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Case Report

Potential recycling of mine tailings for PMC's Padcal Mine, Philippines

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ABSTRACT

Industrialized countries attempted to obtain minerals, resulting in a developed method to extract valuable minerals from the ground. Consequently, waste mine tailings are produced and, when left to pile up, will potentially be hazardous to the environment and the people. However, more mine tailings become a problem when the organization needs clarification on the minerals' value and what they can be used for. This study focuses on a multi-criteria analysis of the potential repurposing of the Philex Mining Corporation (PMC) tailings in Benguet, Philippines. While mining policies were considered, findings show that piles of mine tailings had not been considered for refining to produce more resources for development, construction, and economic growth The study employs qualitative inquiry to understand better the grassroots processes and reconnaissance of the stored tailings. The analysis tries to promote sustainable practices – presenting a higher sustainability priority, resource conservation, and the responsible management of mining waste, making it a more favorable alternative to traditional tailing storage facilities. Several industrial uses for the tailings have been suggested to reinforce waste diversion.

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INTRODUCTION

The global community benefits from mining because it makes the resources accessible for technology, infrastructure, and energy. Mining pollution can cause water pollution, with heavy metals and radionuclides being the most common pollutants [1]. Today's mining methods contribute to solid waste accumulation, accounting for a significant portion of the world's waste streams. Not only that, but the amount of waste generated each year totals millions of tons [2, 3]. Mining is an unavoidable anthropogenic process that occurs worldwide and frequently alters the land's shape. A large amount of land or earth must be moved, and most of the process involves extracting valuable minerals and elements from waste. In today's world, metal mining is increasingly important. As a result, more metals, particularly copper, are extracted from the ground [4, 5].

Historically, mine tailings have been disposed of in large impoundments or ponds near the mining site. The fact that tailings are typically dumped into lakes, rivers, or even the ocean is a significant source of concern in the mining process. They are backfilled or dumped into gauges as mining waste [6]. It is worth noting that mine tailings are stored in dams, which can be reused for other purposes. Environmental disasters are frequently a problem in mining, and they are unavoidable. This results in social disasters. More than anything else, how mine tailings are handled and controlled determines the likelihood of environmental disasters caused by mining [7].

Mining operations in the Philippines have frequently been complex, harming the environment and making it difficult for people to live their everyday lives. The disposal or stor-

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age of large amounts of mining waste, known as tailings, impacts the environment and the people who live there and is an integral part of the mining company [8]. Tailings show the global impact of the mining industry. When precious minerals and metals from mined ore are processed and extracted, a liquid slurry of tiny mineral particles known as tailing is created. Pipes are used to transport these tiny mineral fragments to extensive tailings storage facilities (TSFs), where they are kept for many years or even decades [7].

Heavy metal pollution has always been a significant issue because mining harms people's health. Because of the wind, arsenic, and cadmium move around in nature evenly. As a result, temperatures rise, worsening health conditions [9]. Most mining companies' most significant problem is tailings dam failures, which are said to be the cause of three-fourths of mining-related environmental disasters [10]. Tailings storage capacity can be challenging to manage. In the study of [7], for example, wet storage capacity for wet tailings necessitates a more efficient dam to store the tailings for an extended period. When the handling and storage processes fail, it poses a significant threat to the system and the environment due to radioactive reactions based on time management.

In 2012, a mining incident at Padcal mine, Philex Mining Corporation in Benguet, released 20.6 million tons of toxic tailings into rivers [11]. Recent interest in repurposing mine tailings is growing, with the potential to reduce environmental and social impacts, such as water contamination and habitat destruction.

Large private and governmental mining industries do not repurpose their waste mine tailings to generate additional revenue while ensuring the environment's and its inhabitants' safety [12]. Vitti & Arnold (2022) stated that mining can help the country's economy in a variety of ways, and reusing waste mine tailings can significantly contribute to the country's revenue growth [13, 14].

However, there has been growing interest in exploring potential repurposing opportunities for mine tailings. Despite the fact that more mining companies are doing their part to reduce the damage they cause, most mining companies have established systems for disposing of mine waste, such as dams, embankments, and a variety of other things. One of the main reasons for considering the repurposing of mine tailings is to mitigate the environmental and social impacts associated with their disposal. Traditional tailings storage methods can pose risks such as water contamination, habitat destruction, and the release of potentially harmful substances into the surrounding environment. Repurposing mine tailings can mitigate environmental and social impacts, such as water contamination, habitat destruction, and the release of harmful substances into the environment [15].

As a result, this study focuses on the recycling applicability and potential of PMC's mine tailings in Benguet's Padcal. Also, the study considered how mine tailings, such as iron, aluminum, and other metals, could be reused and recycled to eliminate the requirement for storage facilities and lessen the impact of mine tailings on the environment. This study looked into how these mine tailings could be repurposed and areas where they could be reused, which justifies the conduct of this study. 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.

This research intends to the promote reduction of waste generation, to contribute to sustainable resource utilization and the promotion of circular economy principles. Implementing effective tailings recycling practices can contribute to more sustainable and responsible mining operations, benefiting both the industry and the surrounding communities. The implications of the findings will provide valuable insights for policymakers, mining companies, future researchers, students, and stakeholders interested in transforming mine tailings into valuable resources while minimizing their environmental footprint.

MATERIALS AND METHODS

Locale of the Study

Padcal, Benguet in the Philippines, is home to the PMC, a copper-gold Mine. It is situated southeast of Baguio City at a height of around 1500 meters. The rainy season lasts from May to October, with an annual rainfall of about 4500 mm. Since the mine's underground block cave operations began in 1958, copper concentrates containing copper, gold, and silver have been produced. Their mining product is typical porphyry copper, with primary copper ore minerals chalcopyrite and bornite and gold and silver as byproducts [16].

The Padcal mine production capacity generates a total milled ore of 7,945,879 metric tons in 2021, higher than the tonnage of 7,837,536 in 2020 and lower than that of 8,112,791 in 2019. Also, the budget tonnage per day is 23,200 as of 2022. Moreover, as of 2023, the average tonnage per day is 18,968.87, the average tonnage per month is 572,859.9, and the land area covered by the tailing pond for TSF 3 is 165 hectares. Based on the current tailing output, it is projected to be full by the end of October 2025, assuming a 647 m reduced level (mRL) as final crest elevation and 642 mRL slimes elevation. The volume capacity calculation to 642 mRL elevation based on the September 2023 Bathymetric survey is 12.9M DMT.

Population Sampling

The research is based on qualitative inquiry processes, with the goal of better understanding how mine repurposing is beneficial with respect to the current practices of PMC. The study used purposive sampling to identify informants for the investigation, which involved interviewing current informants and suggesting others who meet the criteria. The study focused on the corporation's staff, ensuring that everyone in the sample had experienced the subject matter.

The environmental protection and enhancement officer and the tailing storage facility departmental head working at PMC with three or more years of experience were included. The environmental protection and enhancement officer was relevant to this study because the participants gave technical expertise in areas such as environmental impact assessment, mine tailing management, and waste management. The tailing storage facility departmental head was relevant to this study because the participant gave valuable insights into the management and operation of tailing storage facilities.

Data Gathering Procedure

This study's primary data source was a semi-structured, one-on-one interactive session. The researcher spoke with the mining staff and elicited information about mine waste repurposing, the mine tailing characteristics, the possible applications of their tailings, and the benefits of utilizing the mine tailings in Padcal by asking open-ended questions. The interviews were recorded with the informants' permission. Reflective notes were taken throughout the interviews, particularly at the end, and as a result, other information from the PMC's internal and published reports was included. This helped the researcher identify their strengths and weaknesses while also providing some transcription prompts [17]. Each interview lasted about 45 minutes. In addition, the written notes contained immediate personal thoughts about the interview as well as observations of both verbal and nonverbal behaviors as they occurred. The researcher transcribed the audio recording after the interviews ended. The researcher ascertained that the participant's language accurately reflected the meanings embedded in the experience. Through the participants' consent and voluntary participation, the researcher initially established a connection with them. Data collection continued until no new discoveries were made and category saturation was reached.

Ethics approval was obtained from the Saint Louis University Research Ethics Committee, and the various mining companies endorsed the introductory letters before conducting the study. The study participants were protected by getting detailed information via written informed consent, which means that potential research participants were fully informed about the research procedures and dangers before agreeing to participate. Participation in this study was voluntary and posed no significant risk to physical or psychological wellbeing. Up until the point of data analysis, all participants had the option to withdraw from the study for any reason.

The information gathered for this research is private and confidential. There was no personal information about the participants in the study report, such as name or address. After examining the data, the researcher removed all identifying information, and the study results were sent without any identifying information. The data was kept on a password-protected laptop with a locked file. The raw data would be accessible only to the researcher and the research panel. The researcher can decline to ask for the interview if it appears inappropriate for the study, and the participants would not be held liable to the researcher or the study.

Characterization Method of Mine Tailings

During the data gathering, a representative sample of PMC mine tailings was taken from tailing storage facility 3. Three Samples were sourced and labeled North, Middle, and South, respectively, and the analysis was carried out at Saint Louis University Mining Laboratory, Baguio City. The samples were subjected to X-ray Fluorescence Spectroscopy (XRF) to determine the elemental analysis and reported as oxides.

RESULTS AND DISCUSSION

Philippine Regulations

The Department of Environment and Natural Resources (DENR) oversees both the Mines and Geosciences Bureau (MGB) and the Environmental Management Bureau (EMB), which monitor mining activities and ensure compliance when issuing permits for treatment, storage, and disposal (TSD) to facilities with high volume wastes. MGB is in charge of mining operations administration and oversight, while EMB is in charge of monitoring and controlling the environment. Before the MGB issues any permits, the relevant local government units must determine whether a mining plan is viable. Currently, these government agencies only require storage of mine tailings.

PMC conducts its operations under the highest ethical standards, adhering to good governance as a responsible corporate citizen. It strives to abide by its Code of Conduct and all relevant laws, guidelines, and mining industry requirements. Additionally, it provides partners in the mining industry with its expertise and starts enlightening and productive discussions about issues that concern the sector and society.

Tailing Management Practices

PMC has implemented some mine tailing management practices to minimize the environmental impact of its operations. Their mine tailings are not utilized, but instead stored in the tailings pond. The company has constructed TSFs that are designed to collect and store mine tailings, which are the waste materials generated during mining operations. These are engineered to prevent leaks and spills and are regularly monitored to ensure their integrity. They are currently on their third TSF.

Their only plan for their tailings is to store them because their tailings are only allowed to be stored in the tailing storage facilities. If the waste cannot be converted into something useful, mine waste tailing storage is usually beneficial. If waste is not converted into something useful, it tends to accumulate in the environment and cause problems for people there.

While storing mine tailings in a pond can be a viable option for tailings management, it is important for mining companies to carefully consider the specific characteristics of the tailings, the local environment, and regulatory requirements and to implement appropriate monitoring and management measures to ensure the safety and sustainability of the TSF.

Table 1. Composition of PMC tailings and particular regions of samples taken at TSF 3. The numbers displayed are oxide-form reports of the entire elemental analysis

Sample	Composition*						
	Al_2O_3 wt %	CaO wt %	Fe_2O_3 wt %	Cu wt %	MgO wt %	SiO_2 wt %	S wt %
Sample north	8.23	3.94	8.19	0.048	3.3	32.41	1.29
Sample middle	6.63	3.98	8.53	0.044	2.0	28.78	1.36
Sample south	7.37	3.77	8.79	0.044	2.0	28.66	1.29
Mean average	7.41	3.90	8.50	0.05	2.43	29.95	1.31

The participants were asked how long they intended to store their tailings:

Participant 1 also said:

> *"Forever, maybe, since there is nowhere else to store it besides our pond. Unless maybe there will be a new technology to help with that."*

Participant 2 explained further from the response of Participant 1 by saying that the effect of constructing TSFs on the environment is mostly deforestation and some accompanying social issues because of the affected owners where they would have to settle claims as needed.

The participants further explained how their tailings are managed.

> *"We don't treat the tailings; we just store them. We just separate the solids from the water. We use decanting system here."* (Participant 1)

Also, participant 2 said:

> *"We do not do any treatment on the tails. Immediately after we have recovered the metals, it goes through tunnels and pipes to the treatment storage disposal TSFs. Our tailings are not toxic. We do monthly monitoring. There are no heavy metals present in our effluent." there are no significant amounts of mercury, arsenic or cyanide in our tailings.* (Participant 2).

Although the participants had a general idea that mine mill tailings can be used in construction materials, they needed to have initiative on how their mill tailings from their company can be reused. They also had their perception toward the repurposing of mine tailing. Participant 1 explained that repurposing these tailings will have a minimal negative impact on the environment but can maybe contribute economically to the country by reducing the cost of constructing storage facilities.

Participant 2 had a perception about the environmental impact if their company pursues repurposing by utilizing their tailing.

> *"If there is really a diversion of tailings, then definitely, there will be no tailings storage facilities and that means there will be no submerged areas, no loss of habitat, no deforestation and reforestation, and there will be no additional cost. But there is no initiative on that at the moment."* (Participant 2)

Reusing these tailings, according to Participant 1, would not cause much environmental harm, but it might speed up construction and boost the economy by making facilities more accessible and affordable for everyone to use. However, they do not recycle their tailings.

> *"But if we could reuse these tailings, I think there is not much impact on the environment if we would be utilizing the tailing. But if we could use this tailing, I think they will be some sort of economical program. But environmentally, it could be just reprocessing the tailing may be used in the construction materials. I think there will be no environmental impact and if there is, it will be minimal."* (Participant 2)

In all, the repurposing of mine tailings can positively contribute to a country's national economic growth by generating revenue, creating jobs, reducing environmental impact, and supporting the growth of critical industries. On the aspect of recycling applicability, and potential of tailings based on their characteristics, findings show that the absence of copper (Cu), the corporation's main mineral, in the samples suggests that the initial beneficiation and separation process was so effective that there was little to no copper left in the tailings. The typical minerals mine by PMC is porphyry copper.

Since their tailings are not treated nor reused, knowing the composition of their tailings was of importance to this research as they generate tons of tailings daily. Participant 2 said their tailings are basically composed of bornite and chalcopyrite. The company's treatment processes have stayed the same because the still follow the same till date since their tailings are not treated and the quality of the tailings do not cause any degradation.

Characteristics of PMC Mine Tailings at TSF3

The composition of mine tailings varies from one company to another because of the inherent ore characteristics where they mine as well as the processes each employs in mineral beneficiation. The suitability for utilization will be entirely depended on the characterization of the mine tailings. Whether it will require further separation of components or refinement on the intended use. In-depth studies will show the characteristics of mine-tailing composites, such as physical properties, mechanical properties, durability properties, and leaching behavior.

In order to determine how best to use and recycle the tailings, chemical analysis was used to analyze three tailings samples, labeled North, Middle, and South, to determine their potential for recycling and usage using The tables below contain a presentation of the chemical analysis's findings. Based on the analysis, the average mean of the chemical compositions for the mine tailing is presented.

As shown in Table 1, the compositions of copper tailings show that silicon dioxide, iron, and aluminum oxides have higher percentage concentration in the tailings than other metallic oxides. The tailings are composed of low-grade metallic and non-metallic oxides that can be financially recovered and recycled into various manufactured products such as cement manufacturing, glass, ceramics, bricks, etc. in the required percentage. With extensive utilization, the elemental composition of copper tailings, which includes Fe_2O_3, Al_2O_3, MgO, and SiO_2, has good concentration and recovery rates and can be used as additives in construction materials. The concentrations of the compounds present in the PMC tailings are consistent such that as it is, they can be used as an additive or substitute for the fine aggregates added to cement to form concrete. The high silica content makes this a plausible use. Further refinement can mean they can be used in the cement manufacturing industry.

Recycling Applicability and Potential of the PMC Mine Tailings

The mine tailings have good percentages of silicon dioxide, iron, aluminum oxide, and magnesium that can be repurposed for construction materials manufacturing because of their physical properties and chemical composition. Silica-rich mine tailings can also be used as a component in various construction materials, such as concrete, asphalt, tiles, and bricks. The tailings can be mixed with other materials, such as cement, lime, and aggregates to produce high-strength materials.

Several studies have investigated mine tailings as a supplementary cementitious material (SCM) in Portland cement manufacturing and have shown that it is possible to produce high-quality cement with tailings as a partial replacement for traditional raw materials. Due to their high silica content, silica-rich mine tailings can also be used as an SCM. They can react with the calcium hydroxide produced during cement hydration to form additional cementitious compounds [18].

The specific requirements and optimal dosage of mine tailings may vary depending on the type of tailings, their chemical compositions, and the specifications of the cement product. Portland cement is one of the most widely used types of cement. The average composition of Portland cement is CaO, 50–60%; SiO_2, 20–25%; Al_2O_3, 5–10%; MgO, 1–3%; Fe_2O_3, 1–2% and SO3, 1–2% [19]. Ordinary Portland cement contains different ingredients with varied proportions. Each ingredient imparts a different property to the cement. To produce good quality cement, it is important to know the proportions, functions and limitations of different cement ingredients.

- Silica (SiO_2). Silica or silicon dioxide is the second largest quantity of cement ingredients which is about 17 to 25%. Silica can be obtained from sand, argillaceous rock, etc. Enough silica helps to form di-calcium and tri-calcium silicates, which impart strength to the cement.
- Alumina (Al_2O_3). Alumina in cement is present in the form of aluminum oxide. The range of alumina in cement should be 3 to 8%. It is obtained from bauxite, alumina, and clay. Alumina imparts quick setting properties to the cement. In general, high temperature is required to produce the required quality of cement.
- Iron oxide (Fe_2O_3). Iron oxide quantity in cement ranges from 0.5 to 6%. It can be obtained from fly ash, iron ore, and scrap iron. The main function of iron oxide is to impart color to the cement.
- Magnesia (MgO). Cement contains Magnesia or Magnesium oxide in the range of 0.1 to 3%. Magnesia in cement in small quantities imparts hardness and color to the cement. If it is more than 3%, the cement becomes unsound, and the strength of the cement also reduces.

Along with lime and other inorganic oxides, these ingredients can widely be used as a cement additive. A material that can bind other materials together is cement, a binder that sets and hardens. In a process known as calcination, clay and other limestone materials are heated to 14500 °C in a kiln to create calcium oxide (CaO) from calcium carbonate ($CaCO_3$), which is then combined with the additions mentioned above. Portland cement is made by grinding the rigid material, known as clinker, along with a small quantity of gypsum.

To use mine tailings as SCM, they are first ground to a fine powder and then blended with the other raw materials used in cement production, such as limestone and clay [20]. The resulting mixture is then fed into a kiln and heated to high temperatures, which causes chemical reactions that transform the raw materials into cement clinkers to occur. The addition of mine tailings to Portland cement can improve the strength, durability, and workability of the resulting concrete [21].

Mine tailings as a SCM can provide economic benefits by reducing waste disposal costs and creating a new revenue stream. However, careful consideration of chemical composition is necessary to ensure no negative impact on cement performance and safety at the mine site. The use of mine tailings should not compromise the stability of the mine site.

Philex mine tailings are rich in silicon, iron, and aluminum oxides. The composition will be most suitable for cement production, which will eventually make its way to the construction industry, such as in civil works for roads. This environmentally friendly approach offers environmental and economic benefits. However, careful evaluation is necessary to ensure the tailings are not polluting, comply with geotechnical specifications, and are safe. Reprocessing techniques like crushing, grinding, flotation, and leaching may be necessary to remove impurities and adjust chemical composition. The decision to use mine tailings depends on individual mine and cement manufacturing processes. By

Table 2. An analysis based on multiple criteria evaluating the pros and cons of each factor in the reuse and recycling of their mine tailing

Factors	Pros	Cons	Balance
Tailing dam failures	F+ S++ T+		F+ S++ T+
Heavy metal seepage	F+ S+ T+		F+ S+ T+
Tailing dusting	S+ A+		S+ A+
Avoided cost of building more storage facilities	F+ T+		F+ T+
Liberating the area that the tailings dam had previously taken up.	F+		F+
Avoidance of leach collection and treatment	F+ S++ T+		F+ S++ T+
Using up mine tailings	F+ S+		F+ S+
Land recovery	F+		F+
Avoidance cost of post-closure care	F+ T+		F+ T+
Metal recovery	F++		F++
Slag	S+	F-	F- S+
Transport quarry-plant cost		F-	F-
Cost of investment		F-	F-
Machinery		F-	F-
Labour expense		F-	F-
Cost of energy		F-	F-
Cost of maintenance		F-	F-

using mine tailings as a supplementary material in cement manufacturing, the industry can reduce its reliance on virgin raw materials, helping to conserve natural resources and lowering the environmental impact of mining activities. The industry can reduce the energy consumption associated with mining and processing virgin materials, contributing to overall energy conservation.

Ultimately, the decision to reprocess mine tailings for use in cement production will depend on a variety of factors, including the specific characteristics of the tailings, the requirements of the cement manufacturing process, and the applicable regulations and standards.

Table 3. Multi-criteria analysis outlining the pros and cons of mine tailing storage

Factors	Pros	Cons	Balance
Slag	S+	F-	F- S+
Transport quarry-plant cost		F-	F-
Cost of investment		F-	F-
Machinery		F-	F-
Labour expense		F-	F-
Cost of energy		F-	F-
Cost of maintenance		F-	F-

Multi-Criteria Analysis

One of the objectives of this study is to present a multi-criteria analysis of storing the tailings in comparison to their utilization. After thorough consideration of various factors surrounding the idea of economic and environmental benefits of storing versus utilizing mine tailings, it came out that utilization of mine tailings is more beneficial than storing them. This study emphasizes the potential to reduce the consumption of natural resources by recovering valuable materials, minimizing waste, conserving energy, promoting environmental stewardship, and creating economic incentives for sustainable mining practices. Multi-criteria analysis is a decision-making tool that evaluates options based on multiple criteria, taking into account various factors and their relative importance [22]. It provides a structured approach to assessing and comparing different factors based on various criteria, which helps in making informed decisions that consider environmental sustainability [23]. In conducting a multi-criteria analysis of tailings utilization, it is necessary to evaluate each option and compare them with the advantages and disadvantages of other options for managing mine tailings [24]. The analysis should consider its immediate and prospective pros and cons and the risks and uncertainties associated with each option.

In this regard, the aim is to determine whether the advantages of recycling and reusing mine tailings outweigh the disadvantages. A factor item will be given symbols according to its relevance precedence, a method described by Hillebrandt [25] and used by Lu et al. [26] will be employed here. This is thoroughly integrated with the Bio-Economic Model since it states that the multi-criteria analysis can be a powerful approach in the decision whether to pursue repurposing of mine tailings. This combined allows for a comprehensive evaluation of various criteria and objectives, considering both economic and environmental factors [27].

Table 4. Pros and cons of reusing mine tailings compared to storing them in tailing storage facilities are compared in a brief and preferred order of results

Factors	Mine tailing	Storing tailing	Preferred order	
			Mine tailing	Storing tailing
Tailing dam failures	F+ S++ T+	-	1	2
Heavy metal seepage	F+ S+ T+	-	1	2
Tailing dusting	S+ A+	-	1	2
Avoided cost of building more storage facilities	F+ T+	-	1	2
Liberating the area that the tailings dam had previously taken up.	F+	-	1	2
Avoidance of leach collection and treatment	F+ S++ T+	-	1	2
Using up mine tailings	F+ S+	-	1	2
Land recovery	F+	-	1	2
Avoidance cost of post closure care	F+ T+	-	1	2
Metal recovery	F++	-	1	2
Slag	F-S+	F-S+	1	1
Transport quarry-plant cost	F-	F-	1	1
Cost of investment	F-	F-	1	1
Machinery	F-	F-	1	1
Labour expense	F-	F-	1	1
Cost of energy	F-	F-	1	1
Cost of maintenance	F-	F-	1	1
Totals for preferred orders			17	27
Overall priority			1	2

This means that the multi-criteria analysis of repurposing the tailings should be evaluated not only in terms of economic value, but also in terms of the environmental and social impacts of the repurposing process. When examining environmental challenges, it is often challenging to put clear monetary values on the benefits associated with sustainability initiatives [28].

It is agreed to use an acronym for each of the four scoring criteria: F for financial impact, S for safety, A for abstract, and T for time-efficiency to quantify the immeasurable. These acronyms stand for the annual flow of the advantages and disadvantages of repurposing mine tailings. In addition, a plus symbol (+) and a minus sign (-) will be used to indicate pros and cons, respectively. A double sign will denote greater significance. The advantages and disadvantages of this strategy for recycling tailings and conventionally storing tailings are shown in Tables 2, 3, and 4, respectively.

Multi-criteria analysis has been found to be an effective approach for evaluating the various factors related to the reuse and recycling of mine tailings [29]. By employing a multi-criteria analysis technique, Table 2 outlines the pros and cons associated with recycling and reusing mine tailings. Table 3 illustrates how multi-criteria analysis is a valuable technique in assessing various approaches to managing mine tailings storage, depending on a variety of factors [30]. Lottermoser, B.G. conducted a study in 2011 that analyzed the environmental impacts and management strategies associated with mine wastes, particularly mine tailings [31]. The study is a valuable resource for understanding the advantages and disadvantages of reusing mine tailings compared to storing them in tailings storage facilities from an environmental perspective. Table 4 depicts the decision to reuse mine tailings instead of storing them in tailings storage facilities, which was made after considering the pros and cons presented in Tables 2 and 3.

The advantages of mine environmental quality regulations in terms of economic, health, physical, and social benefits transcend the disadvantages. In a real economic sense, mine environmental regulations benefit citizens by fostering their health, safety, welfare, tranquility, and permanence. The findings from this research study suggest the multi-criteria analysis some sense of direction regarding the systematic approach involved in the mine tailings dam, the danger involved in lathering mine tailings, and possible managerial skills to minimize ecosystem and subsequently improve the industrial benefit of the mine tailings. It showed that there are far more financial advantages in terms of environmental sustainability for utilizing mine tailing than storing them. As a result, using this mine tailings for other purposes presents a higher sustainability priority resource. The acquisition of mine tailings and crushed waste rock from mines is easier and more cost-effective than dredging, quarrying, and mining. The use of mine tailings and waste rock from mines reduces the need to extract these materials from the earth and thus prevents the disturbance of ecosystems in such environment. Therefore, multi-criteria analysis offers several economic and environmental advantages.

In PMC, tailings are disposed using traditional tailings management procedures, which involve storing them in tailings dams. When valued within the context of the sustainable economy, it is thought that tailings might be regarded as a supply of raw materials. Consequently, there are no links between the academic community and industry that support research for such. The corporation strictly adheres to mining regulations, policies, and laws in the Philippines by making sure the tailings are stored properly. Repurposed tailings are perceived to have minimal to no negative impact on the environment.

The findings indicate that there are elements other than copper in the tailing from the mining process. Exploration could lead to the discovery of more of them, which would aid in other areas of science, technology, and invention. The PMC tailings are rich in silica which has the potential to be used as a supplementary cementitious material in cement production. This finding concurs with [32] the analogy that refined elements such as SiO_2 can be added to cement manufacturing for the construction of buildings. Since the tailings have values in the construction industry, recycling of the tailings should be ascertained.

Repurposing mine tailings, according to Cheng, T. C., Kassimi, F., & Zinck, J. M. (2016), tends to preserve natural resources, reduce dams, reduce environmental impact, and then contribute massively to economic growth by 9% [33]. It emphasizes the importance of promoting tailings recycling in order to reduce excessive consumption of natural resources.

The advantage of recycling can be easily justified and offset by significant savings if we take into account all of the expenses associated with a tailings dam throughout its entire life cycle, including the costs related to closure and rehabilitation, the risk of a potential failure both during operation and after closure, the possibility for the disastrous loss of life, the rebuilding process, remediation of the environment, production loss, damage to the company, and closure costs.

The multi-criteria analysis shows that repurposing mine tailing has far more advantage than traditional way of storing the mine tailings. It provides a robust decision-making framework that considers environmental, economic, social, and long-term liability aspects. This approach promotes sustainable practices, resource conservation, and the responsible management of mining waste, making it a more favorable alternative to traditional tailing storage facilities. It can encourage the development of improved tailings management practices, including innovative methods for tailings dewatering, consolidation, and compaction. These practices can reduce the volume of tailings that need to be stored, thus minimizing the environmental footprint of storage facilities. It can also lead to identifying and evaluating new technologies and approaches for tailings management. Additional research studies can help optimize the use of space within storage facilities, potentially extending their operational lifespans and reducing the need for expansion or construction of new impounding facilities.

Repurposing mine tailings can offer environmental and economic benefits, but it also comes with potential risks that need to be carefully considered. Some of the risks associated with the repurposing of mine tailings include environmental contamination, geotechnical stability, and long-term stability. To mitigate these risks, several measures can be taken, such as thoroughly characterize the chemical and physical properties of the mine tailings and applying monitoring programs to track any changes in their properties over time. Place measures to contain and isolate the mine tailings to prevent the release of contaminants into the surrounding environment, such as using impermeable liners and barriers. Implement appropriate engineering controls when repurposing mine tailings, such as compaction, reinforcement, and proper slope design to guarantee geotechnical stability and ensure that the repurposing of mine tailings complies with relevant environmental regulations and standards to minimize potential risks to human health and the environment. Develop and implement long-term management plans for the repurposed mine tailings, including ongoing monitoring, maintenance, and contingency measures for potential environmental impacts.

CONCLUSION

The study explores the repurposing of mine tailings, focusing on the impact on the environment and resource recovery. The PMC stores a significant amount of mine tailings without reusing them, believing that repurposed tailings will have minimal environmental impact. However, the sample analysis reveals that the tailings contain elements like silicon, aluminum, and iron dioxide, which could be utilized in construction manufacturing industries. These elements and minerals are beneficial to economic growth and could contribute to the sustainability of the mining sector. The development of new processes and technologies for repurposing mine tailings can drive innovation in the mining sector. This can lead to the creation of new intellectual property, the growth of a technology-driven ecosystem, and the fostering of a culture of continuous improvement within the industry. These advancements can contribute to economic growth by enhancing the sector's competitiveness and attracting investment in research and development. This can create opportunities for job creation and local economic development. New processing facilities, research centers, and reclamation projects related to tailings repurposing can generate employment and economic activity in mining regions, contributing to the diversification and resilience of local economies.

The study also highlights the potential of reusing mine tailings in Portland cement manufacturing, conserving natural resources, and reducing the cost of constructing additional storage facilities. By incorporating these mine tailings into the cement manufacturing process, the need to extract and consume raw materials can be reduced, conserving natural resources and promoting sustainable practices.

A multi-criteria analysis approach for recycling mine tailings offers several advantages, enabling a comprehensive evaluation of various criteria and factors, allowing for a more informed decision-making process. By incorporating mine tailings into the Portland cement manufacturing process, the company can conserve natural resources and promote sustainable practices.

Compared to several developed nations, the Philippines' current rate of mine waste utilization is below average. Vast amounts of mine tailings are just deposited in the tailing storage facilities. To address concerns about the economy and the environment;

1. The research also encourages mining companies to focus on the efficient use of their mine waste in the construction sector. By researching how to use these waste materials in the manufacturing construction materials, it is possible to lessen the detrimental effects of mine tailings and better use the potential uses of mine tailings.
2. Consider the social acceptability of the proposed repurposing methods. Engage with local communities, stakeholders, and Indigenous groups to understand their concerns, interests, and potential benefits. The National Commission on Indigenous People (NCIP) Administrative Order 3 outlines the participation of local communities in the decision-making process of new projects through collaborative and inclusive approaches respecting the socio-political structures of the locale. This could involve assessing impacts on health, livelihoods, cultural heritage, and community wellbeing. Also, develop a clear, transparent, and accessible communication strategies to inform the public about the potential benefits and risks associated with repurposing mine tailings.
3. Mining companies in the Philippines should evaluate their mine tailings and conduct more experimental studies on the characteristics of their mine tailings. They are encouraged to explore reprocessing and recycling their mine tailings to reduce the tailings' environmental impact and maintenance cost of tailing storage facilities.
4. Mining companies should conduct a comprehensive risk assessment to identify and mitigate potential risks associated with the repurposing of their mine tailings. This includes considerations for safety, health hazards, and financial risks. By considering these factors and conducting a thorough multi-criteria analysis, you can effectively identify the resources and potential utilization options for mine tailings.
5. The corporation or government should look into this research study to see the recycling possibility of the tailings due to the concentration of SiO_2, Al_2O_3, Fe_2O_3, Etc., which justifies recycling potential in the cement industry, pottery industry, Etc., for the generation of income to the company and the country as well.

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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