



Environmental Impact of Mining Activities: A Review of Management Strategies and Rehabilitation Techniques

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Abstract

Mining activities have played a pivotal role in global economic development but are often associated with significant environmental challenges. This review critically examines the environmental impact of mining operations and evaluates various management strategies and rehabilitation techniques employed to mitigate these effects. The assessment encompasses a broad spectrum of mining-related environmental concerns, including soil degradation, water pollution, deforestation, biodiversity loss, and air quality degradation. The first section of the review provides an overview of the diverse environmental impacts associated with mining activities, highlighting the complexities and interdependencies of these issues. Following this, a comprehensive examination of current management strategies is presented, focusing on regulatory frameworks, sustainable practices, and technological advancements aimed at minimizing negative environmental consequences. The review emphasizes the importance of adopting a holistic and integrated approach that considers the unique characteristics of each mining operation and the ecosystems it affects. Furthermore, the discussion delves into rehabilitation techniques designed to restore ecosystems impacted by mining activities. This includes the exploration of ecological restoration methodologies, such as reforestation, wetland restoration, and soil stabilization, as well as innovative approaches involving the use of native plant species and soil amendments. The effectiveness of these techniques in promoting sustainable landscapes and fostering biodiversity recovery is evaluated based on case studies and empirical evidence. This review highlights the imperative for a proactive and adaptive approach to address the environmental challenges posed by mining activities. The synthesis of effective management strategies and rehabilitation techniques is essential to strike a balance between economic development and environmental preservation. Future research directions are proposed, emphasizing the need for collaborative efforts among stakeholders, continued technological innovation, and the integration of sustainable practices into mining industry operations. Ultimately, this review aims to contribute to the ongoing discourse on achieving responsible and sustainable mining practices globally.

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1. Introduction

The rapid pace of industrialization and global economic growth over the past century has significantly escalated the demand for minerals and metals, propelling mining activities to the forefront of essential industries. While mining plays an indispensable role in supplying raw materials for various sectors, its environmental impact has emerged as a substantial concern, prompting a

critical examination of management strategies and rehabilitation techniques (Azapagic, 2004). This comprehensive review seeks to explore the intricate dynamics between mining activities and the environment, evaluating the effectiveness of existing approaches in mitigating the environmental consequences and fostering sustainable practices. Mining activities encompass a diverse range of operations, from surface and underground mining to extraction and processing, each leaving a distinct imprint on the environment (Agboola, *et al.*, 2020). The extensive removal of earth, disruption of ecosystems, and the release of pollutants during extraction and processing have given rise to a spectrum of environmental challenges (Vasilachi, *et al.*, 2021). Soil degradation, characterized by the disruption of soil structure, composition, and fertility, is a prominent concern, often leading to long-lasting ecological consequences. Water pollution, another critical issue, results from the release of heavy metals, sediments, and chemicals into water bodies, adversely affecting aquatic ecosystems and posing risks to human health (Zamora-Ledezma, *et al.*, 2021). Deforestation is an inevitable by-product of many mining activities, with large expanses of forest often cleared to make way for mining infrastructure. This not only contributes to the loss of biodiversity but also exacerbates climate change by reducing carbon sequestration capacities (Lal, 2004). Biodiversity loss, both direct and indirect, further amplifies environmental degradation, disrupting ecosystems and diminishing their resilience. Additionally, the release of particulate matter, gases, and dust during mining operations contributes to air quality degradation, impacting both human health and the overall environmental balance (Csavina, *et al.*, 2012). In response to these environmental challenges, various management strategies have been implemented on local, national, and international scales. Regulatory frameworks, encompassing environmental impact assessments, zoning regulations, and mining permits, aim to establish guidelines for responsible mining practices (Mancini and Sala, 2018). While such regulations are crucial, their effectiveness depends on enforcement mechanisms and adaptability to the evolving nature of mining technologies and practices. Sustainable mining practices, including the adoption of cleaner technologies, waste reduction, and efficient resource use, represent another facet of management strategies aimed at minimizing environmental footprints (Aznar-Sánchez, *et al.*, 2019). Technological advancements have played a pivotal role in enhancing mining efficiency and reducing environmental impact. Innovations such as remote sensing, artificial intelligence, and automation contribute to better resource management, minimization of waste, and early detection of environmental anomalies. These advancements, however, need to be coupled with stringent regulations and industry-wide adoption to ensure their positive impact on environmental conservation (Naylor, *et al.*, 2021). In parallel with management strategies, rehabilitation techniques have gained prominence in recent years as essential components of responsible mining practices. Ecological restoration, involving the reestablishment of natural ecosystems post-mining, has become a focal point. Reforestation initiatives, wetland restoration projects, and soil stabilization techniques are employed to reclaim disturbed areas and reinstate biodiversity (Williams, 1999). Native plant species, adapted to local conditions, are often utilized in rehabilitation efforts to accelerate the restoration process. This review aims to provide a holistic understanding of the environmental impact

of mining activities, critically assessing the strengths and limitations of current management strategies and rehabilitation techniques. By synthesizing knowledge from diverse sources, including academic studies, industry reports, and case studies, we aim to contribute to the ongoing discourse on achieving a sustainable balance between mining-driven economic development and environmental preservation (Buchanan and Dawson, 2007). As we delve into the complexities of mining-related environmental impacts, the goal is to inform stakeholders, policymakers, and industry professionals about effective strategies for responsible mining practices that safeguard the environment and promote long-term ecological resilience. Mining, a cornerstone of global economic development, has been instrumental in supplying essential raw materials for industries worldwide (Heffron, 2020). From the extraction of minerals fueling technological advancements to the production of metals driving infrastructure growth, the significance of mining in shaping modern societies cannot be overstated. However, as mining activities continue to expand to meet the demands of a growing global population, the environmental concerns associated with these operations have come to the forefront, prompting a critical examination of management strategies and rehabilitation techniques (Igogo, *et al.*, 2020). This review endeavours to delve into the intricate dynamics between mining activities and their environmental consequences, with a focused aim of evaluating approaches to mitigate these impacts and foster sustainable practices. Mining activities have been integral to human civilization, shaping economies, cultures, and landscapes throughout history (Hughes, 2009). The extraction of minerals, metals, and other geological resources provides the foundational elements for various industries, ranging from construction and manufacturing to technology and energy production. The economic significance of mining is underscored by its contribution to job creation, revenue generation, and the supply chain for numerous sectors (Banchirigah and Hilson, 2010). In the context of global economic development, mining stands as a driving force behind infrastructure projects, urbanization, and technological innovation. The demand for metals like copper, aluminium, and rare earth elements has surged with the rise of renewable energy technologies, electronic devices, and electric vehicles (Rietveld, *et al.*, 2019). Similarly, the extraction of coal, oil, and natural gas remains pivotal for meeting the world's energy needs. As developing and emerging economies strive for industrialization, the role of mining becomes even more pronounced, reflecting the interconnected nature of mineral resources and economic progress (Mountjoy, 2017). While mining is undeniably essential for economic growth, the environmental repercussions of these activities cannot be overlooked. The extraction, processing, and disposal of minerals often lead to a range of environmental impacts, raising concerns about long-term sustainability and ecological integrity (Moran, *et al.*, 2014). The key environmental concerns associated with mining operations include: The extensive removal of soil during mining operations can disrupt its structure, composition, and fertility, leading to erosion, compaction, and loss of arable land (Mensah, 2015). Mining activities release pollutants such as heavy metals, sediments, and chemicals into water bodies, contaminating freshwater resources and jeopardizing aquatic ecosystems. Clearing large tracts of land for mining infrastructure contributes to

deforestation, disrupting ecosystems, and diminishing biodiversity. Habitat destruction, pollution, and altered landscapes result in the loss of plant and animal species, affecting the overall biodiversity of affected regions (Gibbons, *et al.*, 2000). Particulate matter, gases, and dust released during mining operations can degrade air quality, impacting both human health and the broader environment. The cumulative effect of these environmental impacts poses challenges not only for the ecosystems directly affected by mining but also for global efforts towards environmental conservation and climate change mitigation (Bebbington and Bury, 2009). To Evaluate Management Strategies and Rehabilitation Techniques Addressing Environmental Impacts. The overarching objective of this review is to critically assess the various management strategies and rehabilitation techniques employed in response to the environmental impacts of mining activities (King, *et al.*, 2003). As the mining industry continues to expand, the imperative to reconcile economic development with environmental preservation becomes increasingly urgent. This review seeks to achieve the following specific goals: Evaluate the effectiveness of existing management strategies employed in the mining industry to mitigate environmental impacts. This includes an analysis of regulatory frameworks, sustainable practices, and technological innovations aimed at minimizing the ecological footprint of mining operations (Basu and van, 2006). Delve into rehabilitation techniques designed to restore ecosystems affected by mining activities. This encompasses ecological restoration approaches, reforestation initiatives, wetland restoration, soil stabilization techniques, and the utilization of native plant species in post-mining landscapes (Gastauer, *et al.*, 2018). Through a comprehensive synthesis of current knowledge and empirical evidence, contribute to the ongoing discourse on achieving a delicate balance between economic development and environmental conservation in the mining industry. Inform future research, policy-making, and industry practices by identifying successful strategies, lessons learned from both successes and failures, and proposing recommendations for fostering responsible and sustainable mining practices globally (Henderson, *et al.*, 2011). In undertaking this review, the aim is not only to highlight the challenges posed by mining-related environmental impacts but also to shed light on the potential solutions and strategies that can pave the way towards a more sustainable and harmonious coexistence between mining activities and the environment. By critically evaluating the current state of environmental management in the mining sector, this review aspires to contribute to the development of informed practices that align with the principles of responsible resource extraction and environmental stewardship.

1.1 Environmental Impact of Mining Activities

Mining activities, essential for providing raw materials driving industrial growth, have left an indelible mark on the environment, presenting a complex web of challenges that demand careful examination. The environmental impact of mining is multifaceted, encompassing soil degradation, water pollution, deforestation, biodiversity loss, and air quality degradation (Castello and Macedo, 2016). In this section, we delve into the intricacies of each aspect, exploring their manifestations, impacts, and notable case studies. Mining operations often involve the extensive removal of soil, disrupting its structure and composition (Sheoran, *et al.*,

2010). The physical disturbance can lead to compaction, erosion, and alteration of nutrient levels. Chemical and biological properties undergo changes, impacting the soil's ability to support plant life (Gupta and Germida, 2015). Fertility loss becomes a significant concern, affecting the long-term sustainability of ecosystems. Open-pit mining, mountaintop removal, and strip mining are examples of practices causing profound soil disruption (Irene, *et al.*, 2021). The removal of vegetation and topsoil exposes underlying mineral deposits, leaving the terrain vulnerable to erosion. This process can result in the creation of barren landscapes, hindering the natural regenerative capacity of the soil (Nikolic, *et al.*, 2008). Mining activities introduce a plethora of pollutants into water bodies, including heavy metals, sediments, and chemicals. Runoff from mining sites carries these contaminants into rivers, lakes, and groundwater. The composition of pollutants varies based on the minerals being extracted, posing unique challenges for water quality management (Bagatin, *et al.*, 2014). The release of pollutants has severe implications for aquatic ecosystems, causing habitat degradation and disrupting the balance of aquatic flora and fauna. Heavy metals, such as mercury and lead, can accumulate in aquatic organisms, posing risks to human health through the consumption of contaminated water and seafood. Instances like the Ok Tedi mine in Papua New Guinea and the Minamata Bay mercury contamination in Japan serve as stark reminders of the far-reaching consequences of water pollution from mining activities (Boswell, R). These incidents highlight the need for stringent regulations and effective management strategies to prevent and mitigate water pollution. Mining often requires significant land clearance, leading to deforestation on a large scale (Peterson and Heemskerk, 2001). Forests are cleared to make way for infrastructure, including mine pits, roads, and processing plants. This direct impact on ecosystems disrupts the delicate balance of flora and fauna. Deforestation resulting from mining activities contributes to climate change by reducing the capacity of forests to sequester carbon dioxide (Kabir, *et al.*, 2023). Figure 1 is the schematic diagram of Production of CO₂ from building & other sources polluting the environment.

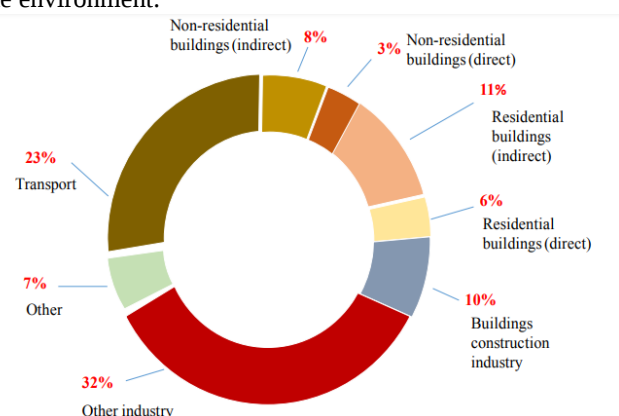


Fig 1: Production of CO₂ from building & other sources polluting the environment

The loss of biodiversity and disruption of ecosystem services exacerbate the global environmental footprint of mining operations. The connection between mining-induced deforestation and biodiversity loss is profound (Lloyd, *et al.*, 2023). Forest ecosystems, rich in biodiversity, are essential for maintaining ecological balance. The destruction of these

habitats threatens the survival of numerous plant and animal species and compromises the invaluable ecosystem services forests provide. Mining activities directly impact biodiversity through habitat destruction and fragmentation (Siqueira-Gay, *et al.*, 2020). Indirectly, the releases of pollutants and alterations to soil and water quality further contribute to biodiversity loss. The interconnected nature of ecosystems makes these impacts pervasive and often irreversible. Disrupted ecosystems struggle to recover, and the loss of key species can impair the resilience of entire ecosystems (Mora, *et al.*, 2016). Biodiversity loss compromises the ability of ecosystems to adapt to environmental changes, making them more susceptible to disturbances (Dornelas, 2010). From the destruction of the Amazon rainforest due to gold mining to the impact of coal mining on the biodiversity of Appalachia in the United States, numerous examples underscore the global and regional ramifications of biodiversity loss linked to mining activities. Mining operations release various airborne pollutants, including particulate matter, sulfur dioxide, nitrogen oxides, and other gases (Abaje, *et al.*, 2020). Dust generated during activities such as blasting and transportation can have far-reaching consequences for air quality. Airborne pollutants can pose risks to human health, causing respiratory issues and other health complications (Kampa and Castanas, 2008). Additionally, these pollutants contribute to environmental imbalances, impacting vegetation, water bodies, and overall ecosystem health. The environmental impact of mining activities spans a spectrum of interconnected challenges. Understanding the nuances of soil degradation, water pollution, deforestation, biodiversity loss, and air quality degradation is crucial for developing effective management strategies and rehabilitation techniques. The next sections of this review will explore the various approaches employed to mitigate these environmental impacts and foster sustainable mining practices.

1.2 Management Strategies

Mining activities, indispensable for global industrial development, necessitate robust management strategies to address their significant environmental impact. This section explores key management approaches, including regulatory frameworks, sustainable practices, and technological advancements, evaluating their effectiveness in mitigating environmental consequences and promoting responsible mining practices. Regulatory frameworks play a pivotal role in shaping the environmental performance of mining operations (Pangestuti, *et al.*, 2023). Environmental Impact Assessments (EIAs) provide a systematic evaluation of potential environmental impacts before mining activities commence. Zoning regulations establish guidelines for land use and help minimize conflicts between mining and other activities. Mining permits, issued based on compliance with environmental standards, serve as gatekeepers for responsible mining. The effectiveness of regulatory frameworks depends on their stringency, enforcement mechanisms, and adaptability to evolving mining technologies. Stringent regulations coupled with proactive enforcement contribute to better environmental outcomes. However, challenges arise when regulatory bodies struggle to keep pace with rapidly advancing mining methods and technologies. Notable examples, such as the stringent regulations imposed on mining activities in Australia and Canada, demonstrate successful frameworks that have

effectively balanced economic interests with environmental preservation. These countries showcase the importance of robust regulatory mechanisms in fostering responsible mining practices and minimizing environmental impacts. Sustainable practices in mining involve adopting technologies that reduce environmental footprints (Giurco and Petrie, 2007). Cleaner technologies aim to minimize emissions, waste generation, and energy consumption. Additionally, efficient resource use focuses on optimizing the extraction and processing of minerals, reducing the overall impact on ecosystems. While sustainable practices offer promising solutions, industry-wide adoption faces challenges. High initial investment costs, resistance to change within established mining practices, and the need for specialized knowledge can impede the widespread implementation of sustainable approaches. Overcoming these barriers requires collaboration among industry stakeholders, policymakers, and the research community. Innovations such as sensor-based ore sorting, advanced recycling techniques, and eco-friendly extraction methods showcase the potential of sustainable practices in reducing environmental footprints. These technologies contribute to resource efficiency, waste reduction, and minimized ecological disruption, aligning with the broader goal of responsible and sustainable mining. Technological advancements have revolutionized the mining industry, enhancing its environmental performance. Remote sensing technologies provide real-time data on environmental conditions, aiding in proactive decision-making. Artificial intelligence (AI) and automation optimize processes, leading to increased efficiency and reduced environmental impact (Benzidia, *et al.*, 2021). Technology facilitates improved resource management by enabling precise extraction methods, reducing waste generation, and promoting efficient use of resources. AI algorithms can detect anomalies in environmental parameters, allowing for early intervention to prevent or minimize adverse effects on ecosystems. The synergy between technological advancements and regulatory measures is crucial for achieving meaningful environmental outcomes. While regulations set the baseline standards, technology provides the means to surpass these standards, creating a pathway for continuous improvement in environmental performance. Effective management strategies are pivotal in navigating the complex terrain of mining-related environmental impacts. Regulatory frameworks, sustainable practices, and technological advancements represent complementary pillars that, when integrated and implemented cohesively, can foster responsible mining practices. The next section will delve into rehabilitation techniques designed to restore ecosystems impacted by mining activities, completing the comprehensive exploration of strategies for achieving sustainable mining practices globally.

1.3 Rehabilitation Techniques

Mining operations, often synonymous with environmental disruption, necessitate robust rehabilitation techniques to restore ecosystems impacted by extraction activities. In this section, we explore the significance of ecological restoration, including reforestation initiatives, wetland restoration, and soil stabilization techniques. Additionally, we delve into case studies, examining both successful and unsuccessful rehabilitation projects to glean valuable lessons and assess the long-term impact of these efforts on ecosystems and biodiversity. Ecological restoration is the process of assisting

the recovery of ecosystems that have been degraded, damaged, or destroyed (Allison, 2012). In the context of mining, where landscapes often bear the scars of extraction, ecological restoration is imperative for mitigating the environmental impact and fostering the return of biodiversity. Restoration aims to re-establish natural processes, functions, and biodiversity levels, ultimately promoting the resilience of ecosystems. Planting trees in mined areas is a common practice to restore vegetative cover and enhance biodiversity. Native tree species are often preferred for their adaptability to local conditions. The establishment of forested areas aids in soil stabilization, prevents erosion, and creates habitats for various species (Coppin and Stiles, 2003). Mining activities can alter hydrological patterns and impact wetland ecosystems. Wetland restoration involves re-establishing water flow, vegetation, and nutrient cycles. Techniques include recreating natural topography, reintroducing native plant species, and managing water levels to support the return of wetland habitats. Disturbed soils in mined areas are prone to erosion and lack the stability required for healthy ecosystems. Stabilization techniques include the use of cover crops, contour ploughing, and bioengineering methods. These techniques aim to prevent soil erosion, promote water retention, and create a suitable environment for vegetation to thrive. The use of native plant species in rehabilitation efforts is crucial for restoring ecosystems to their natural state. Native plants are adapted to local climatic and soil conditions, making them resilient and better suited to establish stable, self-sustaining communities. Their introduction enhances biodiversity, supports local wildlife, and contributes to the overall success of ecological restoration. Alcoa's rehabilitation efforts in Western Australia's bauxite mines are considered a success story. The company employs a systematic approach, including topsoil conservation, seed collection, and careful reforestation. Monitoring over several decades has shown the re-establishment of diverse ecosystems, demonstrating the effectiveness of proactive rehabilitation strategies (Zimmer, *et al.*, 2022). The Soudan Underground Mine, once a thriving iron ore mine, has been transformed into a state park. Reforestation initiatives, wetland restoration, and community engagement have played key roles in the successful rehabilitation of the site. The park now stands as a testament to the potential for mining landscapes to regain ecological value. Projects that intervene early in the mining lifecycle tend to be more successful. Proactive measures, such as seed banking and topsoil preservation, contribute to the availability of necessary resources for rehabilitation. Success often hinges on the careful selection of native plant species that are well-adapted to local environmental conditions. This adaptability ensures the resilience of rehabilitated ecosystems against external pressures. Lack of comprehensive planning and monitoring can lead to unsuccessful rehabilitation attempts. Without continuous assessment, it becomes challenging to address emerging issues and adjust strategies accordingly. Projects that neglect community involvement may face challenges in sustaining rehabilitation efforts. Engaging local communities fosters a sense of ownership and promotes long-term commitment to ecosystem recovery. The Hemlo Mines rehabilitation project showcases the enduring impact of ecosystem recovery. The integration of sustainable practices, including reforestation and wetland restoration, has resulted in thriving ecosystems decades after the cessation of mining activities. Biodiversity has rebounded, and the area

now serves as a model for responsible mine closure. Despite success stories, the long-term impact of rehabilitation efforts can be challenging to assess (Anderson, *et al.*, 2014). Monitoring must extend over extended periods to account for ecological succession, climate fluctuations, and potential human interventions. Effective rehabilitation techniques are pivotal for restoring ecosystems affected by mining activities. The combination of ecological restoration principles, reforestation initiatives, wetland restoration, and soil stabilization techniques contributes to the recovery of biodiversity and ecosystem functionality. Case studies provide valuable insights, emphasizing the importance of early intervention, adaptability to local conditions, community engagement, and sustained monitoring for successful rehabilitation. As the mining industry continues to evolve, the lessons learned from rehabilitation efforts serve as crucial guides for promoting responsible and sustainable practices globally.

2. Conclusion

The comprehensive review of the environmental impact of mining activities, management strategies, and rehabilitation techniques provides a nuanced understanding of the complexities inherent in balancing economic development with environmental stewardship. As we summarize the key findings, emphasize the importance of a balanced approach to mining, and propose future research directions and policy recommendations, it becomes evident that the quest for sustainable mining practices demands collaborative efforts from industry, policymakers, researchers, and local communities. The exploration of environmental impacts revealed the multifaceted challenges posed by mining activities, ranging from soil degradation and water pollution to deforestation, biodiversity loss, and air quality degradation. Management strategies, including regulatory frameworks, sustainable practices, and technological advancements, were examined for their effectiveness in mitigating these impacts. Additionally, rehabilitation techniques such as ecological restoration, reforestation, and wetland restoration were explored as means to restore ecosystems post-mining. The review underscored the interconnectedness of these components, emphasizing the need for an integrated and holistic approach. Mining activities exert significant pressure on ecosystems, leading to soil disruption, water pollution, deforestation, biodiversity loss, and air quality degradation. Regulatory frameworks, sustainable practices, and technological advancements represent crucial pillars in mitigating environmental impacts. Effective regulation, the adoption of sustainable technologies, and proactive management contribute to responsible mining practices. Ecological restoration, incorporating reforestation, wetland restoration, and soil stabilization techniques, plays a pivotal role in rejuvenating post-mining landscapes. Native plant species are instrumental in restoring biodiversity and ecosystem functionality. Case studies highlighted successful rehabilitation projects, showcasing the importance of early intervention, adaptability to local conditions, and community engagement. However, challenges such as insufficient planning, monitoring, and limited community involvement can impede rehabilitation success. The findings underscore the critical need for a balanced approach to mining activities, acknowledging the simultaneous pursuit of economic development and environmental conservation. Striking this

equilibrium requires a paradigm shift within the industry, prioritizing sustainable practices and responsible resource management. Achieving this balance involves: Mining companies must embed sustainability into their core practices, adopting technologies that reduce environmental footprints, optimize resource use, and prioritize ecosystem health. Regulatory frameworks need to evolve in tandem with advancements in mining technologies. Stricter enforcement, periodic updates, and adaptability to emerging challenges will enhance the effectiveness of regulations. Meaningful engagement with local communities, including Indigenous groups, is paramount. Collaboration fosters a sense of shared responsibility and ensures that the benefits and risks associated with mining Continuous investment in research and development is essential for advancing sustainable mining practices. Innovation in technologies, rehabilitation techniques, and monitoring tools is crucial for addressing evolving environmental challenges. Research should focus on understanding the long-term resilience of ecosystems post-mining. This includes assessing the recovery trajectories, biodiversity dynamics, and ecosystem functionality over extended periods. Continued research into innovative rehabilitation techniques, including the use of advanced technologies and bioengineering methods, can enhance the effectiveness of restoration efforts. Expanding research beyond environmental considerations to include social and economic impacts is crucial. Understanding how mining activities affect local communities, livelihoods, and regional economies informs more comprehensive decision-making. Exploring circular economy principles within the mining sector can promote resource efficiency, recycling, and reduced waste generation. Research into closed-loop systems and sustainable material cycles is key. Policymakers should encourage strategic mine planning that integrates environmental considerations from the outset. Comprehensive Environmental Impact Assessments (EIAs) should be mandatory, emphasizing the importance of preventing, minimizing, and mitigating adverse impacts. Governments can provide incentives, such as tax breaks or preferential permits, to mining companies adopting sustainable practices. Financial benefits can drive industry-wide adoption of environmentally responsible technologies. Policies should mandate meaningful community participation in decision-making processes related to mining activities. Ensuring local communities have a voice in the planning and execution of mining projects contributes to more inclusive and sustainable outcomes. Strengthening monitoring mechanisms and enforcement capabilities is essential. Regular audits, inspections, and the use of satellite technologies can enhance regulatory oversight, ensuring compliance with environmental standards. Clear policies on mine closure and post-closure obligations should be established. Mining companies should be held accountable for rehabilitation efforts, including financial provisions for long-term monitoring and maintenance of rehabilitated sites. The pursuit of sustainable mining practices is an evolving journey that demands collaboration, innovation, and a commitment to balancing economic prosperity with environmental preservation. The insights gained from this review provide a foundation for informed decision-making, encouraging stakeholders to collectively navigate towards a future where responsible mining practices coexist harmoniously with the natural world. Through ongoing research, policy evolution, and industry adaptation, the

mining sector can play a pivotal role in shaping a sustainable and resilient future for our planet.

3. Reference

1. Abaje IB, Bello Y, Ahmad SA. A review of air quality and concentrations of air pollutants in Nigeria. *J Appl Sci Environ Manag.* 2020;24(2):373-379.
2. Agboola O, Babatunde DE, Fayomi OSI, *et al.* A review on the impact of mining operation: Monitoring, assessment and management. *Results Eng.* 2020;8:100181.
3. Anderson JH, Pess GR, Carmichael RW, *et al.* Planning Pacific salmon and steelhead reintroductions aimed at long-term viability and recovery. *N Am J Fish Manag.* 2014;34(1):72-93.
4. Azapagic A. Developing a framework for sustainable development indicators for the mining and minerals industry. *J Clean Prod.* 2004;12(6):639-662.
5. Aznar-Sánchez JA, Velasco-Muñoz JF, Belmonte-Ureña LJ, Manzano-Agugliaro F. Innovation and technology for sustainable mining activity: A worldwide research assessment. *J Clean Prod.* 2019;221:38-54.
6. Bagatin R, Klemeš JJ, Reverberi AP, Huisingh D. Conservation and improvements in water resource management: a global challenge. *J Clean Prod.* 2014;77:1-9.
7. Banchirigah SM, Hilson G. De-agrarianization, re-agrarianization and local economic development: Re-orientating livelihoods in African artisanal mining communities. *Policy Sci.* 2010;43:157-180.
8. Basu AJ, van Zyl DJ. Industrial ecology framework for achieving cleaner production in the mining and minerals industry. *J Clean Prod.* 2006;14(3-4):299-304.
9. Bebbington AJ, Bury JT. Institutional challenges for mining and sustainability in Peru. *Proc Natl Acad Sci USA.* 2009;106(41):17296-17301.
10. Benzidia S, Makaoui N, Bentahar O. The impact of big data analytics and artificial intelligence on green supply chain process integration and hospital environmental performance. *Technol Forecast Soc Change.* 2021;165:120557.
11. Buchanan D, Dawson P. Discourse and audience: organizational change as multi-story process. *J Manag Stud.* 2007;44(5):669-686.
12. Castello L, Macedo MN. Large-scale degradation of Amazonian freshwater ecosystems. *Glob Change Biol.* 2016;22(3):990-1007.
13. Csavina J, Field J, Taylor MP, *et al.* A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations. *Sci Total Environ.* 2012;433:58-73.
14. Lakshmi S, Bitragunta V. Designing of SEPIC PFC based Plug-in Electric Vehicle Charging Station. *International Journal of Core Engineering & Management.* 2022, 7(1).
15. Dornelas M. Disturbance and change in biodiversity. *Philos Trans R Soc Lond B Biol Sci.* 2010;365(1558):3719-3727.
16. Gastauer M, Silva JR, Junior CFC, *et al.* Mine land rehabilitation: Modern ecological approaches for more sustainable mining. *J Clean Prod.* 2018;172:1409-1422.
17. Gibbons JW, Scott DE, Ryan TJ, *et al.* The Global Decline of Reptiles, Déjà Vu Amphibians. *BioScience.* 2000;50(8):653-666.

18. Giurco D, Petrie JG. Strategies for reducing the carbon footprint of copper: New technologies, more recycling or demand management? *Miner Eng.* 2007;20(9):842-853.
19. Gupta VV, Germida JJ. Soil aggregation: Influence on microbial biomass and implications for biological processes. *Soil Biol Biochem.* 2015;80:A3-A9.
20. Heffron RJ. The role of justice in developing critical minerals. *Extr Ind Soc.* 2020;7(3):855-863.
21. Henderson C, Beach A, Finkelstein N. Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *J Res Sci Teach.* 2011;48(8):952-984.
22. Irene WM, Raphael GW, Daniel WI. Impact of mining on environment: A case study of Taita Taveta County, Kenya. *Afr J Environ Sci Technol.* 2021;15(5):202-213.
23. Kabir M, Habiba U, Iqbal MZ, *et al.* Impacts of anthropogenic activities & climate change resulting from increasing concentration of Carbon dioxide on environment in 21st Century; A Critical Review. *IOP Conf Ser Earth Environ Sci.* 2023;1194(1):012010.
24. Kampa M, Castanas E. Human health effects of air pollution. *Environ Pollut.* 2008;151(2):362-367.
25. King JM, Scheepers ACT, Fisher RC, Reinecke MK, Smith LB. River rehabilitation: literature review, case studies and emerging principles. *Water Res Comm Rep.* 2003;1161(1):03.
26. Lal R. Soil carbon sequestration impacts on global climate change and food security. *Science.* 2004;304(5677):1623-1627.
27. Lloyd TJ, Oliveira U, Soares-Filho BS, *et al.* Multiple facets of biodiversity are threatened by mining-induced land-use change in the Brazilian Amazon. *Divers Distrib.* 2023;29(9):1190-1204.
28. Mancini L, Sala S. Social impact assessment in the mining sector: Review and comparison of indicators frameworks. *Resour Policy.* 2018;57:98-111.
29. Mensah AK. Role of revegetation in restoring fertility of degraded mined soils in Ghana: A review. *Int J Biodivers Conserv.* 2015;7(2):57-80.
30. Mora C, Graham NA, Nyström M. Ecological limitations to the resilience of coral reefs. *Coral Reefs.* 2016;35:1271-1280.
31. Moran CJ, Lodhia S, Kunz NC, Huisinigh D. Sustainability in mining, minerals and energy: new processes, pathways and human interactions for a cautiously optimistic future. *J Clean Prod.* 2014;84:1-15.
32. Naylor RL, Hardy RW, Buschmann AH, *et al.* A 20-year retrospective review of global aquaculture. *Nature.* 2021;591(7851):551-563.
33. Nikolic N, Schultze-Kraft R, Nikolic M, Böcker R, Holz I. Land degradation on barren hills: a case study in northeast Vietnam. *Environ Manage.* 2008;42:19-36.
34. Pangestuti DC, Muktiyanto A, Geraldina I. Modified of ERM Index for Southeast Asia. *Cogent Bus Manag.* 2023;10(2):2199906.
35. Peterson GD, Heemskerk M. Deforestation and forest regeneration following small-scale gold mining in the Amazon: the case of Suriname. *Environ Conserv.* 2001;28(2):117-126.
36. Sheoran V, Sheoran AS, Poonia P. Soil reclamation of abandoned mine land by revegetation: a review. *Int J Soil Sediment Water.* 2010;3(2):13.
37. Siqueira-Gay J, Sonter LJ, Sánchez LE. Exploring potential impacts of mining on forest loss and fragmentation within a biodiverse region of Brazil's northeastern Amazon. *Resour Policy.* 2020;67:101662.
38. Vasilachi IC, Asiminicesei DM, Fertu DI, Gavrilescu M. Occurrence and fate of emerging pollutants in water environment and options for their removal. *Water.* 2021;13(2):181.
39. Williams JR. Addressing global warming and biodiversity through forest restoration and coastal wetlands creation. *Sci Total Environ.* 1999;240(1-3):1-9.
40. Zamora-Ledezma C, Negrete-Bolagay D, Figueroa F, *et al.* Heavy metal water pollution: A fresh look about hazards, novel and conventional remediation methods. *Environ Technol Innov.* 2021;22:101504.
41. Zimmer M, Ajonina GN, Amir AA, *et al.* When nature needs a helping hand: Different levels of human intervention for mangrove (re-) establishment. *Front For Glob Change.* 2022;5:784322.
41. Allison SK. *Ecological Restoration and Environmental Change: Renewing Damaged Ecosystems.* Routledge; 2012.
42. Hughes JD. *An Environmental History of the World: Humankind's Changing Role in the Community of Life.* Routledge; 2009.
43. Mountjoy AB. *Industrialization and Underdeveloped Countries.* Routledge; 2017.
44. Rietveld E, Boonman H, van Harmelen T, Hauck M, Bastein T. *Global Energy Transition and Metal Demand. An Introduction and Circular Economy Perspectives.* TNO; 2019.
45. Boswell R. Surveyed Scientists Agree Global Warming Is Real. *Human-induced global warming is real, according to a recent US survey based on the opinions of 3,146 scientists.*
46. Coppin N, Stiles R. Ecological principles for vegetation establishment and maintenance. In: *Slope Stabilization and Erosion Control: A Bioengineering Approach.* Taylor & Francis; 2003:61-99.
47. Igogo T, Lowder T, Engel-Cox J, Newman AM, Awuah-Offei K. Integrating clean energy in mining operations: opportunities, challenges, and enabling approaches.