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DEPARTMENT OF NATURAL RESOURCE MANAGEMENT

CHROMIUM (Cr) CONTAMINATION AND EFFECTS AROUND POST MINED SITES ALONG THE GREAT DYKE IN ZIMBABWE.

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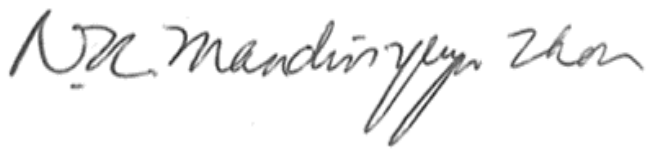

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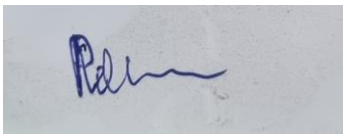
Student  signature.....

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DECLARATION

I, Pelagia Nduna , am officially declaring that this dissertation is a product of my original research and that I am the sole author of the work; as such borrowed ideas are cited accordingly as references. This work has not been accepted elsewhere for the conferment of any academic entitlement and is not concurrently submitted in candidature of any such awards.

DEDICATION

This dissertation is dedicated to my beloved parents, Mr. and Mrs. NDUNA, who have always supported and encouraged me throughout my academic journey. Their unwavering love and guidance have been instrumental in shaping me into the person I am today.

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ABSTRACT

In Zimbabwe, chromium mining has led to the deposition of tailings and waste materials in various sites which are sources of chromium enrichment in soils and water systems, in the surrounding area. This study examined the level of chromium (Cr) contamination and the associated environmental impacts in post-mined sites in the Great Dyke of Zimbabwe at Mutorashanga, Lalapanzi and the Railway Block Stream. These areas are characterized by chrome mining operations that produce significant amounts of tailings and waste material from the chrome mining process, which are a significant source of enrichment of the soils and water of these areas with chromium. Soil, tailings and water samples were collected using a purposive sampling technique, based on the proximity of the sampling points to the mining operations. The elements of chromium were analyzed by Atomic Absorption Spectrophotometry (AAS) and pH and organic matter by chemical analysis to assess the effects of pH and organic matter on chromium distribution and mobility. The results indicated that the level of chromium was found to be highest in the mine tailings with a lower concentration being seen in the surrounding soils. This pattern suggested that the contamination of chromium was highly correlated with the location of the mine tailings and decreased away from the tailings. Tailings had a low organic matter content and soil pH was slightly acidic to neutral, indicating poor soil quality at the mined sites. The movement of chromium and the risk to the environment was found to be affected by the properties of the soil, particularly pH and organic matter. Continuous environmental monitoring, and effective rehabilitation strategies for lands as a recommendation to improve mine waste management to support sustainable mineral resources management.

Key words: Post mined areas, Heavy metals, Chromium enrichment, Tailings

ABBREVIATIONS

AAS – Atomic Absorption Spectrophotometry

APHA – American Public Health Association

Cr – Chromium

Cr^{3+} – Trivalent Chromium

Cr^{6+} – Hexavalent Chromium

EMA – Environmental Management Agency

LOI – Loss on Ignition

mg/kg – Milligrams per kilogram

mm – Millimetres

pH – Potential of Hydrogen

% – Percent

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

The mining of chrome is mainly concentrated in the Great Dyke region of Zimbabwe, notably at Lalapanzi and Mutorashanga, which is one of the big producers of chrome in Africa. Though the rocks contain chromium naturally, the mining operations alter the geology and release chromium, which is a contaminant to the surface environment. Much of the waste rock and tailings are produced during extraction and processing. Alloway (2013) reported that these waste products can include high levels of chromium that can be carried off by surface run-off, erosion and leaching into the surrounding soils and water bodies.

Post-mined soils may have changes in soil pH, organic matter, and vegetation cover because of soil disturbance (Bradshaw, 1997). These changes may impact soil productivity and the possibility of restoration. The behaviour of heavy metals is strongly affected by the soil properties. Metal solubility and mobility is one of the most important soil properties that influences it. Some metals are more available for transport through the soil under acid conditions (Brady and Weil, 2016). Organic matter is also an important factor in binding heavy metals by adsorption and complexation, which decreases their mobility and bioavailability (Nelson and Sommers, 1996; Kabata-Pendias, 2011).

Information on the concentrations of chromium in soil, tailings, and in water in the immediate vicinity of the mining operations is therefore of interest to understanding levels of environmental quality and to support sustainable management of mineral resources. Data from the local area are critical to understanding if the levels of chromium are natural geological background or if they are associated with the mining activity.

With the rise of mining activities along the Great Dyke (also small scale mining) there is growing concerns around environmental chromium contamination and long term degradation of land.

1.2 STATEMENT OF THE PROBLEM

To date, there are some tailing and wastes sites, such as Mutorashanga and Lalapanzi, along the Great Dyke where chrome mining has left deposits. These materials act as the source of

enrichment of adjacent soils and adjacent water systems with chromium. However, little comparative information is available on chromium concentrations in tailings, soils in adjacent areas and nearby streams in selected post-mined areas. Also, soil properties which affect the mobility and environmental risk of chromium (e.g. pH and organic matter content) have not been well documented and have not been related to chromium distribution in the selected study sites. This is because information is lacking to enable an assessment of the impact of a mineral contaminant in the environment to suggest the most suitable management and rehabilitation plan.

1.3 JUSTIFICATION

This study makes the following contributions to the environmental assessment and mineral resource management in Zimbabwe. In the first instance it supplies local information on the concentrations of chromium in soils, tailing and water at sites all along the Great Dyke, one of the most economically important geological formations in the country (Frost and Groves, 1989). Secondly, it evaluates soil pH and organic matter content, which are important indicators of soil health and land restoration potential (Brady and Weil, 2016).Thirdly, knowledge of the pattern of chromium enrichment aids in the identification of natural geogenic background levels from any possible chromium related contamination sources. This type of information is valuable for the environmental monitoring, planning and policy process for rehabilitation and balancing mineral extraction with environmental protection.

1.4 OBJECTIVES

The objectives of the study are

1.4.1 To identify post chrome mined areas in Mutorashanga and Lalapansi areas along the Great Dyke in Zimbabwe and assess chromium (Cr) concentration in environment/soil around and nearby water sources within selected sites in the study areas.

1.4.2 To compare levels of chromium concentration between mine tailings, adjacent soils and nearby stream environments in order to determine possible patterns of contamination.

1.4.3 To explore other sources of chromium concentration in the study areas, particularly those associated with chrome mining activities and mine waste materials.

1.4.4 To suggest ways by which management and rehabilitation strategies that could help reduce chromium contamination in post-mining environments could be developed to improve mineral resources management in the area.

1.5 RESEARCH QUESTIONS

In order to achieve these objectives, the following research questions were formulated.

1. Where are post chrome-mined areas located along the Great Dyke?

2. What are the levels of chromium content in soils, tailings and water at the selected sites?

3. How do soil pH and organic matter influence the distribution of chromium in the study areas?

1.6 RESEARCH DESIGN

The design of this project comprises introduction in which a background, problem statement, justification and objectives have been included. This is followed by detailed formulation of research questions and elaboration of methodology which involved laboratory analyses to determine the concentration of chromium by employing Atomic Absorption Spectrophotometry (AAS) and standard laboratory procedures. They represent a basic process of data collection, as outlined in the Methodology, as part of the project design. The methodology is followed by the results presentation, discussion, conclusions and recommendations for better environmental management.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

In many countries, mineral resource extraction is an important part of the economy and plays a major role in economic development. But, these activities are usually linked with environmental problems, especially soils and water sources polluted with heavy metals. Heavy elements are long lasting and can bind to living things and sediments in water, to soils and pose risk to ecosystems and human health (Alloway, 2013).

The presence of chromium is one of the major concerns in the environment in the areas where the chromite is being mined. The concentration of chromium and other heavy metals in waste materials like mine tailings and waste rock may be high, and these waste materials are produced in significant volumes during mining and mineral processing operations. Heavy metals may be released to surface soils and waters by the environmental processes that affect these wastes, including rainfall and soil erosion and weathering.

Relevant literature pertaining to the Occurrence of Chromium in Mining environments is reviewed in this chapter. It addresses the presence and reactivity of chromium in the environment, environmental consequences of chrome mining, the effect of soil characteristics like pH and organic matter on the mobility of heavy metals, and the environmental hazards of chrome mine tailings. In addition, the chapter also examines environmental management and land rehabilitation practices in mining areas.

2.2 OCCURRENCE AND BEHAVIOUR OF CHROMIUM IN THE ENVIRONMENT

Chromium is a naturally occurring element and is plentiful in the earth's crust. It is mainly associated with ultramafic and mafic rocks that contain chromite minerals. Areas with appreciable contents of chromite are therefore significant chromium mining centres. The Great Dyke, in Zimbabwe, is one of the major geological formations containing chromium ore and is where large deposits of chromite are found.

Chromium can be found in a number of oxidation states, but the most stable ones in the environment are +3 (Cr^{3+}) and +6 (Cr^{6+}). The two forms have very dissimilar chemical properties and toxicity. The trivalent chromium is relatively stable and less toxic, while hexavalent chromium is much more soluble and is more toxic to living things (Alloway, 2013).

Chromium levels can be raised considerably in the environment around mining operations. During the mining process chromium-bearing rocks are removed from the earth and are broken up and exposed to weathering processes. This can result in the release of chromium into the soils, sediments and water bodies via erosion, run-off and leaching (Kabata-Pendias, 2011). Thus, nearby locations to chrome mining operations may have higher concentrations of chromium.

2.3 ENVIRONMENTAL IMPACTS OF CHROME MINING

Mining activities may produce significant amounts of waste material such as mine tailing and waste rock. These materials could include large amounts of heavy metals which could cause a problem if not managed properly if released in the surrounding environment. Exposure to rainfall and surface runoff can result in the transport of contaminants into adjacent soils, streams and groundwater systems (Alloway, 2013).

One of the significant sources of environmental pollution in chrome mining areas is the mine tailings. Tailings are a by-product of ore processing, or coarser residue that stick to the valuable minerals during this operation. Tailings are very fine particles, and can be easily blown or washed off into nearby ecosystems.

Research has indicated that the concentrations of heavy metals tend to be highest in mine tailings and fall off as distance from the point of contamination increases (Kabata-Pendias, 2011). Heavy metal accumulation in soils could have a negative impact on soil fertility, soil microbial activity and plant growth. Heavy metals may interfere with the absorption of nutrients and be detrimental to agricultural productivity at high levels (Brady and Weil, 2016).

Furthermore, polluted soils can be a threat to human well-being because of the contamination of crops and water sources. Soil sampling to determine the level of heavy metals around the mining site is therefore important in order to measure environmental effects.

2.4 STUDIES ON CHROMIUM CONTAMINATION IN ZIMBABWE AND SOUTHERN AFRICA

There are several studies that have investigated the presence of heavy metals in mining related activities in Zimbabwe and other Southern African countries. Zimbabwe is one of the major

producers of chromite, with operations largely located along the Great Dyke. The extraction of these resources has been of concern due to the possibility of chromium being released into surrounding ecosystems.

The study by Mapanda et al. (2005) revealed that the heavy metals associated with mining and industrial activities can be deposited in soils and may be incorporated into agricultural or water bodies at some time. It was noted that soil monitoring is important in areas that are close to mining operations in order to ensure that levels of heavy metals are monitored in the soil.

Likewise, Nriagu (1996) reported that heavy metal pollution in developing countries is caused by many activities, including mining. Poor waste disposal and environmental monitoring can sometimes be a source of contamination.

Soil properties also have a significant impact on the distribution and mobility of heavy metals in contaminated soils as found in Southern Africa studies (Moyo et al., 2012). The results show that soil properties should be taken into account when the environmental contamination in mining regions is assessed.

Although these studies offer good general information on heavy metal contamination in mining areas, the majority of these are on trends rather than on site within the Great Dyke. Furthermore, little research has been conducted to consider the interaction between soil parameters such as pH and organic matter on the behaviour of the element chromium in post-mined landscapes. The need for local studies, which consider both the chemical analysis and the soil characteristic, is emphasized to better understand the contamination dynamics and to better guide the appropriate environmental management plan is highlighted.

2.5 INFLUENCE OF SOIL PH ON HEAVY METAL MOBILITY

One of the most important factors that affect the behaviour and mobility of heavy metals in soils is soil pH. Acidity or alkalinity of soil may greatly influence the solubility and soil particle interactions of metals.

Heavy metals are more mobile and soluble in acidic soil. As pH decreases, the minerals containing metals become more soluble and the metals are able to travel more easily through the soil profile and may leach into local waterways (Brady & Weil, 2016).

In contrast, neutral to slightly alkaline soils tend to decrease mobility of metals. Under such circumstances, metals can be attached to soil particles or bound into stable complexes that reduce the ability of metals to migrate in the soil system (Alloway, 2013). Soil pH thus is important in determining the environmental behaviour of chromium.

2.6 ROLE OF ORGANIC MATTER IN HEAVY METAL RETENTION

Organic matter is one of the significant soil components, which affect soil structure, fertility and biological activity. It also is an important regulator of the behavior of heavy metals in soils.

Organic matter has functional groups which can form complexes with metal ions and adsorb metal ions. These processes tend to decrease the mobility and bioavailability of heavy metals in soils (Nelson and Sommers, 1996).

Soils with higher organic matter content tend to have a higher ability to bind heavy metals and keep them from leaching into other water resources, particularly groundwater. But, the clearing of the trees and topsoil in mining operations can often result in a decrease in the amount of organic matter in the soil. This decrease could affect the mobility of heavy metal and promote soil pollution (Lal, 2004).

2.7 MINE TAILINGS AND ENVIRONMENTAL CONTAMINATION

One of the biggest environmental problems posed by mining activities is mine tailings. Mineral waste material remaining after the valuable minerals have been extracted from various ores and is finely ground, is called tailings. These materials are typically dumped into tailing dams where they are susceptible to the environment.

Heavy metals such as chromium can be found in high levels in tailings. Heavy metals might be released into the surrounding environment from tailings due to leaching and runoff from rain and weathering (Alloway, 2013).

Another way wind erosion can contribute to the contamination of adjacent soils and vegetation is by transporting tailing particles to nearby areas. Therefore, the proper management of tailings storage facilities is crucial to reduce the environmental impacts of mining operations.

2.8 CONCEPTUAL FRAMEWORK OF THE STUDY

This study's conceptual framework shows the relationship between mining activities and chromium contamination of soils. Co-products from chrome mining include high volumes of waste materials including waste rock and mine tailings that can be a source of chromium.

Under environmental conditions like rain, erosion and weathering, chromium can be leached into surrounding soils and water systems. Soil properties such as soil pH and organic matter affect the mobility and accumulation of chromium in soils.

The solubility and mobility of chromium is related to soil pH, and the soil organic matter affects its capacity to hold heavy metals as a result of adsorption. Under the acidic, low organic matter soils, chromium can become more soluble and can be deposited in the surrounding soil.

The knowledge of these relationships is significant in the understanding of contamination in mining environments, and is relevant to the implementation of land management and rehabilitation plans.

CHAPTER 3 METHODOLOGY

3.1 DESCRIPTION OF THE STUDY AREA

3.1.1 Location

The study took place at four selected chrome-mined sites located along the Great Dyke of Zimbabwe, namely, at Railway Block Stream near the Mutorashanga mining area, Lalapanzi in Midlands Province and at Mutorashanga in Mashonaland West Province.

3.1.2 Climate

The study areas are located in a tropical savannah climate type with two distinct seasons: dry and wet (World Bank 2021). Precipitation falls primarily in the summer (November to March) and the annual amount is 700 mm to 1000 mm in most areas of the region.

3.1.3 Topography

The Great Dyke is a gently rolling area of hills and lowland valleys. For other places like Mutorashanga and Lalapanzi, however, the natural landscape has been significantly changed as a result of mining.

3.1.4 Geology

Geologically, the study area is part of the Great Dyke, which is a thick, intrusive mafic and ultramafic rock body of high chromium and other ferro-alloy mineral content (Dirks and Jelsma, 2006).

There are naturally occurring chromite deposits within the Great Dyke which makes this area one of the major sources of chromium mining in Zimbabwe. .

3.1.5 Soils

The soils of the study areas are Fersiallitic (Thompson and Purves, 1979) .They are typically shallow, moderately well developed and low in organic matter, especially in mining impacted regions.

3.1.6 Vegetation

There are differences in the amount of vegetation cover among the study sites. In the vicinity of Mutorashanga tailings, vegetation is rather scarce and is mainly comprised of grass species, most of which is disturbed by mining activities and has poor soil quality (Sheoran, Sheoran &

Poonia, 2010). But within the Lalapanzi tailings and the Railway Block Stream, relatively more natural vegetation (grasses and scattered shrubs) is found.

3.1.7 Present Land Use

The most significant land-use that impacts the study areas is mining. Mines pits, tailing dumps, and waste rock piles cover extensive areas of land. The surrounding areas are primarily used for small-scale farming and communities cultivate crops like maize and vegetables. Mining operations could, however, impact agricultural productivity through soil quality changes and by enhancing the potential for soil heavy metal contamination.

3.2 DATA COLLECTION

3.2.1 Soil sampling

The samples were collected using a purposive sampling method with sampling points selected in those locations that are most likely to be impacted by mining activity.

Four sampling locations were chosen because of their close proximity to chrome mining operations and exposure potential to the waste materials of the mines. These sampling sites were Mutorashanga tailing dump, adjacent soil near tailing dump, Lalapanzi tailing and Railway Block Stream.

The chosen sites enabled comparisons to be made between areas where the mining operations could have impacted the environment and areas where contamination could have occurred, but only as a result of natural processes like runoff and erosion.

3.2.2 Soil Sampling

Soil samples were collected from areas adjacent to the Mutorashanga tailings dump (Point 2) using a soil auger at a depth of 0–15 cm. The samples were then placed in clean labelled plastic bags and transported to the laboratory for further analysis. The sampling depth was selected because surface soils are more likely to accumulate contaminants from mine tailings and other environmental sources.

3.2.3 Water Sampling

Water samples were taken at Railway Block Stream (Point 4). Water was collected in pre-rinsed plastic bottles, about 500 ml of water was collected.

Before shipping to the laboratory for analysis, the bottles were carefully sealed and labelled. To evaluate the likelihood that chromium might be migrating in nearby surface waters, water samples were taken.

3.2.4 Tailings Sampling

Samples of tailings were taken from the Mutorashanga tailing dump (Point 3). A clean stainless steel shovel was used to take samples to a depth of 0-10 cm. The samples were then bagged and labelled and sent to the lab for analysis. The study included tailings because they were a significant potential source of chromium contamination to surrounding soil and water.

3.3 LABORATORY DETERMINATIONS

The samples collected were analysed for chromium using Atomic Absorption Spectrophotometry (AAS) after nitric acid digestion of the samples (APHA, 2017). The soil pH was determined by a calibrated pH meter in a soil-water ratio of 1:2.5 (Thomas, 1996). The pH of the soils is one of the factors that affects the mobility and bioavailability of the heavy metals in the soil. Loss on Ignition (LOI) method (Nelson and Sommers, 1996) was used to determine the content of organic matter. Organic matter is also involved in the fertility of soils and affects binding and retention of heavy metals in the soil environmental conditions.

3.4 STATISTICAL ANALYSIS

The data collected were analyzed using descriptive statistical methods. Patterns and differences in chromium enrichment among the sampling locations were identified through the statistical analysis. To determine the level of contamination to the environment from chrome mining activities, samples were taken from the mine sites, compared with the soil and water samples in the vicinity of the mines and samples from the tailings.

CHAPTER 4 RESULTS

4.1 CHROMIUM CONCENTRATION IN THE STUDY AREAS

The concentrations of chromium in the soil and the tailings from the mines and the stream sediment samples collected from the Mutorashanga, Lalapanzi and Railway Block stream are presented in Table 4.

Table 4.1 Table showing Chromium concentrations (mg/kg) and mineral enrichment in soil, tailings and stream sediment samples from selected study sites along the Great Dyke

Site	Chromium mg/kg
Mutorashanga tailings	12
Mutorashanga adjacent soils	2.3
Lalapanzi tailings	10.5
Railway Block Stream	0.9

The concentrations of chromium measured at the four sampling sites are presented in Table 4.1. Mutorashanga tailing recorded the highest concentration of chromium (12mg/kg) which is followed by Lalapanzi tailing (10.5mg/kg). These high chromium levels are being seen as expected since tailing are waste products from chromite ore mining and processing.

The Mutorashanga adjacent soil recorded 2.3 mg/kg, which is significantly lower than the tailings but still indicates some level of chromium enrichment. This indicates that the tailing could be migrating into the surrounding soil by wind erosion, runoff, and leaching. The lowest chromium concentration was recorded at Railway Block Stream (0.9 mg/kg). This could be due to dilution from flowing water, and natural buffer processes which inhibit chromium buildup in aquatic systems.

These results therefore suggest that chromium contamination decreases with increasing distance from the mine tailings, indicating that mining activities are the main source of chromium enrichment in the area. The same situation has been described for other mining areas where the heavy metals accumulate in the mine wastes and slowly decline in concentrations in neighbouring soils (Kabata-Pendias, 2011).

Table 4.2 Table showing a summary of statistical values for chromium concentration (mg/kg) in the study area

Statistic	Value
Mean	6.43
Median	6.40
Mode	None
Standard deviation	5.60
Coefficient of variation	87%

Table 4.2 presents the descriptive statistical summary of chromium concentrations across the sampling sites. The mean chromium concentration of 6.43 mg/kg represents the average level of chromium recorded in the study area. The level of chromium contamination in the sampled environments is at moderate levels. The median value of 6.40 mg/kg is very close to the mean, suggesting that the distribution of chromium concentrations is relatively balanced between the sampling sites.

The standard deviation of 5.60 mg/kg indicates that there is a considerable spread in chromium concentrations among the sites. This variation is due to the high impact from the mining operation as the tailing areas have much higher concentrations of chromium compared to other soil and stream sediment areas. The coefficient of variation (87%) indicates very high variability in chromium concentrations. High variability implies that chromium contamination is not homogeneously distributed and that the location of the mining waste materials plays an important role. This is a pattern common to environments where mining activity has resulted in the build-up of heavy elements in mine tailings and subsequent loss of these elements in surrounding areas (Kabata-Pendias, 2011).

4.2 SOIL PH

Table 4.3 Soil pH values at the sampling sites

Sampling site	Soil PH	Remarks
Mutorashanga tailings	5.8	Acidic
Mutorashanga adjacent Soil	6.5	Slightly Acidic
Lalapanzi tailings	5.6	Acidic
Railway Block Stream	7.1	Neutral to slightly Alkaline

The soil pH values at the various sampling sites are given in Table 4.3. The results show that the tailing areas are slightly acid with the pH found to be 5.8 and 5.6 at Mutorashanga and Lalapanzi respectively. Slightly acidic to near neutral soil was recorded for the adjacent soil Mutorashanga with a pH of 6.5. This may be due to the vegetation and organic matter in the soil which helps to stabilize its chemistry.

The pH of the Railway Block Stream was 7.1 and is neutral. This may be attributed to buffering ability of water systems which can control the pH levels and lessen the acidity.

Table 4.4 Table showing a summary of statistical values for soil pH across the sampling sites

Statistic	Value	Remarks
Mean	6.25	Acidic
Median	6.15	Acidic
Mode	Non	N/A
Standard Deviation	0.68	
Coefficient of variation	10.9%	CV% < 25; Low CV%; fairly homogeneous

The mean pH value of 6.25 (Table 4.4) indicates that the soils in the study area are generally slightly acidic to near neutral. Descriptive statistics including mean,median,standard deviation and coefficient of variation were calculated using Microsoft excel. The median pH is close to the mean value of 6.15 indicating that the pH values are reasonably distributed around the sampling locations. The standard deviation of 0.68 shows that there is not a lot of variation in pH between the sites. This indicates that there is not much difference in the acidity of soils in various environments. Coefficient of variation (10.9%) suggests low variability, that the pH conditions within the study area are fairly consistent.

4.3 ORGANIC MATTER CONTENT IN THE STUDY AREAS

Organic matter is an important component of soil because it influences soil fertility, nutrient availability and the ability of soils to bind heavy metals.

Table 4.5 Table showing organic matter (OM) content (%) of soils and tailings in the study area

Sampling Site	Organic matter (%)	Remarks
Mutorashanga Tailings	0.4	Low
Mutorashanga Adjacent Soil	1.2	High
Lalapanzi Tailings	0.3	Low
Railway Block Stream	-------	N/A

The results indicate that mine tailings areas contain very low organic matter, with values of 0.4% and 0.3% recorded at Mutorashanga and Lalapanzi respectively (Table 4.5). The soil of Mutorashanga had the highest percentage of organic matter (1.2%), which is due to the presence of vegetation and natural process of soil development. The organic matter content is expected to be low as mine wastes have low biological activity.

Table 4.6 Table showing a summary of statistical values for organic matter (%)

Statistic	Value %	Remarks
Mean	0.63	low
Median	0.40	low
Mode	None	N/A
Standard Deviation	0.49	low
Coefficient of Variation	78	Very diverse

The area generally contains low levels of organic matter (Table 4.6). The median value of 0.40% suggests that most of the sites have low organic matter levels, although one site with higher organic matter increases the average value. The standard deviation (SD) is 0.49%, reflecting moderate variation between sites. The coefficient of variation (78%) indicates high variability, suggesting significant differences in organic matter levels between mine tailings areas and surrounding soils. This high variability is due to the difference in the vegetation cover, land disturbance and soil development among the sampling sites.

CHAPTER 5 DISCUSSION

5.1 INTRODUCTION

The high concentration of chromium in soils, mine tailings and stream sediments in post mining areas is a concern for environmental quality and ecosystem stability. The Great Dyke of Zimbabwe is an active mining area of Zimbabwe where substantial quantities of mine wastes have been deposited, these wastes may have impacts on the chemical properties of the soils and the distribution of heavy metals in the areas around the mines. Soil physical and chemical properties like the pH, organic matter and environmental factors like precipitation, geology, and vegetation cover may relate to variations in chromium concentration among the study areas. These conditions play an important role in determining the mobility, availability and environmental impacts of chromium in post-mining landscapes.

5.2 CONCENTRATION OF HEAVY METAL CHROMIUM (CR) ITS MAGNITUDE AND EFFECTS

The results of this study show that chromium concentrations vary significantly across the sampling sites due to differences in proximity to mine tailings and other mining-related waste materials. Tailings dumps are the major source of enrichment of chromium as it is the waste generated during extraction and processing of chromite ore.

But as far as I'm aware, the results of such research do indicate that the main contributor of chromium enrichment to the environment is mine tailings. Tailings are the waste by-product of the extraction and processing of chromite ore and may have high levels of heavy metals. Geological formations, in which naturally occur the chromite minerals, are disturbed by mining activities along the Great Dyke. A large amount of waste materials like tailings and waste rock are produced during the mining process. These materials may also have high levels of chromium in them and can release chromium into the environment through weathering. Thus, chromium may accumulate in soils near the mines and in adjacent water bodies. Soils with high levels of chromium may have negative impacts on soil health and productivity. Chromium contamination can have negative effects on microbial function, nutrient availability and plant growth. High concentrations of heavy metals in soil can affect biological activity and the fertility of the soil (Alloway (2013)

Environmental concerns also exist because of chromium contamination. In some chemical forms, particularly hexavalent chromium (Cr^{6+}), chromium is highly toxic and can pose risks to human and animal health through exposure to contaminated soil, water, or crops (Kabata-Pendias, 2011). Therefore, the communities in the vicinity of the mining operation may be vulnerable to environmental hazards if the mine waste is not managed properly. Furthermore, chromium contamination could impact on the agriculture sector in Zimbabwe, especially in the localities where the mining operations are carried out near farms. Contamination of soils can decrease productivity of crops and can affect the viability of land for crop production. In other parts of the world, where soil quality is affected by heavy metal contamination, and agriculture is vulnerable to the impact of these contaminants, similar concerns have been voiced in mining areas (Alloway, 2013).

5.3 SOIL PH IN POST-MINED AREAS AND ITS EFFECT ON LAND RESTORATION

One of the most important soil factors that affect soil fertility, metal mobility and plant growth is soil pH. The pH values of the soil in the present study indicated that the values at the sampling points varied from 5.6 to 7.1. The pH at the mine tailings sites was slightly acidic and stream environment was near neutral. Heavy metals like chromium may be more mobile in slightly acidic soils. In acidic soils, the metals can be more soluble and can move more readily in the soil and water. (Kabata-Pendias, 2011)

The natural landscape of the study area has also been affected by the mining activities. The natural topography has been changed by open-pit mining operations, and by waste rock dump sites and tailings disposal areas, which have caused artificial changes to the surface topography, affecting surface runoff, soil erosion and sediment transport. The alterations in land surface conditions may lead to the redistribution of heavy metals like chromium in adjacent soil and water environment.

The pH of the soil is also important in the restoration of lands. Numerous plants prefer near neutral soil conditions. Excessive acidity can be caused by mining operations and affect the ability of vegetation to establish. This can result in the deceleration of the recovery of the ecology of post-mining landscapes (Tordoff, Baker & Willis, 2000). The relatively low pH values obtained in this study, however, indicate that the soils still have some potential for vegetational use if proper rehabilitation measures are taken. Lime application and adding of organic matter can improve soil conditions which may be beneficial to land restoration.

5.4 ORGANIC MATTER CONTENT AND PERSPECTIVES FOR REVEGETATION

Organic matter is a key element of healthy soils due to its ability to help soil to retain water, nutrients, improve soil structure and encourage soil life to grow. Results of this study revealed that the organic matter content in the mine tailings was very low (0.3–0.4%) compared to the adjacent natural soils having higher organic matter content (1.2%). Lack of vegetation and biological activity is indicated by low amounts of organic matter in the tailing areas. The tailings usually contain mineral matter that is unable to integrate with organic inputs required for soil development (Brady and Weil, 2016).

Therefore, it is necessary to increase the amount of organic matter in post-mining environments for revegetation and land rehabilitation. Vegetation establishment can incrementally improve soil organic carbon by plant litter, root growth and microbial processes (Brady & Weil, 2016). Soils can also be carbon sinks, sequestering carbon, because of the accumulation of organic matter. Lal (2004) notes that land rehabilitation by vegetation and soil management can enhance storage of carbon in soils. Thus, revegetation in post-mining sites not only enhances soil properties, but also brings climate change mitigation effects.

5.5 GOVERNMENT ROLE IN MANAGING CONTAMINATION FROM SMALL-SCALE MINING IN ZIMBABWE

The Great Dyke of Zimbabwe is now being mined on a small-scale, with this activity having grown considerably, mainly as a way of generating income and alleviating poverty in rural communities. These activities offer economic advantages to the local communities but also lead to environmental problems such as soil contamination and degradation. Government authorities have a crucial role in monitoring and protecting the environment by regulating mining activities. Mining operators are obliged to follow appropriate waste disposal and land rehabilitation procedures as per Environmental management policies (Zimbabwe Environmental Management Agency, 2017). Enforcement of environmental laws, however, can be challenging, especially in regions with high informal/artisanal mining. Environmental monitoring is sometimes difficult due to limited resources, technical capacity and economic pressures.

Literature indicates that vegetation is important in the maintenance of soil quality in disturbed mining areas. The litter and root structure add organic matter to the soil, enhancing soil

structure and nutrient cycling. Vegetation cover also stabilizes soil surfaces, thus minimizing soil erosion and the release of heavy metals (e.g., chromium) to the environment.

The challenge for Zimbabwe's policy makers is thus to balance economic development with environmental protection. To minimize environmental impacts from mining, environmental regulations can be strengthened and sustainable mining practices promoted, and community involvement in land restoration can be encouraged.

5.6 IMPLICATIONS FOR MINERAL RESOURCES MANAGEMENT

The findings from this research provide important insights for mineral resources management in Zimbabwe. The outcomes emphasize the environmental consequences of the chromium mining activities and the significance of the management of the wastes of the mines. Mineral resource management should incorporate post-mining land rehabilitation, sustainable mining and environmental protection. Containment and stabilization of mine tailings should be done correctly to reduce the spread of contaminants to surrounding ecosystems.

In addition, environmental monitoring should be conducted to monitor soil and water quality in mining areas regularly. This may allow for the early detection of contamination and provide a basis for taking action to manage the contamination. Adopting sustainable mining practices and implementing successful land restoration projects can help ensure that the extraction of minerals is not a long-term environmental hazard, but rather contributes to the economic development of a region.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 The study confirmed that the chromium concentrations were different between the sampled sites, with the chromium concentrations of the mine tailings were found to be higher than the other soils and stream sediments. This means that Chromium enrichment in the study area is mainly due to mine tailings. The pattern also indicates that the distance from the mining waste materials source to the contamination decreases with increasing distance and that the contamination through the pattern can be traced to environmental processes such as runoff, erosion and leaching.

6.1.2 Soil characteristics in the study area, particularly soil pH, may influence the behaviour and mobility of chromium in post-mining environments. The pH of soil conditions slightly acidic to near neutral may impact the solubility and distribution of the chromium in soil and environmental systems.

6.1.3 Organic matter content was generally low in the mine tailings compared to adjacent soils, indicating degraded soil conditions in areas affected by mining activities. Low levels of organic matter indicate low soil fertility and ability to support vegetation growth and ecological recovery.

6.1.4 Chrome mining activities along the Great Dyke contribute to environmental changes, including heavy metal enrichment, soil degradation and reduced soil quality in post-mining landscapes. Therefore, minimizing the contamination and ensuring sustainable management of mineral resources is important for proper environmental management of the wastes produced by the mining operation.

6.2 RECOMMENDATIONS

6.2.1 Mining companies operating along the Great Dyke should implement effective management and containment of mine tailings and waste rock in order to minimize the release and spread of chromium into surrounding soils and water systems.

6.2.2 Regular monitoring of soil and water quality should be conducted in mining areas to detect heavy metal contamination and assess the long-term environmental impacts associated with chrome mining activities.

6.2.3 Land rehabilitation programmes should be implemented in post-mined areas through revegetation and soil improvement practices such as the addition of organic matter and soil amendments to enhance soil fertility and reduce heavy metal mobility.

6.2.4 Government authorities and environmental regulatory bodies should strengthen environmental monitoring and enforcement of mining regulations to ensure that mining operations follow sustainable environmental management practices.

6.2.5 Additional studies are needed to assess the long-term environmental effects of chromium contaminated mining areas and to design more effective mining waste management and land rehabilitation strategies.

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