A characterization study on nickel laterite mine waste towards the application of circular economy in the Philippine mining industry

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ABSTRACT

Nickel laterite mining is one of the major mining activities of the Caraga region in the Philippines. Massive amounts of waste are produced during the extraction process and are typically left on the site. In this study, nickel laterite mine waste was characterized as an important initial component in the application of a circular economy in the Philippine mining industry. A circular economy model for nickel laterite mines in the Philippines was also proposed. The chemical composition analysis showed low-grade elements and their oxides which were uneconomical to extract. The pH was at a normal to moderately alkaline level and the organic matter was at a level acceptable for plant growth but low to support soil for prevention of soil erosion. To apply the circular economy concept, the waste could either be reused or repurposed. The elements in the waste could be further extracted by metallurgical processing when an economical way of doing it was established. Bioprocessing and phytomining could also be used to concentrate the metals. The mined-out areas could potentially be utilized in renewable energy production like solar, wind, and biomass. The use of waste in the production of bricks, ceramic tiles, and other products was also seen as a possible option. The implementation of a circular economy in the Philippine mining industry was at a very early stage and it needed the support and

commitment from the government, industry, academe, community, and other stakeholders.

Keyword: mining waste, mine waste management, Philippine mining, waste utilization, circular economy

1. INTRODUCTION

The Philippines is second to Indonesia in 2020 for nickel ore production [1]. It has 24 nickel laterite mines of which 16 are found in the Caraga region, Philippines [2]. Along the process of mining is the production of solid, liquid, or gaseous unwanted by-products of no current economic value called mine waste [3, 4], which may still contain potentially valuable resources [5]. Most nickel laterite mines do not have mineral processing plants to process the ores. The nickel and iron ores in the Philippines are mostly exported as ore to countries like China to extract and refine nickel, iron, chromium, cobalt, and even some highly valued metals such as platinum, vanadium, and titanium [6]. After the extraction, hectares of unproductive land are left with the mine wastes. If not maintained properly nickel laterite mine waste easily erode during rainfall events and can contaminate nearby ecosystem.

Characterization is an important step in understanding the problem to provide appropriate treatment and action [7]. The characterisation of minerals in mine waste also aids in risk assessment, provides direction for effective mining planning, and optimizes pollution control design [8]. In order to choose the most dependable and affordable treatments that will result in successful site reclamation and restoration, information on the characteristics of mine wastes is also necessary [9]. This study conducted the elemental characterization, pH, and organic matter content of nickel laterite mine waste as an important initial step towards the application of the circular economy concept, the idea of using the waste of one industry as input to another industry.

2. LITERATURE REVIEW

Circular economy concept

The current waste management practices in mining are based on the "take-make-waste" principle of the linear economy.[4, 5]. Cradle to cradle is an idea that tries to continuously use materials that were previously considered "waste" as a result of previous activities [11,12,13]. The application of this idea leads to the concept of a circular economic activity or “circular economy”. This concept aims to make the most out of finite resources like minerals. The circular economy in mining has long been introduced like in the works of Zhao et al. [14], Singh et al [12] but unfortunately, has not taken off that far because the reprocessing of waste is not seen as an urgent matter because of the availability of fresh mineral sources. Also, it has many constraints like regulatory, economic, technical, and even social/ cultural as discussed by the works of Upadhyay et al., Kinnunen et al., Neves et al. [11, 13, 15]. Applying circular economy in mine industry has an important effect on addressing the issue of finite mineral resource, environmental pollution, increasing resource utilization ratio and sustainable development [14].

Circular economy in the Philippine mining industry

The concept of circular economy in the Philippine mines is at a very young phase. Most nickel laterite mines in the country do not have mineral processing plants and find the direct shipment of ore as the easiest and most economical way to do business in nickel laterite mining. After the exhaustion of nickel laterite ore (>1.2% Ni) the mine waste is back-filled to the mined-out area and rehabilitated by planting trees and other plants which are known to thrive under the challenging environmental conditions in the mine. The possibility of re-mining the waste is not considered an option at the moment though most mines are supportive of the government and academe efforts to conduct a study of the waste for possible utilization. On the side of the government, the Department of Science and Technology (DOST) has included the mining and mineral sector in their priority areas for research. In 2017, DOST-PCIEERD

signed an agreement with the Philippine Chamber of Mines. Among the list of priorities was the promotion of green mining, which is using appropriate technologies to reduce environmental impact, and the development of value-adding industries. The Philippine government also has a program under the DOST Collaborative Research and Development to Leverage Philippine Economy (CRADLE) program which requires academe-industry partnership in research to ensure that the developed technology is used in the community. One of the projects under the program in 2022 is on the utilization of gold mill tailings in the development of products for socioeconomic benefits. The academic community is also active in researching the possible utilization of nickel laterite mining waste. Some of the published research on the use of nickel laterite waste from Caraga region is on indirect carbon sequestration [16], as geopolymer precursors [17], ceramic tiles [18], and bricks.

3. METHODOLOGY

The samples for this study was taken from a nickel laterite mine in Caraga region, Philippines. This mine is currently in mine rehabilitation stage. The random samples were taken from the eight mine settling ponds and stockpile of waste rocks. The samples were analyzed for pH, organic matter, and elemental composition. The pH is measured using a 1:1 mine waste/ deionized water suspension method using a pH meter [19]. Organic matter content was analyzed using loss-on ignition method and the elemental analysis using X-Ray Fluorescence (XRF) [20]. Published research were gathered to know the ways mine waste can be used for the application of circular economy.

4. RESULT AND DISCUSSION

The results in Table 1 show that organic matter is at the range 1.8-7.9%. This level is low for mine soil to support soil erosion. Soil erosion in a mined-out area is a frequent phenomenon. Controls are necessary to prevent the eroded soil from reaching the ecosystem outside the mine. In the past, there have been many cases of siltation problem near the shore during heavy rainfall and typhoon. The pH range is at

7.2-8.6 which can be interpreted as normal to moderately alkaline. Soil at 7.6 – 8.3 pH are normally controlled by the presence of calcium carbonate which usually do not need further treatment [14]. This also indicates that this type of waste will not cause acid mine drainage, which is a prevalent problem in some mines.

Table 1 pH and OM of nickel laterite mine waste

Properties	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 7	Mine 9	Exit
OM(%)	1.8	4.9	3.9	6.5	7.9	3.2	2.8	3.8
pH	8.6	7.8	7.7	7.5	7.2	7.9	7.7	8.2

Table 2 shows the elemental and their oxide composition of the nickel laterite mine waste. The average nickel and iron content is 0.50 to 1.10%, and 9.52%-46.83% by weight, respectively. This is a typical percentage for limonite and saprolite nickel lateritic soil. These percentages of nickel, iron and other elements are too low to allow economic extraction at present.

Table 2 Elemental Composition and their oxide

Mine	Ni	Fe	Co	Al	Mg	NiO	Fe_2O_3	CoO	Al_2O_3	MgO
1	0.83	9.52	0.04	0.47	16.80	1.06	13.62	0.05	0.89	27.86
2	0.95	24.53	0.06	2.54	9.57	1.22	35.07	0.07	4.81	15.88
3	1.10	17.71	0.06	0.98	12.11	1.40	25.34	0.06	1.85	20.08
4	1.04	28.04	0.06	1.75	11.54	1.33	40.09	0.08	3.31	19.13
5	0.91	46.38	0.11	2.55	4.10	1.16	66.30	0.14	4.81	6.80
7	0.94	19.63	0.06	1.07	13.54	1.20	28.07	0.07	2.02	22.46
9	0.83	19.08	0.05	1.01	13.72	1.06	27.28	0.06	1.90	22.76
Exit	0.50	15.38	0.04	3.00	9.42	0.64	21.98	0.06	5.66	15.64

Application of circular economy

A model for the implementation of circular economy in the Philippine nickel laterite mining is proposed in Figure 1. The low-grade nickel can be reserved for future use in the mine. The mapping of the low-grade nickel and strategic mine rehabilitation to allow easy access in the future is recommended. When economic extraction by metallurgical processing is available, then the lower-grade today can be remined and

processed. Biomining, the use of microorganisms and phytomining, the use of element-specific plant in concentrating the metals can also be considered. Some examples are the works of Oliveira et al. using *Acidithiobacillus ferooxidants* to enhance the concentration of nickel from 1.2% to 1.46% [21], and the extraction of iron, aluminum, manganese, and chromium from nickel laterite using *Penicillium chrysogenum* [22]. For phytomining on the otherhand, there are over 400 identified nickel hyperaccumulator plants [23] and it is best to consider their biomass potential if this is to be considered.

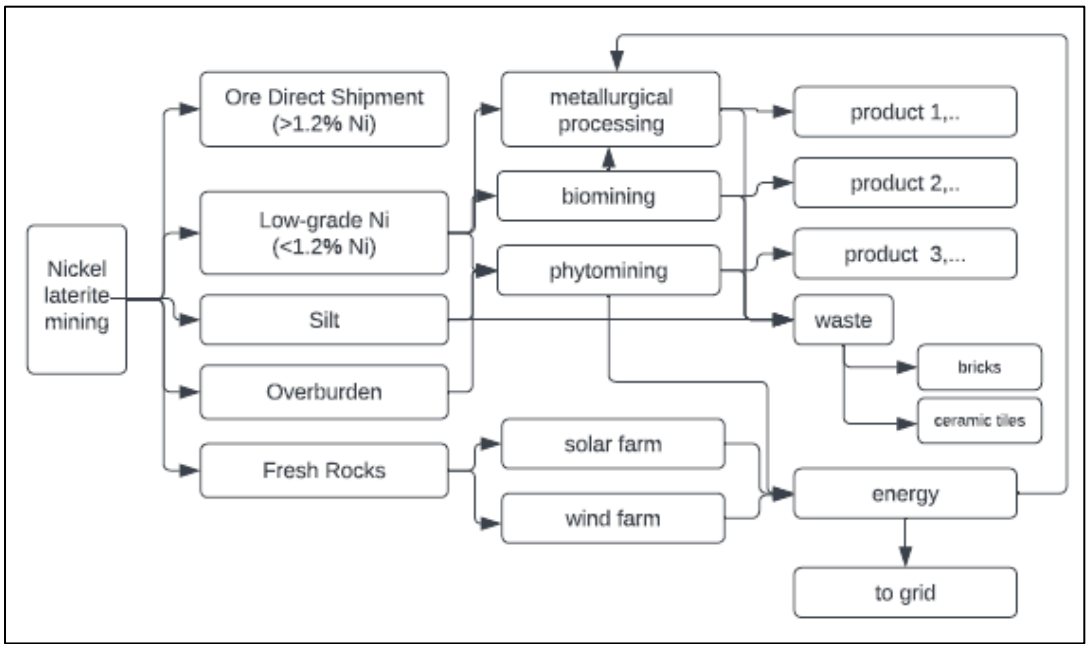

Fig. 1 Circular Economy model for Philippine nickel laterite mine

Both biomining and phytomining are more environmentally friendly but the major drawback of these processes is the long time production. After the extraction the generated waste can be used for the production of bricks [24], ceramics[18], or used as filling material to the area. The mined-out area with fresh rocks can also be converted to solar or wind farms [25] to produce energy which can be used to power metallurgical processing plants or connected to the grid for the community.

5. CONCLUSION

Nickel laterite mine waste contains elements and their oxides of low concentration and uneconomic to extract at present. However, this can be the best source when higher grade material are exhausted or when profitable technology is available. The pH is normal to moderately alkaline which unlikely to cause acid mine drainage problem. The organic matter requires little amendment to qualify as good soil for plant growth but needs enhancement if it is to support the soil from erosion. The best option for nickel laterite mine waste is to extract the remaining nickel-iron and other metals which can be of potential value using technologies which allow its economical extraction. With these findings, strategic mine rehabilitation is recommended. This includes advanced mine rehabilitation planning which consider the potential for re-mining of waste. Grading and mapping of the waste is to be considered for easier access of the waste which can be economic to work in the future. Researchers must prepare economically feasible technologies for future use. The use of hyperaccumulator plants with high biogas/ bioenergy potential is also a good option for mine rehabilitation. This is more environmental friendly and this process has potential in energy production. The use of waste to develop products like bricks maybe considered after the extraction of the valuable elements to maximize the use of metals present in the waste. Conversion of mined-out areas to solar and wind farm is also very good option since nickel mines are elevated-open-field which are exposed to wind and sunlight all day. These are the ways circular economy can be applied in Philippine nickel laterite mining industry.

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