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Economic and Technological Evaluation of Mine Tailings Reprocessing for Sustainable Resources Recovery

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ABSTRACT

Mine tailings and waste, a by-product of mineral extraction, represent both an environmental challenge and a potential resource for secondary mineral recovery and further use. In response to increasing global demand for critical raw materials and the drive toward sustainable mining practices, this study evaluates the economic and technological feasibility of tailings reprocessing. The research focuses on maximizing the recovery of residual minerals, repurposing tailings for industrial applications, and minimizing environmental impact. Key areas explored include the commercial viability of tailings utilization, cost-effective technological techniques, and a proposed processing scheme aimed at optimizing mineral recovery while reducing operational costs. Market analysis suggests strong demand for processed tailings in the production of white ware ceramics, bricks, pipes, tiles, and other materials essential for sustainable infrastructure. Hypothetical data indicate that approximately 70,000 tons of tailings could be repurposed annually, generating estimated cost savings of up to $5.5 million. These findings underscore the potential for transforming mine tailings from waste into a commercially viable and environmentally sustainable resource. The study contributes to the ongoing discourse on responsible resource management and circular economy strategies in the mining sector.

Keywords: Mine, waste, Tailings, Economics, Recovery.

1.0 Introduction

The world as a global community benefits from the whole process of mining because it makes the end product accessible for the 21st century's technology, infrastructure, and energy demands. Amongst the end products, some products are not properly utilized, mine tailings. Generally, mine tailings are disposed of in large impoundments or ponds near the mining site. Because mining waste and tailings are typically dumped into lakes, rivers, or even the ocean is a significant source of concern in the mining industry. The environmental impact of these improper disposals is more evident now than ever, as they continue to accumulate, with estimates showing global generation of over 100 billion tonnes of waste rock and 10–15 billion tonnes of tailings annually (Azapagic, 2004; Lottermoser, 2011). These practices often result in acid mine drainage, heavy metal contamination, land and environmental degradation to the ecosystem and surrounding communities.

According to Vitti & Arnold (2022), mining waste utilization can benefit the host community/country's economy in a variety of ways, boosting the local economy and international trade while conserving the environment (Reconalla and Eguia, 2024). However, due to advancements in mineral recovery technologies and the growing scarcity of high-grade ores, tailings have gathered attention as possible sources of valuable minerals and other industrial materials (Edraki *et al*., 2014). This would reduce the use of other natural building materials and eliminate the need for extensive land areas to store mine tailings, lowering the economic and environmental costs.

2.0 Background and Literature Context

Mining is an unavoidable anthropogenic process that occurs worldwide and frequently

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alters the land's shape and environment as a whole. More than 101 minerals are being produced yearly around the world from different mines, which include but are not limited to fuels, metallic, non-metallic, atomic, and minor minerals. Mitigating the environmental and social impacts (water contamination, habitat destruction, and the release of potentially harmful substances) associated with their disposal is one of the main reasons for considering the utilization of waste mine tailings. This study will reveal how mine tailings from sites could be further assessed and utilized for greater products while helping to eliminate and lessen the environmental impact and be economically sustainable. In the last few decades, mining activities have globally increased tremendously to produce the required quantity to meet the technology, energy, and infrastructure demands. In a real sense, the annual amount of mine tailings generated by industries exceeds 10 billion tons (Adiansyah *et al*., 2015) and is expected to grow due to the increasing production forecast by 2035; the proportion of tailings will double (CESCO, 2019). Simultaneously, the problems faced by mining industries are also going to increase with an increased production rate.

The efficiency of chemical and mechanical extraction processes is never 100% and it is neither possible to reclaim all reusable and expended processing chemicals and reagents. They may also contain many other valuable elements, as has been shown in numerous studies (Khorasanipour and Jafari, 2017; Andersson *et al*., 2015). However, due to improvements in mineral recovery technologies and the growing scarcity of high-grade ores, tailings have gathered momentum as potential sources of raw materials. They will be valuable minerals and industrial materials in the present global circular economy (Edraki *et al*., 2015; Jeswiet, 2017).

3.0 Methodology

This research adopts a literature-based review analytical methodology combined with hypothetical data modelling.

3.1 Data Sources

i. Peer-reviewed journals such as Journal of Cleaner Production, Minerals Engineering, and Resources Policy.
ii. Case studies from UNEP and ICMM
iii. Technical databases and industry reports, including those from the U.S. Geological Survey (USGS), World Bank mining reports, and environmental agencies.
iv. Books and academic texts focused on mining waste management and mineral processing technologies.

3.2 Evaluation Criteria

Tailing reuse potential was assessed using:

i. Economic Viability: Cost-benefit analysis of reprocessing tailings against using traditional raw materials.
ii. Mineral Content: Chemical and physical properties of the tailings, with emphasis on silica, alumina, and residual metals.
iii. Environmental Sustainability: Impact on reducing ecological degradation, tailings footprint, and potential to mitigate environmental hazards.
iv. Market Demand: Industrial relevance and demand for potential products such as ceramic tiles, construction materials, and pipes.
v. Technology Assessment: Various processing techniques are evaluated and assessed using key performance indicators such as scalability, cost effectiveness, and recovery efficiency. They were analyzed to determine the most appropriate technologies for different types of tailings.

3.3 Hypothetical Scenario

Two types of mine sites were assumed:

i. A gold mining operation.
ii. A feldspar and Kaolin plant producing ceramic-quality residue.

In both cases, the tailings are presumed to contain high concentrations of silica and alumina, which are critical for ceramic and tile production. These assumptions are

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based on average geochemical profiles reported in the relevant literature reviewed. These tailings are hypothesized to hold significant potential for reuse in industrial applications.

3.4 Reliability of Secondary Data

All secondary data used in this study were cross-referenced and validated through multiple sources to ensure reliability. Where possible, datasets were selected from institutions known for their methodological transparency and adherence to quality control and research standards (e.g., Elsevier peer-reviewed publications and recognized industry bodies). The hypothetical scenario was built using averaged values from at least three independent studies to reduce the risk of data skew or bias.

3.5 Limitations

i. All estimates are based on theoretical yields and generalized market data.
ii. Environmental permitting and regulatory approvals are not factored into cost models.
iii. Real-world applications may vary due to site-specific geochemical variability and infrastructure availability.

4.0 Results and Economic Modelling

4.1 Tailing Composition (Hypothetical Example)

Table 4.1: Assumed geochemical composition of mine tailings indicating high silica and alumina content suitable for ceramic and industrial applications.

Component	Percentage %
Silica SiO_2	58
Alumina Al_2O_3	21
Iron oxide Fe2O	8
Feldspar	6
Kaolinite	11
Magnesium oxide MgO	2
Potassium Oxide K_2O	4
Sodium Oxide Na_2O	2

High silica and alumina levels indicate strong suitability for ceramics, tiles, and pipes.

4.2 Estimated Volumes

i. **Annual Tailings Volume**: Estimated at **1.5 million tonnes/year**, based on average discharge rates from mid-scale mining operations.
ii. **Recovery Volume**: **1.2 million tonnes/year**, assuming an **80% operational efficiency** in collection and processing.
iii. **Workable Portion for Construction**: Assumed to be **900,000 tonnes/year**, factoring in losses due to impurities, fines unsuitable for processing, and moisture content.

4.3 Product Recovery Rates

The recovery rates of valuable materials from tailings can vary based on the different processing methods used. For this model, the following product-specific recovery rates are assumed. These are based on benchmarks from pilot-scale studies

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(Francisco *et al.,* 2021) and adjusted to reflect hypothetical yield conditions in a developing-country context. These are:

i. Ceramic whitewares 70%
ii. Pipes: 65%
iii. Tiles: 75%

4.4 Costing (per ton)

The total cost associated with utilizing tailings includes processing costs, transport costs, production costs, and labor costs. Below is a hypothetical cost estimation breakdown.

i. Processing cost: $30/ton
ii. Transportation cost: $10/ton
iii. Production cost: $50/ton

Total cost per ton= processing cost + transport cost + production ($90/ton)

4.5 Market Price

i. Ceramics whitewares: $150/ton
ii. Pipes: $120/ton
iii. Tiles: $130/ton

4.6 Example Profit Calculation

i. Ceramic Whitewares*:*
Revenue = Volume * Price = 70,000 tons * $150/ton = $10,500,000
Cost = Volume * Cost per ton = 70,000 tons * $90/ton = $6,300,000
Profit = Revenue - Cost = $10,500,000 - $6,300,000 = $4,200,000

ii. Pipes**:**
Revenue = Volume * Price = 65,000 tons * $120/ton = $7,800,000
Cost = Volume * Cost per ton = 65,000 tons * $90/ton = $5,850,000
Profit = Revenue - Cost = $7,800,000 - $5,850,000 = $1,950,000

iii. Tiles**:**
Revenue = Volume * Price = 75,000 tons * $130/ton = $9,750,000
Cost = Volume * Cost per ton = 75,000 tons * $90/ton = $6,750,000
Profit = Revenue - Cost = $9,750,000 - $6,750,000 = $3,000,000

Summary of Financial Outcomes*:*
Total Profit from Ceramic Whitewares: $4,200,000
Total Profit from Pipes: $1,950,000
Total Profit from Tiles: $3,000,000

4.7 Feasibility Comparison

Table 4.7 Feasibility comparison of traditional disposal and reprocessing models for mine tailings

Feature	Traditional Disposal	Reprocessing Model
Cost	High	Revenue-generating
Environmental Risk	High	Low
Land Use	Large pond	Modular plants
Jobs	Minimal	High
Sustainability	Low	High

5.0 Discussion

The increasing volume of mine tailings generated annually presents not only a persistent environmental and geological challenge but also an underexplored economic opportunity. With the global shift towards sustainable development, the mining industry must evolve to meet environmental and resource efficiency standards. One idea is to leverage mine tailings as a raw material in the manufacturing and construction industry, reducing waste and potentially lowering costs compared to the traditional methods. Transforming tailings into secondary resources offers numerous socio-economic, geological, and environmental benefits. For instance, successful tailings repurposing projects in South Africa and Chile have demonstrated reduced reliance on virgin

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materials, cost savings, and decreased ecological impact (Tutu *et al.,* 2020; Navarro *et al*., 2019), and some studies in Namibia and Costa Rica (Harrison and others, 2002). This approach can contribute to a sustainable and circular economy with the potential to save time, cost, and resource consumption in the mining, construction industries, leading to environmental protection. It is quite important to develop cost-effective technology that uses these tailings can reduce environmental risks and benefit communities by eliminating the dangers of storing tailings on the surface (Yu *et al.,* 2021).

As stipulated by Calderon *et al.* (2020), bricks and other materials could be designed from these wastes, and can support buildings, facades, floors of civil works, sidewalks, parks, central squares, and even tracks and roads due to their excellent resistance. The reuse of mineral residues as aggregates to prepare concrete materials for road and bridge construction presents the state of development of mining community construction in a more friendly and competitive cost.

However, while these case studies show promising results, replicating such success at a global scale across different countries and regions faces several contextual challenges**.** As reported by Kossoff *et al.* (2014) and Chen *et al.* (2023), for instance, tailings from different regions often exhibit significant variability in mineralogical and geochemical composition, which can limit the standardization of reuse technologies. Additionally, regions with weak environmental regulations or political instability, especially across some African countries, may find it difficult to attract the investments necessary for large-scale tailings reprocessing. Differences in infrastructure, logistics, and energy access further complicate implementations accordingly. For example, exporting and transporting tailings from remote mines to processing centers may be economically prohibitive unless on-site processing solutions are adopted. Therefore, broader implementation requires adaptable, decentralized technologies and flexible policy frameworks that consider local realities. Another critical factor influencing tailings utilization is market volatility, particularly in metals pricing and construction material demand. For instance, during periods of low metal prices, the economic incentive to reprocess tailings for metal recovery diminishes sharply (Ghorbani *et al.,* 2021). Similarly, the demand for construction materials such as bricks or ceramics may fluctuate based on regional housing booms, global supply chain disruptions, or inflationary pressures. These market dynamics necessitate robust financial modelling and risk mitigation strategies in any proposed tailings valorization project. Situations like the 2023 slump in copper prices, for instance, delayed several reprocessing ventures in South America that were previously considered economically feasible (Ghorbani *et al.,* 2021).

Additionally, changes in environmental and mining policies play a dual role, either enabling or restricting tailings reuse. Recent policy shifts, such as the EU's Green Deal and Canada's strengthened tailings management rules under the Metal and Diamond Mining Effluent Regulations (2021), have encouraged industries to invest in circular economy practices (European Commission, 2022). On the other hand, in jurisdictions where mining codes are outdated or enforcement is weak (e.g., across African countries), tailings reprocessing may face bureaucratic bottlenecks or public resistance due to historical environmental harm. A lack of inter-ministerial coordination between the mining, environment, and construction sectors also often leads to fragmented implementation.

6. 0 Conclusion

This study has demonstrated that mine tailings, traditionally viewed as waste, possess significant potential for economic and environmental protection. By utilizing tailings into construction materials such as ceramics, tiles, bricks, and pipes, the mining

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sector can contribute to a circular economy while mitigating environmental liabilities. With appropriate processing technologies such as flotation, beneficiation, and bioleaching, residual minerals can be recovered. Market analysis revealed a growing demand for affordable green-certified building materials.

The sustainability of construction and road materials depends on selecting quality granular inputs found in mine residues. Alternative materials from mining by-products offer a viable, sustainable solution, and proper on-site processing is essential to meet global standards. Despite these outcomes, the study acknowledges limitations, as economic estimates are based on hypothetical data and may vary with mineralogy, market fluctuations, and regulatory frameworks. Technical feasibility can be constrained by heterogeneity in tailings composition and inadequate infrastructure. Nevertheless, integrating mine tailings reuse into national mineral policies and aligning with Sustainable Development Goals can enhance sustainability efforts. Encouraging legal frameworks and investments in advanced processing technologies can accelerate adoption and promote resilience in mining-dependent communities.

7. 0 Recommendations

Future works and research should focus on the analysis of detailed geochemical and mineralogical characterization of diverse tailings sites to refine recovery methods and economic models. Pilot-scale testing and life cycle assessments are needed to validate laboratory findings to quantify long-term environmental benefits while understanding impacts on carbon savings and resource efficiency gains of various reuse scenarios. These analyses can help inform policy decisions, attract green investment, and shape certification standards for tailings-derived products. Furthermore, interdisciplinary studies combining geology, engineering, and socio-economic analysis will be crucial to developing tailored, scalable models for sustainable tailings reprocessing across different mining regions. Stakeholders in the mining industry, including but not limited to mining companies, regulators, research institutions, and community organizations, must be strategically engaged in this transformation journey. Some specific recommendations are listed in Table 8 below.

An engineering and scientific collaborative-driven policy supported approach is essential to fully unlock the value of mine tailings as a resource, while ensuring environmental stewardship, economic viability, and social inclusion in mining-affected regions. Future research should also explore innovative processing technologies such as microwave-assisted leaching, biomineralization, or carbon sequestration via mineral carbonation.

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