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An Investigation of Concentrations of Copper, Cobalt and Cadmium Minerals in Soils and Mango Fruits Growing on Konkola Copper Mine Tailings Dam in Chingola, Zambia

Kayika P[1], Siachoono SM[1*], Kalinda C[2] and Kwenye JM[1]

[1]*Copperbelt University, School of Natural Resources, Kitwe, Zambia*

[2]*School of Nursing and Public Health, College of Health Sciences, Howard College Campus, University of KwaZulu-Natal, Durban, South Africa.*

[*]**Corresponding author**: Stanford M Siachoono, Copperbelt University, School of Natural Resources, Kitwe, Zambia, Tel: +260-977-487-711, E-mail: Stanford.siachoono@cbu.ac.zm

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Abstract

There is a growing potential public health risk over the consumption of food crops growing on the mining waste disposal sites on the Copperbelt in Zambia. Accumulation of heavy metals in soils may lead to raised heavy metal concentration in fruits that are growing on such mine tailings dams. A study was conducted to determine the concentration of selected heavy metals, namely Copper (Cu), Cobalt (Co) and Cadmium (Cd) in both the mango fruits and soil samples collected from three levels of the Konkola Copper Mine (KCM) tailings dam. Heavy metal determination was done using the Atomic Absorption Spectrometry (AAS) at the Copperbelt University School of Mines laboratory.

The results obtained showed that the concentration of Copper (Cu) was significantly high in both the soil samples and the fruits. No significance differences were observed in the concentration of Cobalt (Co) and Cadmium (Cd) in the soil and fruit samples.

This study highlights the fact that copper accumulates more in the soils samples and fruits compared to cobalt and cadmium. This may increase the health risks that are associated with heavy metal contamination especially among the urban population who consume these fruits. Therefore, there is need to develop an environmental monitoring protocol for tailings dam because of the effects heavy metals may have on the environment.

Keywords: Mango fruit; Mining tailings dam; Heavy metals

Introduction

Mango (*Mangifera indica*) trees grow and produce fruits that are widely eaten in Zambia. The mango tree is a tropical plant that originates from the Indian sub-continent and produces a tropical seasonal fruit, the mango [1]. The mango fruit is a good source of vitamins, proteins, carbohydrates, fats, and dietary minerals such as calcium, potassium, magnesium, iron, copper, zinc and many other [2]. These nutritional attributes and mineral content vary from variety to variety, growth stage, and from one growth medium to another [3].

In Zambia, mango trees are planted around family homesteads. However, they may also grow wherever the nutrients are favorable from mainly human seed dispersal mechanisms. Mango trees that grow on tailings dam mostly arise from human seed dispersal and find fertile ground on which to grow by chance. When in season, fruits from these trees are accessible by the general public for consumption.

Fruits can accumulate heavy metals in their edible parts [4] arising from the accumulation of such metals in their growth medium, the soil. Accumulation of heavy metals in soils has been observed to be a major contributor to environmental pollution in areas with high anthropogenic activities such as mining. Another factor of great concern is that excessive content of heavy metals in food such as fruits increases risks to diseases such as cardiovascular, kidney, nervous as well as bone diseases [5-9]. Consequently, determining the concentration of heavy metals in fruits growing mining tailings dams that are consumed by the general public is fundamental. In this regard, this study determined the concentration of selected heavy metals, namely Copper (Cu), Cobalt (Co) and Cadmium (Cd) in both the mango fruits and soil samples collected from three levels of the Konkola Copper Mine (KCM) tailings dam.

Health Effects of Cobalt, Cadmium and Copper

Mining in Zambia has been going on for more than 80 years and a lot of waste is generated from mining. The waste carries with it copper, and other trace minerals including cobalt and cadmium. Cobalt is a component of an essential vitamin B12 and occurs naturally in soil hence small amounts are ingested by humans to stay health. The toxicity of cobalt is quite low compared to many other metals in the soil, however, exposure to very high levels through ingestion, inhalation and skin contact can cause health problems over time and these include cardiomyopathy, nerve problems thickening of blood and thyroid related problems [10]. These effects have been found on workers exposed to high levels of cobalt [11].

Although human beings can tolerate levels of up to 10 mg/l of copper [12], amounts higher than this leads to health problems [13]. Suggested safe levels of copper in food and drinking water vary depending on the source but tends to be pegged at 2.0 mg/l [14]. High uptake of copper may cause liver and kidney damage and even death

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[13]. It can also affect other parts of the body such as eyes, mouth and nose irritations besides affecting the stomach and causing headaches [15].

Cadmium has been classified as a probable carcinogen and an endocrine system disruptor [16]. The uptake of cadmium levels exceeding recommended levels of is associated with renal, prostrate and ovarian cancer [17].

It is therefore paramount to check the concentration of heavy metals in food products, such as mango fruits, especially those irrigated using sewage sludge, wastewater and those growing on tailings dams. This is essential to ensure that the amounts of heavy metals in such food products meet the recommended levels [12,18].

Methodology

Study site

This study was conducted in Chingola in January 2015, at the Mutimpa tailings dam located south-west of the town. The tailings dam lies at 12° 37'04"S and 27° 53'07" E. It is one of the largest tailings dam on the Copperbelt in Figure 1.

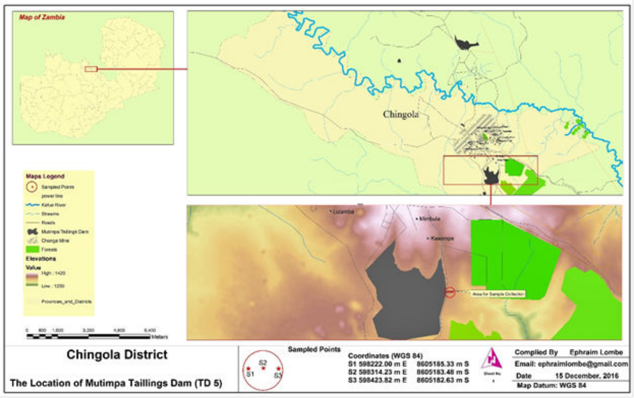

Figure 1: Map of study site indicating the location of Mutimpa Tailings Dam and Sampled points in covers an area of 1786 hectares and carries more than 285,000.000 m^3 of tailings.

Chingola is one of the seven mining towns on the Copperbelt province. Mining activities have been taking place since the 1930s when the copper ore were discovered [19]. The mine ownership has changed ownership with time. Currently, the mine is run by Konkola Copper Mine (KCM), a subsidiary of the Vedanta Resources. The mine produces mainly copper. However, cobalt is also produced as it is part of the copper ore deposits. After processing of the ore into metal, the mining wastes are disposed into mine tailings dam. This waste has therefore accumulated over a long period of mining.

A number of tropical fruit trees especially mangoes grow on these tailings dams. When in season, fruits from these trees are accessible by the general public for consumption.

Sampling Strategy

Mango samples: Stratified random sampling was used for this experiment. Because of the steep slope of the tailings disposal dam where mangoes are growing, the area was stratified in three strata. The first stratum was on the top of the slope, the second was at middle of the slope and the third was at the bottom of the slope. The strata were divided in 100 meter intervals. Then random sampling was used to collect the mangoes in three strata. Seven ripe mangoes were collected from each stratum and put in polythene bags. A total of 21 mangoes taken for laboratory analysis.

Soil samples: Using the mango collection points, soil samples were collected by digging up to 20 cm in the ground next to the mango trees. An equal number of samples, as in the mangoes, were collected from the tailings dam.

Sample preparation

The collected fruit samples were thoroughly washed and rinsed with distilled water. The samples collected from each stratum were treated independently of the samples from the other strata. The samples were then sliced to small pieces and oven dried at 70°C for 72 hours. The dried samples were then ground into powder and stored in fresh plastic polythene bags in readiness for mineral content analysis.

Mineral Content Analysis in Fruit Samples

Analysis of fruit tissue followed the wet digestion methods suggested by Cui et al. [20] from each sample of the ground fruits, 2.5 grams of the powder was obtained and put into beakers. Then 25 ml of Nitric acid was added to each beaker and left for 24 hours. After digestion with Nitric acid, 15 ml of per chloric acid was added to each of the mixture prepared earlier. The samples in the beakers were then heated until white fumes appeared (per chloric acid fumes).

50 ml of distilled water was added to each beaker and heated for 20 minutes. After cooling, the solution was thoroughly mixed and diluted using distilled water up to 100 ml per sample using a 100 ml measuring cylinder and then rinsed using filter papers. The concentration of Copper, Cobalt and Cadmium in the filtrate was determined using a flame atomic absorption spectrophotometer (AAS) with high resolution continuum source.

The Atomic Absorption Spectrometer (AAS) was set up following the appropriate operating procedure for the particular model and the instrument was calibrated so that the mineral content of Copper, Cobalt and Cadmium in the samples can be ascertained.

Mineral Content Analysis in Soil Samples

Soil samples collected from the tailing dams were also taken to the laboratory. The samples were mixed and then sieved to obtain homogenous samples. Two (2) grams of each of the soil samples collected from the three (3) tailings plus two (2) duplicates for each were put in beakers, in total 9 samples. Then 3-4 drops of Hydrofluoric acid (HF) were added to each sample to break the silicate in the soils. Then 30 ml of Nitric acid was added to each sample for decomposition to take place. The samples were then heated on the hot plate for 15 minutes. The samples for analysis of Copper, Cadmium and Cobalt were then diluted up to 100 ml with distilled water using flasks of 100 ml. The samples in the flasks were then thoroughly shaken thereafter filtered using filter papers. Atomic Absorption Spectrometer (AAS) was then used to determine the contents of Copper, Cobalt and Cadmium in all the samples.

Quality Control

All glassware used during the study was washed with distilled water and immersed in Nitric acid for 24 hours before being used [21]. Fruit samples were cleaned with distilled water and peeled with a stainless knife and shred into pieces for drying. After drying the pieces were put in an electrical grinder with stainless blades and ground into powder used for heavy metal analysis. Distilled water was used throughout the sample preparation and analysis.

Data Analysis

To evaluate the Copper, Cobalt and Cadmium in mangoes and soils from different strata, we used a one way Analysis of Variance. This was after testing for normality. Mean separation was done using Boniferoni Post Hoc Analysis as this was a planned experiment.

Results

Mineral content in the fruits

Results showed that concentration of copper in the three strata differed significantly ($p<0.0001$). The concentration of the copper in the fruits ranged from 16 ppm-50 ppm in stratum one, 8 ppm-32 ppm in stratum two and 8 ppm-44 ppm in stratum three. No significant differences ($P=0.9964$) were observed in the concentration of cobalt The concentration of cobalt in the fruits ranged from 4 ppm-44 ppm in stratum one, 4 ppm-40 ppm in stratum two and 8 ppm to 48 ppm in stratum three. The study also observed that the concentration of cobalt in the fruits ranged from 1 ppm-8 ppm across all the strata.

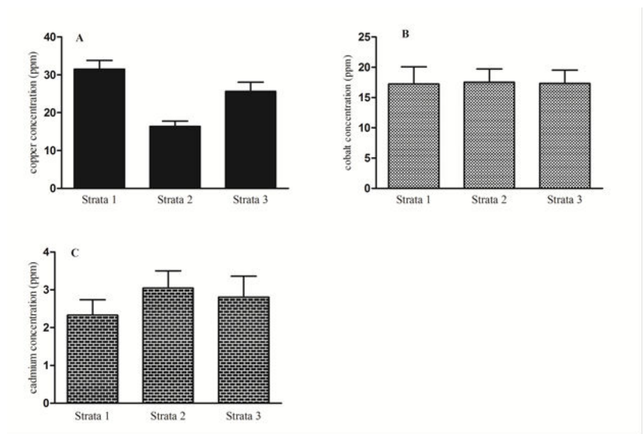

Figure 2: Mineral content in fruit samples (A) Copper (B) Cobalt (C) Cadmium

Mineral content in the soil

It was observed that the amount of copper in the fruits obtained from different strata differed significantly ($p<0.0001$). The concentrations ranged from 175 ppm-475 ppm in stratum one, 100 ppm-300 ppm in stratum two and 120 ppm-400 ppm in stratum three. Significant differences ($p=0.003$) were also observed in amount of Cobalt contained in the soil. The concentration of cobalt in soil samples ranged from 15 ppm-85 ppm in stratum one, 10 ppm-35 ppm in stratum two and 15 ppm to 110 ppm in stratum three. However, no significant difference ($p=0.3058$) were observed in the cadmium content. The contents of cadmium ranged from 0.5-5.5 ppm in stratum one, 0.5-6.0 ppm in stratum two and 0.5-7.0 ppm in stratum.

Discussion

Copper levels in Mango fruit samples and soil samples

The results from the study indicate that the soils and fruit samples from the study areas were heavily contaminated with cadmium, copper and cobalt. Our results corroborate the finding of Muchuweti et al. [22] who observed high concentration of heavy metals in crops irrigated with wastewater and sewage. Copper is an essential dietary element whose function as biocatalysts is necessary for body pigmentation and is widely distributed in the environment. It is always present in food and animals which are exposed to copper sources in the environment. A daily dietary intake of (2-3) ppm of copper is recommended for human intake [12]. The permissible limit of 10 ppm for plants and fruits has been recommended by WHO [23]. The differences in the content of copper in the fruit and soil samples from the different strata may be attributed to the topography of the study area. The amount of copper content in the soil reflected the amounts that were obtained in the fruits. This suggested that the abstraction of copper from the soil by the trees is higher. The increased levels of copper in the fruits and soils were attributed to the mining activities happening in the study areas.

Cobalt levels in Mango fruit samples and soil samples

The levels of cobalt that were in the fruits were lower than the amounts found in the soil samples. This may suggest the only limited amounts were absorbed from the soil. This may be attributed to the reduction in the translocation of the metal from the roots to the plant [24]. The safety limit for human consumption of Co is 0.05 to 1 mg/day in humans [25]. This suggests that the concentrations of cobalt in all the mango fruits fall above the safety limit.

The study also shows that the levels of cadmium in the soil and fruit were also high as compared to the recommended. About 0.2 ppm [24] of cadmium has been recommended thus increasing the health risks. On the other hand, the European Economic Community (EEC) Maximum Permissible (MP) soil cadmium concentration is 3.0 ppm soil. Cadmium has been proven to be easily absorbed by plants, and accumulated in the edible portions of crop plants to a level which could potentially be injurious to humans [26]. The contents of Cadmium in fruit samples were directly proportional to the concentrations of Cadmium in soils. Although the impact of these metals on human health is not immediate, they are toxic and may affect the functionalities of the body. Monitoring of metal concentrations on food grown on tailing dams as well as adjacent fields may need to be monitored in-order to prevent build-up both in humans and fruits.

Conclusion

Our study shows that the daily intake of cadmium and copper through mangoes from the tailing dams may constitute a health hazard. Our study suggests that there is need to reclaim these areas to reduce the contamination of the metals. The study also suggests that consumption and sale of fruits obtained from these areas should be discouraged to reduce health hazards for the consumers.

Mining operations in the study area has led to the accumulation of trace metals in soil and consequently into the fruits. Trace metal concentrations varied among the soil samples and fruit samples, which reflect the differences in their uptake capabilities and their further translocation to edible portion of the plants. The metals (Cu, Co and Cd) investigated in this study were detected in all the soil and fruit samples, but their concentrations in most of the soil and fruit samples studied were above the recommended safe limits of heavy metals by WHO, FAO, and EU Standards. High levels of the trace metals above the recommended limits [24] as assessed in the fresh fruits was a health concern due to the potential risks it might pose to consumers. It was therefore concluded that the mango fruits growing around KCM tailing dams have significantly high levels of trace metals and not fit for human consumption. Therefore consumption of Mango fruits growing around KCM tailing dams should be discouraged.

Pieces of legislation that can play a vital role in addressing concerns raised in this study are available in Zambia, for instance, the Zambia Environmental Management Act (ZEMA ACT) [27]. However, these frameworks are confined to point pollution in form of effluents from industries and sewerage discharges. Therefore, there is need to include diffuse pollution in these frameworks given the health risks associated with intake of heavy metals through the consumption of mango fruits growing on tailing dams as demonstrated in this study.

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