve soil fertility and control erosion, and water quality management through sedimentation ponds, constructed wetlands, and riparian vegetation. The implementation of these strategies has been shown to reduce sediment and heavy metal loads, improve water quality, and support the recovery of aquatic ecological functions. Furthermore, community involvement and sustainable management practices are essential to ensure long-term rehabilitation success. With well-planned and sustainable rehabilitation efforts, post-nickel mining areas have the potential to be restored into healthy and productive aquatic ecosystems that provide ecological as well as socio-economic benefits for surrounding communities.

Keywords: *Nickel mining; land rehabilitation; revegetation; water quality management; post-mining aquatic resources*

Abstrak

Kegiatan pertambangan nikel memiliki peran strategis dalam mendukung perekonomian nasional, khususnya bagi industri logam dan energi baru. Namun, aktivitas ini juga menimbulkan dampak lingkungan yang signifikan, terutama terhadap degradasi lahan dan penurunan kualitas sumber daya akuatik akibat peningkatan sedimentasi, perubahan sifat fisika-kimia tanah dan air, serta masuknya logam berat ke badan perairan. Penurunan kualitas perairan tersebut berimplikasi langsung pada terganggunya ekosistem akuatik dan berkurangnya keanekaragaman hayati. Artikel ini bertujuan mengkaji strategi rehabilitasi dan pelestarian sumber daya akuatik pada lahan bekas tambang nikel melalui pendekatan tinjauan pustaka. Metode yang digunakan adalah analisis deskriptif-kualitatif terhadap berbagai jurnal ilmiah nasional dan internasional yang membahas reklamasi lahan, revegetasi, pengelolaan kualitas air, serta restorasi ekosistem perairan pascatambang. Hasil kajian menunjukkan bahwa rehabilitasi sumber daya akuatik memerlukan pendekatan terpadu yang meliputi reklamasi lahan untuk menstabilkan kondisi fisik tanah, revegetasi dengan spesies adaptif guna memperbaiki kesuburan dan mengendalikan erosi, serta pengelolaan kualitas air melalui pembangunan kolam pengendapan, lahan basah buatan, dan vegetasi riparian. Penerapan strategi tersebut terbukti mampu menurunkan beban sedimen dan logam berat, memperbaiki kualitas air, serta mendukung pemulihan fungsi ekologis perairan. Selain itu, keterlibatan masyarakat lokal dan pengelolaan berkelanjutan menjadi faktor penting dalam menjaga keberhasilan rehabilitasi jangka panjang. Dengan penerapan upaya rehabilitasi yang terencana dan berkelanjutan, lahan bekas tambang nikel berpotensi dipulihkan menjadi ekosistem perairan yang sehat, produktif, dan memberikan manfaat ekologis maupun sosial ekonomi bagi masyarakat sekitar.

***Kata Kunci**: kualitas air; rehabilitasi lahan; revegetasi; sumber daya akuatik pascatambang; tambang nikel*

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INTRODUCTION

The rapid development of nickel mining activities, driven by the increasing global demand for stainless steel and electric vehicle batteries, has created significant environmental pressures, particularly on the aquatic ecosystems around mining areas. Mining activities often cause changes in land morphology, disturbances of natural hydrological systems, increased sediment loads, and the entry of heavy metals into surface water bodies and groundwater. These conditions have an impact on declining water quality, degradation of aquatic habitats, and loss of aquatic biodiversity, which ultimately also affects the sustainability of the livelihoods of people who depend on water resources.

Therefore, the rehabilitation and conservation of aquatic resources on former nickel mining land is a strategic issue in post-mining environmental management. Rehabilitation efforts not only focus on land reclamation and revegetation, but also include the restoration of hydrological functions, erosion and sedimentation control, and restoration of aquatic habitats so that ecosystems can return to optimal functioning. An ecosystem-based restoration approach that is integrated with water resource management is essential to ensure environmental sustainability, minimize the risk of long-term pollution, and support the sustainable use of water resources in post-mining areas.

Despite increasing attention to this issue, scientific studies on the rehabilitation and conservation of aquatic resources on former nickel mining land are still fragmented and cross-disciplinary. These studies are spread across the fields of ecology, hydrology, environmental engineering, and regional planning, so a comprehensive synthesis of knowledge is needed. Therefore, this study is important to summarize strategies, approaches, and best practices that have been implemented, as well as identify challenges and opportunities in the management of post-mining aquatic resources to support ecosystem sustainability and long-term socio-ecological resilience.

As an important component of Indonesia's economy, nickel mining provides raw materials for sectors such as batteries and stainless steel. This process often results in major changes to the land, including slope erosion, rock and soil formation, and the loss of the topsoil layer that supports crop development, regardless of whether the miner uses open-pit mining or other methods. According to Aji Bimantara et al., (2024) These changes can make land less stable and worsen the surrounding ecosystems, including aquatic systems and other natural places. According to Widiatmaka et al., (2010) that the greatest impacts include degradation of soil structure, increased erosion and movement of mud into water, as well as water pollution from toxic metals and mining acidity.

Rivers, lakes, and swamps close to old nickel mining areas are particularly vulnerable to environmental change. As turbidity increases, acidity changes, and the buildup of harmful metals such as nickel, iron, and manganese, the quality of the water decreases. Aquatic life is harmed by certain metals. As a result, these animals may struggle to survive, the number of species present may decrease, and the balance of the ecosystem's food chain may be disrupted (Fynnisa Z et al., 2024). This situation can lead to the loss of aquatic life, decrease water productivity, and disrupt the ability of ecosystems to benefit the environment if not managed properly.

Therefore, the restoration and protection of aquatic resources in places previously used for nickel mining is critical. In addition to improving soil quality, the improvement of these places also includes the restoration of the natural function of the water. After mining, more stable and sustainable ecosystems, such as land use for fisheries, can be created by combining techniques such as water quality control, planting of new flora, and land restoration. The goal of the restoration process is to restore the post-nickel mining site to a

healthy and sustainable ecosystem by integrating physical, chemical, and biological processes (Randrikasari, 2023).

METHOD

The writing of this article uses a *literature review* methodology by systematically examining various national and international scientific journals that discuss post-mining land restoration, reclamation of mining areas, vegetation planting, and water resource management. This approach aims to gain a comprehensive understanding of the principles, methods, and achievements of water resource restoration in nickel mining areas through descriptive and qualitative analysis of previous research findings, (Palmer et al., 2014). The literature studied includes ecosystem rehabilitation strategies, restoration of hydrological functions, erosion and sediment control, and vegetation integration in supporting the sustainability of post-mining aquatic ecosystems. Through the synthesis of the results of the research, this article provides a detailed overview of the rehabilitation of former nickel mining land and its implications for the support of water-based activities and sustainable environmental management, (Martín-Moreno et al., 2018; Mudd, 2010).

RESULT AND DISCUSSION

Impact of Nickel Mining on Aquatic Resources

Nickel mining, particularly open-pit mining, puts significant pressure on the surrounding aquatic environment. Soil and waste from mining can be easily carried into rivers, lakes, and wetlands through surface runoff. This causes more contaminants and heavy metals in the water, increasing sediment levels and degrading water quality (Pedrozo-Acuña et al., 2025). Increased sedimentation directly impacts water quality. When there is a lot of sediment in the water, the water becomes cloudy and blocks sunlight from reaching the bottom. This interferes with the ability of plants and small algae in the water to photosynthesize, which is how they make food. Since these plants are the main food source for many aquatic animals, their decline affects all animals that depend on them for food. Nickel mining leads to extensive land clearing, which removes vegetation and topsoil layers. This causes more water to flow over the land and increases erosion. High sediment levels block sunlight, prevent plants from making food, and destroy habitats at the bottom of water bodies (Saputro et al., 2024).

Acid mine wastewater from nickel mining can contain heavy metals such as manganese, iron, and nickel. These metals can harm fish and other aquatic life when they enter the water. Over time, this pollution can lead to a decline in species diversity in waters and disrupt the functioning of the food chain. Species that inhabit aquatic environments can be harmed by heavy metal buildup. High concentrations of these metals can harm aquatic life by causing disease, stunted growth, reproductive problems, and even death. Over time, this can change the way different species of animals coexist and reduce the richness of aquatic life (Sheoran & Sheoran, 2006). The physical, chemical, and biological characteristics of water bodies are all influenced by the intricate and diverse effects of nickel mining on aquatic resources. As a result, post-mining rehabilitation initiatives need to be integrated and focused on improving water quality, controlling sedimentation, and restoring aquatic habitats in addition to land restoration. In areas affected by nickel mining, ecosystem-based strategies are needed to ensure the long-term survival of aquatic resources. The following land restoration techniques can be used in nickel mining sites.

Land Reclamation

The first phase of post-mining land rehabilitation is reclamation, which aims to restore the physical condition of the land so that it is safe, stable, and no longer has a negative impact on the environment. To reduce the amount of sludge and pollutants entering water bodies, reclamation activities include land development, erosion control, topsoil layer management, and drainage system improvements (Bradshaw, 1997). Some of the initiatives that have been carried out by the company are based on Arumsari et al., (2025) It is noted that by using soil reserves made from the topsoil layer collected before mining, some companies have taken action to restore the land. To increase soil fertility, they also use manure. They also grow pioneer crops and other native plants that thrive on certain types of land.

Meanwhile, land rearrangement, contour improvement, topsoil layer management, and erosion and sedimentation control, according to (Randrikasari, 2023) The following are the control steps that can be taken: (1) Making planting holes for plants that can thrive in the former nickel mining area is one approach to do this. These holes provide the plant with enough space for healthy root growth. To ensure that it is evenly distributed throughout the area, the plants are arranged in a regular pattern. Additionally, by improving the soil's ability to breathe and facilitating easier water infiltration, this technique promotes healthier plant growth. To replace the nutrients lost during excavation, another technique is to combine the top layer of soil with compost. (2) The addition of compost increases the amount of essential nutrients such as nitrogen and phosphorus and reduces the amount of harmful iron in the soil by 3-5 times. This compost can be spread in the soil to create a good growing environment for plants, helping them get the nutrients they need. (Fikria Sagitarini & Made Amelia Ratnata Dewi, 2023); (3) Super Absorbent Polymer (SAP) is a type of hydrogel that can quickly absorb large amounts of water and retain it (Abidin et al., 2012). Materials in diapers, such as hydrogels or SAPs, contain polyacrylate sodium granules, these granules are made from petroleum (Khoo et al., 2019). Therefore, this SAP waste can absorb water up to between 100 and 300 times its weight (Sarifuddin et al., 2021). In areas where nickel has been mined, the soil is often deficient in nutrients and unable to hold water properly. The use of SAP waste, which is rich in nutrients and can absorb a lot of water, can help improve the quality of this damaged soil. This is because SAP can retain moisture in the soil longer. Proper recovery in this area helps to create stable and safe conditions, which is critical for subsequent phases of recovery.

Revegetation and Revitalization

For the former mining land to return to its natural functioning, vegetation is essential. Increased land cover, improvement of soil structure, and increase in organic matter are benefits of plants. It has been proven that the use of rapidly adapting plants and species that can thrive in challenging and less fertile environments can accelerate the natural recovery of ecosystems and reduce the amount of water flowing from land to surrounding water bodies (Parrotta & Knowles, 2001). Since soils are typically highly acidic and low in nutrients, choosing the right crop is essential. To improve soil quality, add organic matter, and prevent soil from being carried into the surrounding water bodies, native plants, ground cover plants, and fast-growing species are used.

The recovery of ex-mining land is known as revitalization and is a component of broader disaster recovery efforts. To ensure its success and sustainability, this approach must be implemented carefully and gradually. According to Aji Bimantara et al., (2024) The following actions must be taken to recover post-mining land, namely: (1) The first step in understanding and assessing land conditions after mining is the identification and assessment of land

conditions. This procedure includes monitoring the condition of the local ecosystem, the amount of organic matter in the soil, the level of pollution, and its structure. This assessment helps identify the types of plants that can thrive there as well as the steps that should be taken to improve the habitat and soil. (2) The next stage is land restoration. Restoring soil health is the next step after the assessment. Former mining soils often lack organic matter and are not suitable for crop cultivation. To improve fertility, we add organic matter, such as compost, organic fertilizer, or soil rich in organic matter. (3) Building a water and drainage management system is essential for land restoration. Poor drainage of degraded soil often results in flooding and waterlogging. Creating effective drainage channels reduces the risk of flooding due to soil erosion, controls water flow, and prevents waterlogging. (4) Another important step is to plant the right type of flora. It is very important to choose plants that can improve soil quality and thrive in less fertile soils. In addition, these plants can support and aid in the restoration of the local environment. (5) Restoring biodiversity and ecosystems is also very important. Reintroducing a variety of native plants and animals that contribute to diverse and healthy ecosystems should be part of land restoration. (6) An important component of this strategy is the empowerment of local communities. Communities living near mining sites often suffer the most from environmental damage and have less access to local business prospects. Involving these communities in the development, implementation, and maintenance of revitalization initiatives is essential. (7) Consistent observation and assessment contribute to a smooth revitalization process. This includes an assessment of how plants grow and how land and soil conditions are improving, how the environment is changing and how plants are growing. These checks help determine the success of the program and identify new issues. (8) The last phase is sustainable economic development. After restoration, land can be used for agriculture, forestry, fisheries, or nature tourism, all of which can generate income for local communities.

Water Quality Management

To preserve and improve aquatic habitats near former mining sites, water quality management is implemented. This includes building artificial wetlands, planting crops along the edges of water bodies, and building settling ponds. This action ultimately contributes to a better aquatic environment by lowering the concentration of pollutants and harmful metals in the water (Vymazal, 2014). Before the water reaches a river or lake, this system helps remove pollutants and reduce heavy metal concentrations. To control the flow of water from a mining site, a settling pond is essential. These pools allow pollutants to settle naturally to the bottom by slowing the flow of water. By allowing dissolved heavy metals to adhere to sedimentary particles, these pools not only help reduce pollution but also lower the levels of dissolved heavy metals (Schmidt et al., 2005).

It has been proven that well-built settling ponds can reduce the impact of water contamination in downstream communities affected by mining. An increasingly popular eco-friendly method for managing water after mining is wetland development. They filter water using the relationships between aquatic plants, microscopic organisms, and materials found in wetlands. By settling, sticking to surfaces, forming solids, and using living organisms to transform contaminants, they remove pollution. According to research, artificial wetlands are beneficial in lowering the concentration of heavy metals including nickel, iron, and manganese and help maintain stable water acidity levels in areas affected by mining (Sheoran & Sheoran, 2006).

To keep the air clean, plants along the banks of the river are very important. In addition to absorbing pollutants and harmful substances such as fertilizers and heavy metals before they enter the atmosphere, plants also help prevent rainfall from flowing too heavily. In

addition, the presence of plants near rivers improves living conditions for plants and animals, keeps the air cool, and strengthens riverbanks (Gregory et al., 1991). A combination of engineering techniques and ecological tactics is needed to improve air quality in places formerly used for nickel mining. In addition to effectively lowering pollution levels, the use of settling ponds, artificial wetlands, and riverside vegetation also helps restore the natural functioning of air ecosystems and ensures the long-term sustainability and health of water resources.

Rehabilitation and Conservation of Aquatic Resources

Rehabilitation of aquatic resources on former nickel mining land is inseparable from the cooperation of terrestrial and aquatic ecosystems directly related to the rehabilitation of aquatic resources in former nickel mining areas. The soil absorbs mining waste, which then enters the river. Hazardous metals can spread and contaminate groundwater. The components found in water are also affected by the natural characteristics of various regions, which can result in higher concentrations of harmful substances and poison the water. A book of works Basuki, (2024) states that freshwater and marine life can be severely harmed by pollution from rivers, lakes, and oceans caused by resource-consuming, manufacturing, and agricultural businesses.

People who depend on fish for their livelihoods lose money due to this pollution, which also makes fish unfit for human consumption. In addition, it affects the fishing industry because polluted fish cannot be sold at a profit in domestic and international markets, which has a negative impact on the economy. Planting plants near water bodies can help prevent some pollutants from getting into the water. Reintroducing native fish and other aquatic species can also help restore the environment once the water is clean enough. One of the bioindicators that shows that the waters have improved and are suitable for other fishing activities is the presence of native fish in areas that were once used for nickel mining.

Careful management is required to ensure the safety of water resources, including regular water quality inspections, limiting the use of the area by communities, and involving local communities. Long-term ecosystem health is maintained when local communities participate in maintaining soil and water health. Preventing soil erosion and keeping water clean are two ways to protect land and water around watersheds (Rozana et al., 2025). Maintaining a healthy balance between post-mining land use and environmental conservation requires the application of ecosystem-focused techniques.

CONCLUSION

The reihabiiliitasii and the irrigation of aquatic power sumbeir on the land of niikeil mining is a complex process and requires the preparation of the teirpadu. Reiklamasii, reiveigeitasii, and peingeilolaan of aiir quality are the main components that are mutually related in improving the function of eikosiisteim. Based on literature studies, the application of reihabiiliitasii strategies that are teireincana and beirkei are able to impeirbaiikii the conditions of the post-mining environment while supporting the development of aquatic resources. This effort is not only for the sake of the continuation of the environment, but also for the well-being of the community in the surrounding area of the mining area.

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