MINE WASTE: SOURCES, PROBLEMS AND MITIGATIONS.

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ABSTRACT

Mine wastes are unwanted, currently uneconomic, solid and liquid materials found at or near mine sites. Mining waste originates from the processes of excavation, dressing and further physical and chemical processing of wide range of metalliferous and non-metalliferous minerals by opencast and deep shaft methods. It comprises overburden, run-of-mine rock as well as discard, slurry and tailings from the preparation/beneficiation or extraction plants. The major problem is Acid Mine Drainage (AMD) which can lead to poor water quality, soil contamination and air pollution when the wastes are dry in the summers. The conventional method of treatment has been through methods such as lime neutralization, ion exchange, calcium silicate neutralization and carbonate neutralization; but the best way to treat AMD is prevention which can be done by using proper reclamation methods, which prevents air and/or water from reaching the pyritic materials. Generally, conventional technologies for remediation of mine tailings have focused on physical and chemical stabilization. Physical stabilization entails covering mine waste with an innocuous material, waste rock from mining operations, gravel, topsoil from an adjacent site, or a clay capping, to reduce wind and water erosion. Presently, alternative methods for the remediation of mine waste have been prescribed and adopted in various countries. Such methods includes bioremediations and phytoremediations.

Keywords: Mine wastes, Acid Mine Drainage, Bioremediation, Phytoremediations

1.0 Introduction

Mine wastes are unwanted, currently uneconomic, solid and liquid materials found at or near mine sites [1]. Volumetrically they are one of the world's largest waste streams, and they often contain high concentrations of elements and compounds that can have severe effects on ecosystems and humans. Mining wastes is generated during the process of extraction, beneficiation and processing of minerals. Extraction is the first phase that consists of the initial removal of ore from the earth. This is normally done by the process of blasting, which results in generation of large volume of waste (soil, debris and other material). This is useless for the industry and is normally just stored in big piles within the mine lease area, and sometimes, on public land. The bigger the scale of the mine, greater is the quantum of waste generated. Opencast mines are therefore more pollution intensive as they generate much higher quantities of waste compared to the underground mines. Open-pit mines produce 8 to 10 times as much waste as underground mines [2]. Once the ore is brought to the surface, it is processed to extract the mineral, which itself generates immense quantities of waste. That's because the amount of recoverable metal in even high-grade ores is generally just a small fraction of their total mass. Moreover, as the higher grade mineral deposits are getting exhausted, the mineral industry is generating more and more quantity of waste, as they have to now depend on lower grades of reserve. For example, in the United States, the copper ore mined at the beginning of the 20th century consisted of about 2.5 percent usable metal by weight; today that proportion has dropped to 0.51 percent [3].

2.0 Sources of Mine Wastes

Mine wastes comprises overburden, run-of-mine rock as well as discard, slurry and tailings from the preparation/beneficiation or extraction plants. Wastes that have the potential to generate acid as a result of metal mining activity include mined material such as spent ore from heap leach operations, tailings, and waste rock units, including overburden material.

Sub-surface mining often progresses below the water table, so water must be constantly pumped out of the mine in order to prevent flooding. When a mine is abandoned, the pumping ceases, and water floods the mine. This introduction of water is the initial step in most acid rock drainage situations. Tailings piles or ponds, mine waste rock dumps [4] and coal spoils are also an important source of acid mine drainage.

After being exposed to air and water, oxidation of metal sulfides (often pyrite, which is iron-sulfide) within the surrounding rock and overburden generates acidity. Colonies of bacteria and archaea greatly accelerate the decomposition of metal ions, although the reactions also occur in an abiotic environment. These microbes, called extremophiles for their ability to survive in harsh conditions, occur naturally in the rock, but limited water and oxygen supplies usually keep their numbers low. Special extremophiles known as Acidophiles especially favor the low pH levels of abandoned mines [1].

In particular, *Acidithiobacillus ferrooxidans* is a key contributor to pyrite oxidation [5]. Metal mines may generate highly acidic discharges where the ore is a sulfide mineral or is associated with pyrite. In these cases the predominant metal ion may not be iron but rather zinc, copper, or nickel. The most commonly mined ore of copper, chalcopyrite, is itself a copper-iron-sulfide and occurs with a range of other sulfides. Thus, copper mines are often major culprits of acid mine drainage. At some mines, acidic drainage is detected within 2–5 years after mining begins, whereas at other mines, it is not detected for several decades. In addition, acidic drainage may be generated for decades or centuries after it is first detected. For this reason, acid mine drainage is considered a serious long-term environmental problem associated with mining.

2.1 Waste rock

Mining operations generate two types of waste rock – overburden and mine development rock. Overburden results from the development of surface mines, while mine development rock is a byproduct of mineral extraction in underground mines. The quantity and composition of waste rock varies greatly from site to site, but these wastes essentially contain the minerals associated with both the ore and host rock. The ratio of overburden excavated to the amount of mineral removed is called the overburden ratio or stripping ratio.

Figure 1: Typical examples of waste rock [6]

2.2 Tailings

Tailings are the result of mineral beneficiation/milling process. Many minerals cannot be used for metal extraction directly as the concentration of the basic ore is less and has to be concentrated before it can be used. During the process of concentration, which involves grinding and milling, tailings are generated which is in a form of slurry [1]. The characteristic of tailings depends on the type of ore and hence varies from mineral to mineral. It also depends on the ore physical and chemical processes used to extract the economic product. However, there are certain common contents of tailings such as arsenic, barite, calcite, cyanide, fluorite, mercury, pyrite and quartz [1].

3.0 Problems of Mine Wastes

The environmental problems associated with mining are diverse. The removal of vegetation, topsoil, overburden/waste and ore, brings about the inevitable natural consequences, which manifest in many ways, deforestation, climatic change, erosion, air and water pollution and health hazards.

One of the chief problems of mine wastes is Acid Mine Drainage (AMD) which emanates from both surface and underground mining, waste and development rock, and tailings piles and ponds [7]. Also referred to as acid rock drainage (ARD), AMD emanating from mine waste rock, tailings, and mine structures, such as pits and underground workings, is primarily a function of the mineralogy of local rock material and the availability of water and oxygen [8]. Acid mine drainage usually contains a high load of heavy metals, in addition to having a low pH, which poses a major risk to surrounding water and soil systems [9].

$$\mathbf{4FeS_2 + 14\,H_2O + 15\,O_2 \rightarrow 4Fe(OH)_3 + 8\,SO_4^{2-} + 16\,H^+}$$

Acid Mine Drainage (AMD) is produced when sulfide-bearing material is exposed to oxygen and water (Akcil and Koldas, 2005). The production of AMD usually e but not exclusively e occurs in iron sulfide-aggregated rocks. Although this process occurs naturally, mining can promote AMD generation simply through increasing the quantity of sulfides exposed. Naturally-occurring bacteria can accelerate AMD production by assisting in the breakdown of sulfide minerals [8].

Table 1: Sources of Acid Mine Drainage (Adapted from [8])

Primary Sources	**Secondary Sources**
Mine rock dumps	Treatment sludge pounds
Underground and open pit mine workings	Rock cuts

Pumped/nature discharged underground water	Concentrated load-out
Diffuse seeps from replaced overburden in rehabilitated areas	Stockpiles
Construction rock used in roads, dams, etc.	Concentrate spills along roads
Tailings impoundment	Emergency ponds

Below are some of the environmental problems of mining which leads to mine wastes;

3.1 Water Pollution

Exposed ore, overburden piles, waste rock and ore piles, tailings impoundments, and other disturbed areas can contribute sediment and increase the total solids load to surface water bodies. Other potential sources of surface and groundwater contamination include fuel spills, flotation reagents, cleaning solutions, and other chemicals used or stored at the site [10].

3.2 Air Pollution

Based on the studies of [10], the primary sources of air contamination at mine sites are fugitive dust from dry surfaces of dry tailings impoundments, as well as overburden, waste rock, and ore piles. Often, tailings impoundments are not completely covered by pooled water; thus, dry tailings may be available for windblown transport. Deposition of windblown tailings provides exposure routes for contamination of ground water, surface water, and soil. Air pollution is also a major problem in the mines area, with concentration of suspended particulate matter (SPM) in ambient air much above the permissible limit in many places, particularly at crusher loading and transfer points [10].

3.3 Soil Erosion and Contamination

Environmental impacts to soils as a result of mining activities are most commonly associated with erosion and contamination. Erosion may be caused by land disturbances and removal of vegetation related to mining activities. Under these conditions, precipitation events, such as snowmelt, may lead to erosion of soils. Contamination of soils may result from water discharge, runoff, seepage from tailings impoundments, pits and mine workings, as well as from the overburden, waste rock, and ore piles directly to soils. In addition, deposition of windblown particulates from piles and dry tailings impoundments may also be a source of soil contamination. Other sources of soils contamination include spills of fuels, flotation reagents, cleaning solutions, as well as other chemicals used or stored at the site [10].

4.0 Mitigations of Mine Wastes

Disposal of mine wastes historically involved either returning the materials to the mining site; dumping into the ocean, a stream, or lake; or placing them into a receiving pond. Today, surface containment of tailings within embankments remains a commonly used approach. In 1995, it was estimated that on an annual basis over 700 million kg of Metals in mine tailings were disposed on land [11]. Alternatively, tailings may be returned to the mine (in-pit storage or backfilling) or mixed with coarse mine waste (codisposal) [10]. However, they remain unstable and subject to eolian dispersion and water erosion with the potential to contaminate nearby communities and environmentally sensitive areas.

Conventional technologies for remediation of mine tailings have focused on physical and chemical stabilization. Physical stabilization entails covering mine waste with an innocuous material, generally waste rock from mining operations, gravel, topsoil from an adjacent site, or a clay capping, to reduce wind and water erosion. These solutions are often temporary in nature because of the impermanence of the capping process [10, 12]. Engineering techniques such as soil washing, burning, excavation and removal are used to remediate heavy metal- contaminated soils.

5.0 Case Histories

5.1 A Case History of the Impact of Mine Water on Water Quality of South Africa

Pollution has been identified as one of the many pressures affecting freshwater systems and resources in South Africa [13]. Mine water is a growing concern in water quality management. Mine water impacts negatively on the water environment by increasing the levels of suspended solids, leading to mobilization of elements such as iron, aluminum, cadmium, cobalt, manganese and zinc and also decreasing pH of the receiving water. The overall effect of mine water is the deterioration in water quality in many surface water sources that may impact on the domestic, industrial and agricultural users [14].

South Africa has a long history of mining and has limited natural water resources, leading to a situation where it also has a number of significant mine-water related challenges. With over 10, 000 km2 of hydraulically interlinked coal mines and over 300 km of interlinked gold mines, mine-water challenges are not only at local mine level but at regional level too [15]. According to a study by [16] which revealed that the groundwater in the mining district of Johannesburg, South Africa, is heavily contaminated and acidified as a result of oxidation of pyrite contained in the mine tailings dumps and has elevated concentrations of heavy metals. Where the groundwater table is close to surface, the upper 20 cm of soil profiles are severely contaminated by heavy metals due to capillary rise and evaporation of the groundwater.

The polluted groundwater is discharging into streams in the area and contributes up to 20% of the stream flow, causing an increase in the acidity of the stream water.

The effect of the contaminated water from the mines can persist for more than 10 km beyond the source [16]. Evidence of AMD was found in the blesbokspruit catchments [17].

Figure 2: Partially treated mine water from the Grootvlei Dam enters the Blesbokspruit (After 8, 19]).

Figure 3: Water pollution in wonderfontienspruit resulting in mine water effluents from nearby stream (After [18, 19]).

5.2 A Case History of Phytoremediation for Reclamation of Abandoned Mine Sites in India

The restoration of a dense vegetation cover is the most useful to physically stabilize mine wastes and to reduce metal pollution effects [10]. Different plant species that are well-adapted to the local conditions, capable of excluding and accumulating heavy metals without showing toxic symptoms are the ideal species that should be considered for early stages of revegetation of the "green corridor" or establishment of "green belt" [10]. According to [10], several of the grasses, legumes and trees can be a suitable material for this purpose. Bermuda grass (*Cynodondactylon*), has been suggested for stabilizing metalliferous soils. Populations of a variety of higher plant species are known to colonize degraded mine soils in which other cultivated plants cannot survive. Thus, the plant community tolerant to heavy metals plays a major role in remediation of degraded mine soils. So far, approximately 400 metal hyperaccumulators have been identified. The success of any phytoremediation technique depends upon the identification of suitable plant species that hyperaccumulate heavy metals and produce large amount of biomass using established crop production and management. Tree-grass-legume association was found to be the best combination for restoration of mica, copper, tungsten, marble, dolomite, limestone, and mine spoils of Rajasthan state and elsewhere in India [10].

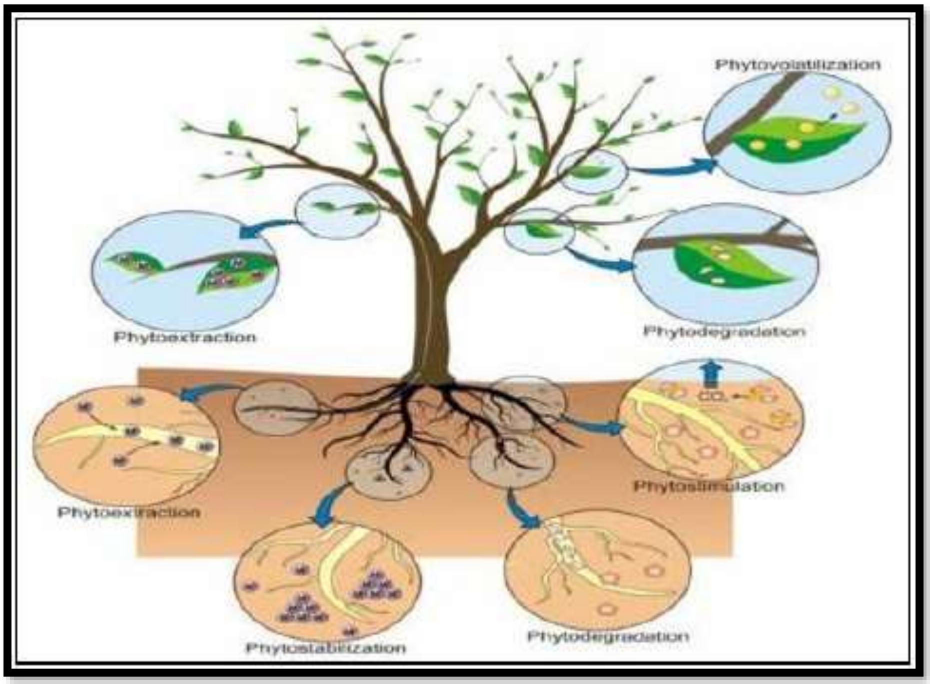

Figure 4: Phytoremediation processes (After [10])

5.3 A Case History of Newmont Rain Facility, Elko County, NV

EPA visited Newmont Gold Company's Rain facility in September of 1991 [1]. The facility is located on approximately 627 acres, 9 miles southeast of Carlin in Elko County, Nevada. Projected waste rock tonnage was estimated to be 41.4 million tons by the end of 1990, and 62.5 million tons during the life of the mine [1]. Following detection of the acid generation in 1991, Newmont's Rain facility Water Pollution Control Permit was revised. As part of the revised Permit, Newmont is required to report quarterly on results of Meteoric Water Mobility testing and Waste Rock Analysis. In response to the drainage, Newmont took the following actions. By May 9 (one day after the drainage was noted), a small pond was constructed to collect the flow from the dump. As a long-term mitigation/prevention measure, Newmont began encapsulating sulfidic waste rock within oxidized and/or calcareous waste rock that has either no net acid generating potential or some acid neutralizing potential [1]. As of late 1991, this was being accomplished by placing a pervious layer of coarse oxidized waste rock on the native soil [1].

Figure 5: Hydrogen Peroxide Method of Treatment [1]

5.4 A Case History of Iron Mountain Mine

According to [1], the Iron Mountain Mine is a 4,400-acre NPL site in Shasta County, California, approximately nine miles northwest of the City of Redding. Between 1865 and 1963, the area was used for the mining and processing of copper, silver, gold, zinc, and pyrite [1]. In 1983, Iron Mountain Mine was added to the NPL. Acid mine drainage, leaching from both the underground mine workings and from the tailings piles located at the site, is causing zinc, cadmium, and copper contamination of the Spring Creek Watershed and the Sacramento River. Environmental damage is primarily in the Sacramento River and tributaries in the Spring Creek and Flat Creek watersheds, where fishery productivity loss and periodic fish kills have been observed [1]. Drinking water drawn from the Sacramento River for the City of Redding (population 50,000) is also threatened [20].

Figure 6: Effect of Acid Mine Drainage from Iron Mountain Mine, California [1]

6.0 CONCLUSION

Mine wastes management in most part of the world is extremely poor; in most cases, the 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 of mine 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 mines are characterised 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 pollutes both as. During dry seasons, these dumps become a key source of air pollution for the surrounding areas. From studies, it has been revealed that acid mines drainage is a major problem from these wastes. Therefore, in terms of mitigations, methods such as lime neutralization, ion exchange, calcium silicate neutralization and carbonate neutralization has been prescribed and used for treatment; but the best way to treat AMD is prevention which can be done by using proper reclamation methods, which prevents air and/or water from reaching the pyritic materials.

Presently, alternative methods for the remediation of mine waste have been prescribed and adopted in various countries. Such methods includes bioremediations and phytoremediations. It has proven to be successful according to studies of [10].

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