BINDURA UNIVERSITY OF SCIENCE EDUCATION

DEPARTMENT OF NATURAL RESOURCES

A STUDY ON PHYSIOCHEMICAL ASSESSMENT OF GROUNDWATER. AT POMONA LANDFILL HARARE.

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF REQUIREMENTS OF THE BACHELOR OF SCIENCE HONOURS DEGREE IN NATURAL RESOURCES MANAGEMENT

30 MAY 2023

RELEASE FORM

NAME OF AUTHOR TINAYE MUDZVITI

PROJECT TITLE PHYSIOCHEMICAL ASSESSSMENT OF GROUNDWATER AT POMONA LANDFILL HARARE

DEGREE TITLE NATURAL RESOURCE MANAGEMENT

YEAR TO BE GRANTED 2023

SIGNED ……………………..

CELL 0787379823

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APPROVAL FORM

The person who signed attest that a research project entitled (Physiochemical assessment of groundwater Case study of Pomona Landfill Harare) submitted by Tinaye Mudzviti as a partial fulfilment of the Bachelor of Science Honours Degree in Natural Resources Management program has been supervised ,read and recommended to the Bindura University of Science Education for acceptance .

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DECLARATION

I , Tinaye Mudzviti ,declare that the study project is original to me and has not been reproduced or taken precisely from any source without due credit .

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DEDICATION

This project is dedicated to my family

ACKNOWLEDGEMENT

I give God the greatest praise for giving me life in the first place and for bringing me where I am today. You undoubtedly saw a good thing through to the completion that you started in my life. I would like to express my sincere gratitude to the following individuals and groups for their crucial support during my study period

-To all my family members. God bless you all.

-To my academic supervisor MRS MASONA thank you for your tireless working spirit

-To MRS NDAWANA Landfill Manager Harare City Council.

-To MR RUSERE, water laboratory technician Harare City Council Department of quality assurance

This thesis' completion was made possible by the participation, ongoing encouragement, and support of all the people named above. Their perseverance and dedication allowed this work to be successfully completed.

ABSTRACT

One of the main dangers to the quality of groundwater are landfills. The Pomona landfill in Harare, which is the only recognized operational landfill in the city council of Harare, was the subject of the study. This study primary goal was to assess the physiochemical characteristics of the groundwater in the area of the Pomona dump. Groundwater samples were collected from 5 boreholes, examined for physiochemical water quality characteristics, and then compared to WHO guidelines.Outside the landfill boreholes were 4boreholes including a control and one borehole was inside the landfill.Statistical Packaging for Social Science was used for analysing the results (ANOVA) . The findings indicated that borehole within landfills were more contaminated than those outside the landfill, indicating that distance has a larger role in groundwater contamination for example nitrates concentrations was higher in the borehole within the landfill, the highest was(18.7mg/l)and the lowest obtained in borehole outside the dump (8.2mg/l) Regular groundwater monitoring is advised, and a properly engineered landfill should be built.

List of acronyms and abbreviations

WHO World Health Organisation

TDS Total Dissolved Solids

WB World Bank

PH Potential Hydrogen

EC Electrical Conductivity

MSW Municipal Solid Waste

BH Borehole

TDS Total dissolved solids

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CHAPTER ONE

1. Background of the study area

A study by Berisa (2015) claims that various locations, including residences, businesses, and enterprises, bring waste to the Jigjiga dump site in Ethiopia. Organic waste, plastics, paper, glass, and metals are among the waste kinds disposed of in the Pomona dump site, (Mapurazi et al. 2017). According to a study by (Goswami and Sarma 2008), rising industrialization and urbanization result in the daily production of enormous amounts of solid waste. Prasad, et al. (2009), a number of socio-environmental problems may arise if solid waste dumps are not properly managed. Solid wastes are created by industrialization and urbanization and are ultimately disposed of in landfills (Srivastava et al 2015).Van Passel et al. (2012), landfills that are built poorly could harm the soil, plants, air, surface water, and groundwater. Up to 95% of all municipal solid waste generated is disposed of at dump sites, according to the World Bank (1992). In 2016, the Environmental Management Agency reported that just 38% of the waste produced daily by the City of Harare was collected and disposed of appropriately. As a result, there are currently numerous illegal dump sites on the outskirts of the city, which has an impact on the people' health and ecology (Lopez and Hynes 2006).

The majority solid trash created in Harare is biodegradable (UNEP 2011).Leachate can be created when chemicals and liquid in the waste mixed (USEPA 2009)..Leachates are composed of a variety of chemicals, the concentration of which changes depending on a number of factors, including organic compounds, inorganic and organic salts (Townsend and Moody 2017). According to(Najafi Salehet al 2020) the incorrect location and use of the landfill may have an adverse effect on groundwater nearby the municipal solid waste disposal. Additionally, according to (Medina 2010), improper solid waste management can pollute cities and have a significant negative influence on both human health and the environment. It has a high strength and toxicity and contains dissolved and suspended waste from the dump site (Zhao and Youcai, 2018). Leachates can seriously contaminate groundwater, making it unsafe for use as household water (Lasis 2011).

In most cities around the world, particularly in developing countries, solid waste management has become a concern, according to a June 2012 World Report. It was claimed by (Chidavaenzi 2006) that the majority of the waste produced does not reach the approved places and is dumped in open pits, and that the majority of the municipal solid waste in Zimbabwe. According to (Nedziwe and Murairwa 2022), solid waste management has become a significant problem in Zimbabwe's towns and cities due to urbanization, population growth, industrialization, and an increase in the use of non-biodegradable products.According to (Teta and Hikwa 2017), a variety of harmful compounds are frequently found in landfill Leachates and present contamination threats to the nearby sub-surface water because of the various composition of solid wastes in landfills.

1.2 Statement of the problem

The Pomona dump site, the primary waste site for the city of Harare, Zimbabwe, has drawn criticism for its design and lining. The Environmental Management Agency report stated in (2005) that the Pomona dump site was improperly built and lined, which raised issues with the environment and human health. A study by (Hoko e, al., 2002), also discovered that communities living near the Pomona dump site were more likely to contract water-borne illnesses including cholera and typhoid fever, which are frequently related to contact with contaminated water. The investigation also by (Tongesayi et al 2018) discovered that the Pomona dump site is a large source of greenhouse gas emissions, which can have negative impacts on the environment and human health. According to (Hranova 2006), landfills pose some of the biggest hazards to groundwater resources, particularly if they are unlined, which is typical in poor countries. Leachate contamination from municipal solid waste dumps is frequently a major cause of surface and groundwater pollution, (Harriman 2018) reported that suspected typhoid outbreak cases had been identified in Harare. Therefore, Pomona dumpsite could be a point of groundwater contamination so it is important to investigate the effects of the landfill to groundwater .

1.3Justification

Investigating dump sites is crucial to ensuring that waste is being handled, disposed of, and leached correctly. The risk of contamination to the neighbouring water sources of the dumpsite can be ascertained by knowing what is in the leachate according to (Mato, 1999). The data will help the government to enhance the waste disposal facility and put mitigation measures in place to reduce groundwater pollution both inside and outside the dump. Additionally, it will be advantageous for the community to actively participate in garbage separation at the source, and EMA should encourage everyone to follow the rules of current environmental legislation, including individuals and the waste Management

Department.The Environment Management Act 13 (Chapter 20:27) of 2002 and Statutory Instrument 6 of 2009 (effluent and waste disposal) both contain a number of significant provisions that are important to the assessment of the effect of solid waste disposal on the quality of underground water.. In addition, (IWC 2013) projects a 40% rise in global water consumption in 20 years. Because our community lacks the means and technology to efficiently clean up the pollution that will arise from these developments, determining the quality of groundwater is essential. The Pomona dumpsite, which is located downstream of the site, was found to be a significant source of pollution of the Mukuvisi River, (Hoko et al.2002). The survey found that the leachate from the landfill contained significant levels of pathogens, heavy metals, and organic pollutants, all of which pose serious health risks to both people and animals.

1.4 OBJECTIVES

Main objectives

To investigate the groundwater vulnerability to physiochemical pollution within the area of Pomona landfill in Harare.

1.5 Specific objectives

1. To determine the variability of physiochemical parameters (pH, total dissolved solids, nitrates, electrical conductivity)and selected heavy metals (iron,manganese,lead in groundwater at Pomona landfill

11. To compare the variation in physiochemical parameters and selected heavy metals from boreholes within and outside the dump site

Research questions

What are the temporal variations in the physiochemical properties of groundwater at Pomona Landfill in Harare, and what factors, such as seasonal variations in rainfall, climate, geology soil type and landfill operations, may influence these variations

What is the current physiochemical composition of groundwater at Pomona Landfill in Harare,in relation to distance of boreholes from the landfill and specifically focusing on parameters such as pH, electrical conductivity, total dissolved solids, and concentrations of major ions?

CHAPTER TWO

2.0 Introduction

According to (UNEP 2013), as urban populations continue to rise and consumer habits change, waste management has turned into a global issue. More over half of the population now resides in urban areas, (Tacoli 2012) indicates that the rate of urbanization has currently increased. The growing urbanization has also greatly worsened the issue of managing municipal waste disposal (Bhella 2013).World Bank (2012), open dumps are the most popular method for developing nations to dispose of solid waste. Leachate is additionally created when waste is dissolved in water, claim (Benson and Marian 1999). According to Khan (2001), nearby soils and water sources may get contaminated by the leachate that solid waste dumps emit.Various negative health impacts, including problems with the skin and eyes, have been associated with dump sites(Vrijheld 2000).

2.1 Groundwater resources

IAEA (2014) states that groundwater is the main source of drinking water for half of the world's population. According to the World Bank (1998), around 1.5 billion people around the world rely on groundwater for their drinking water source. According to (Taylor and Allen 2006), landfills are the locations most frequently associated with groundwater contamination due to waste-derived liquids. Any location where trash is concentrated, processed, and stored, even if only temporarily, has the potential to contaminate groundwater at a point. According to (Akinbile,and Yusoff, 2011), leachate from about 75% of the estimated 75000 sanitary landfills contaminates nearby groundwater. It is well known that conventional open and unlined dump sites leak significant quantities of toxic and other dangerous chemicals into groundwater surfaces and soils via Leachates and landfill gases. According to (Sener and Davraz 2013), heavy metals and other organic compounds are just a few of the pollutants that seem to predominate in groundwater. According to (Melloul and Collin 1994), the introduction of pollutants into groundwater from various sources lowers the water's quality and decreases its value to consumers. According to by (Gleeson et al,2012) groundwater accounts for about 30% of the world's freshwater supplies, making it the largest source of usable freshwater on the planet. But over use of these resources is becoming more widespread, especially in areas with active agriculture and high populations. According to a study by (Sophocleous 2002,) the misuse of groundwater resources could lead to their depletion, which could have detrimental consequences on ecosystems as well as economic and social effects on the affected populations.

2.2 Drinking water quality

Drinking water quality is the combination of a water's physical, chemical, and biological characteristics that render it suitable for human consumption (WHO 2017). The quality of drinking water, which is essential for public health, can be impacted by water contamination from both natural and human-made causes.The World Health Organization (WHO) has established global water quality (WQ) standards as guidance for drinking water monitoring or evaluation in order to support and safeguard human health. The water quality standards are a set of quantitative requirements created to maintain the purity of the water (Parry 1998). The maximum concentration of each element that is permissible in drinking water is listed in these regulations by WHO (2006).The concentration of physical, chemical, and biological constituents detected in tested and permitted water using the recognized techniques also affects the quality of potable water for usage. Pollutants are contaminants that have concentrations over the WHO-recommended acceptable range for drinking water quality. The blue infant syndrome and other infectious illnesses can be brought on by high nitrate and heavy metal concentrations (WHO, 2007). Changes have been made to the WHO standards for drinking water quality in order to remove and lessen the hazards brought on by the well-known bacteria. It has been established and advised that risks should be below expected ranges within the WHO guidelines in order to consider water safe for consumption, but this does not imply that the water will be risk-free of contamination or that the quality of the water must not be decreased by purifications or water treatments, according to Tobin et al. (2003).

2.3 Leachate generation and Composition

When water comes into contact with solid waste, a liquid called leachate is created that dissolves toxins and pollutants and carries them away (Muthu, 2015). If this contaminated water is not properly managed, it could lead to major environmental and health issues. In landfills, when waste is heaped up and covered with soil, leachate is frequently produced. Leachate is produced as a result of precipitation seeping into the landfill, coming into touch with the garbage and picking up toxins (Pawowska et al., 2017).

According to (Bidhendi et al 2010), a number of variables, such as the age of the landfill, the amount of waste present, and the hydraulics of the dump, influence the Leachates chemical composition and level of pollution. Leachate formation is influenced by the kind of waste, the season, the climate, the time of year, and the management strategy, while its migration and pollution are affected by surface water, topography, distance, the underlying geology of the soil, and the depth of the land in relation to the piezometric level (Afolayan et al. 2012).(Asuma and Aweto 2013) argued that the depth and distance of the sink from the source of the leachate had a higher impact on the level and extent of ground and surface water contamination . The amount of water that can reach the waste will significantly determine how quickly it decomposes, which might take decades. In addition, leachate slowly seeps into groundwater systems, altering the physical and chemical properties of groundwater(Vasanthi et al. 2008).Heavy metals, organic and inorganic acids, nutrients, and numerous hazardous substances are among the organic and inorganic components that leachate commonly comprises(Herath 2016). The quantity and age of the waste, waste management techniques, climate, and hydrogeological variables all have an impact on the composition of leachate.

2.4Waste disposal and Landfill Management

In the past and in many regions of the world today, landfills have been the most popular ways to dispose of organized garbage. Landfills for solid waste are essential in today's society because they reduce risks to public health and safety by collecting and disposing of trash in concentrated areas.Sanitary landfills, which have surface areas ranging from tens to hundreds of hectares, are places where trash is disposed of in a controlled manner.However, (Mor et al., 2006) have identified them as one of the primary threats to groundwater resources. They are also referred to as landfills since they continue to use the earliest form of waste treatment. These landfills are notorious for being filthy and ugly. The poisoning of the environment and groundwater by waste that is dropped and liquids derived from it through penetration are the main ecological problems that arise from dump sites. Due to these factors, landfills have to be constructed and engineered to reduce leachate seepage. A liner system is part of the physical design of a landfill(Bell (1998).

The site selection, design, building, operation, and closure of landfills are among the different processes involved in landfill management, according to Harvard University's Sustainability Science Program (2006). In order to reduce landfills' negative environmental effects, site selection is crucial. The type of trash to be disposed of, the hydrogeological conditions of the site, and the possibility of air and water contamination are all aspects that must be taken into account during the planning and construction of landfills.

Every safely allowed landfill must have four essential components: a line, a leachate collection system, a cover, and the local hydrological environment (Magadzire, 2005).. The bottom and sides of a landfall are lined with a protective layer made of earth or synthetic materials to stop and decrease the passage of leachate into the environment.Layering, compacting, and soil-covering of waste are daily tasks at a landfill. Site preparations must be planned to reduce surface run-off and percolating rainwater's contact with waste. According to World Bank environmental regulations (WB 2004), the leachate collection network and the landfills liners need to be correctly sloped, with a 2% slope allowing polluted water to flow to treatment ponds by gravity.

2.5 Effect of Leachates on groundwater

When liquid percolates through wastes like landfill or compost, a liquid called leachate is created(USEPA 2015). Leachates can have a variety of negative effects on the quality of the water and the ecosystem once they get into the groundwater (Christensen et al., 2001).contamination of sources of drinking water, Groundwater leachate contamination can result in the contamination of sources of drinking water, posing a serious concern to the public's health (Kjeldsen et al., 2002).Study by (Eggen et al. 2010) discovered that the Leachates from domestic waste landfills had contaminated the groundwater in the area with endocrine-disrupting substances, which can have harmful impacts on both humans and wildlife.contamination from heavy metals, Heavy metals including lead, cadmium, and mercury can enter groundwater through Leachates. When ingested through drinking water, these metals can harm aquatic ecosystems and endanger human health (Chen et al., 2017). For instance, a study by (El-Fadel et al. 2013) discovered that groundwater near a landfill in Lebanon has become contaminated with faecal coliform bacteria, potentially endangering the health of the surrounding communities. Leachate, if improperly managed, has the ability to flow into groundwater and contaminate surrounding water sources, such as boreholes.

Effect of physiochemical water parameters on groundwater

2.6 Nitrates

According to the (EPA 2016), high nitrate levels in drinking water can result in disease known as blue baby syndrome. Additionally, excessive levels of nitrate in groundwater may indicate the presence of other contaminants including pesticides and herbicides, which are detrimental to both human health and the environment, according to (USGS 2018).The quality of borehole water can be significantly impacted by nitrates. According to a (2006) study by Harvard University's Centre for Health and the Global Environment, high nitrate concentrations in borehole water can be extremely dangerous to people's health, especially for

pregnant women

2.6.1 Total dissolved solids

Groundwater quality and value can be impacted in many ways by total dissolved solids. A study by (Panday.and Singh,2018) found that high TDS levels can increase salinity and hardness, making the water unfit for drinking. The taste and odour of water can also be impacted by TDS, as stated by (Saxena and Sahu 2018). High nitrate concentrations can also result in a decline in groundwater quality, potentially making it unsafe for human consumption (Nolan et al. 2002). High TDS levels in borehole water can produce a disagreeable taste and odour that might make the water undesirable. According Georgieva. 2015), this may be caused by the presence of minerals like iron, manganese, or sulphur, which can give a metallic or rotten egg stench.

2.6.2 Water pH

Changes in subsurface redox conditions may result from changes in groundwater pH. According to (Kolbe et al 2019) by removing oxygen and protons, acidic circumstances can provide reducing environments, whereas basic conditions can produce oxidizing environments. Redox conditions have a significant impact on the oxidation state, solubility, and toxicity of contaminants. According to (WHO 2017) the evolution and toxicity of pollutants are influenced by pH, the pH has a significant impact on the speciation of pollutants like ammonia and the evolution of the pollutants affects both their toxicity and mobility

2.6.3 Electrical Conductivity

Electrical conductivity, or EC, can significantly affect the quality of borehole water. High concentrations of EC in borehole water may signal the presence of dissolved salts, which may have negative impacts on both human health and the environment, according to research from Harvard University's School of Public Health (2012).Borehole water with high EC levels may contain more sodium, chloride, and other dissolved salts, which can corrode pipes and other infrastructure and affect taste and odour. High sodium and chloride concentrations can also impair the flavour and quality of drinking water as well as the development and health of crops that are irrigated with the water.

Effects of heavy metals parameters on Groundwater

2.7 Lead

The major origin of lead in drinking water is the corrosion of the lead used to join the copper plumbing. With activated carbon in a water softener, lead can be significantly decreased; filtering can also reduce lead to some extent. According to (Myers 2004) red blood cells, the neurological system, the kidneys, and the brain can all suffer major harm from the body. According to WHO (1989),the most vulnerable groups for unfavourable health effects from lead exposure are infants, kids up to age 6, the foetus, and pregnant women. Lead is a cumulative general poison. The effects it can have on the central nervous system can be quite severe. A dangerous metal that occurs naturally is lead. Due to its widespread use, many parts of the world now experience severe environmental degradation, human exposure, and health issues. It is a cumulative toxin that may have an impact on several bodily systems. Lead neurotic effects are particularly dangerous for children (WHO, 2016a).

2.7.1Iron

According to (Srinivasa et al 2010) iron can cause water a metallic taste and odour, as well as a discoloured appearance. In addition, (Alabdulaaly and AL –Rehaili 2015) indicated that iron can also cause stains on garments. These aesthetic problems may reduce the appeal of water for drinking and other applications.. According to (Wang et al 2018), certain species of bacteria, such as iron bacteria, can develop in particular situations where there is a high concentration of iron in groundwater. These bacteria can clog pipes and other water infrastructure. Various physiological functions in the body depend on iron, a vital vitamin. A high level of iron in drinking water, however, can have a number of negative health impacts, including gastrointestinal discomfort and tooth and garment discolouration.

2.7.2Manganese

Due to its large atomic weight (54.94) and density, manganese is often categorized as a heavy metal (ATSDR, 2012).(Kim and Kim 2017) noted that heavy metals, a category of metallic elements with a large atomic weight and density, can have harmful impacts on both human health and the environment when present in higher concentrations. .Although manganese is necessary for metabolic functions, excessive amounts may be harmful to health. It prevents the production of haemoglobin from using iron. It results in apathy, headaches, and sleeplessness. High manganese levels in drinking water have been linked to adverse health effects, especially in children' studies (Grandjean and Landrigan 2014).According to (Levy and Nassetta 2003) stated that prolonged exposure to excessive manganese levels in drinking water might cause neurological effects such tumours, rigidity of the muscles, and cognitive deficiency.

Field Code Changed

2.8 Challenges of waste management in Zimbabwe

According to (Chikozho et al, 2018), the lack of regulatory enforcement and compliance with waste management legislation is one of the problems facing waste management in Zimbabwe. In order to make sure that waste management procedures adhere to regional, national, and international standards, stronger enforcement measures are required. (Mukwakwami et al. (2020) stated that although the informal sector in Zimbabwe contributes significantly to waste management, it does so outside of official regulatory frameworks, which makes monitoring and control difficult. According to (Makoni 2016), there are substantial institutional and financial issues with trash management in Harare, including insufficient budget, a lack of technical capability, and lax enforcement of waste management laws. According to (Kaseke 2005), the growing population is a further problem in addition to a lack of waste vehicles. There is a significant demand for services due to the large population. Instead of one bag per household as was once the case, (Chidavayenzi 2006) reports that the waste management division now charges a flat cost for the collection of trash. The amount paid today does not match the amount of trash being produced.Attempts have been made to enhance waste management in Zimbabwe despite these obstacles. To promote sustainable waste management methods, for instance, the government has created laws and regulations, and some localities have put recycling and garbage separation programs into place. To solve the underlying issues behind Zimbabwe's waste management challenges, more assistance and funding are required.

2.9 Legislation of waste disposal

Legislation on waste disposal refers to the rules and regulation that control how waste is managed and disposed (UNEP,2015) . These rules control how waste is handled, moved, and disposed of in order to safeguard public health and the environment.The Environmental Management Act (Chapter 20:27) is the main legislative framework for environmental management in Zimbabwe, including waste management. It provides for the establishment of the Environmental Management Agency (EMA) as the regulatory body responsible for the management and protection of the environment EMA, (2015). According to (EMA 2015), the act also sets out provisions for waste management, including the licensing of waste management facilities and the regulation of hazardous waste. In addition to the Environmental Management Act, there are also a number of regulations related to waste disposal in Zimbabwe. The Hazardous Substances and Articles (Control) Regulations, 2017 provides for the control and management of hazardous substances and articles, including their storage, transportation, and disposal (Government of Zimbabwe, 2017). According to the Public Health (waste Management) Regulations, 2018 waste must be transported, managed, and disposed of in a way that safeguards the public's health (Government of Zimbabwe, 2018).

CHAPTER THREE
METHODOLOGY

3.1 Description of the study area

According to Tsiko and Togarepi, (2012), Pomona Landfill is situated in Harare, 12km from the city's central business district, (figure 3.1). The geographic coordinates of the dump are 17° 45' 15" South and 31° 5' 11" East. The Zimbabwe National Statistics Agency (ZIMSTAT) estimates that Harare will have 3.1 million residents in 2020 (ZIMSTAT, 2022). The landfill has a 10,000 m2 total surface area and has been in operation since 1982. According to (Tsiko and Togarepi 2012) Pomona Landfill lacks an artificial liner to prevent leachate from damaging water resources (Chihanga 2015). The dump lies close to the headwaters of the upper Manyame River, a very contaminated tributary of the Gwebi Stream, according to (Baldock et al 1991). Residential suburbs can be found west of the dump and reach as far as the south and south-east. (Muswere and Rodi Wiersma 2004), Pomona landfill is also located at the site of a previous gravel pit just outside the city boundaries, south of the Wingate Country Club.

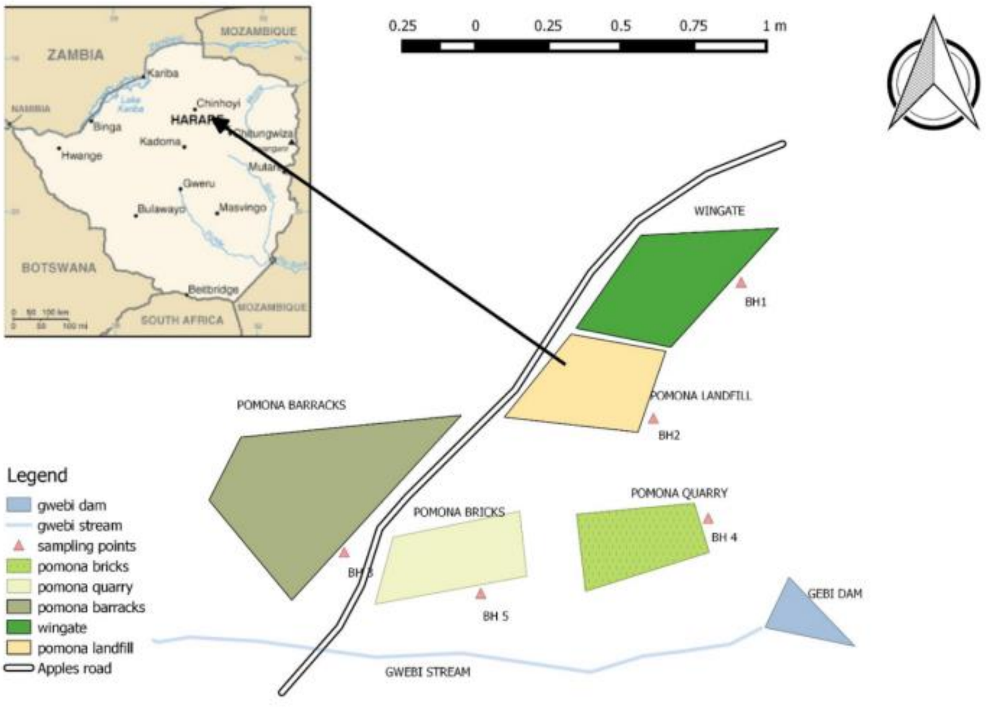


Figure 3.1 map of study area

3.2 Climate

The subtropical highland city of Harare in Zimbabwe experiences different rainy and dry seasons. Data from the Zimbabwe Meteorological Services Department show that there have been some changes in Harare's climate between 2006 and 2023.Typically starting in November and lasting until March, Harare's rainy season has January as its wettest month. The total amount of rainfall that was received throughout the rainy season has, however, been trending downward in recent years. For instance, a research by (Muzerengi et al. 2017) found that Harare's total rainfall during the rainy season of 2015–2016 decreased.Harare's temperatures can get fairly cool during the dry season, which lasts from April to October, with July being the coldest month. However, there has been a rise in dry season temperatures during the past few years. According to research by (Mushore et al. 2018), the average temperature during the dry season of 2016–2017 was higher than the long-term standard.

3.3Geology and drainage in Harare

According to a (1989)study by Child and Heath, the Harare region lies on a watershed that spans from north to west. The Gwebi and Manyame Rivers, which converge and run northward to the Zambezi, are the rivers that drain the western and south-western sections in a westward and a southerly direction, respectively. Since the main watershed dividing the Zambezi and Saves drainage basins is located north of the entire region, it can be said that. According to (Baldock et al., 1991), secondary aquifers make up the majority of the groundwater in the Harare metropolitan region, with severe stratigraphic and lithological limitations on the occurrence. It is known that all rocks are either igneous or metamorphic in nature, making the majority of them massive and crystalline, despite (Broderick 2012) claiming that Harare's geology is extremely diversified.

3.4 Soil types

The Pomona landfill area in Harare, Zimbabwe, is characterized by a mixture of soil types, including sandy loam, silt loam, and clay soils. According to a study by (Chihanga 2015)The soils in the Harare region are categorized as ferralitic soils, which are soils that have undergone weathering and leaching processes that have led to the loss of soluble minerals and the enrichment of clay minerals, according to study done by the University of Zimbabwe in (2015).Sandy, loamy, and clay soils are other soil types that can be found in the Harare region in addition to ferralitic soils. These soils can have different compositions and properties based on geography, parent material, and land use.

3.5Research Design

Sampling boreholes were selected using a purposive sampling design. Purposive sampling is appropriate when addressing site-specific groundwater contamination issues(Environmental Protection Agency 2002). Five sampling boreholes were chosen , borehole 5(1500m)control , borehole 1 (0m) within the dumpsite , borehole 2 (200m) outside the dumpsite ,borehole 3(250m)and borehole 4(350m) outside the dumpsite .

Table 3..1 Locations of boreholes, coordinates and distance from dumpsite

Borehole	Distance from dump	Coordinate of boreholes latitude	Coordinates longitude
BH1(within)	**0m**	**-1772871541**	**31.0753247**
BH2(outside)	**200m**	**-17.7342**	**31.0689**
BH3 (outside)	**250m**	**-17.832576**	**31.045675**
BH4 (outside)	**350m**	**-17.729439**	**31.071501**
BH5(Control)upslope	**1500m**	**17.714917575**	**31.07822403**

3.6 Sampling procedures

A total of 5 boreholes were sampled, one borehole inside the dumpsite, other 3boreholes outside the dump site and borehole 5(upslope) was the control borehole outside the Pomona landfill .Samples were collected using 2liters bottles which were rinsed with distilled water to avoid contamination. Nitric acid was used to clean boreholes before samples were taken. At every borehole, separate samples for nitrates tests were collected in 250ml bottles and labelled.Three samples were collected per borehole and all samples collected were (105)samples , on same day and were analysed in laboratory .Samples were sealed tightly and put in a cooler box with ice after being treated with a few drops of sulphuric acid. Samples were delivered to the Harare City Council Laboratory at Cleveland House.

3.7Methods of analysis

Physical, chemical, and heavy metal analyses are only a few of the different techniques used to evaluate the quality of water..Water pH was done on ground and standard methods was used to analyse for nitrates ,TDS,EC,iron,manganese and lead (table 3.2)

Table 3.2; Methods of analysis

Parameter	**Method**	**Unit**
Ph	Ph. meter	
Nitrates	Phenoldisulphonic acid	Mg/l
EC	Conductivity meter	s/m
TDS	TDS meter	Mg/l
Iron	Titration	Mg/lf
Manganese	Titration	Mg/l
Lead	Atomic absorption spectroscopy	Mg/l

3.9Data analysis

Variation of means of physiochemical and heavy metals were evaluated using ANOVA in Statistical Packing for Social Science (spss)version 20,with 95% confidence interval and it was also used to evaluate concentration of physiochemical water parameters and heavy metal parameters against the WHO international guidelines of drinking water quality.Also the results were used to compare differences in variation between physiochemical parameters and heavy metals of boreholes within and outside the dumpsite.

CHAPTER FOUR

4.1Comparison of the results from boreholes with WHO water quality guidelines

Nitrates mean concentrations showed that there was a significant difference in BH1(18.633± 0.67) and BH2(17.3.667 ±0.13) (table 4.1)..There was a significant difference in nitrates concentration in BH1(18..633 ±0.67)and BH5control borehole (.8.233± 0.33).Among all boreholes means, only borehole (5) was within WHO guidelines and was complied with WHO guidelines on water quality for drinking limit of 10mg/l (table 4.1).

There was a significant difference in TDS concentrations in BH1(4.7467± 0.03) and BH4(0.3967± 0.003) ,the results also show that there was no significant difference(p>0.05) in TDS concentration in BH3(0.4800± 0.00) and BH4 (0.3967 ±0.003) as shown on the (table 4.1).There was a significant difference between BH1 and BH4 (table 4.1). The results overall showed that TDS means among all boreholes were within WHO guidelines limit of 500mg/l (table4.1).

Electrical conductivity means showed no significant difference between boreholes4(213.33±3.33)and borehole 5(226.6± 3.33), there was also a significant difference in BH1 and BH42 in means values (shown on table 4.1).Also there was a significant difference(p<0.05) in BH1(453.33 ±3.33) and BH5 (226.66 ± 3.33) (table 4.1).Among all boreholes were within WHO guidelines (2017)limit of between(200-800ppm).

There was a significant difference(P<0.05) in pH in BH1(8.4667 ±0.33) and BH4(6.6067± 0.33) ,there was also a significant difference (p<0.05) pH means in BH1 and BH2 as shown on (table 4.1)Also, there was no significant difference(p>0.05) in pH means in BH3(6.7667± 0.33) and BH4(6.6067± 0.33) (table 4.1). All boreholes were within WHO guidelines limit of (6.5-8.5) as show on the (table 4.1)

There was a significance difference (p<0.05) in Iron means between BH1(0.3667 0.33) and BH5(0.1167± 0.02)(table 4.1).There was a no significance difference(p>0.05) iron means in BH2(0.4333 ±0.0.33) and BH4(0.2333 ±0.33)..Overall, among all boreholes borehole 1and 2 were not complied with WHO guidelines limit of (0.3mg/l)(table 4.1) as there were above WHO limit guidelines .

There was a significant difference(P<0.05) in Manganese means in BH1(0.700± 0.00) and BH2(0.5667 ±0.33),similar to boreholes 4and 5 as shown on (table 4.1).Among all boreholes only boreholes3,4 and 5 were within WHO limit (0.4mg/l), however other 2boreholes were not complied with WHO guidelines limit 0f 0.4mg/l(table4.1)

There was also significant difference (p<0.05)in lead in BH1(0.333± 0.33) and BH2 (0.200 ±0..00).Also , there was no significant difference(p>0.05) in boreholes 3 and borehole 4 means as shown on (table 4.1).

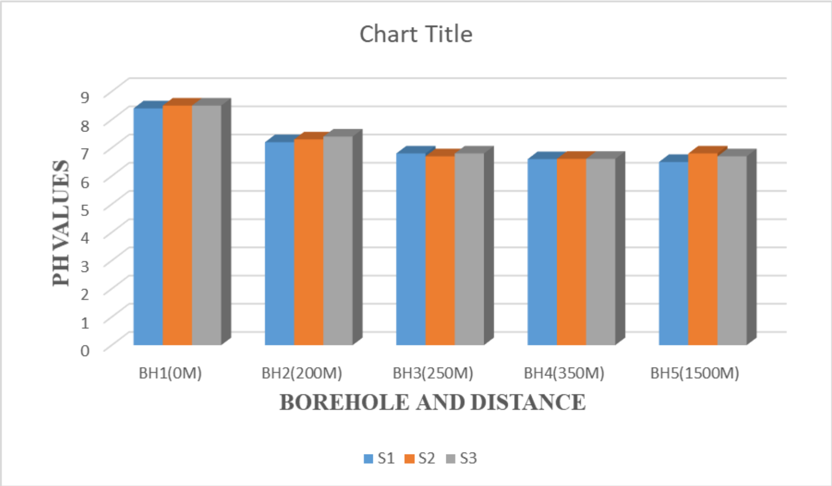
Table 4.1;Comparison of results from boreholes with WHO water quality guidelines

BORE-HOLES	**NI-TRATES**	**TDS**	**EC**	**pH**	**IRON**	**MANGA-NESE**	**LEAD**
BH1	18.6333± 0.67[a]	4.7467± ± 0.03[a]	453.333 ±3.33[a]	8.4667 ±0.33[a]	0.5667 ±0.33[a]	0.7000± 0.00[a]	0.333 ± 0.33a
BH2	17.3667± 0.13[b]	3.9200 ±0.005[b]	286.6667± 6.67[b]	7.2557± 0.33[b]	0.4333 ± 0.33[b]	0.5667 ±0.33[b]	0.2000± 0.00[b]
BH3	14.6333± 0.17[c]	0.4800± 0.00[c]	246.667± 3.33[b]	6.7667± 0.33[c]	0.300 ±0.00[c]	0.4167± 0.02[c]	0.1833± 0.02[c]
BH4	13.033 ±0.33[c]	0.3967± 0.003[c]	213.333± 3.33[b]	6.6067± 0.33[c]	0.2333± 0.33[c]	0.2333± 0.33[d]	0.1333± 0.02[c]
BH5	8.2333 ±0.33[d]	0.1900± 0.00[c]	226.666± 3.33[b]	6.6667 ±0.89[c]	0.1167 ±0.02[d]	0.1333 ±0.33[e]	0.1667± 0.33[c]
WHO GUIDE-LINES	**10MG/l**	**500mg/l**	**200-800ppm**	**6.5-8.5**	**0.3mg/l**	**0.4mg/l**	**0.01mg/l**

Different superscripts indicate significance difference ($p<0.05$).Similar superscripts indicate no significant deference ($p>0.05$) in columns.

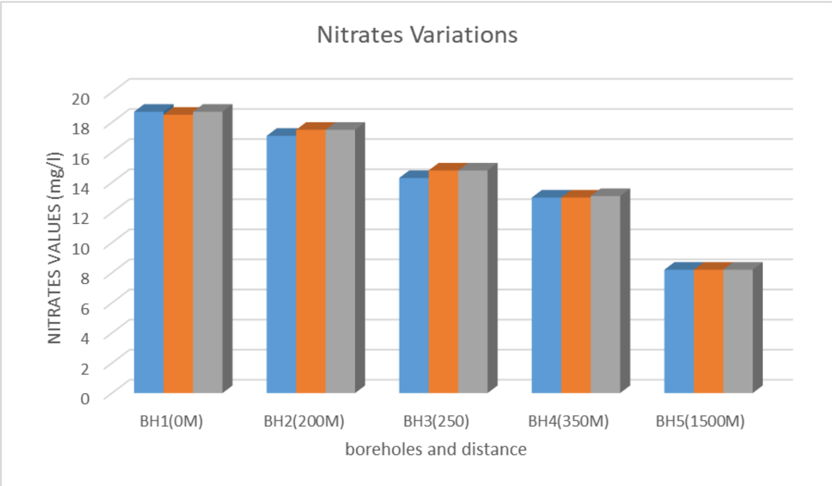
4.2Comparison of Variations in physiochemical parameters nitrates, tds, ec ph and heavy metal parameters of boreholes within and outside the Pomona dumpsite(table 4.1)

Figure 4.1 ;PH variations between boreholes within and outside pomona dump site



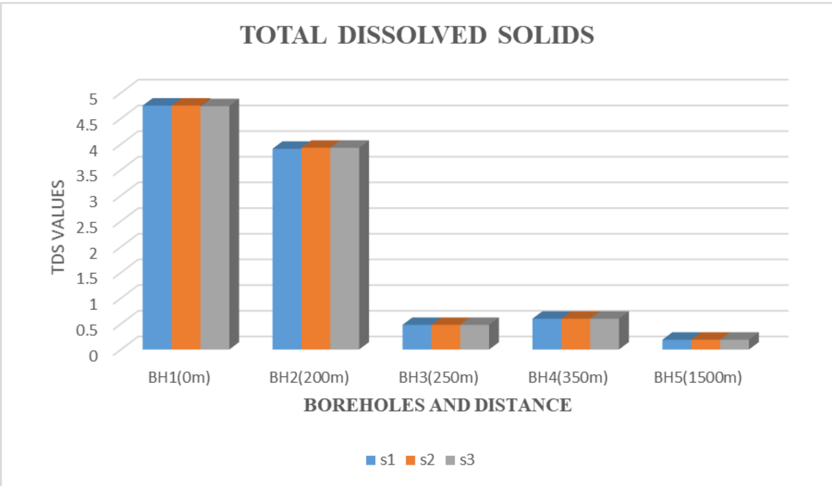
The pH showed clear trend across the borehole (figure 4.1).The pH range from 6.5 up to 8.5.PH levels decreased from alkaline to normal with distance from the pomona landfill .BH1(0m) within the landfill has higher range of pH and BH4 and 5(control) recorded the lower pH level(figure 4.1).

Figure 4.2 Nitrates variations between boreholes within compared to boreholes outside Pomona landfill



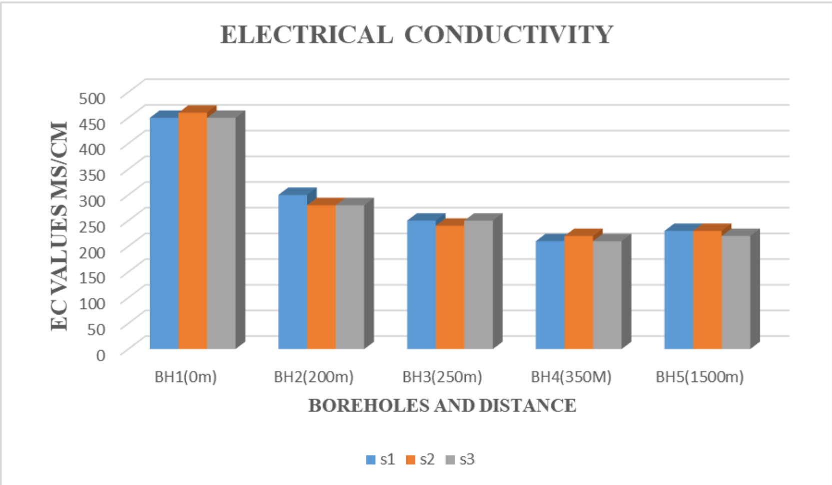
Nitrates was higher in the borehole 1 within the landfill ranged 18.7mg/l(figure 4.2).It then decreased in boreholes outside the landfill with the lower nitrates ranged 8.2 in the control borehole 5(1500m) (figure 4.2) .

Figure 4..3 Total Dissolved Solids variations between boreholes within and outside the pomona dumpsite



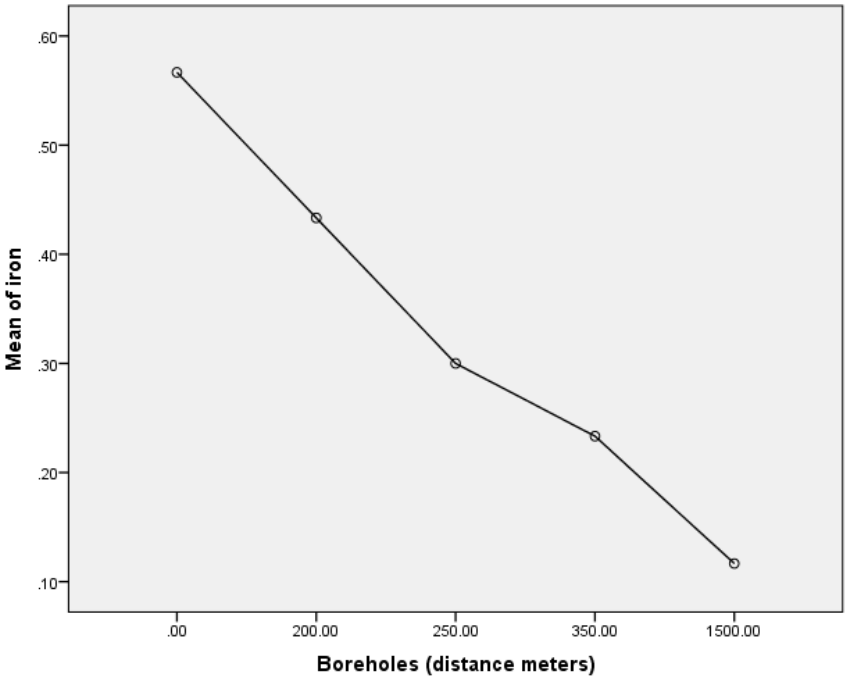
Total dissolved solids were also higher in borehole 1(00.m) as shown (figure 4.3).Concentration of tds was lower in the control borehole(1500m) and it increases as the distance as one approaches the borehole near the landfill (figure 4.3)

Figure 4.4 Electrical conductivity variations in boreholes within compared to boreholes outside pomona landfill



Conductivity was lower in borehole 4 (350m) with an average of 213ms/cm .It then increase by two times from borehole 4 (350m) to 450ms/cm to the borehole within the landfill (figure 4.4).

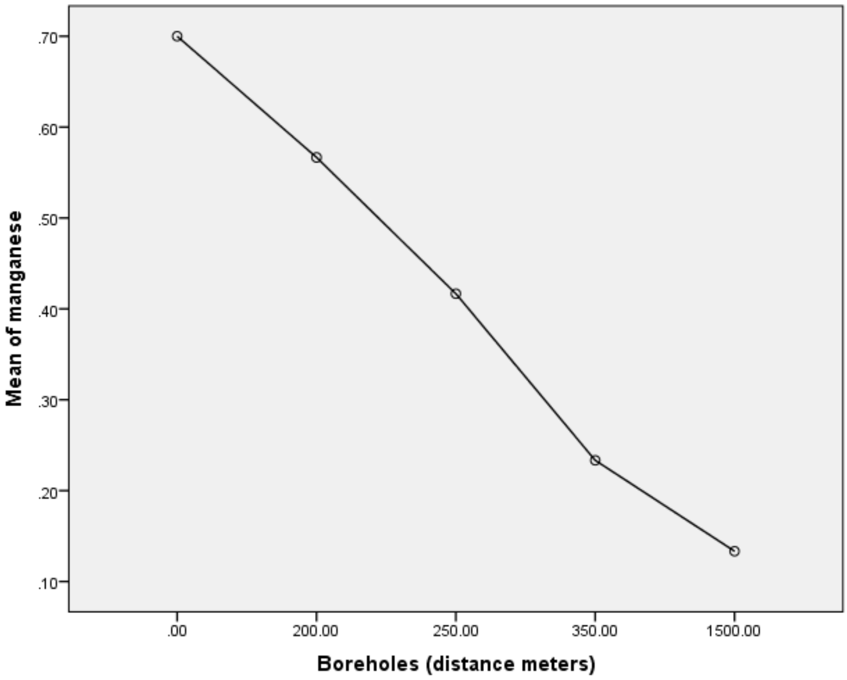
Figure 4.5 Iron variations in boreholes within the dumpsite compared to boreholes outside the Pomona dumpsite



Iron concentration was also lower in the control borehole (1500m) with an average of o.11mg/l(figure 4.5) .

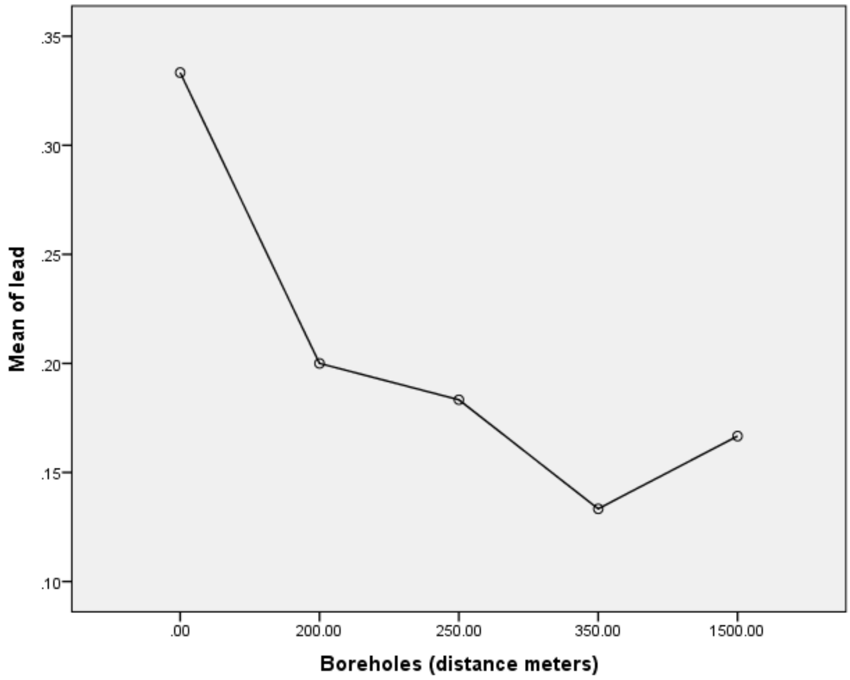
Borehole 1 (00m) within the landfill had higher concentration in iron (0.57mg/l) (figure 4.5) .Iron concentrations as shown on the graph decreased as distance from the landfill increased(figure 4,5)

Figure 4.6 ;Manganese variations in boreholes within the landfill compared to boreholes outside the pomona dumpsite



Manganese concentration was higher in borehole 1(00m) within the landfill with an average of 0.7mg/l.It then decreased as distance increased from the landfill(figure4.6).Also the control borehole (1500m) had lower average of 0.13m/l .There was a sharp decrease in manganese concentrations from borehole (00m) within the landfill to all the boreholes outside the landfill (figure 4.6)

Figure 4.7 ;Lead variations in boreholes within the pomona landfill compared to boreholes outside the pomona landfill



Low concentration in lead was recorded in borehole 4(350m) outside the pomona landfill with an average of 0.13mg/l (figure 4.7) .The concentration increased as distance close to the landfill , with the borehole within recorded an average of o.33mg/l which was the highest (figure 4.7).

CHAPTER FIVE
5.0 DISCUSSIONS

5.1Comparison of results from boreholes within and outside Pomona landfill with WHO guidelines

Nitrates concentrations was significant difference ($p<0.05$) in BH1 and BH2.There was also significant difference in nitrates concentration between borehole 1 and boreholes 5.Only borehole 5 complied with WHO recommendations guidelines on water quality limit of below 10mg/l.The type of waste disposed at Pomona Landfill in Harare, Zimbabwe that is contributing to higher levels of nitrates in boreholes near the landfill is mainly municipal solid waste (MSW). MSW includes household waste, commercial waste, and construction waste. This waste contains a variety of organic and inorganic materials, such as food waste, paper, plastics, and metals. When MSW decomposes, it releases a variety of pollutants, including nitrates, into the groundwater.In other studies on nitrates concentrations according to (Mmolawa et al , 2012) discovered that groundwater contamination in area of landfill site in Gaborone , Botswana was mostly caused by leachate .

Total dissolved solids concentrations were also significant ($p<0.050$) difference in BH1 and BH4 ,also in BH2 and BH3 .There was no significance differences in borehole3 and borehole 4 .However all boreholes were within WHO guidelines of (2017) on water quality. The Pomona landfills age (20 years) played a role because older landfills typically have higher TDS values as a result of the waste and toxins that have accumulated there over time. Differences in TDS levels in groundwater close to landfills, according to (Mugumbate et al. 2016), can be attributable to the type of waste disposed of in the dump and the landfall's age.According to (Magidi 2018)TDS is a measure of the total amount of dissolved solids in water, including salts, minerals, and other inorganic compounds. Nitrates are a type of salt that can contribute to the TDS levels in the water.

There was also a significant ($p<0.05$) difference in electrical conductivity concentration in BH1 and BH2, BH1 and BH3 and also BH2 and BH5 .There was no significant difference in BH4 and BH5. All boreholes were complied with WHO guidelines on water quality Nitrates are a type of salt that can contribute to the TDS levels in the water. When the TDS levels in water increase, the EC levels also increase, as more charged particles are present in the water.Therefore , nitrates contributes to increase in electrical conductivity .

There was a significant difference in pH (<0.05) in borehole 1 and borehole 4 and there was also significant difference in ph levels in borehole 2 and borehole 4 .Borehole 1 and borehole 2 were alkaline while other 3 were acidic although all boreholes were within who guidelines

Concentrations of iron was significantly difference ($p<0.05$)in BH1 and BH2 , was significant difference in BH1 and BH4(table 4.1) .Only boreholes3,4and 5 were below WHO guidelines(2017) in iron limit for water quality for drinking of (0.3mg/l).Construction and demolition waste being disposed at pomona landfill, this type of waste can include materials such as concrete, bricks, and metals, which can contain high levels of iron. When these materials are poor disposed of at the landfill, they can leach iron and other metals into the surrounding soil and groundwater.Therefore ,higher concentrations in iron in boreholes 1and 2 were as a result of waste disposed at the pomona landfill .

Manganese concentration was significantly different in BH1 and BH2 , in BH1 and BH3 .There was no significant difference in BH4 and BH5. Overall boreholes 1 and 2 were above WHO standards(2017) and limits for water quality. Lead concentration was significantly different in BH1 and BH5, BH1 and BH3 and BH2 and BH5.Lead was higher boreholes 1 and 2 which were above WHO guidelines on water quality of (2017) .As a result of disposal of Batteries at pomona landfill which including lead-acid batteries and rechargeable batteries, which contain high levels of lead and manganese.These batteries are not properly disposed of or recycled hence end up in the landfill and contribute to the leaching of these metals to the groundwater .

5.2 Variation comparisons of the results acquired from boreholes within and boreholes outside the pomona landfill

Higher Manganese Concentrations was within the Landfill. Borehole 1 (00m) inside the landfill displayed the highest average manganese concentration at 0.7 mg/l. This suggests that the landfill is a significant source of manganese contamination in the groundwater.Boreholes within the dumpsite have higher concentrations due to the disposal of electronic waste, such as discarded computers, televisions, and cell phones which contains high levels of lead and manganese. When this waste disposed of at the Pomona landfill, the metals leach into the surrounding soil and groundwater.Decreasing Manganese concentrations with distance: As the distance from the landfill increased, manganese concentrations in the groundwater decreased. This was evident from the drop in manganese levels in boreholes situated farther away from the landfill (Figure 4.6).Control Borehole Indicates lower Manganese Levels: The control borehole, located 1500 meters away from the landfill, showed a significantly lower levels in manganese concentration of 0.13 mg/l. This indicates that the influence of the landfill on manganese contamination decreases with distance.

The pH values showed an increasing trend from the control boreholes (BH4 and BH5) towards the borehole within the Pomona landfill (BH1). The pH was highest in BH1 which is located within the landfill. This indicates that the waste materials in the landfill are releasing alkaline compounds that are increasing the pH. Due to the disposal of medical waste at pomona landfill such as batteries from medical devices and certain medications, can contain alkaline substances that can contribute to higher pH levels in the groundwater.The pH then decreases with increasing distance from the landfill as the alkaline effect reduces.

Nitrate concentrations were highest in BH1 within the landfill and decreased with increasing distance from the landfill. The high nitrates in BH1 are likely due to nitrification of ammonia from the decomposing waste in the landfill. The nitrates then get diluted and reduced further away from the landfill due to factors like dispersion, adsorption, de nitrification .The parameters (pH, nitrates and TDS) in the control boreholes (BH4 and BH5) indicate the background groundwater quality, unaffected by the landfill. The increasing trends of these parameters towards BH1 show the impact of leachate which contains ammonia and organic nitrogen .

The parameters (pH, nitrates and TDS) in the control boreholes (BH4 and BH5) indicate the background groundwater quality, unaffected by the landfill (figure 4.1)l. The increasing trends of these parameters towards BH1 show the impact of leachate which contains ammonia and nitrogen compounds. The impact reduces with increasing lateral distance from the landfill. High clay content soils outside pomona landfill can have a higher capacity to retain water and dissolved substances, which can limit the movement of contaminants and reduce their concentration in groundwater.

CHAPTER SIX

6.1 Conclusion

According to this study, borehole (2) is not safe for drinking according to WHO requirements due to higher levels in both physiochemical and heavy metals concentrations. Also, all results from boreholes within and outside the landfill point to the pollution coming from the leachate in the dumpsite. It has been noted that uncontrolled leachate accumulation of the landfill provides a possible danger of groundwater resource contamination in the absence of a properly constructed leachate collection system. The study findings demonstrated that the dumpsite had an adverse impact on groundwater quality, especially with regard to nitrates. High levels of physical and chemical contaminants, such as nitrates and pH, are a sign that the Pomona landfill has not been properly managed.Therefore , there is no homogeneity of varying levels throughout the dump site, and borehole samples from within the dumpsite have the highest concentration of contaminants with increasing distance from the dumpsite, they revealed a significant difference in water quality. As a result of metals and various chemicals in some industrial wastes dumped at the Pomona dumpsite, groundwater, and other water sources may get contaminated. According to this study at currently exists, it is possible that the high concentrations of heavy metals like iron, manganese, and lead in groundwater close to the Pomona landfill in Harare are due to the landfills unlined design, which allows leachate to seep into the soil and contaminate the groundwater. Water percolates through waste to create leachate, a liquid that may contain heavy metals as well as other toxins.

6.2 Recommendations

1.The municipal council's disposal facilities are known for their flurry of activity because there aren't many businesses involved in recycling and because waste will eventually find its way back. Modern waste management and treatment procedures should be used at the dumpsite, and pre-treatment before or after disposal of waste must be mandated. If at all practicable, treatment facilities for waste and leachate should be divided into separate compartments for recycling and other uses. This is how a sanitary landfill should function. A detailed analysis of the hydro-geology and groundwater flow direction in the area is necessary to safeguard groundwater exploitation and select the ideal location for a dumpsite.Governmental institutions should conduct more research to monitor pollutant levels and create mitigating strategies. Raising public awareness of the unique applications of groundwater in the research area, such as recycling and source-based waste separation, is also necessary.

2.Furthermore, it is advised that the boreholes used for drinking close to the dump be monitored frequently. To identify contaminants in drinking water more easily, monitoring wells must be placed in the best possible area.

3.All local authorities should make sure that a full evaluation of the trash and the prospective dumpsite site is done before building dump sites.Analysing the types and quantities of trash that are anticipated to be discharged at the dumpsite will make it possible to use the right lining material. If this is done, leachate won't be able to enter underground water sources. In other parts of the world, leachate from landfills is collected, added to a methanol reactor, and biodegradable utilizing efficient micro-organisms to produce methane gas, a crucial fuel.

4. Before pollutants reach the groundwater, treatment of the leachate generated by the Pomona landfill may help lower their concentration. Depending on the particular characteristics of the leachate, treatment technologies including reverse osmosis, activated carbon filtration, and bioreactors may be taken into consideration.

5.Reduce the amount of waste that needs to be disposed of in the landfill by using effective waste management techniques. The Pomona Landfill should use techniques including proper waste segregation, composting, and recycling. This can assist in lowering the possibility of environmental pollution and Working together with stakeholders ,The Pomona Landfill and the City of Harare should work together with relevant groups, such as neighbourhood associations, non-governmental organizations, and regulatory bodies, to create and put into action effective plans for resolving borehole pollution and safeguarding the public's health. This can involve collaborating to create and implement monitoring programs, choosing and putting into effect corrective actions, and creating long-term plans for sustainable waste management techniques.

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Descriptives(appendix 1)

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
ph	.00	3	8.4667	.05774	.03333	8.3232	8.6101	8.40	8.50
	200.00	3	7.2667	.05774	.03333	7.1232	7.4101	7.20	7.30
	250.00	3	6.7667	.05774	.03333	6.6232	6.9101	6.70	6.80
	350.00	3	6.6067	.00577	.00333	6.5923	6.6210	6.60	6.61
	1500.00	3	6.6667	.15275	.08819	6.2872	7.0461	6.50	6.80
	Total	15	7.1547	.72385	.18690	6.7538	7.5555	6.50	8.50
nitrates	.00	3	18.6333	.11547	.06667	18.3465	18.9202	18.50	18.70
	200.00	3	17.3667	.23094	.13333	16.7930	17.9404	17.10	17.50
	250.00	3	14.6333	.28868	.16667	13.9162	15.3504	14.30	14.80
	350.00	3	13.0333	.05774	.03333	12.8899	13.1768	13.00	13.10
	1500.00	3	8.2333	.05774	.03333	8.0899	8.3768	8.20	8.30
	Total	15	14.3800	3.78271	.97669	12.2852	16.4748	8.20	18.70
manganese	.00	3	.7000	.00000	.00000	.7000	.7000	.70	.70
	200.00	3	.5667	.05774	.03333	.4232	.7101	.50	.60
	250.00	3	.4167	.02887	.01667	.3450	.4884	.40	.45
	350.00	3	.2333	.05774	.03333	.0899	.3768	.20	.30
	1500.00	3	.1333	.05774	.03333	-.0101	.2768	.10	.20

	Total	15	.4100	.21893	.05653	.2888	.5312	.10	.70
tds	.00	3	4.7467	.00577	.00333	4.7323	4.7610	4.74	4.75
	200.00	3	3.9200	.01000	.00577	3.8952	3.9448	3.91	3.93
	250.00	3	.4800	.00000	.00000	.4800	.4800	.48	.48
	350.00	3	.3967	.00577	.00333	.3823	.4110	.39	.40
	1500.00	3	.1900	.00000	.00000	.1900	.1900	.19	.19
	Total	15	1.9467	2.03752	.52609	.8183	3.0750	.19	4.75
ec	.00	3	453.3333	5.77350	3.33333	438.9912	467.6755	450.00	460.00
	200.00	3	286.6667	11.54701	6.66667	257.9823	315.3510	280.00	300.00
	250.00	3	246.6667	5.77350	3.33333	232.3245	261.0088	240.00	250.00
	350.00	3	213.3333	5.77350	3.33333	198.9912	227.6755	210.00	220.00
	1500.00	3	226.6667	5.77350	3.33333	212.3245	241.0088	220.00	230.00
	Total	15	285.3333	90.85834	23.45952	235.0177	335.6490	210.00	460.00
iron	.00	3	.5667	.05774	.03333	.4232	.7101	.50	.60
	200.00	3	.4333	.05774	.03333	.2899	.5768	.40	.50
	250.00	3	.3000	.00000	.00000	.3000	.3000	.30	.30
	350.00	3	.2333	.05774	.03333	.0899	.3768	.20	.30
	1500.00	3	.1167	.02887	.01667	.0450	.1884	.10	.15
	Total	15	.3300	.16669	.04304	.2377	.4223	.10	.60
lead	.00	3	.3333	.05774	.03333	.1899	.4768	.30	.40
	200.00	3	.2000	.00000	.00000	.2000	.2000	.20	.20
	250.00	3	.1833	.02887	.01667	.1116	.2550	.15	.20
	350.00	3	.1333	.02887	.01667	.0616	.2050	.10	.15
	1500.00	3	.1667	.05774	.03333	.0232	.3101	.10	.20
	Total	15	.2033	.07898	.02039	.1596	.2471	.10	.40

ANOVA(appendix 2)

		Sum of Squares	df	Mean Square	F	Sig.
ph	Between Groups	7.269	4	1.817	272.302	.000
	Within Groups	.067	10	.007		
	Total	7.335	14			
nitrates	Between Groups	200.011	4	50.003	1595.830	.000
	Within Groups	.313	10	.031		
	Total	200.324	14			
manganese	Between Groups	.649	4	.162	74.923	.000
	Within Groups	.022	10	.002		
	Total	.671	14			
tds	Between Groups	58.121	4	14.530	435904.500	.000
	Within Groups	.000	10	.000		
	Total	58.121	14			
ec	Between Groups	115040.000	4	28760.000	539.250	.000
	Within Groups	533.333	10	53.333		
	Total	115573.333	14			
iron	Between Groups	.367	4	.092	42.385	.000
	Within Groups	.022	10	.002		
	Total	.389	14			

lead	Between Groups	.071	4	.018	10.600	.001
	Within Groups	.017	10	.002		
	Total	.087	14			

Multiple Comparisons (appendix 3)

LSD

Dependent Variable	(I) BOREHOLES	(J) BOREHOLES	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
ph	.00	200.00	1.20000*	.06670	.000	1.0514	1.3486
		250.00	1.70000*	.06670	.000	1.5514	1.8486
		350.00	1.86000*	.06670	.000	1.7114	2.0086
		1500.00	1.80000*	.06670	.000	1.6514	1.9486
	200.00	.00	-1.20000*	.06670	.000	-1.3486	-1.0514
		250.00	.50000*	.06670	.000	.3514	.6486
		350.00	.66000*	.06670	.000	.5114	.8086
		1500.00	.60000*	.06670	.000	.4514	.7486
	250.00	.00	-1.70000*	.06670	.000	-1.8486	-1.5514
		200.00	-.50000*	.06670	.000	-.6486	-.3514
		350.00	.16000*	.06670	.037	.0114	.3086
		1500.00	.10000	.06670	.165	-.0486	.2486
	350.00	.00	-1.86000*	.06670	.000	-2.0086	-1.7114
		200.00	-.66000*	.06670	.000	-.8086	-.5114
		250.00	-.16000*	.06670	.037	-.3086	-.0114

		1500.00	-.06000	.06670	.390	-.2086	.0886
	1500.00	.00	-1.80000*	.06670	.000	-1.9486	-1.6514
		200.00	-.60000*	.06670	.000	-.7486	-.4514
		250.00	-.10000	.06670	.165	-.2486	.0486
		350.00	.06000	.06670	.390	-.0886	.2086
nitrates	.00	200.00	1.26667*	.14453	.000	.9446	1.5887
		250.00	4.00000*	.14453	.000	3.6780	4.3220
		350.00	5.60000*	.14453	.000	5.2780	5.9220
		1500.00	10.40000*	.14453	.000	10.0780	10.7220
	200.00	.00	-1.26667*	.14453	.000	-1.5887	-.9446
		250.00	2.73333*	.14453	.000	2.4113	3.0554
		350.00	4.33333*	.14453	.000	4.0113	4.6554
		1500.00	9.13333*	.14453	.000	8.8113	9.4554
	250.00	.00	-4.00000*	.14453	.000	-4.3220	-3.6780
		200.00	-2.73333*	.14453	.000	-3.0554	-2.4113
		350.00	1.60000*	.14453	.000	1.2780	1.9220
		1500.00	6.40000*	.14453	.000	6.0780	6.7220
	350.00	.00	-5.60000*	.14453	.000	-5.9220	-5.2780
		200.00	-4.33333*	.14453	.000	-4.6554	-4.0113
		250.00	-1.60000*	.14453	.000	-1.9220	-1.2780
		1500.00	4.80000*	.14453	.000	4.4780	5.1220
	1500.00	.00	-10.40000*	.14453	.000	-10.7220	-10.0780
		200.00	-9.13333*	.14453	.000	-9.4554	-8.8113
		250.00	-6.40000*	.14453	.000	-6.7220	-6.0780
		350.00	-4.80000*	.14453	.000	-5.1220	-4.4780
manganese	.00	200.00	.13333*	.03801	.006	.0487	.2180
		250.00	.28333*	.03801	.000	.1987	.3680
		350.00	.46667*	.03801	.000	.3820	.5513
		1500.00	.56667*	.03801	.000	.4820	.6513
	200.00	.00	-.13333*	.03801	.006	-.2180	-.0487

		250.00	.15000*	.03801	.003	.0653	.2347
		350.00	.33333*	.03801	.000	.2487	.4180
		1500.00	.43333*	.03801	.000	.3487	.5180
	250.00	.00	-.28333*	.03801	.000	-.3680	-.1987
		200.00	-.15000*	.03801	.003	-.2347	-.0653
		350.00	.18333*	.03801	.001	.0987	.2680
		1500.00	.28333*	.03801	.000	.1987	.3680
	350.00	.00	-.46667*	.03801	.000	-.5513	-.3820
		200.00	-.33333*	.03801	.000	-.4180	-.2487
		250.00	-.18333*	.03801	.001	-.2680	-.0987
		1500.00	.10000*	.03801	.025	.0153	.1847
	1500.00	.00	-.56667*	.03801	.000	-.6513	-.4820
		200.00	-.43333*	.03801	.000	-.5180	-.3487
		250.00	-.28333*	.03801	.000	-.3680	-.1987
		350.00	-.10000*	.03801	.025	-.1847	-.0153
tds	.00	200.00	.82667*	.00471	.000	.8162	.8372
		250.00	4.26667*	.00471	.000	4.2562	4.2772
		350.00	4.35000*	.00471	.000	4.3395	4.3605
		1500.00	4.55667*	.00471	.000	4.5462	4.5672
	200.00	.00	-.82667*	.00471	.000	-.8372	-.8162
		250.00	3.44000*	.00471	.000	3.4295	3.4505
		350.00	3.52333*	.00471	.000	3.5128	3.5338
		1500.00	3.73000*	.00471	.000	3.7195	3.7405
	250.00	.00	-4.26667*	.00471	.000	-4.2772	-4.2562
		200.00	-3.44000*	.00471	.000	-3.4505	-3.4295
		350.00	.08333*	.00471	.000	.0728	.0938
		1500.00	.29000*	.00471	.000	.2795	.3005
	350.00	.00	-4.35000*	.00471	.000	-4.3605	-4.3395
		200.00	-3.52333*	.00471	.000	-3.5338	-3.5128
		250.00	-.08333*	.00471	.000	-.0938	-.0728
		1500.00	.20667*	.00471	.000	.1962	.2172

	1500.00	.00	-4.55667*	.00471	.000	-4.5672	-4.5462
		200.00	-3.73000*	.00471	.000	-3.7405	-3.7195
		250.00	-.29000*	.00471	.000	-.3005	-.2795
		350.00	-.20667*	.00471	.000	-.2172	-.1962
ec	.00	200.00	166.66667*	5.96285	.000	153.3806	179.9527
		250.00	206.66667*	5.96285	.000	193.3806	219.9527
		350.00	240.00000*	5.96285	.000	226.7139	253.2861
		1500.00	226.66667*	5.96285	.000	213.3806	239.9527
	200.00	.00	-166.66667*	5.96285	.000	-179.9527	-153.3806
		250.00	40.00000*	5.96285	.000	26.7139	53.2861
		350.00	73.33333*	5.96285	.000	60.0473	86.6194
		1500.00	60.00000*	5.96285	.000	46.7139	73.2861
	250.00	.00	-206.66667*	5.96285	.000	-219.9527	-193.3806
		200.00	-40.00000*	5.96285	.000	-53.2861	-26.7139
		350.00	33.33333*	5.96285	.000	20.0473	46.6194
		1500.00	20.00000*	5.96285	.007	6.7139	33.2861
	350.00	.00	-240.00000*	5.96285	.000	-253.2861	-226.7139
		200.00	-73.33333*	5.96285	.000	-86.6194	-60.0473
		250.00	-33.33333*	5.96285	.000	-46.6194	-20.0473
		1500.00	-13.33333*	5.96285	.049	-26.6194	-.0473
	1500.00	.00	-226.66667*	5.96285	.000	-239.9527	-213.3806
		200.00	-60.00000*	5.96285	.000	-73.2861	-46.7139
		250.00	-20.00000*	5.96285	.007	-33.2861	-6.7139
		350.00	13.33333*	5.96285	.049	.0473	26.6194
iron	.00	200.00	.13333*	.03801	.006	.0487	.2180
		250.00	.26667*	.03801	.000	.1820	.3513
		350.00	.33333*	.03801	.000	.2487	.4180
		1500.00	.45000*	.03801	.000	.3653	.5347
	200.00	.00	-.13333*	.03801	.006	-.2180	-.0487
		250.00	.13333*	.03801	.006	.0487	.2180
		350.00	.20000*	.03801	.000	.1153	.2847

		1500.00	.31667*	.03801	.000	.2320	.4013
	250.00	.00	-.26667*	.03801	.000	-.3513	-.1820
		200.00	-.13333*	.03801	.006	-.2180	-.0487
		350.00	.06667	.03801	.110	-.0180	.1513
		1500.00	.18333*	.03801	.001	.0987	.2680
	350.00	.00	-.33333*	.03801	.000	-.4180	-.2487
		200.00	-.20000*	.03801	.000	-.2847	-.1153
		250.00	-.06667	.03801	.110	-.1513	.0180
		1500.00	.11667*	.03801	.012	.0320	.2013
	1500.00	.00	-.45000*	.03801	.000	-.5347	-.3653
		200.00	-.31667*	.03801	.000	-.4013	-.2320
		250.00	-.18333*	.03801	.001	-.2680	-.0987
		350.00	-.11667*	.03801	.012	-.2013	-.0320
lead	.00	200.00	.13333*	.03333	.003	.0591	.2076
		250.00	.15000*	.03333	.001	.0757	.2243
		350.00	.20000*	.03333	.000	.1257	.2743
		1500.00	.16667*	.03333	.001	.0924	.2409
	200.00	.00	-.13333*	.03333	.003	-.2076	-.0591
		250.00	.01667	.03333	.628	-.0576	.0909
		350.00	.06667	.03333	.073	-.0076	.1409
		1500.00	.03333	.03333	.341	-.0409	.1076
	250.00	.00	-.15000*	.03333	.001	-.2243	-.0757
		200.00	-.01667	.03333	.628	-.0909	.0576
		350.00	.05000	.03333	.165	-.0243	.1243
		1500.00	.01667	.03333	.628	-.0576	.0909
	350.00	.00	-.20000*	.03333	.000	-.2743	-.1257
		200.00	-.06667	.03333	.073	-.1409	.0076
		250.00	-.05000	.03333	.165	-.1243	.0243
		1500.00	-.03333	.03333	.341	-.1076	.0409

1500.00	.00	-.16667*	.03333	.001	-.2409	-.0924
	200.00	-.03333	.03333	.341	-.1076	.0409
	250.00	-.01667	.03333	.628	-.0909	.0576
	350.00	.03333	.03333	.341	-.0409	.1076

*. The mean difference is significant at the 0.05 level.