Investigating the Soil Quality of Mindolo in Kitwe District

Mubanga Lupupa[1*] Grandwell Mumba, Lufupa Joseph, and Stephanie Mwamba
1. School of Education, Copperbelt University, PO box 21692, Kitwe, Zambia
* E-mail of the corresponding author: lupupams@yahoo.co.uk

Abstract
The study sough to investigate the quality of soil in Mindolo area in Kitwe of the Copperbelt province. The main objective of this study is to establish the effects that mining activities have on the soil quality of Mindolo township in Kitwe. A total of five (5) samples were used for the analysis. The soil samples were taken to the Copperbelt University laboratory for analysis. To determine the metal concentrates in the soil, Atomic Absorption Spectrometry (AAS) was used. The results of the study were that the soil quality of Mindolo had high alkaline levels due to contamination with heavy metals, which include Fe, Cu, Co, and Pb.
Keywords: Soil Quality, Contamination,and the study adopted Atomic Absorption Spectrometry (AAS).
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1. Introduction

The economy of Zambia depends heavily on the mining of copper. Generally speaking, mining provides revenue to the government through taxes and contributes to the development of the country through job creation and infrastructure development. Mining contributes 87% of total foreign direct investment (FDI) and 12% of the Gross Domestic Product (GDP) of Zambia. Concerning employment, the mining industry employs 1.7% labour force, which is about 8.7% of total formal employment in Zambia. The operation of mines in Zambia also contributes to other social-economical activities, such as the construction of roads and schools, and operations of healthy facilities, among other means of cooperate social responsibilities.

However, despite its benefits, mining has negative impacts. On the environmental scale, the impacts of mining are significant and usually severe, especially in developing nations that lack adequate management of the mining sector (Lindahl, 2014). Mining activities pollute the soils, air, and water bodies of the surrounding areas (Haddaway, 2019). The main soil contaminants that occur in high concentrations that have the potential to pose human health risks and hazards are copper and cobalt. The compromise of soil quality that results from heavy metal contamination and pH change in soils pose risks and hazards to human health and the ecosystem. The crops grown in these soils may take up toxic levels of heavy which may pose a risk to human health.

In Zambia, the main environmental problems that are attributed to mining activities are pollution of air, soil and, geotechnical issues, and land degradation (Lindahl, 2014). It is postulated in the literature that when crops are grown in soils that have excess concentrations of heavy metals, they may absorb elevated levels of these elements thereby endangering consumers (Namweemba, 2017). Heavy metals in the food chain are a health hazard to consumers because they contribute to increased toxic build-up in people's bodies, Some heavy metals such as copper and cobalt do not decompose but they bio-accumulate in soils and food crops which include; fruit trees, maize (*Zeal Mays ssp.mays*), cassava (*Manihot exculanta*), soybeans (*Glycinemax*), sweet potatoes (*Ipomoea batatas*), groundnuts (*Arachishy pogaema*), sugar cane (*Saccharum officinarum*), sorghum (*Sorghum bicolor*), beans (*phaseolus vulgaris*), and varieties of vegetables (Namweemba 2017). Once the soil is contaminated, it will not only affect the rapid growth of crops and quality yield of agricultural products but pose a threat to human health via the food chain (Emurotu and Onianwa 2017).

The soil contamination may be more pronounced in Kitwe, where there have been mining activities since 1928 (UN-HBITA, 2009), hence the need to analyze the soil quality of Mindolo and determine the concentration of heavy metals and PH in the soil. Thus, the main objective of this study is to establish the effects that mining activities have on the soil quality of Mindolo township in Kitwe. Various kinds of substances are released during mining operations, these substances usually end up contaminating the environment in general (Environmental Risks of Mining, 2016). However, this study is interested in the substances that contaminate the soil and affect its quality. Chiefly among the substances that affect the soil quality is the heavy metals and those substances that alter the pH of the soil.

1.1 Literature Review

Several studies have been conducted on the impact of mining activities on the environment. There is significant heavy metal soil contamination as a result of mining activities at various stages of production in the mines (Namweemba 2017). The soil is made vulnerable to heavy metal contamination by mining activities such as excavations in open-pit and underground mining, metallurgical processes, transportation, and dumping sites such as tailing dumps and waste rock dumps (The World Bank, 2002). Heavy metal contamination leads to the soil being unproductive, which is a result of a reduction in quality and its natural balance being upset (Namweemba, 2017). Namweemba (2017), further, points out that other sources of contamination from mining activities include seepage from the waste rock, leakages of gasses and effluents, discharge of water into the natural water, and emission of gasses into the atmosphere.

In addition, the copper mine waste rocks are highly contaminated by heavy metals and contribute to heavy metal soil contamination (Mutale, 2019). Mutale (2019) added that the highly contaminated waste rocks might in turn pose serious hazards to human health and agricultural productivity. Additionally, poor macro-nutrient availability, substrate compaction, and acidity soil (particularly on overburdened sites) coupled with toxic levels of heavy metals would be the main challenges for successful phytostabilization of copper mine wastelands (Mutale, 2019).

Moreover, mine wastes from the abandoned mine or decommissioned waste sites, when exposed to weathering processes overtime, may lead to the development of soil type referred to as mine soil (which is generally young soil). Heavy metal presence in the metalliferous soils is in high concentrations, which negatively affects the quality of soil and destroys their functional ecosystems, leaving these wastelands devoid of vegetation for extended periods according to Mutale (2019).

Waste rock, usually stored above the ground in large free-draining piles, contains acid-generated sulfides, heavy metals, and other contaminants that have the potential to pollute soil and retard plant growth (Namweeemba 2017). It was further added by Namweemba (2017), massive soil contamination results in the areas that surround mining activities, this is due to the potentially damaging effects that co-exist the mineral ore. The waste rock leach acids that liberate heavy metals such as copper, cobalt, cadmium, lead, arsenic, and mercury, these metals and acids find their way into the soil and they create a serious effect on the micro-organism that barrow and improve soil quality (Namweemba 2017).

The metallurgical process is the most significant activity that brings about heavy metal soil contamination; this leads to the mining industry usually taking the blame for some of the biggest pollution of soil disasters as a result of heavy metals and chemicals (Alkorta et al 2004). At the processing stage in the mines, toxic metals such as mercury, cyanide, and sulphuric acid are added to the slurry to separate the waste from the target minerals (Namweemba 2017). Further, Namweemba (2017) stated that these highly toxic chemicals along with other affluent get to be discharged through still pipes into tailing dumps to be best stored in free air open spaces. However, these contaminants overflow and percolate through the soil, leading to the contamination of food crops in the nearby agricultural areas.

Further, Acid mine drainage (AMD) production, due to extensive sulfide mining activities, is a serious environmental problem (Dong et al., 2018). During mining, large amounts of sulfide minerals, such as pyrite ore are exposed to air, eater, and micro-bacteria and eventually generate acid mine drainage (AMD) (Dong et al., 2018). AMD is a special type of acidic drainage that has a low pH and contains high levels of Fe, $SO4$, and heavy metals. These characteristics contribute to both surface water pollution and soil pollution. Soil acidification, soil heavy metals pollution, soil iron, and sulfate pollution, and crop health in AMD-polluted soil environments are critical issues that have been investigated across the world (Dong et al 2018). Schmidt et al (2007) argued that contamination of large areas by industrial or mining activities is a serious environmental problem, and selection pressure in these polluted habitats has led to adaptation in microorganisms now containing special resistance mechanisms as a result of the permanent exposure to exceedingly high concentrations of heavy metals.

In addition, tailing dumps contributes to soil quality contamination. Tailings consist of ground rock and process effluents that are generated in a mine process plant. They are composed of finely ground-up rock after minerals of interest have been extracted from mined minerals and the related process water containing dissolved metals and reagents for the processing of minerals (Kosgei 2020). Additionally, Kosgei (2020) argued that tailings are of no incentive to nature, however, they have tremendous ecological impacts if not appropriately overseen. These effects cause unrest in the habitat making it hazardous to human and animal health.

Tailing dumps contain heavy metals and toxic effluents discharged from metallurgical processes that contaminate the soil. Toxic effluents are usually impounded in tailings dumps and cover large tracts of land (Namweemba 2017). However, when the pressure in the tailings dump builds up more especially when heavy rain falls, water in the dumps has to be decanted or risk the dam burst or collapsing (Namweemba). The author further pointed out that in either case, it contaminates the adjacent agricultural land.

Heavy metals affect the soil is several ways. Heavy metal contamination of food crops is an issue of global concern that ultimately results in toxicity and diseases in humans and animals through the consumption of contaminated soils and food crops (Onakpa et al., 2018). Heavy metals have atomic densities higher than 4 g/cm3, and these include lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver (Ag), chromium (Cr), copper (Cu), iron (Fe), and platinum (Pt). The high level of environmental contamination by these metals is dangerous because their uptake by plants and subsequent accumulation in food crops consumed by humans and animals is deleterious to health (Onakpa et al 2018).

Heavy metals in the food chain are a health hazard to consumers because they contribute to increased toxic build-up in people's bodies, Some heavy metals such as copper and cobalt do not decompose but they bio-accumulate in soils and food crops which include; fruit trees, maize (*Zeal Mays ssp.mays*), cassava (*Manihot exculanta*), soybeans (*Glycine max*), sweet potatoes (*Ipomoea batatas*), groundnuts (*Arachishy pogaema*), sugar cane (*Saccharum officinarum*), sorghum (*Sorghum bicolor*), beans (*phaseolus Vulgaris*), and varieties of vegetables (Namweemba 2017). Once the soil is contaminated, it will not only affect the rapid growth of crops and the quality yield of agricultural products but pose a threat to human health via the food chain (Emurotu and Onianwa 2017).

Several heavy metals are considered to be essential to life but if they are present in high concentrations, they become toxic because they can build up in biological systems and this is dangerous for human health (Al-Lami et al., 2020). Others such as cadmium, mercury, lead, chromium, silver, and arsenic in minute quantities have delirious effects on the body causing acute and chronic toxicities in humans (Engwa et al., 2019).

Vegetables are an important part of the local diet, therefore ingestion of these vegetables maybe an important pathway through which humans maybe exposed to elevated levels of harmful and toxic metals. Namweemba (2017) states that, in the Copperbelt Province, vegetables are often grown near or on the tailings dam as well as on the downwind side of the metallurgical plant. Such food crops are of concern if consumed by either animals or humans. Prolonged consumption of unsafe concentrations of heavy metals through foodstuffs, may lead to the chronic accumulation of heavy metals in the kidney and liver of humans disrupting numerous biochemical processes that make people vulnerable to incurable diseases such as cardiovascular, gastrointestinal cancer, nervousness, kidney and bone diseases and eventually death (Namweemba, 2017). The foregoing demonstrates that heavy metals in the soil are hazardous to both humans and plants.

1.1.1 Materials and methods

The study was based on laboratory analysis. In particular, the study adopted Atomic Absorption Spectrometry (AAS). This technique has used the determination of the heavy metals in the soil samples. In AAS element specific light absorption is used to determine the concentration of a metal in a solution. The mixture is combusted to reduce the elements of interest into free atoms that absorb light at a specific wavelength, this is following Atomic Absorption Spectroscopy for Metal Analysis (http://science.vu.nl).

Sample Collection

A total of about ten grab samples were picked from the Mindolo mining area of Kitwe and sent for laboratory analysis. This area was selected because its soil was assumed to have heavy metals that needed assessment. Therefore, the Google map sketch was used to indicate various locations to have the samples collected. Samples were collected in a circular manner around the mining plant where the first five samples were collected about ten meters from the plant fence and the other 5 were collected in a range of 50 to 100 meters into the residential area. At each sampling point bigger, solid particles like stones and plant matter were removed from the surface then the sampler (shovel) was used to dig the sample up to about 20 cm depth. The soil sample was placed into a 1-liter zip lock bag and labelled appropriately.

Sample Analysis

For the determination of the heavy metal concentration, the following equipment was involved: a digestive furnace, for digesting the samples. A flame atomic absorption spectrophotometer equipped with deuterium lamp background correction and hollow cathode lamps was used for the analysis of the heavy metals (Fe, Zn, Mn, Cu, Co, Ni, Cd, and Pb). An electronic analytical balance was used for weighing the samples. In addition, 60 percent of hydrochloric acid (HCL) and another 60 percent of nitric acid (HNO3) and hydrogen peroxide were used in sample digestion. Also, 1000 ppm stock standard solutions of heavy metals lead (Pb), iron (Fe), copper (Cu), and cobalt (Co) were used to prepare calibration standards and spiking standard solutions. Double distilled water was used throughout the study. The glassware and polyethylene containers used for analysis were washed with tap water and rinsed.

PH Analysis

To determine the potential of hydrogen (PH) and the concentration of the heavy metals in the soil samples, PH levels were analysed and the results are presented in table 1 below.

Table 1: Sample pH Table

Sample Number	pH Values
1	8.05
2	7.73
3	7.95
4	7.9
5	7.85

Table 1 shows the pH values of the sample's soils. Sample 1 had the highest pH value (8.05), while sample 2 had the lowest pH value. The results in table 1 indicate that the soil is alkaline, specifically falling into the moderately alkaline range. Nitrogen, Potassium, and Sulphur are major plant nutrients that appear to be less affected directly by soil pH than many others.

Heavy Metal Analysis

In the analysis of heavy metals, five different samples were analysed using Atomic Absorption spectrometry to determine the concentrations of certain heavy metals namely; copper (Cu), cobalt (Co), lead (Pb), and iron (Fe). The results were as follows:

Table 2: Sample AAS Values of Copper (CU)

Sample Number	AAS Values
1	9.25
2	6.169
3	5.123
4	17.42
5	2.358

Table 2 shows the Atomic Absorption Spectrometry (AAS) of copper concentrates in the soil. The table shows that sample 4 had the highest copper concentrates while sample 5 had the lowest copper concentrates. This shows that the soil had high concentrations of copper.

Table 2, based on the calculation of concentration, shows that the concentration of the metal copper as per sample collected shows higher to very high concentrations in comparison with the permissible soil concentrations of copper. The permissible soil concentrations of copper stand at 36ppm according to the World Health Organisation (WHO). Sample 4 shows the highest copper concentration, which is about 4-5 times higher than the world health organization's (WHO) permissible value of copper in the soil.

Table 3: Sample AAS Values of Iron (FE)

Sample Number	AAS Value
1	1.828
2	11.26
3	9.215
4	3.287
5	8.186

Table 3 shows the Atomic Absorption Spectrometry (AAS) of Iron (FE) concentrates in the soil. The table shows that sample 2 had the highest copper concentrates while sample 1 had the lowest copper concentrates. This shows that the soil had high concentrations of Iron. The values obtained were beyond the permissible Iron in soil allowed by the World Health Organisation.

Table 4: Sample AAS Values of Cobalt (CO)

Sample Number	AAS Values
1	0.9572
2	0.434
3	0.299
4	0.924
5	0.924

Table 4 shows the Atomic Absorption Spectrometry (AAS) of Cobalt (CO) concentrates in the soil. The results showed that the samples had low levels of cobalt.

Table 5: Sample AAS Values of Lead (Pb)

Sample Number	AAS Values
1	9.184
2	7.80
3	9.115
4	14.1
5	10.6

Table 5 shows the results of the sample AAS of Lead (Pb). From the analytical data, it can be noted that the concentrations of the metal lead from samples 1,2, 3, 4, and 5 are higher than the maximum permissible value of lead in soil, which is 85mg/kg(ppm).

1.1.2 Discussion of the results

The PH is an important parameter in assessing the mobility and retention of heavy metals in the soil. The average PH value in the research area of Mindolo of Kitwe district was 8.0. A PH range from 7.73 to 8.05 indicates the soils in the area are neutral to alkaline. Fluctuations of PH seem to be one of the major factors influencing the mobility of heavy metals in the soil, soil acidity increases the absorption of heavy metals in the soil while alkalinity of the soil may reduce the retention of heavy metals in the soil (Harrison, 2007). The main cause of soil contamination is the mining and processing of copper in the area.

Considering the concentration of copper in our analyses conducted it is clear that it is higher than the maximum permissible limits in the soil as given by the World Health Organization. Noting that this is a residential area in which these higher concentrations are it is worthy of concern and attention looking and the domestic agricultural activities in this area this is gardening and other plantations. Copper's presence in the soil can mainly be attributed to the industrial activity of Mindolo which is copper processing copper is one of the effluents from this industrial plant via dry deposition into the soil and the presence of copper has a photosynthetic effect on the plants in this area (Wong & Chang 1991). Copper as heavy metal has been shown to harm chlorophyll biosynthesis (Ouzounidou, 1992).

Further, heavy metals are thought to be one of the most dangerous stressors that occur in the environment (Nicholls & Mal, 2003). For this reason, there have been numerous studies on the toxicity of heavy metals, including lead and copper (Pahlsson, 1989)- Heavy metals impede the growth of plants, leading to smaller leaves that tend to be chlorotic (Kovacevic et al., 1999). These effects can be explained physiologically and biochemically. The treatment with heavy metals can lead to the interruption of activities of several essential enzymes, various aspects of the photosynthetic processes, uptake of essential nutrients, various aspects of the photosynthetic processes, uptake of essential nutrients, and ultra-structures also water usage in the cells (Sayed, 1999).

Following (Romeu et al., 1999) roots of plants are more severely affected than any other plant parts and other studies have indicated that heavy metals are mostly accumulated in the roots than in leaves and stems, this brings our attention to copper in these undesirable concentrations as evident from our research carried out. When a plant is exposed to more than one pollutant, interactions between those pollutants may occur. Although heavy metals may have antagonistic, additive, or synergistic effects in plants, synergistic interactions are found to be most common (Keltjens & van Beusichem, 1998; Wong & Chang 1991; Pahlsson, 1989). Synergistic interactions are very important to the ecological processes in the natural world because, in many polluted environments, pollution is caused by more than one pollutant (Keltjens & van Beusichem, 1998). This is especially true in areas where sewage sludge is disposed of on land and metal mining wastes are dumped (Luo & Rimmer, 1995). This study attempted to simulate a multi-metal contaminated environment in our research, but a synergistic relationship was not observed. This may be because the metals were added at a level that was too damaging to detect the interactive effects of both metals.

In addition, the study found lead concentrates to be high in the study site. In this research, it has been noted that lead concentration in the samples collected and analyzed is higher than the World Health Organization standards as such this is a point of concern bearing the dangers and effects that lead poses on the environment and animals. Lead is one of the major heavy metals in antiquity and has gained and has gained considerable importance as a potent environmental pollutant (Luo & Rimmer, 1995).

Apart from natural weathering processes, lead contamination of the environment has resulted from mining and metal smelting activities, and the disposal of municipal sewage sludge enriched in lead (Chaney & Ryan, 1994). Despite regulatory measures adopted to limit lead input in the environment it continues to be one of the most serious environmental and human hazards. According to (Yang et al., 2000) soil contamination with lead is not likely to decrease shortly, lead tends to accumulate in the surface ground layer and decreases with depth in concentration with depth in soil (De Abreu et al., 1998), this metal is easily taken up by plants in this regard the plants and vegetation around the Mindolo residential area. Lea is considered a general protoplasmic poison that is cumulative, slow acting, and subtle as soil contaminated with lead causes a sharp decrease in plant productivity thereby posing serious problems to agriculture (Keltjens & van Beusichem, 1998).

1.2 Conclusion

The specific type of metal contamination found in contaminated soil is directly related to the operation that occurred on that site which in this research we have attributed to mining activities in the Mindolo area. The ranges of contaminant concentrations and physical and chemical forms of contaminant seem to depend on activities and disposal patterns for contaminated waste on the site. It is therefore right to conclude that the higher than permissible concentrations of these metals, copper, and lead is as a result of the mining activities and copper processing in Mindolo and also require attention and consideration to mitigate and prevent some of these problems that are at hand in this area. Other metals like iron and cobalt as per our research are within range and cannot cause harm to either plants or the people in this area.

It is, therefore, recommended that the source control should be in line with the treatment of the effluents that are released into the atmosphere either by treating the before ore processing (pre-combustion) or after ore processing (post-combustion). This will in turn result in negligible quantities of these heavy metals that are accumulating in the soils of these residential areas around Mindolo. Below are diagrams illustrating the removal of heavy metals from industrial effluents.

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