BINDURA UNIVERSITY OF SCIENCE EDUCATION

DEPARTMENT OF NATURAL RESOURCES

THE EFFECTS OF ARTISANAL MINING ON SOIL PHYSICOCHEMICAL PROPERTIES AROUND KWEKWE DISTRICT

MUNHONDO NYASHA

B1850864

A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS OF THE BACHELOR OF SCIENCE HONOURS DEGREE IN NATURAL RESOURCES MANAGEMENT.

Submitted 31 AUGUST 2022

DECLARATION

I, Nyasha Munhondo, hereby declare that I have read and understood the University's regulations regarding academic integrity and plagiarism. I affirm that this dissertation is my original work and has not been submitted elsewhere for academic credit.

Student's Name: Nyasha Munhondo (B1850864)

Student's Signature: NM

Date: 15/10/24

Supervisor's Name: Mr A Kundhlande

Supervisor's Signature:

15 October 2024

Chairperson's Name: Mr W Mhlanga

Chairperson's Signature: pp

15 October 2024

Dedication

To my relatives and friends

Acknowledgements

I really appreciate the effort put by my supervisor Mr. J. GOTOSA for the guidance in the formulation of this dissertation. Great thanks to Mr. T. MWAKIWA for the help in my fieldwork and laboratory analysis.

To my parents for the financial support

Acronyms

AAS	-	Atomic Absorption Spectophotometry
AMD	-	Acid Mine Drainage
ANOVA	-	Analysis of Variance
APHA	-	American Public Health Association
As	-	Arsenic
ASM	-	Artisanal and Small-scale Mining
B	-	Boron
BD	-	Bulk Density
Ca	-	Calcium
CBD	-	Central Business District
Cd	-	Cadmium
CEC	-	Cation Exchange Capacity
Cr	-	Chromium
CRBD	-	Complete Randomised Block Design
Cu	-	Copper
EC	-	Electrical Conductivity
FAO	-	Food and Agriculture Organisation
Fe	-	Iron
GIT	-	Gastro Intestinal Tract
HBP	-	High Blood Pressure
Hg	-	Mercury
K	-	Potassium
Mg	-	Magnesium
Mn	-	Manganese
Mo	-	Molybdenum
N	-	Nitrogen
Ni	-	Nickel
P	-	Phosphorus
Pb	-	Lead
SPSS	-	Statistical Package for Social Sciences

WHO	-	World Health Organisation
Zn	-	Zinc

Abstract

The study investigated the impacts of artisanal mining on soil physicochemical properties around three mining sites (Battlefield, Sherwood and Melvin) in Kwekwe district District. This was necessitated by the mining activities' disposal of toxic substances containing heavy metals with potential to cause detrimental effects if they do not adhere to EMA and WHO/FAO permissible limits. The soil parameters to be determined included bulk density, pH, CEC, EC and nutrients, as well as presence of trace elements (Cd, Cu, Hg, Pb and Zn).The soil samples were collected in triplicate from 3 random points around each artisanal mining site using a soil auger at a depth of 0-20cm after removal of surface litter. The samples were placed in polythene samples bags, labelled and properly sealed. All samples were taken to BSR laboratory at Trojan Mine for analysis using standard procedures. Results showed that, soils around the artisanal mining sites were slightly acidic pH, high CEC and EC, low soil nutrients and presence of significant concentrations of trace elements than those required by EMA and WHO. Battlefield recorded the highest soil bulk density (1.64±0.06 g/cm3). All mining sites had a slightly acidic pH ranging from 5.99 to 6.89, whereas the pH for Sherwood was outside the EMA and WHO limits. The CEC was highest in the Control (11.37±0.26 cmols) and all mining sites had EC values above EMA and WHO thresholds. All sites were significantly different in soil N and P content whereas Battlefield and Melvin were not significantly different in soil K content. Battlefield recorded the significantly highest concentrations of Cd (0.016±0.004 ppm) and Pb (0.02±0.01 ppm) whereas, Sherwood had the highest concentrations of Hg (0.045±0.03ppm) and Zn (0.029±0004 ppm), with Melvin recording the highest Cu (0.04±0.002 ppm) concentrations. Comparison of trace element concentration in soils around artisanal mining sites with EMA and WHO guidelines showed that, Cu, Pb and Zn were within both EMA and WHO threshold levels. However, all sites had Hg above both EMA and WHO limits whereas Cd was above EMA limits but within WHO standards. Overall, the total trace element concentrations in the soil around the artisanal mining sites declined in the order Cu > Hg > Zn > Pb > Cd whereas by site comparison it was in the order Control < Melvin < Sherwood < Battlefield. From the study findings, it can be recommended that artisanal miners sites should treat their effluent before disposal, and they should exploit resources sustainably so as to reduce ecosystem disruption. Future research should incorporate the impacts of artisanal mining on ground water and surrounding vegetation quality as well.

Key words: artisanal mining, EMA, soil physicochemical properties, trace elements and WHO.

Contents

List of tables

List of figures

Chapter One: Introduction

1.1 Background to the study

Artisanal and small-scale mining (ASM) refers to mining operations which employ basic tools and machinery, and manual labour for mineral ore excavation (Canavesio, 2014). It contributes to many economies producing approximately 10% of global gold output (World Bank, 2013), infrastructural development and providing a source of livelihood for many people through employment creation (Ralph et al., 2018). Artisanal mining is usually informal and mostly done illegally (Eludoyin et al., 2017) and characterized by poor technology, low productivity and hazardous working conditions (Emel et al., 2011). Though ASM is highly beneficial, it has however left a legacy of adverse environmental footprints (Ralph et al., 2018) that are felt long after the mining activities have ceased (Machacek, 2019).

Studies have reported ASM to cause severe environmental disruptions as seen in the destruction of natural ecosystems through removal of soil and vegetation pollution (air, soil, water) and land degradation (Canavesio, 2014; Melodi et al., 2021). The restoration of mined land in practice has proven to be very difficult and very slow (Machacek, 2019) thus, the footprint will persist for a very long time. This is a result of the haphazard nature of the operations and the use of toxic substances like cyanide and mercury in gold recovery (Velasquez-Lopez et al., 2010).

Heavy metal contamination of the environment might occur as a result of waste disposal containing chemical elements e.g., Cd, Cu, Hg, Ni, Pb. These trace elements in mine waste are poorly soluble in water and non-biodegradable (Patil et al., 2014), hence they tend to accumulate in soils (Khan et al., 2009) and in turn affect soil quality. When soil quality is affected, it leads to a decline in plant quality due to the extraction of contaminants from soil via the roots. In addition, ground water is contaminated through leaching and seepage of toxic substances (Melodi et al., 2021).

Soil attributes such as cation exchange capacity (CEC), electrical conductivity (EC), bulk density, nutrients and pH define soil quality and if they are affected, plant quality deteriorates (Brady and Weil, 2008). The CEC denotes the ability of soil to maintain positively charged ions and is a good indicator of soil fertility and nutrient retention capacity (Yunan et al., 2018). As soil pH increase, the number of negative charges on the colloids increases hence the CEC also increases (Carmo et al., 2015). The EC quantifies how strongly the soil resists or conducts an electric current (Martin et al., 2015). A low resistivity indicates that the soil readily allows an electric current as such the EC increases with the increasing soluble salts, thus, EC expresses the concentration of dissolved salt (Martins et al., 2015). Soil bulk density is a measure of compaction and generally, the greater the bulk density the lesser the pore space for water movement, root growth, penetration and seedling germination (USDA, 2019). Bulk density reflects the ability of the soil to function in structural support, water, solute movement and aeration (USDA, 2019).

When soil quality is affected, it leads to a decline in plant quality (Khan et al., 2009) due to the extraction of contaminants from the soil via the roots. The dispersion of trace elements to crop fields surrounding artisanal mines results in the contamination of food that may be hazardous to humans and animals (Jolly et al., 2013). Some trace elements such as (Cu, Fe and Mn) are essential to human, plant and animal metabolic processes at low concentrations, however, some trace elements such as (As, Cd, Cr, Hg and Pb) are non-biodegradable, persistent, cumulative and toxic even at lower concentrations (Barbieri, 2016). Thus, the exposure of humans to toxic trace elements in soils is worthy investigating.

1.2 Statement of the Problem

Little is known on the quality of soil surrounding artisanal mining sites around Kwekwe district. The artisanal mining activities are done in a haphazard manner using chemicals that contaminate the soil and this has led to bare, compacted and gullied soils. In the long run, soil quality will deteriorate leading to land degradation. Also, crops grown within the vicinity of these contaminated sites may uptake trace elements resulting in clinical effects if consumed by humans. The chemicals used may reach ground water through leaching with detrimental effects to communities around these sites as ground water is their only source of potable water.

1.3 Significance of the Study

It is imperative to assess the quality of soil and determine the nature of degradation in relation to the surrounding matrix. The study will provide baseline data for future researches on soil quality surrounding artisanal mines as well as raise awareness on the consequences of artisanal mining to the environment thus providing a basis for corrective action. The study findings will aid artisanal miners in decision making for pre-treatment of mine waste before disposal and minimize pollution.

1.4 Research aim

To investigate the effects of artisanal mining on soil physicochemical properties. The study examined some physical and chemical characteristics of soils in mined places of Battlefield, Sherwood and Melvin located near Kwekwe district town.

1.5 Research Objectives

1. To determine the soil physicochemical properties (bulk density, pH, CEC, EC, nutrients and heavy metals) around three artisanal mining sites.

2. To compare the soil physicochemical properties between artisanal mining sites and the surrounding matrix.
3. To compare the soil physicochemical properties with EMA and WHO standards

1.6 Hypothesis

1. Different soils have different physicochemical properties.

2. The physicochemical properties of the soil do not differ significantly between the two groups the grid of artisanal mining locations

3. The physicochemical properties of the soil do not meet EMA or WHO standards

Chapter Two: Literature Review

2.1 Artisanal Mining Process

Artisanal mining refers to small scale informal mining activities that use low technology or minimal machinery (Canavesio, 2014) and involves many people compared to those in industrial operations (World Bank, 2013). Artisanal gold mining plays an important role in global gold production and contributes to the GDP of many countries. However, artisanal mining utilizes the mercury (Hg) amalgamation technique (Carranza-Lopez et al., 2019) that unfortunately leads to Hg contamination due to its low recovery during the mining process (Velasquez-Lopez et al., 2010). Another chemical used in gold recovery is cyanide which binds readily with gold, silver and metals but is highly toxic to human, plant and animal life (Nyanzaet al., 2017). After the precious metal has been extracted from the ore, the Hg or cyanide and heavy metal-laden wastewater is discharged as process effluent into the tailings popo (Carranza-Lopez et al., 2019).Tailings are a mixture of crushed rock and processing fluids from mills that remain after mineral extraction from an ore resource (Densmore et al., 2014 and Kossof et al., 2018). Tailings are characterised by heavy metals such as Cd, Pb, Cu, Ni, and Zn, low fertility, limited vegetation establishment and dust emissions (Kossof et al., 2018; Pratush et al., 2018). Due to the nature of artisanal mining activities, the tailings facilities are usually poorly dedesigned constructed and monitored, and contain large quantities of heavy metals (Alloway, 2013).Poisonous substances in the oxide and sulphide forms of these aforementioned metals maymay released into terrestrial environments through weathering processes and pose a potential health risk to residents in the vicinity of mining operations (Alloway, 2013)

2.2 Environmental Impacts of Artisanal Mining

Though mining is of significant benefit, it however mining leads to considerable environmental problems such as deforestation, land degradation, air, soil and water pollution, loss of biodiversity and the landscape shaping (Andriamasinoro and Angel 2012; Leopold et al., 2016). Artisanal mining also leads to soil degradation and loss of soil nutrients (Eludoyin et al., 2017). According to Leopold et al., (2016) artisanal mining is associated with disorderly tree felling which leads to the disappearance of the plant cover. The dilapidation of plant cover resulted in massive soil erosion in the area. Mining pits and trenches are never filled up posing a threat for both animals and humans.

Artisanal mining also leads to soil infertility, as a result of the disappearance of humus layer through erosion (Ahmad and Al-Mahaqeri, 2014) rendering the soils barren. The large area of land disturbed by mining operations and the large quantities of earthen materials may be prone to hydraulic erosion (Leopold et al., 2016). Consequently, erosion may cause significant loading of sediments and pollutants to streams and rivers.Mining has been recognized as the primary source of heavy metals in the surrounding environment (Ahmad and Al-Mahaqeri, 2014; Leopold et al., 2016). The intense mineral extraction in mining areas produces large amounts of waste rock and tailings. Without proper management, the abandoned waste rock and tailings containing heavy metals which are nondegradable, persistent and irreversible thus generate highly pollutant acid mine drainage(AMD) due to pyrite weathering (Acheampong et al., 2013).The AMD results in the leaching of metals and other contaminants forming an acidic solution, high in sulphate and elevated concentrations of As, Cd, Cu, Pb, Zn, etc. This affects both soil and ground water quality through seepage (Jhariya et al., 2016).

2.3 Soil Properties Around Mining Sites

Soil properties are generally altered by nature of land-use with mining activities causing significant adverse changes to soil quality (Eludoyin et al., 2017). Heavy metal contamination of soils around active and abandoned mine areas is a widespread problem with Farraj et al.,(2013) concluding that soils surrounding mining environments had high levels of Cd, Cu, Pb and Zn, thus significantly affecting the soil properties. Similarly, Liu et al., (2015) reported contamination of agricultural soils in southern China due to Pb/Zn mining close by. Elevated heavy metal levels in agricultural soils may inevitably cause crop reduction and pose high potential health risk to humans when continually ingested due to bioaccumulation of pollutants(Usman et al., 2018). In a study by Ma et al., (2015), it was observed that concentrations of As, Cd and Pb in soils adjacent to mine spoils were several times higher than established threshold

2.2 Effects of Trace Elements on Plants, Animals and Human Health

Trace elements have varied adverse effects to plants, animals and humans at different concentrations leading to declines in growth and reproduction of organisms and in some cases death (Pratush et al., 2018; Gabriel et al., 2019). Table 2.1 shows the impacts of some selected trace elements according to Asati et al., (2016), Pratush et al., (2018) and Gabriel et al., (2019)

Table2.1 shows the effects of selected trace elements when in excess

Trace elements	**Adverse effects in plants**	**Adverse effects in animals**	**Adverse effects in human**
Zinc	Senescence and chlorosis	Affects respiration and reproduction	Causes cancer
Lead	Affects seed germination	Damage liver	Causes anaemia and HBP
Copper	Inhabits growth and reduce seed production	Causes tissue nicrosis a	Causes anaemia cancer and GIT damage
Mercury	Chlorosis and stained growth	Affects reproduction systems	Causes kidney failure and brain damage

CHAPTER THREE ; METHODOLOGY

3.2 Location of area of study

Battlefield, Melvin and Sherwood are located ten kilometers away from Kwekwe town along A-5 Highway, which connects Harare and Bulawayo, Zimbabwe's second-largest city, which is about 230 kilometers (140 miles) southwest of Kwekwe district. Battlefield and Melvin will be on your right side when using A-5road from Harare

3.3 Study area map

Fig 3.1:showing the study area map

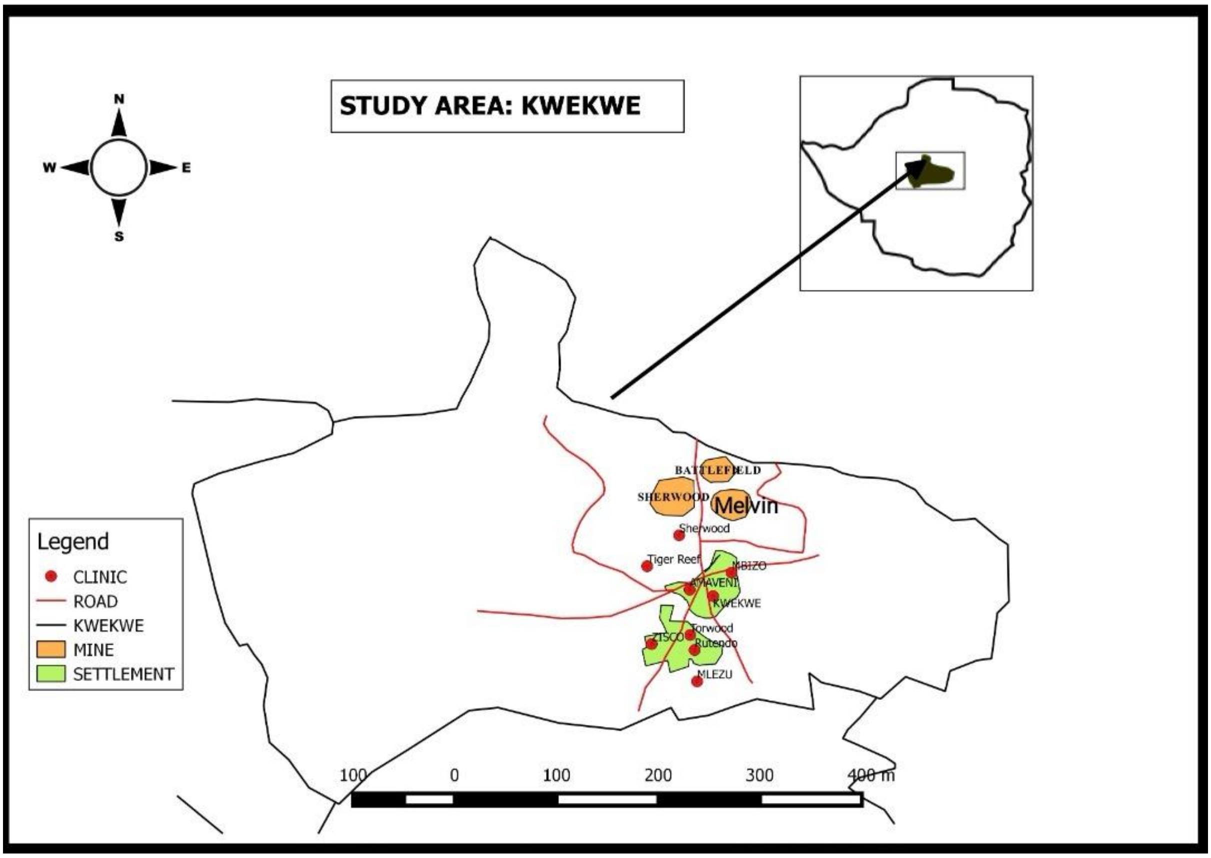
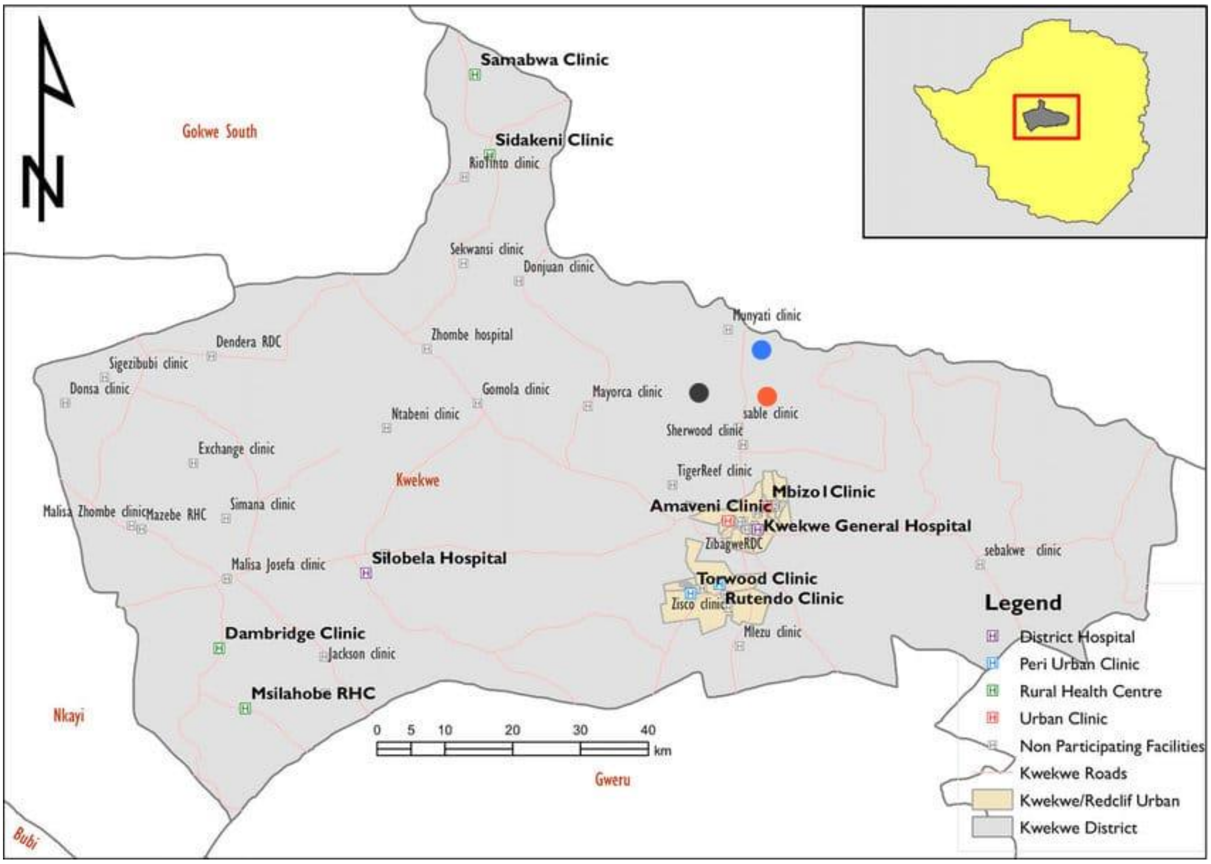


Fig3.2 shows kwekwe district in which the three sites are located



3.5 vegetation

The study sites are in a miombo woodland with Brachystegia boehmii, B. spiciformis, and Julbernardia globiflora as the dominant species. Acacia polyacantha, Bauhinia petersiana, Diplorhynchus condylocarpon, and Pilliostigma thoningii are some of the other woody species found nenear. In addition, the location is located in a Hyparrhernia grassland, which is dominated by Hyparrhenia filipendula.Bothriochloa radicans, Cynodon dactylon, Heteropogon contortus, and Melinis

3.5 Designing Experiments

The study used a split plot were the main plots are battlefield, Melvin, and Sherwood and sub plot was the treatment:(control and mined).

3.6 Soil sampling, sample preparation and analysis

Soil samples were collected at random in triplicate from three different locations. random places around each artisanal mining site following surface litter cleanup (Ito et al., 2014)At a depth of 20cm, a metal auger (5cm x20cm, diameter by height, respectively) was used. For bulk density the samples were taken with a soil corer (7x10cm) around three random spots. On each block two replicates soil samples were taken from each treatment that is mined and control .The soil samples were kept in labelled glass tubs and transported to the lab for analysis.

To reduce mineralization, the soil samples were air-dried at room temperature for 48 hours and then oven-dried to a consistent weight at 70°C (Wu et al., 2015). Prior to testing, the material was pulverized in a mortar and passed through a 2mm mesh screen (Shehata et al., 2010).

3.8 Statistical Analysis

To sort and analyze the data, the Statistical Package for Social Sciences (SPSS) software version 22.0 was utilized data analysis A one-way ANOVA (at a 0.05 level of significance) was used to test the data for normality and test for significant differences in the measured parameters between the sites

Table below shows lists of soil properties that were examined using normal techniques. Bulk density, pH, CEC, EC, nutrients (K, N, P), and heavy metals (Cd, Cu) Pb, Zn, and Hg). The bulk density of the soil was calculated by dividing its oven-dry mass by its volume.

Table 3.1 shows Standard soil sample analysis procedures

Parameter	method	reference
CEC	AAS	APHA, 2012
EC	Electrical conductivity meter	APHA, 2012
Nitrogen	Kjedahl process	Estefan *et al.*, (2013)
pH	CaCl2 of water	APHA, (2012)
Phosphorous	Wet digestion	Estefan *et al.*, (2013)
Potassium	Flame photometry	Estefan *et al.*, (2013)
Trace elements	AAS	Kachout *et al.*, (2011)

CHAPTER FOUF; RESULTS

4.1: Soil Physicochemical Properties around Sherwood, Battlefield and Melvin

Table 4.1 shows the variation in the measured physicochemical properties of soils obtained around three artisanal mining sites in Kwekwe district. Results show that all sites significantly differed in soil bulk density with Sherwood recording the significantly highest soil bulk density value of 1.64±0.06 g/cm^3). There were no prescribed limits by both EMA and WHO for soil bulk density. Battlefield had soil pH outside the EMA and WHO limits whereas Melvin was marginally outside the WHO guideline. In addition, all mining sites had a slightly acidic pH ranging from 5.99 to 6.89. Also, the soil pH for Sherwood and Melvin was not significantly different ($p > 0.05$). Thus, soil pH was in the order Control > Sherwood > Melvin > Battlefield.

The CEC was significantly highest in the Control site attaining a value of 11.37±0.26 cmols/kg and the CEC increased in the sequence Melvin < Battlefield < Sherwood < Control. In addition, Battlefield and Melvin were not significantly different ($p > 0.05$) in CEC values. On the other hand, all sites were however significantly different in EC values ($p < 0.05$) with Melvin recording the significantly highest EC (551.21±35.2 μS/cm). Thus, the EC decreased in the order Melvin > Battlefield > Sherwood > Control. Also, all mining sites had EC values above EMA and WHO thresholds (Table 4.1).

The Control site had the significantly highest concentrations of all nutrients; K (11.95±0.63%), N (6.72±1.49%) and P (13.01±0.82%). On the other hand, lowest soil nutrient contents of K, N and P were recorded in Battlefield, Sherwood and Melvin respectively. There was no prescribed limit for K and P. However, Battlefield had N content above both EMA and WHO thresholds. K and N decreased in the order Control > Sherwood > Melvin > Battlefield, whereas P followed the trend Control > Battlefield > Sherwood > Melvin (Table 4.1). All sites were significantly different in soil N and P content ($p < 0.05$) whereas Sherwood and Melvin were not significantly different in soil K content ($p > 0.05$).

Table 4.1: Mean soil physicochemical properties for the three study sites (values are expressed as mean±SD of triplicate measurements)

Sampling site	BD (g/cm^3)	pH	CEC (cmol)	EC (µS/cm)	K (%)	N (%)	P (%)
Sherwood	1.64 ± 0.06^{a}	6.89 ± 0.37^{a}	7.89 ± 0.19^{a}	263.66 ± 24.7^{a}	9.21 ± 0.47^{a}	9.19 ± 0.63^{a}	7.78 ± 1.97^{a}
Battlefield	1.51 ± 0.03^{b}	5.99 ± 0.17^{b}	5.66 ± 0.17^{b}	331.16 ± 27.1^{b}	7.85 ± 0.47^{b}	11.94 ± 0.65^{b}	8.58 ± 0.93^{b}
Melvin	1.46 ± 0.05^{c}	6.44 ± 0.45^{a}	5.02 ± 0.18^{b}	551.21 ± 35.2^{c}	8.83 ± 0.30^{c}	9.98 ± 0.42^{a}	6.64 ± 1.13^{c}
Control	1.28 ± 0.02^{d}	7.68 ± 0.37^{c}	11.37 ± 0.26^{c}	174.29 ± 14.8^{d}	11.95 ± 0.63^{d}	6.72 ± 1.49^{c}	13.01 ± 0.82^{d}
EMA	NPL	6-8	NPL	< 200	NPL	< 10	NPL
WHO	NPL	6.5-8.5	NPL	< 250	NPL	< 5	NPL

Different superscripts a, b, c, d down a given column indicate significantly different ($p<0.05$). NPL = No Prescribed Limit.

Figures 4.1 to 4.5 show the concentrations of selected trace elements in soils around artisanal mines in Kwekwe district. Sherwood recorded the significantly highest concentrations of Cd (0.016± ppm) whereas, all mining sites were not significantly different ($p > 0.05$) in soil Cd concentrations. The Control had the lowest Cd (0.03± ppm) concentrations. The concentrations of Cd followed the trend Sherwood > Melvin > Battlefield > Control (Figure 4.1).

The concentrations of Cu (0.04± ppm) in soil were significantly highest in Melvin. All mining sites were significantly different in Cu concentrations ($p < 0.05$). However, Sherwood and the Control were not significantly different (p > 005). The Cu concentrations increased in the order

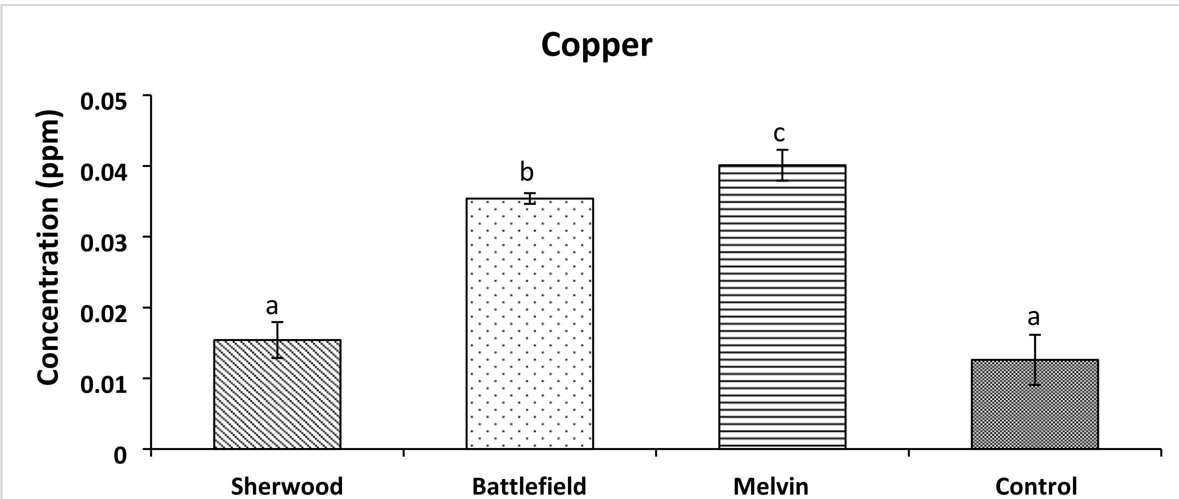


Figure 4.2: Concentration of Copper in soils around the artisanal mining sites

Control < Sherwood < Battlefield < Melvin (Figure 4.2).

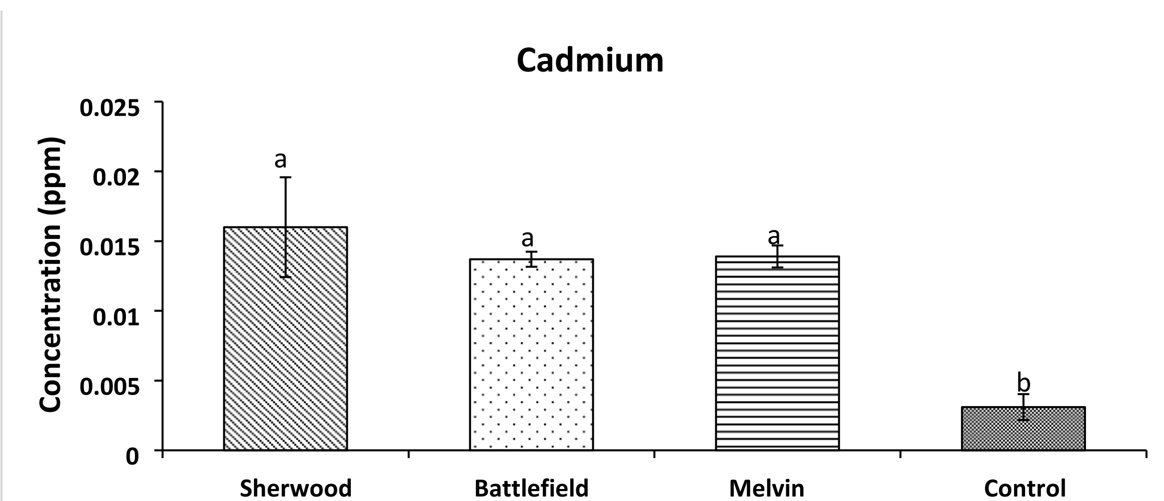


Figure 4.1: Concentration of Cadmium in soils around the artisanal mining sites

Battlefield recorded the significantly highest concentrations of Hg attaining a value of 0.045± ppm. All mining sites were not significantly different in Hg concentrations ($p > 0.05$). In addition, the Hg concentrations followed the pattern Control < Sherwood < Melvin < Battlefield (Figure 4.3).

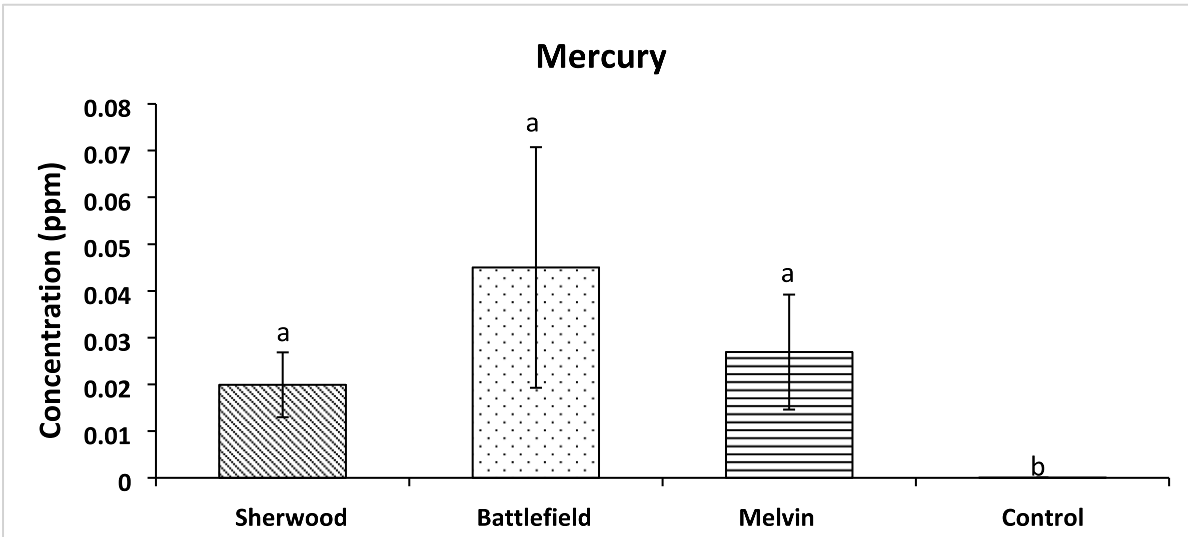


Figure 4.3: Concentration of Mercury in soils around the artisanal mining sites

All sites were not significantly different in Pb concentrations ($p > 0.05$) with Sherwood recording the significantly highest Pb concentrations (0.02± ppm). The Pb concentrations were in the order Sherwood > Melvin > Battlefield > Control (Figure 4.4).

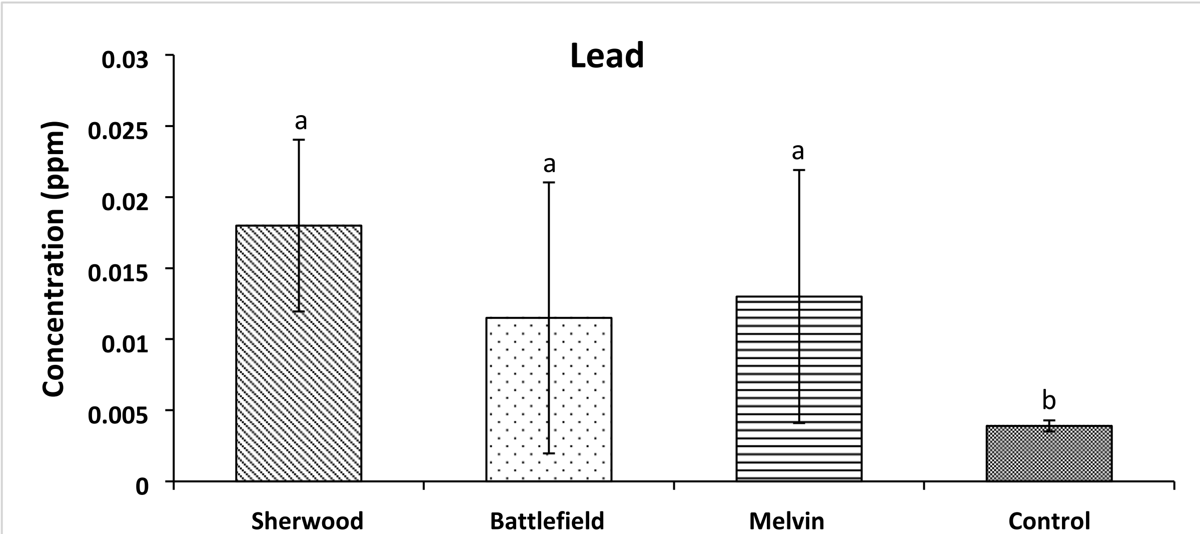


Figure 4.4: Concentration of Lead in soils around the artisanal mining sites

Battlefield recorded the significantly highest Zn concentrations with a value of 0.029± ppm. However, Battlefield and Melvin were not significantly different in Zn concentrations ($p > 0.05$). Also, the Zn concentrations were in the trend Battlefield > Melvin > Sherwood > Control (Figure 4.5).

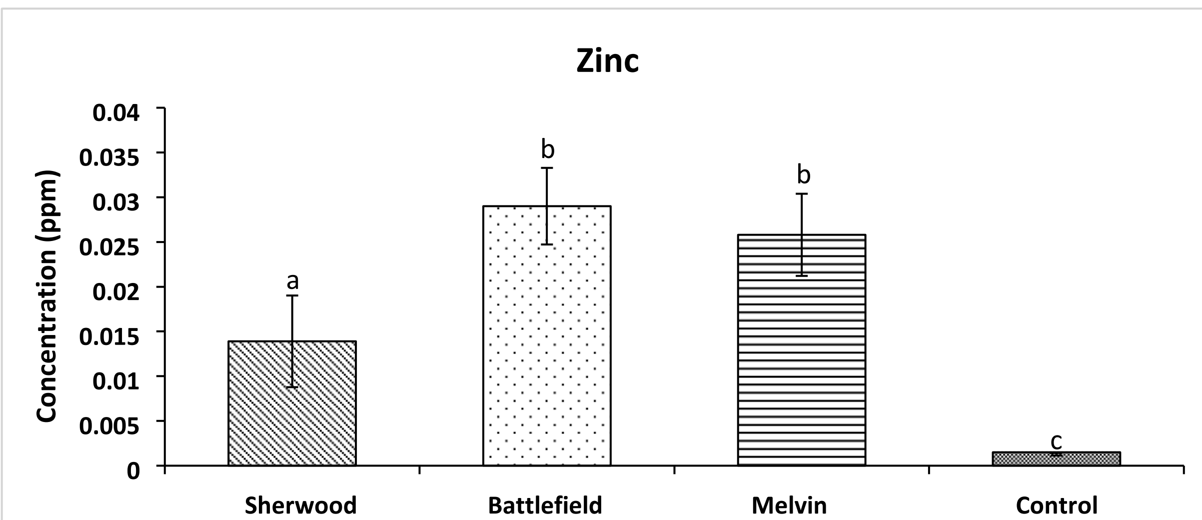


Figure 4.5: Concentrations of Zinc in soils around the artisanal mining sites

Overall, the total trace element concentrations in the soil around the artisanal mining sites declined in the order Cu > Hg > Zn > Pb > Cd whereas by site comparison it was in the order Control < Melvin < Battlefield < Sherwood.

Table 4.2 shows the comparison of trace elements around the artisanal mining sites with EMA and WHO prescribed limits. The concentrations of Cu, Pb and Zn were within both EMA and WHO threshold levels. However, all sites had Hg above both EMA and WHO limits whereas Cd was above EMA limits but within WHO standards.

Table 4.2: Comparison of trace element concentrations around artisanal mines with EMA and WHO guidelines

Site	Trace Element (ppm)				
	Cadmium	Copper	Mercury	Lead	Zinc
Sherwood	0.016 ± 0.004^{a}	0.015 ± 0.002^{a}	0.020 ± 0.07^{a}	0.018 ± 0.01^{a}	0.014 ± 0.005^{a}
Battlefield	0.014 ± 0.001^{b}	0.035 ± 0.001^{b}	0.045 ± 0.03^{b}	0.012 ± 0.09^{b}	0.029 ± 0.004^{b}
Melvin	0.014 ± 0.001^{b}	0.040 ± 0.002^{c}	0.027 ± 0.01^{a}	0.013 ± 0.08^{c}	0.026 ± 0.005^{b}
Control	0.003 ± 0.001^{c}	0.013 ± 0.003^{d}	0.0001 ± 0.0^{c}	0.004 ± 0.00^{d}	0.002 ± 0.00^{c}
EMA	< 0.01	< 1	< 0.001	< 0.05	< 0.3
WHO	< 0.1	< 10	< 0.002	< 1	< 0.3

Different superscripts a, b, c, d down a given column indicate significantly different ($p < 0.05$)

CHAPTER 5

5.1 Soil Physicochemical Properties

Results revealed that soils around the three artisanal mines had high bulk density compared to the Control soil. In addition, the mining sites had a slightly acidic pH. High bulk density could be attributed to the high volumes of traffic and people resulting in soil compaction. The Control soil was not subjected to any anthropogenic activity thus, it was not compacted resulting in lower soil bulk density. Similarly, Abiya *et al.*, (2019) reported higher bulk density around a gold mining site compared to the control site in Nigeria. A high bulk density like in the mining sites results in compacted soil, that reduces water infiltration and promotes high run-off as well as erosion resulting in gullies as observed in the mining sites. Also, a high bulk density affects pore space and soil aeration (Mohammad *et al.*, 2016) with magnified effects on soil biodiversity resulting in low nutrient turnover.

The acidic pH may have been caused by AMD due to the oxidation of sulphide ore considering that the parent material is pyrite in these mining sites. Likewise, Titshall *et al.*, (2013) and Dendooven *et al.*, (2018) asserted that when ore containing sulphidic material is exposed to water and oxygen, it undergoes biogeochemical reactions in the presence of Fe to generate AMD hence there is low pH . This is likely as most of the soils within these mining sites are of fersiallitic nature. In a study by Abiya *et al* (2019), the pH was acidic around mining sites and almost neutral in the control soil. However, Barkouch and Pineau (2016) observed neutral to alkaline pH in mining soils almost similar to control soils. Similarly, Ali *et al.*, (2017) reported alkaline pH attributed to the washing of soil bases and their later removal during gold extraction.

A relatively higher CEC in the Control site than the mining sites could possibly be a result of the release of ions bound to rocks but are disintegrated and washed off during the gold mining process. Likewise, Abiya *et al.*, (2019) reported higher CEC around gold mining soils compared to control soils. On the other hand, the EC was high in the mining sites as a result of high salt content emanating chemicals used in mineral recovery such as cyanide which contains high Na content thus, the EC was above EMA and WHO limits. These findings tally with those of Ali *et al.*, (2017) who reported EC values ranging from 0.13 - 7.43 dSm^{-1} suggesting non-saline to extremely saline conditions. Also, Acheampong *et al.* (2013) reported that the presence of electrolytes such as Fe^{3+} and NO_3^- contributed to high EC due to increased evaporation.

It was determined that the Control site had higher K and P content compared to the mining sites. This could have been attributed to presence of organic matter in the natural matrix as a result of fallen leaf litter and ashes of burnt vegetation as the area is prone to veld fires. However, a high N content for Battlefield may have been caused by the large quantities of Ammonium Nitrate fertilizers used during blasting by artisanal miners access gold ore. Also, unlike in other mining sites (Sherwood and Melvin) where there are better mining equipment and organized mining methods, in Battlefield blasting is done in a haphazard manner. The low soil nutrients around mining sites are similar with the findings of Prematuri *et al.*, (2020) who reported post nickel mining soils having 98% and 11% of total N and available P respectively, lower than natural forest. Low content of nutrients (K and P) obtained in this study is typical of disturbed environments (Dendooven *et al.*, 2018). This is attributed to lack of vegetation cover that provides leaf litter which later decompose to form organic matter. Soil organic matter is lost through initial site stripping and stockpiling. In addition, low pH influences nutrient availability as it causes leaching of these nutrients.

Several studies reported the presence of trace elements in soil around mining sites e.g., Farraj *et al.*, (2013), Ali *et al.*, (2017), Eludoyin *et al.*, (2017) and Chileshe *et al.*, (2020). The presence of trace elements in the sampled soil could have been a result of acidity which affects mobility of metals and readily dissolves them thus making them to occur at high concentrations (Chileshe *et al.*, 2020). According to Bielecka *et al.* (2009), trace elements are higher in soils when the pH is acidic and lower when pH is between 7.1-8.1. As observed in this study, soil pH around the artisanal mining sites was slightly acidic ranging from 5.9-6.8. Such conditions, are conducive to for the dissolution of metals causing them to accumulate at higher concentrations.

Abdul-Wahab and Marikar (2012) reported 80 $mg.kg^{-1}$ of Pb concentrations in gold mining soils in Oman whereas Fazekasova and Fazekas (2020) deduced that Cd, Hg and Cu exceeded the Slovak limit values, though Ni, Pb and Zn were within the desired threshold. Comparably, Odumo *et al.*, (2018) reported Zn (124.4); Pb (244.4); Cu (316.0); Cd (0.29 mg/kg) whereas

Tun *et al.*, (2020) reported Cd ranging 0.61-1.67 mg/kg; Hg (0.58-4.86 mg/kg); Pb (27.3374.67 mg/kg) pH (5.91-8.57) at panning sites. Furthermore, the concentrations of heavy metals were greater than the standard concentrations from other countries.
The significant traces of Cd in the present study could have been derived from battery cell residue emanating from used batteries that are used in touch lights by the artisanal miners. Absence of proper solid waste storage facilities in the artisanal mining sites contributes to the batteries being dumped haphazardly leading to environmental contamination. The Cu content is resultant of the geology of the study area which is made up of pyrite parent material that contains substantial quantities of Cu. Similarly, Chileshe *et al.* (2020) reported high traces of Cu attributed to the parent geology which was a copper belt.

The high Hg concentrations observed in this study are mainly derived from the amalgamation technique used in gold recovery by the artisanal miners (Velasquez-Lopez *et al.*, 2010). The Hg is not soluble and thus cannot be recovered hence it is lost to the environment (CarranzaLopez *et al.*, 2019). This is worsened by the fact that gold panning is also practiced without proper safety, health and environmental (SHE) quality standards. This leads to the leakage of Hg into the environment with potential adverse effects. Especially in Battlefield where there are no leaching and elution tanks to contain the Hg laden wastewater. Similarly, Basri *et al.*, (2020) reported that

Hg concentrations were almost 50 times higher in soils from artisanal gold mining areas compared with control areas. Also, Hg concentrations were twice greater in soils around commercial mining operations (Basri *et al.,* 2020).

Pb concentrates are attributed mainly to automobile exhaust, particularly from leaded gasoline, motor vehicle tyres, and lubricant oils from heavy traffic volumes (Zwolak *et al.,* 2019) are deposited on to the soil and percolates into the ground thus affecting soil quality. For example, there is high traffic volume in the Sherwood mining sites due to vehicles that transport gold ore for processing as well diesel-powered generators. These emit large quantities of Pb which are then deposited on the soil within the mining site. This concurs with Ali *et al.,* (2017) who reported soils around gold miming sites containing elevated levels of Pb being four times greater than prescribed limits. In the present study, agricultural activities are undertaken in the vicinity of these artisanal mining sites. This poses a risk as these pollutants may affect soil quality and in turn reduce soil productivity and food security (Alloway, 2013).

CHAPTER 6

6.1 Conclusion and recommendation

The mined soils are losing essential physicochemical elements that are required for plant growth and establishment. The concentrations of important physicochemical properties such as K, P, Ca, Mg, Na, and OC and the value of EC in the soils have been significantly reduced as a result of the small-scale mining activities. Within the study area, anthropogenic activities did not cause significant variation in the concentrations of heavy metals such as Cu, As, Hg, Pb, and Cd between unmined and mined soils; however, concentrations of some of the heavy metals increased in the mined area.The findings of the present study indicated that the soils around the artisanal mining sites had a high bulk density, slightly acidic, low CEC and high EC, low soil nutrients and presence of significant concentrations of trace elements than those prescribed by EMA and WHO. The concentrations of Cd and Hg were outside EMA and WHO permissible standards whereas Cu, Pb and Zn were within the prescribed limits but have the potential to accumulate overtime as they are persistent and non-biodegradable. Generally, the total concentrations of trace elements in the soil around the artisanal mining sites declined in the order Cu > Hg > Zn > Cd > Pb whereas by site it increased in the order Control Sherwood< Melvin< Battlefield.

6.2 Recommendation

- The effects of artisanal mining on ground water and adjacent vegetation should be studied further.
- Artisanal miners should use resources sustainably to avoid disrupting ecosystems.
- Effluent from artisanal mining sites should be treated before disposal.
- Artisanal miners should fill pits and grow trees to restore the ecosystem

References

Abdul-Wahab, S. and Marikar, F. 2012. The environmental impact of gold mines: pollution by heavy metals. *Open Engineering* 2(2):304-13.

Abiya, S. E., Odiyi, B. O., Ologundudu, F. A., Akinnifesi, O. J. and Akadiri, S. 2019. Assessment of Heavy Metal Pollution in a Gold Mining Site in Southwestern Nigeria. *Biomedical Journal of Scientific and Technical Research* 12(4)-2019.

Acheampong, M. A., Paksirajan, K. and Lens, P. N. L. 2013. Assessment of the effluent quality from a gold mining industry in Ghana. *Environmental Science Pollution and Resources* 20:3799–3811.

Ackerson, J. P. 2018. Soil sampling guidelines. Available online at: https://www/ag.purdue.edu/Agry (Accessed 23 June 2021).

Ahmad, A. K. and Al-Mahaqeri, S. A. 2014. Assessment of Abandoned Mine Impacts on Concentrations and Distribution of Heavy Metals in Surface Sediments of Catchments Around Sungai Lembing Abandoned Tin Mine. *Iranica Journal of Energy & Environment* 5:453-460.

Ali, M., Elhagwa, A., Elfaki, J. and Sulieman, M. 2017. Influence of the artisanal gold mining on soil contamination with heavy metals: A case study from Dar-Mali locality, North of Atbara, River Nile State, Sudan. *Eurasian Journal of Soil Science* 6(1):28-36.

Alloway, B. J., 2013. Sources of heavy metals and metalloids in soils. In: Alloway, B.J. (Ed.), Heavy Metals in Soils. Springer, Netherlands, pp. 11–50.

American Public Health Association (APHA). 2012. American Water Works Association and Water Environment Federation. Standard methods for the examination of water and waste water. American Public Health Association, USA, 20th ed., Washington, DC.

Andriamasinoro, F. and Angel, J.M. 2012. Artisanal and Small-Scale Gold Mining in Burkina Faso: Suggestion of Multi-Agent Methodology as a Complementary Support in Elaborating a Policy. *Resources Policy* 37:385-396.

Asati, A., Pichhode, M. and Nikhil, K. 2016. Effect of Heavy Metals on Plants: An Overview. *International Journal of Application or Innovation in Engineering & Management* 5(3):2319-4847.

Barbieri, M., Nigro, A., Sappa, G. 2016. Soil contamination evaluation by Enrichment Factor (EF) and Geoaccumulation Index (Igeo) 5.

Barkouch, Y. and Pineau, A. 2016. Evaluation of the impact of mine activity on surrounding soils of Draa Lasfar mine in Marrakech- Morocco. *African Journal of Environmental Science and Technology* 10(1):44-49.

Basri, Sakakibara, M. and Sera, K. 2020. Mercury in Soil and Forage Plants from Artisanal and Small-Scale Gold Mining in the Bombana Area, Indonesia. *Toxics* 8(15):1-10.

Brady, N. C. and Weil, R. R. 2008. The nature and properties of soils (14th ed.). Upper Saddle River: Pearson.

Canavesio, R. 2014. Formal mining investments and artisanal mining in southern Madagascar: Effects of spontaneous reactions and adjustment policies on poverty alleviation. *Land Use Policy* 36:145–154.

Carranza-Lopez, L., Caballero-Gallardo, K., Cervantes-Ceballos, L., Turizo-Tapia, A. and Olivero-Verbel, J. 2019. Multicompartment mercury contamination in major gold mining districts at the department of Bolivar, Colombia. Arch. *Environmental Contamination Toxicology* 76:640–649.

Chileshe, M. N., Syampungani, S., Festin, E. S. 2020. Physico-chemical characteristics and heavy metal concentrations of copper mine wastes in Zambia: implications for pollution risk and restoration. *Journal of Forest Resources* 31:1283–1293.

Densmore, J. N., Izbicki, J., Murtaugh, M. 2014. Mine tailings dam: characteristics, failure, environmental impacts and remediation. Elsevier, Carlifornia, United States.

El-Ramady, H. R., Alshaal, T. A., Amer, M., Domokos-Szabolcsy, E., Elhawat, N., Prokisch, J.and Fári, M. 2014. In Ozier-Lafontaine H. and Lesueur-Jannoyer M. (eds.). *Sustainable Agriculture Reviews* 14: Agro-ecology and Global Change.

Eludoyin, A. O., Ojo, A. T., Ojo, T. O. and Awotoye, O. O. 2017. Effects of Artisanal Gold Mining Activities on Soil Properties in a Part of Southwestern Nigeria. *Cogent Environmental Science* 3 (1305650):1-11.

Emel, J., Huber, M. T. and Makene, M. H. 2011. Extracting sovereignty: Capital, territory, and gold mining in Tanzania. *Political Geography,* 30:70–79.

Estefan, G., Sommer, R. and Ryan, J. 2013. Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North Africa Region: Third Edition. Beirut, Lebanon: International Center for Agricultural Research in the Dry Areas (ICARDA).

Farraj, A. S., Usman, A. R. A., Otaibi, S. H. M. 2013. Assessment of trace elements contamination in soils surrounding a goldmine: comparison of two digestion methods. *Journal of Chemistry and Ecology* 29(4):1-19.

Fazekašová, D. and Fazekaš, J. 2020. Soil Quality and Heavy Metal Pollution Assessment of Iron Ore Mines in Nizna Slana (Slovakia). *Sustainability* 12(2549):1-15. doi:10.3390/su12062549

Gabriel N., Perez-Lopez, A. and Santos-Cordova, J. M. 2019. As, Cr, Hg, Pb and Cd concentrations and bioaccumulation in the Dugong and Manatee: A review of body burdens and distribution.

Grossman, R. B. and Reinsch, T. G. 2002. Bulk density and extensibility: Core method. In: Dane, J. H. and Topp, G. C. (Eds.). Methods of Soil Analysis, Part 4. Physical Methods. SSSA, Inc., Madison, WI, pp. 208-228.

Ito, E., Toriyama, J., Araki, M., Kiyono, Y., Kanzaki, M. 2014. Physicochemical Surfacesoil Properties after Litter removal Manipulation in a Cambodian Lowland Dry Evergreen Forest. *JARQ* 48(2):195-211.

Jhariya, D. C., Khan, R and Thakur, G. S. 2016. Impact of Mining Activity on Water Resource: An Overview study. *Recent Practices and Innovations in Mining Industry* :271-277.

Jolly, Y. N., Islam, A. and Akbar, S. 2013. Transfer of metals from soil to vegetables and possible health risk assessment. *SpringerPlus* 2:385. doi:10.1186/2193-1801-2-385.

Kachout, S. S., Mansoura, A. B., Mechergui, R., Leclerc, J. C., Rejebb, M. N. and Ouerghia, Z. 2011. Accumulation of Cu, Pb, Ni and Zn in the halophyte plant Atriplex grown on polluted soil. *Journal of Science Food and Agriculture* 92:336–342.

Khan, Z. H.; Qadir, I.; Yaqoob, S.; Khan, R. A.; Khan, M. A., 2009. Response of range grasses to salinity levels at germination and seedling stage. J. Agric. Res. (Lahore), 47 (2): 179184.

Kossof, D., Dubbin, D. E., Alfrdson, M., Edwards, J. S., Macklin, M. G. and HudsonEdwards, A. K. 2018. Mine tailings dams: Characteristics, failure, environmental impacts and remediation. *Applied Geochemistry.* London, UK.

Lei, K., Giubilato, E., Critto, A., Pan, H., Lin, C., 2016. Contamination and human health risk of lead in soils around lead/zinc smelting areas in China. *Environmental Science and Pollution Resources* 23, 13128–13136.

Léopold, E., Sabine, D., Philémon, Z. and Jung, M. 2016. Physical and Metals Impact of Traditional Gold Mining on Soils in Kombo-Laka Area (Meiganga, Cameroon). *International Journal of Geosciences* 7:1102-1121.

Liu, M., Yang, Y., Yun, X., Zhang, M. and Wang, J. 2015. Concentrations, Distribution, Sources, and Ecological Risk Assessment of Heavy Metals in Agricultural Topsoil of the Three Gorges Dam Region, China. *Environmental Monitoring and Assessment* 187:147.

Ma, L., Sun, J., Yang, Z. and Wang, L. 2015. Trace element contamination of agricultural soils affected by mining activities around the Ganxi River in Chenzhou, Southern China. *Environmental Monitoring and Assessment* 187(731):1-21.

Machacek, J. 2019. Typology of Environmental Impacts of Artisanal and Small-Scale Mining in African Great Lakes Region. A Review. *Sustainability* 11(3027):1-24.

Martin, M. A., Pachepsky, Y. A., Garcia-Gutierrez, C. and Reyes, M. 2017. On soil textural classifications and soil texture-based estimations. Solid Earth Discussions. https://doi.org/10.5194/se-2017-84. Manuscript under review for journal Solid Earth.

Melodi, M. M., Ojulari, M. K. and Oluwafemi, V. I. 2021. Economic and Environmental Impacts of Artisanal Gold Mining on Near-By Community of Sauka-Kahuta, Nigeria. *Research* :340-352. DOI: 10.13140/RG.2.2.31820.33925.

Mugandani, R., Wuta, M., Makarau, A. and Chipindu, B. 2012. Re-classification of AgroEcological Regions of Zimbabwe in conformity with climate variability and change. *African Crop Science Journal* 20(2):361-369.

Nyanza, E.C., Yohana, P., Thomas, D. S. K., Thurston, W. E., Konje, E. and Dewey, D. 2017. Knowledge of and Adherence to the Cyanide Code Among Small-scale Gold Miners in Northern Tanzania. Journal of Health and Pollution 7:4–14.

Odumo, B. O., Nanos, N., Carbonell, G.,Torrijos, M., Patel, J. P. and Rodríguez-Martín, J. A. 2018. Artisanal gold mining in a rural environment: Land degradation in Kenya. *Land Degradation and Development* 29:3285–3293.

Patil, S. S., Thakur, V. R. and Ghorade, I. B. 2014. Analysis of Heavy Metals in Jaikwadi Dam Water, Maharashtra (India). *International Journal of Research in Applied, Natural and Social Sciences* 2(5):69-74.

Pratush, M., Ajay, K. and Hu, Z. 2018. Adverse effect of heavy metals (As, Pb, Hg and Cr) on health and their bioremediation strategies, North West University, South Africa.

Prematuri, R., Turjaman, M., Sato, T. and Tawaraya, K. 2020. The Impact of Nickel Mining on Soil Properties and Growth of Two Fast-Growing Tropical Trees Species. *International Journal of Forestry Research,* Article ID 8837590. 1-9.

Ralph, O., Gilles, N., Fon, N., Luma, H. and Greg, N. 2018. Impact of Artisanal Gold Mining on Human Health and the Environment in the Batouri Gold District, East Cameroon. *Acad. J. Interdiscip. Stud*. 8(7):25–44.

Reddy, S. K. and Reddy, G. V. S. 2017. The Mobility of Trace Metals from Soil to Plant in Irrigation Fields around Tummalapalle Uranium Mine in Kadapa District, Andhra Pradesh. *Madras Agriculture Journal* 104(1-3):32-36.

Tun, A. Z., Wongsasuluk, P. and Siriwong, W. 2020. Heavy Metals in the Soils of Placer Small-Scale Gold Mining Sites in Myanmar. *Journal of Health and Pollution* 10(27):1-12.

United States Department of Agriculture (USDA). 2019. Natural Resources Conservation Services. Soil Quality Kit – Guide for Educators.

Usman, K., Al-Ghouti, M. A. and Abu-Dieyeh, M. H. 2019. The assessment of cadmium, chromium, copper, and nickel tolerance and bioaccumulation by shrub plant *Tetraena qataranse. Scientific Reports* 9(5658):1-11.

van Herk, A. 2012. Physicochemical Parameters in Soil and Vegetable Samples from Gongulon Agricultural Site, Maiduguri, Borno State, Nigeria. *International Journal of Chemistry* 21-36. [01] ISSN 2306-6415.

Velásquez-López, P. C., Veiga, M. M. and Hall, K., 2010. Mercury balance in amalgamation in artisanal and small-scale gold mining: identifying strategies for reducing environmental pollution in Portovelo-Zaruma, Ecuador. *Journal of Cleaner Production* 18:226–232.

WHO (2008) Guidelines for drinking water - water quality, 3rd edition incorporating the first and second agenda volume 1. Recommendations, World Health Organisation, Geneva, Switzerland.

World Bank, 2013. Mining together: large-scale mining meets artisanal mining - a guide for action. World Bank, Washington, DC. 〈http://documents.worldbank.org/curated/en/148081468163163514/Mining-together-large-scale-mining-meets-artisanalmining-a-guide-for-action〉.

Wu, G., Kang, H., Zhang, X., Shao, H., Chu, L., and Ruan, C. 2015. A critical review on the bio-removal of hazardous heavy metals from contaminated soils: issues, progress, ecoenvironmental concerns and opportunities. *Journal of Hazardous Materials* 174:1–8.

Xiao, R., Wang, S., Li, R., Wang, J.J., Zhang, Z., 2017. Soil heavy metal contamination and health risks associated with artisanal gold mining in Tongguan, Shaanxi, China. *Ecotoxicol. Environ. Saf*. 141, 17–24.

Yunan, D., Xianliang, Q. and Xiaochen, W. 2018. Study on cation exchange capacity of agricultural soils," IOP Conference Series: *Materials Science and Engineering* 392.

Zwolak, A., Sarzyńska, M., Szpyrka, E. *et al.* 2019. Sources of Soil Pollution by Heavy Metals and Their Accumulation in Vegetables: A Review. *Water, Air and Soil Pollution* 230:164.