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GOLD ORE WASTE MANAGEMENT CHALLENGES AT RENCO MINE, ZIMBABWE

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Abstract:
The question of the sustainability of a mine is extremely difficult to answer, and requires substantive data and other issues to be put into context. This study highlights the major types of waste that are accumulating in a mine both surface and underground. The study also reveals what has been done by Renco Mine in dealing with waste associated with the mining of gold. It shows that little has been done in the reduction of waste generated by mining activities. The issue of waste management is correctly perceived to be a major issue for municipal councils and the manufacturing, construction and chemicals industries. There is less recognition, however, of the vastly larger quantity of solid wastes produced by the mining industry. The reasons for this are most likely due to the perceived relatively benign nature of mine wastes, remoteness from populations, apparent success in mine waste management, or other factors. Waste rock is generally the only waste type which could pose a significant long term environmental threat, as it could contain significant sulfide mineralization. This paper examines waste management challenges at Renco Mine (Zimbabwe) and makes several recommendations at the end.

Keywords: gold mining, waste, challenges, Renco Mine, Zimbabwe

1. Introduction

Mine disasters have been a focal point among mine operators, safety and health personnel, and miners, as well as mine safety and health researchers in the world for

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decades (Ajusa, 2003). Hundreds of disasters, resulting in thousands of mine worker deaths, have occurred in mines since 1900. The focus of many Health and Safety researchers has been mainly centered on the prevention and challenges posed on human safety due to mining operations. In recent years, the focus has also shifted into considering the environmental effects of mining as well as the after effects on flora and fauna. Globally the environment seems to have gathered relevance and countries have since begun to engage the mining industries with environmental sensitivity. The modern mining industry is truly a global enterprise, and in the past decade has embraced the sustainability debate and the challenges and opportunities it presents. At first glance, however, the concept of 'sustainable mining' seems like an oxymoron – a logical misnomer. There is strong evidence, however, that although an individual mine may not be 'sustainable', when the sum of mines in a sector or region are considered together over time, the mining industry can be argued as contributing to sustainable development.

This more complex view of sustainable mining is the new position of the modern mining industry, and moves beyond a simplistic notion of a single mine to a holistic view of the industry and its role in society. Further issues which need to be considered in conjunction are the fundamental trends in modern mining with respect to the effort required for a given unit metal or mineral production. This paper presents wide ranging data to address this area, showing that production is increasing at substantive rates (sometimes exponentially so), ore grades are in terminal decline, there is a major shift from underground to open cast mining, waste rock production is increasing at a dramatic rate, a gap in rehabilitation of formerly mined land, and the economic resources of some metals and minerals have increased while others have apparently stabilized. This stability has led to a shift in the mining zone in Zimbabwe in that several small scale mines have entered the mining square in a bid to get the precious stones especially gold. Gold mining in Zimbabwe is one of the principal solid waste producers in the land. They are quite numerous with some of the top mines being operated by RIOZIM such as Renco Mine and Cam and Motor Mine. This study was aimed at investigating the impact of waste management challenges associated with gold mining in Zimbabwe. The study made use of the transaction model which evaluates the challenges faced by gold mines in Zimbabwe in managing solid waste.

The mining sector plays a crucial role in the economies of many countries, especially through both backward and forward linkages. Significant contributions can be noted in the form of employment creation and foreign currency earnings that are essential for socio-economic development. In Zimbabwe, the mining industry is one of the last industries that remain viable within the country and has harbored a number of employees. The greatest numbers of employees who still enjoy a better life are employed within the mining industry. Tchobanoglous (1993) postulates that Waste Management (WM) is a practice that focuses on controlling the production, storage, collecting, transferring, transporting, processing and disposing of waste.

Tchobanoglous (1993) further argues that this practice has to be done in a way that is in cordiale alignment with the principles of public health, economic engineering, and aesthetics at the same time responding to public attitudes. This also ensures that there is a mutual relationship between the way a company manages its waste as well as the legislation of countries such as the EMA Act in Zimbabwe and other international regulating instruments like ISO 14001: 2015. Yap (1995), has it that storage, collection, transportation and disposal of waste has to be done timeously in order to prevent the outbreak of diseases, fire, contamination of water bodies and at the same time maintaining the aesthetic beauty of our natural environment. Ashton (1999) observed that the problem of waste disposal started in the times when mines began to develop into large scale mining due to the need of economic development.

The mining industry has placed more attention on economic development and neglected sustainable environmental development. The efforts that have been made by the Paris Agreement are aimed at achieving sustainable development goals which is part of the integrated global efforts for environmentally friendly production processes (Ajusa, 2003). According to LeBlanc (2017), solid waste is a term used to describe a range of garbage arising from human activities that are discarded as unwanted and useless. Waste is a by-product generated from industrial, residential and commercial activities. A major environmental problem relating to mining is the uncontrolled discharge of mine waste in both rivers and land (EEB, 2000). It is widely acknowledged that this phenomenon is responsible for costly environmental and socio-economic impacts.

The map below shows the geographical location of Renco Mine. The study was carried out at Renco mine which is situated about 150km SE of Masvingo district of Zimbabwe. It is accessible from the North via Mogenster Mission and from the south off the Ngundu-Triangle road. In both cases, there is a 30km poorly maintained dust road. It lies at an altitude of 680m above sea level. The area around Renco and its satellite mines consists of a series of rugged East –North –East trending hills surrounded by undulating lower lying areas. The area is deeply weathered and rock outcrops are rare therefore surface mapping depends largely on road cuttings and river exposures. The main vegetation consists of Mopani trees and knee high scrub. The country is intensively cultivated in the mine vicinity, characterized by flat valleys between broken granite terrains covered with brachystegia woodland.

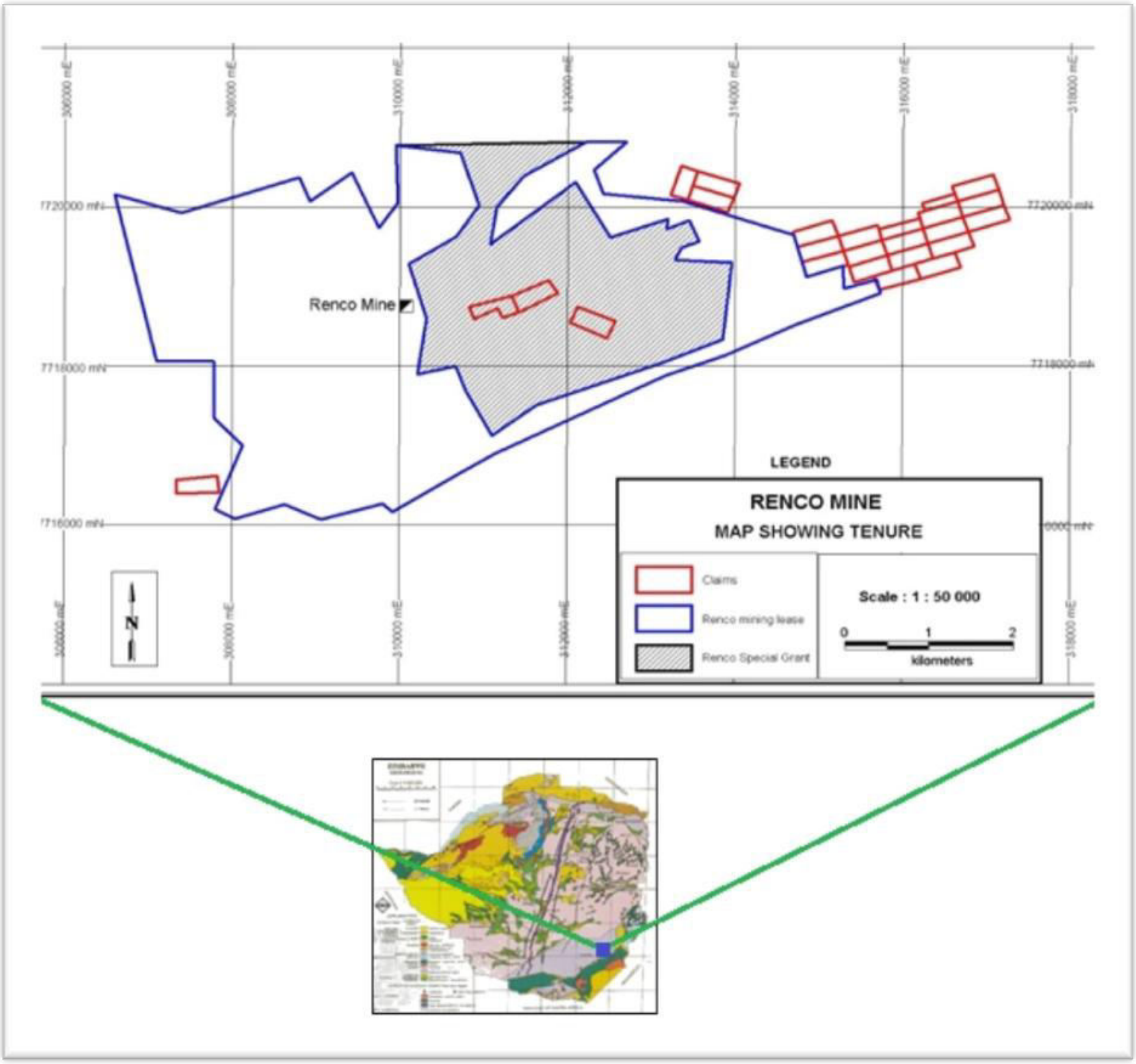

Figure 1: Map showing the location of Renco Mine

Renco is situated within the Limpopo mobile belt, a 700km long by 300km wide zone of highly metamorphosed rocks. Renco is the only major gold deposit outside the Zimbabwean Archean greenstone terrain. Main episodes in the formation of the Renco deposit are: 3200 Ma formation of a Primitive Zimbabwean craton consisting of granites and gneiss which are also2870-2600 Ma gradual uplift and deformation.

2. Research Methodology

A case study approach was adopted to complete the research because it enhanced the understanding of problems based on a representative mining environment. Concentrating on a single point entails the production of quality representative data compared to studying a large area with partiality. Limited time to move around in all mining industries also made the researcher to focus on Renco Mine as a representative area for the research as well as of the acquaintance of the researcher to the organization made the researcher more confident in using it as a touchstone for the research since the researcher was once attached at the organization. According to Punch (1998) a case study produces greater detail than what is available through new questions and variables for further research. The researcher used both the qualitative and quantitative methods of data collection and analysis because the two methods supplement each other in data collection and analysis. The method employed is referred to as triangulation. The drive towards the use of such a method is that each research paradigm has various weaknesses in which the researcher attempted to quarantine in using both methods of research. The quantitative analysis method was used to get the numerical information and the latter was used to get factors which contribute to the problem of accident causation and minimization measures. Qualitative data collection method was used because it explored attitudes, behavior and experiences through data collection instruments such as interviews and questionnaires.

2.1 Environmental impacts of mine waste

At the global level, industrial wastes have done harm to the environment and human health. The first step towards prevention and control of pollution of industrial solid wastes that the types, is a full understanding of amounts and effects. The intrinsic characteristics of industrial wastes include occupying land when stockpiling, dumping, disposing or storing, having large categories and quantity. The environment effects are posing threats on the natural environment, atmosphere, water and soil environment due to mining solid wastes. Mining poses risks associated with not only potential pollutant source (*e.g.* acidity and heavy metals in non-ferrous metallic ore) but also the specific environmental context and the presence of targets in the event of liberation. The possible risks from the potential pollutant source (such as acidity and heavy metals) in waste is dependent not only on the mineral characterization of the solid but also on the quality of the potential leachates, the direct environment (soil, groundwater, surface water, air) and the potential targets (human, fauna and flora).

Vallero (2007) suggests that six workers were killed on 9th December 2006 when iron ore mining waste dumps collapsed in the Tollem mines in Goa. The nearly 100-metre high overburden dumps - covering an area in a 200-metre radius - gave way burying the excavating machines as well as the operators beneath them in the interior Sanguem iron-ore mining heartland of the state. The landslide was so sudden that those trapped were unable to even react. Military personnel were called in to carry out the rescue operations. A case of negligence was filed against the board of directors and managers of the mine. The low priority given by the mine operators, especially in small-scale and illegal mines, to overburden management culminated in this tragedy. There are several such cases, many of which are not even reported. In Zimbabwe, on the 6th of June, 1972 some 400 miners died at Hwange due to the collapse of the mine.

2.2 Merriespruit Tailings Dam Failure in South Africa

Allen (1995) noted that on 22 February 1994, the Merriespruit tailings dam failed by overtopping due to heavy rains that caused a flowslide of part of the embankment. 6,00,000 m3 of tailings flowed out of the impoundment to eventually stop 2 km away in the town. Seventeen people were killed and scores of houses were demolished. The 31 m high embankments had problems prior to the major failure. Small slips had caused the impoundment to close temporarily, and only mine water with small amounts of tailings were deposited. The deposition of these tailings caused the supernatant pond to move to the opposite side of the impoundment which rendered the decant system useless. Heavy rains that fell on the day of the failure (30 – 55 mm in 30 minutes) caused the overtopping. The failure could have been prevented if a suitable operating manual and emergency plan had existed.

2.3 Failure of the Omai Tailings Dam

The Omai gold mine is in the humid tropics of Guyana. The open-pit mining operations started in 1993. Both the tailings dam to contain the wastes and the mine itself lie on the banks of the river. On Aug 19, 1995, a major breach of the tailings pond dam occurred and an estimated 3.2 million cubic meters of tailing pond water (which contained high concentrations of cyanide) spilled into the Omai River. Production was suspended at the mine. The spill was contained on August 24. The Omai case demonstrated that no dam without adequate seepage protection around conduits or without adequate filters can be expected to survive for long (Younger, Banwart and Hedin, 2002).

2.4 Tailings Dam Failure in Brazil

Brazil's state government of Minas Gerais had to shut down the Mineracao Rio Pomba bauxite mine after the failure of a tailings dam on January 22, 2007. Streets and houses in the towns of Mirai and Muriae - in the south-western Brazilian state of Minas Gerais bordering the state of Rio de Janeiro - were partially buried several metres deep in mud. Plants and animals in the area also suffered serious damage. Furthermore, the water supply of several towns was interrupted as the mudslide affected the rivers. Heavy rains caused the dam to break, releasing 2 million m3 of mud into the Muriae River. However, state environmental regulators said the mud did not contain any toxic waste (Lottermoser, 2011).

2.5 The San Marcelino (Philippines) Tailings Dam Spill

Mine wastes from two damaged tailings dams and spillways of the Dizon Copper Silver Mines Inc. (DCSMI) in San Marcelino, Zambales, in Philippines spilled into the Mapanuepe Lake and eventually into the Sto. Tomas River on Friday Aug. 30, 2002. The inspection by the environment protection authority revealed that heavy rains impounded water on the Bayarong and Camalca dams and spillways, eroding these and eventually causing the mine wastes to leak to the lake below. Each dam's catchment area spans 50 hectares. About 2,000 families live near the mine site, located in an upland area some 30 kilometers east of the San Marcelino town proper, according to the Zambales Disaster Response Network. The lake and the river remained as fishing grounds and irrigation sources for five Zambales towns (Rankin, 2011).

2.6 Overburden management of Indian mines is extremely poor

Waste is just piled up in huge heaps, and mining companies do not bother themselves with measures to prevent run-off or fugitive dust from waste piles. The best use for overburden waste is to backfill the excavated land, but it is rarely done in practice as companies keep opening different faces of the mines without completely exhausting any one of them. The result is that Indian mines are characterized by large numbers of pits surrounded by big dumps all around. Fines from these dumps are carried by rainwater into nearby watercourses or lands and pollute both. During dry summers, these dumps become a key source of air pollution for the surrounding areas (Anon, 2006).

2.7 Remedial actions done to deal with mine waste

There is an increasing production of ore that is in the form of concentrates. The concentration of the basic ore is done by the grinding and milling process. Tailings are generally in the form of slurry which contains certain hazardous contents such as arsenic, barite, calcite, cyanide, fluorite, mercury, pyrite and quartz. The slurry or the tailings are stored in a storage area called as the Tailings Dam or a Tailings Management Facility (TMF). As these tailings are very hazardous both for the human beings and too for the environment, so a proper disposal method of the tailings is to be done. In this method, the exhausted open pit mines are refilled with the tailings. Here in this process the dewatering of tailings is done using vacuums and filters which save the water and reduces the impact on the environment. In this process, the disposal of the tailings is done in the exhausted underground mines and is truly a complex method. It is also known as STD (Submarine Tailings Disposal) or Deep Sea Tailings Disposal. Tailings can be conveyed using a pipeline then discharged so as to eventually descend into the depths. Anon (2006) suggest that practically, it is not an ideal method, as the close proximity to off-shelf depths is rare. STD is used, the depth of discharge is often what would be considered shallow, and extensive damage to the seafloor can result due to covering by the tailings product. It is also critical to control the density and temperature of the tailings product, to prevent it from travelling long distances or even floating to the surface.

2.8 Water treatment sludge

Lapakko (1991) suggests that sludge is produced at active water treatment plants used at some mine sites, and consists of the solids that had been removed from the water as well as any chemicals that had been added to improve the efficiency of the process. Although ways of recycling the sludge are being explored, the majority of sludge has little economic value and is handled as waste. Disposal of water treatment residues in underground mine workings is the least expensive option where it is permitted and environmentally safe. In extreme cases where the sludge is rich in cadmium or arsenic, it may be classified as hazardous waste and require special handling and disposal.

2.9 Arsenic Contamination in Gold Mining

According to Lottermoser (2011) Phyto-stabilization is a form of phytoremediation that uses plants for long-term stabilization and containment of tailings, by sequestering pollutants in soil near the roots. The plant's presence can reduce wind erosion, or the plant's roots can prevent water erosion, immobilize metals by adsorption or accumulation, and provide a zone around the roots where the metals can precipitate and stabilize. Pollutants become less bioavailable and livestock, wildlife, and human exposure is reduced. This approach can be especially useful in dry environments, which are subject to wind and water dispersion. Tailings are of great and growing concern in mining sector, specifically due to presence of heavy metals. The storage of tailings is commonly identified as the one of most important source of environmental impact for many mining operations. This is not surprising considering that the volume of tailings requiring storage can often exceed the in-situ total volume of the ore being mined and processed. In a single year, around 6.5 million tons of tailings are generated in the world (Vallerro, 2006).

Elevated arsenic content is found in the surface and the ground water in the gold mining areas all round the world as the high content of arsenic in the surface as well as in the ground water is hazardous to the human beings and the several species that have the particular mining area as their habitat. As a large amount of overburden is being generated by the mining industry which is a great threat to the environment, therefore a perfect well management of this overburden should be done. The best use for overburden waste is to backfill the excavated land, some of the most common method of stabilization is by plantation. Overburden dumps are generally reclaimed by tree species as plantation improves the moisture contents, bulk density, pH and overall nutrient contents of soils. Rankin (2011) suggests that tree species like Dalbergiasissoo, Eucalyptus, Cassia seamea, Acacciamangium and Peltaphorum are ideal for bio-reclamation of overburden dumps. Some other preventive measures to be taken at the initial stage are: excavation from a new pit should begin only after an existing pit has been exhausted and till a pit is exhausted, the overburden should be properly compacted and stacked in specified locations in low-lying non-mineralized zones within the lease area.

2.10 Turning mine wastes into a resource

According to the European Environment Berau (2000) the large volumes of waste produced at mining operations are expensive to manage, and are frequently cited as an obstacle in the environmental sustainability of mining. The mining industry plays a leading role in waste management, and is one of few industries that recycle its own waste.

- Waste rock: Can be reprocessed to extract minerals and metals, used as backfill, landscaping material, aggregate in road construction, or feedstock for cement and concrete.
- Manganese tailings: Manganese tailings have been used in agro-forestry, buildings and construction materials, coatings, resin, glass, and glazes.

- Clay-rich tailings: Clay-rich tailings have been used for making bricks, floor tiles, and cement.
- Slag: Slag is often used for road construction, and in concrete and cement.
- Red mud: Bauxite red mud is solid alkaline waste produced in aluminium refineries. Red mud has been used as a soil amender, in waste water treatment, and as a raw material for glass, ceramics, and bricks.
- Mine water: Mine water is used for dust suppression and mineral processing, industrial and agricultural uses, as a coolant, and as a source of drinking water.
- Water treatment sludge: Sludge from ARD treatment, which is high in iron, has been sold commercially for use in pigments.
- Sulphur oxide emissions: Many smelters have installed acid plants to convert sulphur dioxide to sulphuric acid, a useful industrial chemical.

3. Results and Discussion

The modern mining industry is truly a global enterprise, and in the past decade has embraced the sustainability debate and the challenges and opportunities it presents. At first glance, however, the concept of 'sustainable mining' seems like an oxymoron – a logical misnomer. There is strong evidence, however, that although an individual mine may not be 'sustainable', when the sum of mines in a sector or region are considered together over time, the mining industry can be argued as contributing to sustainable development. In an effort to achieve sustainable development, there are several challenges being faced by the mining companies particularly in the developing world in achieving this reverie. This chapter presents the data and results that were obtained pertaining to the nature and challenges of waste management at Renco Mine. The research methodology encompassed the qualitative and quantitative research designs. Primary data was collected through field work which includes questionnaires and observations and these are displayed in this chapter in the form of pie charts, graphs, tables and explanations.

Table 1: Comparison of waste generated during the month of November and December 2017

Department	**Waste**	**Quantities Generated**	
		November 2017	**December 2017**
Department	Waste Rock		547t
Mining and Processing	Empty Cyanide containers		0.0093t
	Used Cupels	1.390t	1.425t
	Used Crucibles	2.482t	2.101t
	Broken flasks and beakers	0.00063t	0.00066t
	Cadmium fluid tins		0.0033t
	Linatex rubber	0.00035t	0.0062t
	Caustic soda bags	0.0069t	0.0012t
	Empty Yang flock bags		0.0011t
	Empty Carbon bags		0.0011t
	Empty Crude sulphur bags		0.0008t
	Empty Ferrous Sulphate bags	0.000	0.0021t

	Empty Lime bags	0.0002t	0t
	Empty Aluminum Sulphate bags	0.0003t	0.0277t
	Borax papers	0.00022t	0.00077t
	Empty HTH Containers	8	8
	Hydrochloric Acid containers	2	2
	Clinkers	0.838t	0.860t
	Empty Nitric Acid Containers	2	3
	Used Rubber gloves		0.00036t
Human Resources	Refuse	7.5t	4.50t
	Used Oil	440 Litres	500
	Manganese	0.540t	20.5t

The table above shows the amount of waste being generated as a sample for the months of November and December. The statistics above shows that the amount of waste is huge and given that there is no proper waste management strategy, there is a great possibility of contamination going on giving a breeding ground for health, sanitation and environmental problems. The waste is just stored and chemical containers will result in pollution of critical sectors such as the water sector. The table below table 4.2 confirms that the water discharged into tailings is contaminated and contains chemicals that hinder the quality of the water both surface and groundwater.

Table 2: Sampled water Quality Readings

Element	Mine	Sewage
	Discharge	**Effluent**
pH	8.7	7.3
Conductivity	1411	495

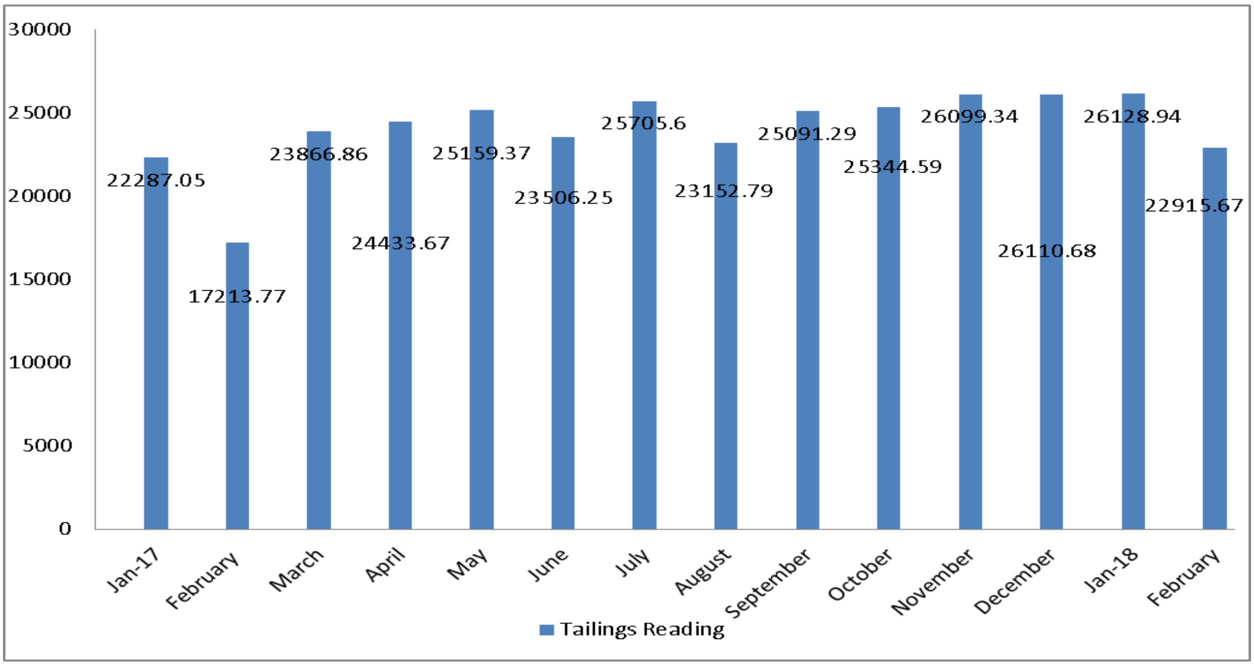

Figure 2: Monthly Tailings Readings

An average of 2000tons of waste is generated monthly at Renco Mine revealing that there is great need for a waste management strategy to be put intact. The waste being generated is stored at tailings dams without and mechanism or planned disposal method initiated and operational. Hence the problem of waste management remains a great one and unabated. This greater amount of waste being generated has led to the development of large tracts of land being used as tailings dams. These areas are highly risky and numerous issues have been reported where livestock which belongs to the local communities drown in these areas. Strategies have been employed however of growing trees around the tailings dams to suck out the water and chemicals in them and to leach the areas with nutrients as shown in fig 4.5,4.7 and 4.8 below. Despite these efforts, they have worked to a very minimal rate due to the unsuitability of the soils to plant and grow trees. These have not produced much since they wither and die soon after the manure they are planted with becomes contaminated. Efforts need to be realized in order to come up with better strategies to manage the waste.

Figure 3: Tailings Dam

Fig 4.5 above shows large tracts of land that has been used as a storage area for waste rock and processing refuse from the mining operations. The entire area has been contaminated with chemicals like cyanide and caustic soda which are used during gold processing and metals like gold, copper and silver though in small quantities. When effluent is released from the processing plant to the tailings dam, it is not treated to minimize the effects of such chemicals and metals.

Figure 4: Waste Rock

Figure 4.6 shows rock waste dump site where unwanted rock is deposited by the mining department. Each month, about 2 2894 tons of ore is hoisted and an average of 528 tons of waste rock is produced which makes it a total of 6 945 tons per year. This proves that waste rock is becoming more and more difficult to manage although it is used for road renovations and building pavements within the mine premises.

Figure 5: Tree plantations

Figure 6: Eucalyptus Plantations

The pictures in the figures above reveal that the management of tailings being implemented is a tried and tested method which has since then proved to be futile since no major trees have been planted and survived for long. The method being employed only ceases when the trees start to grow and are affected by the contaminants within the tailings. Hence waste management should be given first priority should the problem of waste accumulation be catered for and be solved.

4. Conclusions

One of the main objectives of the study was to examine the types of waste and the challenges being faced in managing the waste. From the findings of the study, it could be concluded that, there is an increase in the accumulation of waste. This is an indication that measures being implemented are not adequate enough to put the problem to an end. Another objective of the study was to show some of the measures being used to prevent waste accumulation and pollution related to waste. Despite the existence of these measures, the amount of waste continues to be on the rise which shows these methods need supplementary controls that can reduce waste accumulation in mines. The research was also aimed at targeting the major causes of challenges and the ways in which waste can be managed to reduce the impact on the environment. Hence there is evidence that the root cause analysis of problems is not being adequately taken care of so as to curb and reduce the occurrence of massive waste production.

The findings of the study reflected the state of vulnerability of employees and the local community due to their susceptibility to waste that contains both chemical and toxic metals released by the mining operations. There is release of caustic soda and cyanide among other chemicals that are very toxic to the environment and the residents. These hamper the environment and the health of people. The major challenges of waste management are largely attributed to the lack of a management system such as ISO 14001 or ISO 9001 which helps the organization to comply with best environmental performance and compliance standards. There is an inadequate baseline with which the operations of the mine can be guided. In this respect, the results of the research have revealed that these challenges are making it difficult to manage waste at the mine.

The focus of most organizations is certification and certification becomes an end point to itself. However for best performance and to boost the market base of the company, there is need to be more focused on the protection of its employees from tragedies that arise from hazards than to put focus on securing their operational certificates. Also, one of the key aspects is to ensure that the environment is given apt significance as much as production is considered vital within the sphere. This will ensure that the challenges being faced in relation to waste both solid waste and fluid waste are curbed and environmental degradation is maintained at a minimum rate.

4.1 Recommendations

The results obtained from the study indicate the importance of reviewing safety and environmental documents. This ensures the tracking of waste being generated and its rate of accumulation. Tracking the accumulation rates of waste being generated by departments will ensure that there is monitoring of all inputs that are used by the company and the outputs (waste). The relationship will determine the efficiency level of products within the organization and waste reduction strategies which can be implemented. Cost reduction can also be realized through this monitoring.

Regular safety auditing of organizational premises, machines and equipment can ensure that machinery tools and equipment are maintained in good condition and are not often deposited to waste before their use is exhausted. Auditing organizational premises will also help in monitoring major points where waste is generated and control measures related to the reduce, reuse and recycle principle are implemented. The major challenges of waste management per department can also be noted and due care taken correctly to ensure that there is little produced for refuse.

One of the most critical initiatives that help in reduction of challenges that are in line with waste management is the initiation of a SHE management system. A system refers to the management of all the inputs, processes and outputs. In particular for the environment, there is need to implement either ISO14001:2015 and or ISO9001. These systems help in the monitoring of environmental quality and management. Each department has the challenge and obligation to comply with the standards set forthwith and hence there is joint accountability of the environment from all the departments. Hence there installation of a system is a strikethrough solution for waste management.

Safety and health management as well as the Training management should develop a system that promotes effective distribution and dissemination of safety and environmental information because from the results very limited employees have access to environmental newsletters, safety fliers and attend environmental workshops. Distribution and dissemination of environmental information that include bulletins, fliers and videos should be made available and accessible to all affected stakeholders to enhance awareness.

Safety and Health management should provide basic training on procedures to be taken during emergency situations such as chemical leaks or cyanide tank bursts and also emphasis should be put forward on the importance of carrying out risk assessment and routine checks before tasks are performed as it was noticed that some employees lack safety and environmental awareness on various aspects such as carrying out risk assessments before performing tasks leaving the environment vulnerable due to unforeseen discharges of waste into the environment.

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