SPATIAL VARIABILITY OF HEAVY METAL CONCENTRATIONS IN SOILS ADJACENT TO OSHAKATI SOLID WASTE DISPOSAL SITE, NAMIBIA

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Thesis submitted in partial fulfilment of the requirements for the degree of Master **of Natural Resources Management** at the **Namibia University of Science and Technology**

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Declaration

I, *Martha Haukena*, hereby declare that the work contained in the thesis entitled: **Spatial variability of heavy metal concentrations in soils adjacent to Oshakati Solid Waste Disposal Site, Namibia** is my own original work and that I have not previously in its entirety or in part submitted it at any university or higher education institution for the award of a degree.

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Table of Contents

List of Figures

List of Tables

List of Acronyms

°C	Degree Celsius
3Rs	Reduce, Reuse and Recycle
As	Arsenic
ATSDR	Agency for Toxic Substances and Diseases Registry
Cd	Cadmium
Cr	Chromium
Cu	Copper
EC	Electrical Conductivity
EC	European Commission
EIA	Environmental Impact Assessment
EMA	Environmental Management Act
H_2O_2	Hydrogen peroxide
HCL	Hydrochloric acid
HNO_3	Nitric acid
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
IWC	Informal Waste Collectors
M	Metres
MAWF	Ministry of Agriculture water and forestry
MET	Ministry of Environment and Tourism
MHSS	Ministry of Health and Social Services
Mn	Manganese
MSW	Municipal Solid Waste
Nd	Not detected
Ni	Nickel
Pb	Lead
r	Pearson's correlation coefficient
SA	South Africa
WHO	World Health Organisation

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Dedication

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Abstract

Human existence generates massive amount of waste. These wastes are usually dumped at disposal sites especially in developing countries due to lack of landfills. As a result of continuous waste dumping, soils in disposal sites have become sinks of toxic heavy metals. Oshakati disposal site is open and all waste from the town irrespective of the source get dumped at the site. The scoping assessment which was done at the site in 2018 found high levels of heavy metals way above the standard limits. This study was then undertaken to investigate the spatial variability of cadmium (Cd), lead (Pb), arsenic (As), chromium (Cr), manganese (Mn), nickel (Ni), copper (Cu) and Zinc (Zn) concentrations in soils adjacent to Oshakati solid waste disposal site in Namibia, to understand the impacts of the disposal site on soils nearby. This was done by assessing heavy metal occurrence and levels in soil samples taken from an area adjacent to the Oshakati disposal site.

A total of 95 topsoil samples at a depth of 30 cm were collected from Oshakati disposal site vicinity (56 samples), control site 1 (28 soil samples) and control site 2(11 soil samples) using a soil auger. Soil samples were collected from four transects that were laid according to cardinal direction from 10 metres to 150 metres away from the disposal site. A similar method was employed at control sites. The disposal site vicinity was an area comprised mainly of farm fields and homesteads, while control site 1 was an open area, located about 700m away from the disposal site where human activities were limited while control site 2 was a homestead with a farm field situated approximately 2 km away from the disposal site.

Soil samples were analysed for their physicochemical properties such as pH, particle size analysis, texture and electrical conductivity (EC) using a pH meter, pipette method, USDA classification system and conductivity meter respectively. Soil samples were further analysed for the concentrations of the following heavy metals: cadmium, lead, arsenic, chromium, manganese, nickel, copper and Zinc using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) as a standard analytic technique.

Results of physicochemical parameters showed that soil at disposal site vicinity was slightly acidic with high EC compared to control sites and all study sites recorded a sand texture. Heavy metals were found in various concentrations at all study sites except for cadmium which was not detected in the disposal site vicinity. Manganese recorded the highest mean values and arsenic the least in all study sites.

The mean metal concentrations recorded at disposal site vicinity where : Mn > Zn > Cr > Pb > Cu > Ni > As while at control site 1 mean values where : Mn > Zn > Cr > Cu >Ni > Pb > Cd > As and at control site 2: Mn > Zn > Cr > Ni > Cu > Pb > Cd > As. The result showed that the disposal site contributed to the presence of heavy metals present in the disposal site vicinity. A MANOVA test indicated a significant difference ($P < 0.05$) in mean metal values between disposal site vicinity and control sites. These differences stated that beside zinc and lead, heavy metal concentrations were higher at control sites compared to disposal site vicinity. This was attributed to contamination from another anthropogenic source other than the disposal site.

However, all heavy metals analysed in this study from all study sites were found below the standard limits for heavy metals in soil established by SA and WHO. Furthermore, distance did not influence the spatial variability of heavy metal concentrations, as no correlation was detected between them. A Pearson's correlation matrix test indicated that only at 100m distance were significant linear relationship existed in the interaction between mean metal concentrations and distance. Manganese positively correlated strongly with nickel, copper and arsenic ($r = 0.9046$, $r = 0.8283$, $r = 0.6563$, $p > 0.05$) while nickel values correlated strongly with those of manganese, copper, zinc and arsenic ($r = 0.9046$, $r = 0.8686$, $r = 0.6015$, $r = 0.5704$, $p = 0.05$). Nevertheless, chromium, cadmium and lead did not show any interactions with other metals. The interactions were attributed to soil physicochemical parameters such as pH, EC and water holding capacity.

The occurrence of heavy metals, although in low concentrations in soils at the disposal site vicinity requires periodic monitoring, as heavy metals do not degrade. With continuous dumping of waste in the disposal site, heavy metals will continue to accumulate in soil and cause potential threat to soil properties and living organisms inhabiting these soils. The researcher, therefore, recommends that local authorities develop and implement a soil quality monitoring system that will regularly asses heavy metal levels in soils adjacent to disposal sites. This is necessary to ensure healthy environments.

Keywords: Oshakati, soil, heavy metals, disposal site, spatial variability, standard limits.

Chapter 1: General Introduction

1.1 Background

Human activities generate a massive amount of waste daily. Waste from urban inhabitants is termed as municipal solid waste (MSW) since town municipalities collect it from those that generate it (Karishnamurti & Naidu, 2003). MSW comprises of waste from industries, residential, commercial, institutional, construction and demolition, municipal services, treatment plants and agricultural activities (Singh et al., 2011). These wastes are usually dumped at disposal sites especially in developing countries due to lack of landfills. As a result of continuous dumping of different kinds of waste, disposal site soils have turned into sinks of toxic metals including heavy metals (Sawyerr, Adeolu, Afolabi, Salami & Badmos, 2017). Heavy metals have been around for many years as they occur naturally in the earth crust but are now added to soils due to anthropogenic activities. The term 'heavy metal' has been widely used and many experts defined it differently (Duffus, 2002), however, all definitions revolve around a unique common connotation which is all metals and metalloids of high density and linked with contamination, toxicity and Ecotoxicity (Kemp, 1998; Hunt, 1999 & Klaasen, 2001, as cited in Duffus, 2002). Some metals are useful to biotic life in the ecosystems while others are extremely hazardous and cumulative. Metals such zinc, copper and nickel are essential micronutrients for plants and animals as they play an irreplaceable role as sources of vitamins and minerals, but the high amount can be hazardous (Kamunda, Mathuthu & Madhuku, 2016), while cadmium, mercury, arsenic, lead, cobalt, and chromium are of great concern as even at low concentrations could cause serious health consequences to plants, soil organisms, animals as well as humans (Adelekan & Alawode, 2011; Amwele et al., 2017).

Over the years, heavy metals have caused considerable damage to soil fertility and its quality, resulting in soil pollution. Soils are an important part of the biosphere as they support plant and animal life. During rainy seasons, heavy metals infiltrate the soil, get absorbed by plants through their root hair cells from which they enter the food chain (Ideriah et al., 2010). Animals and humans eventually obtain these heavy metals within their bodies upon consumption of the palatable plant products and drinking contaminated water (Chindo, 2016). Furthermore, soils could become contaminated through irrigation with wastewater, which is a common practice in many countries in Africa such as Namibia (personal observation), South Africa (Amwele et al., 2017) and Nigeria (Ideriah et al., 2010; Ogundele, Adio, & Oludele, 2015). Ideriah et al. (2010) further added that apart from consumption, humans and animals could inhale heavy metals directly from the soil that contain them.

Solid waste management, particularly waste disposal has proven difficult in many developing countries in the world (Ali et al., 2014). Due to rapid population growth and industrial development, a lot of waste is generated that ends up at disposal sites. Soil pollution mainly occurs as a result of heavy metals contamination, which often comes from waste dumping. Soils adjacent to disposal sites could equally get contaminated with heavy metals due to proximity to disposal sites. Several studies have been conducted to assess the spatial variability of heavy metal levels in soils adjacent to solid waste disposal sites in countries such as Nigeria (Akpoveta, Osakwe, Okoh, & Otuya, 2010; Ideriah et al., 2010), India (Pillai, Peter, Sunil, & Shrihari, 2014) and Sierra Leone (Sankoh, Yan, & Tran, 2013). Similarly, studies were done to determine heavy metal occurrence in vegetation growing in soils near disposal sites and vegetables irrigated using wastewater or grown in the closed disposal site. All these studies revealed that soils in and around solid waste disposal sites were highly contaminated with different kinds of heavy metals. Soil contamination poses a threat to water, air, animals, vegetation and people at large.

Until recently, waste disposal was not a concern in an independent Namibia, however, due to ineffective and inappropriate solid waste management strategies (Hasheela, 2009), soils in disposal sites in many towns have become contaminated reservoirs and breeding sites for rats, flies and other disease-causing vectors. Soil contamination threatens the health integrity of people living adjacent to disposal sites, as they depend on soil for their livelihood. Disposal sites such as the one at Outapi (Ekandjo, 2015), Ondangwa, Ongwediva, Helao Nafidi, Rundu, Tsumeb are open, lacks treatment measures and are located just a few meters away from residential areas where people live and crops are grown (personal observation). Oshakati town is no exception as the disposal site is surrounded by farmlands and water channels called Oshana (get flooded during good rains). The site boundary is just less than two meters away from these farmlands and Oshana (personal observation). Moreover, there are informal waste collectors (IWC) operating within the site collecting recyclables to sell to recycling companies daily (Haukena, 2017). These IWC are exposed to bad odour, smoke from waste burning and direct handling of waste which puts them at high risk of contracting chronic and infectious diseases. Furthermore, residents around Oshakati disposal site complain of waste dispersion, unbearable odour and awful smoke, similar to what Sankoh et al. (2013) found from residents of Granville Brook in Sierra Leone.

Studies regarding spatial variability of heavy metal concentrations in the soil adjacent to solid waste disposal sites are quite limited in Namibia, therefore a gap exists in understanding how disposal sites affect soils within their vicinities. It is against this background that this study embarked upon identifying the occurrence and concentrations of heavy metals in soils adjacent to Oshakati solid waste disposal site in Namibia.

1.2 Research statement

Waste disposal remains a challenge worldwide (Ali et al., 2014). This is because many countries in the world lack proper disposal site facilities and thus dispose of their waste in an open disposal site (Hoornweg & Bhada-Tata, 2012). Open disposal approach was described by Sankoh et al. (2013) as primitive and poor service delivery offered by municipal departments, while Gupta, Mohan, Prasad, Gupta and Kansal (1998) narrated that it is chaotic and unscientific to dispose of waste in an open space.

In India (Gupta et al., 1998) and Pakistan (Ali et al., 2014) all kinds of waste irrespective of whether hazardous or not are dumped together in an open disposal site. Namibia is no exception from this kind of practice, as only two sanitary landfills exist (Windhoek and Walvis Bay), the rest of the towns dump their waste in an open, in some cases unfenced and unmonitored disposal sites (Hasheela, 2009). Dumping of waste in an open dump reflects a poor waste management strategy from Local authorities as it poses danger to soil properties which in turn affects residents residing nearby and other valuable resources such as water, vegetation and air properties (Ali, Pervaz, Afzal, Hamid & Yasmin, 2014; Hasheela, 2009). In Oshakati town, the disposal site is located four kilometres away from the town centre and sited in the middle of a village called Othingo. The site is surrounded by homesteads and farmlands located less than five metres away from the site boundary. On the western and partly north-western side, the site borders with Oshana, which normally get flooded during good rains. Furthermore, the site was fenced off, but due to lack of monitoring and control, the fence was vandalised and animals where observed roaming freely feeding on cardboard and other waste inside the disposal site (Haukena, 2017). Open dumping practice and incineration practise at Oshakati disposal site could cause soils surrounding the site to become prone to contaminants from the site. In soils, heavy metals contamination influence soil physicochemical properties, microbial activities as well as soil enzyme activities (Friedlova, 2010). Soil contamination is not only hazardous to soil properties but to living organisms dwelling in these soils.

The issue of open waste disposal needs immediate intervention from all stakeholders as it affects the environment, people's wellbeing and their general health (MET, 2018).

There are limited studies done in Namibia, especially in the northern regions concerning spatial variability of heavy metals in soils surrounding the vicinity of the disposal site. Therefore, this study was necessary to provide baseline information in determining whether heavy metals do exist in the soil around disposal sites, their concentrations and whether these concentrations are within the standard limits for heavy metals in soils.

1.3 Research aims and objectives

The study aimed at investigating spatial variability of eight heavy metal (Pb, Cd, Mn, As, Ni, Cr, Zn and Cu) concentrations in soils adjacent to Oshakati solid waste disposal site in Namibia.
This was achieved through the following specific objectives.

1. Assess the presence and concentrations of heavy metals in soil from the disposal site vicinity and control sites.
2. Compare whether soil heavy metal concentrations align with standard guidelines for South Africa (SA) and the World Health Organisation (WHO).
3. Assess spatial variability of heavy metals concentration from disposal site to adjacent areas.
4. Determine the interaction of heavy metals concentration at various distances from the disposal site.

1.4 Thesis outline

This thesis is divided into five main chapters. The first chapter discusses the general introduction where the research aims and objectives are outlined, followed by a review of related literature and a description of the study area. Chapter two describes the methods employed in this study to gather necessary data and the statistical analysis performed to obtain the results, whereas chapter three presents the findings attained from the study. Chapter four deliberates on the results found in views of other researchers' outcomes and the last chapter consolidates on the study results from which recommendations and conclusions were drawn.

Chapter 2: Literature Review

2.1 Legal framework for waste management in Namibia

Before independence in 1990, limited attention was put on waste management and pollution control (MET, 2018). Existing legal frameworks were inadequate, fragmented and out-dated, with overlaps and gaps in institutional responsibilities. There was a lack of clarity as to which legislative applies and which ministry or institution applies it. Environmental issues and pollution control had not been a concern as the population density was low. To date, the land of the brave has developed several legal frameworks such as the Environmental Management Act (EMA), which calls for sustainable development in all aspects of the environment (EMA, 2007), Water Resource Management Act, Public and Environmental Health Act and Pollution Control and Waste Management Bill which was drafted in 2003 and has not yet been endorsed. All these frameworks aim at guiding relevant stakeholders on sustainable environmental management. In Namibia, all citizens, local & regional authorities, government ministries, private sectors and businesses are all stakeholders in waste management, but it is only the government that has overall accountability over waste management through its designated ministries such as Ministry of Environment and Tourism (MET), Ministry of Agriculture, Water and Forestry (MAWF) and Ministry of Health and Social Services (MHSS).

Waste handling is legalized in Namibia; thus, it is a law that dumping of waste at any site that has not been approved by MET is an offence and culprits shall be fined N$ 500 000. 00 or imprisoned for a period not exceeding 25 years or both fine and imprisonment (EMA, 2007). However, regardless of the law, some town municipalities in Namibia have erected disposal sites that have not undergone any Environmental Impact Assessment (EIA), hence not approved by MET (Hasheela, 2009).

The most ignored, but important concept by many towns in Namibia is the proper disposal site selection and monitoring of environments where waste is disposed (MET, 2018). A particular example is observed in some towns in northern Namibia, where disposal sites are placed next to Oshana channels (flowing water), which could pose devastating effects as pollutants could leak in to surface and underground water, causing water pollution and health risks. Although water is a scarce resource in Namibia, as it only comes after good rains, some town municipalities allowed waste systems to be connected to water supply systems, a move that is risky as it could contaminate Namibia precious water resource (Croset, 2014). Amwele et al. (2016) found the occurrence of heavy metals in borehole water in Kuiseb Basin, Namibia.

2.2 Waste management hierarchy

In Namibia, many towns do not have proper disposal site facilities that could contain and prevent waste dispersal as stipulated in EMA, but instead possess open sites, which Medina (2010) believed to create a health hazard to the environment. Hence, concerning hazardous waste in Namibia, Hasheela (2009) observed that current waste management practices are inadequate, as only Windhoek and Walvis Bay hold suitable facilities for safe disposal of hazardous waste. Despite a call for effective waste management by the government, waste management hierarchy (figure 1) and the concept of the 3R's (Reduce, Reuse and Recycle) shown in figure 2 are also still underdeveloped in Namibia, as many towns do not practice it at all and others have no knowledge about it (Haukena, 2017). The waste hierarchy provides a clear step by step guidance on actions to be followed to reduce the amount of waste generated at the source so to create a sustainable living and improve the overall waste management programmes. The core emphasis of the hierarchy is to prevent waste generation, followed by material and energy recovery and disposal is the least preferred option (Jacobsen & Kristoffersen, 2002). This implies that if the first three options are applied correctly by town municipalities, there will be less waste reaching the disposal sites, which in turn reduces negative environmental impacts.

Figure 1: Waste management hierarch
Source: (Hasheela, 2009).

Waste minimization strategies involve reduction, which is the main priority in the hierarchy followed by reuse then recycle. In Namibia, reduce is rarely practised while reuse is mainly done in the northern regions where plastic and glass bottles are reused to store dried seeds, sour milk, traditional brews, millets and other materials (Haukena, 2017). Recycle is mostly practised in the central regions of the country (Hasheela, 2009) where about 45% of waste disposed of at Kupferberg landfill site in Windhoek is recycled and very little in the northern towns. In Oshakati town, nearly 50% of the waste that enters the disposal site each week could be recycled (Alsin, Sundgren, Shooya & Nashongo, 2013).

Figure 2: The hierarchy of 3R's concept
Source: (Hasheela, 2009).

Recycling is the act of reprocessing waste materials for the original purpose or other purposes (MET, 2018). Recycling in Namibia is done in 24 of 35 local authorities by scavengers (Hasheela, 2009), also known as IWC. Informal waste collectors mostly collect bottles and cans to sell to recycling enterprises. It was however observed that eight out of 35 local authorities do transport materials to recycling companies.
The pilot study which was done in Windhoek found the maximum proportion of recyclables in the whole country to be at 54%, while in neighbouring Johannesburg between 30-40%. This difference was attributed to that most food and consumer goods are pre-packed and imported from South Africa to Namibia. These packaging materials form up the largest portion of waste composition in Namibia and are for example plastics, papers, glass bottles, plastic bottles, cardboard and tin cans. Based on extrapolation, the value of recyclables in Oshakati town alone is N$ 473 147 468. 00 (Haukena, 2017). If this value is to be extrapolated to Namibia as a whole, it could be much more, which could provide sufficient revenues to improve solid waste management in Namibia.

2.3 Current waste management status, key concept and terminologies

All living organisms create waste as a result of using energy. Various definitions of waste exist which normally depends on the type of waste under consideration. Some authors defined waste as a liquid, gaseous or solid products from industrial and domestic sources that are no longer wanted (Firth, Ormerods, & Prosser, 1995). Lee and Paik (2011) defined MSW as garbage from homes including those from businesses if similar in characteristics. In Namibia, waste is referred to as "any matter whether gaseous, solid or liquid or any combination thereof, which is from time to time listed by the Minister by notice in the Gazette or by regulation as an undesirable or superfluous by-product, emission, residue or a remainder of any process or activity'' (EMA, 2007).

Human activities generate different kinds of waste, classified into different categories such as municipal solid waste, household waste, commercial waste, industrial waste, hazardous waste, radioactive waste and electronic waste. After waste generation, there is a need for waste to be moved away from those that generated it and be disposed of somewhere safe. A disposal site in Namibia is defined as a "site used for the accumulation of waste with the purpose of disposing or treatment of such waste" (EMA, 2007). EMA further stipulates that if the waste disposal site already exists by any law, it needs to be approved by the minister as a waste disposal site.

For many years, Africa was considered safe regarding the topic of heavy metals contamination, however, due to rapid population expansion and fast industrial development, many towns and cities have been erected without proper planning and with no adequate disposal site facilities (Yabe, Ishizuka & Umemura, 2010). Rural inhabitants migrated to cities and towns resulting in overcrowding and erection of shacks that are not properly organised. The improper planning of informal settlements has led to narrow and inaccessible roads which make it difficult for waste collection and disposal, as a result, waste is dumped anywhere. Furthermore, due to financial constraints and ignorance, many African countries are unable to construct landfill sites which are safer ways of disposing of waste, instead, they dispose of their waste in an uncovered piece of land known as an open dump. Open dumps are a potential threat to the environment as rats and other disease-causing vectors breed in them causing health problems (Adelekan & Alawode, 2011; Ideriah et al., 2010; Sankoh et al., 2013). Furthermore, due to lack of clear legislation, Africa has become a dumping site for electronic and other waste as there is no control to guard the entry of these imports (Yabe et al., 2010).

In Namibia, the situation of solid waste disposal is not different from the rest of the world; this is due to the town's waste management approaches which are not in line with sustainable development. Sustainable development stipulates that any kind of damage to the environment must be prevented at all cost and activities which causes such damage should be limited, reduced or controlled (EMA, 2007). Despite the call for sustainable development, some local and regional authorities continue to dispose of their collected waste in an open, unfenced and unmonitored disposal sites with no proper treatment and control (Hasheela, 2009; Lindel, 2012; Mughal, 2014). Towns such as Henties Bay, Outapi, Arandis, Ongwediva, Ondangwa and Eenhana have open disposal sites, which are in some cases located just a few kilometres away from residential areas and water sources (Alsins, Sundgren, Shooya & Nashongo, 2013; Ekandjo, 2016; Hasheela, 2009). Croset (2014) established that Tsumeb town's disposal site is set on the groundwater reservoir, an act that could potentially contaminate its precious water resources. According to Haukena (2017), Oshakati disposal site is fenced off, but nearby villagers purposefully vandalised the fence to allow domestic animals to enter and feed on waste, especially card boxes (Appendix 7). Similarly, at Outapi, Ekandjo (2016) found out that the disposal site was fenced off but an unknown person removed the fence possibly for own use. It was further observed in Namibia that many town municipalities put more attention on waste collection and transportation rather than safe waste disposal and treatment (Hasheela, 2009).

Apart from waste disposal, waste treatment is another important aspect of the waste management hierarchy. It involves the application of physical, chemical, biological or thermal processes on waste to recover energy from it (Jacobsen & Kristoffersen, 2002). It aims at minimizing the volume of waste disposed of at the disposal sites and its hazardous environmental impacts. Many towns in Namibia treat their waste by either burning or covering waste with sand as a case at Oshakati, Outapi, Tsumeb and Rundu disposal sites (Lindell, 2012; Croset, 2014; Mughal, 2014, Haukena, 2017; Ekandjo, 2016). Such waste management practices could result in soil pollution which could in turn negatively affect Namibia's scarce water resources. Hasheela (2009) further described and listed three main challenges that Namibia is facing concerning solid waste management. These include lack of institutional capacity in some towns to handle some of the serious waste problems (e.g. Hazardous waste); limited capacity to handle general waste and ensure pollution control; and financial limitations. This is true as only two sanitary landfills exist in the country and the rest of the towns dump their waste in an open disposal site.

Regarding the current status of waste management in Namibia, the Minister of Environment and Tourism, Honourable Pohamba Shifeta stated that "waste management has become a pressing national issue and poses significant threats to humans and environmental health'' (MET, 2018). Also, the Ministry of Environment and Tourism recognised the urgent need to improve solid waste management in the country. In response to the urgent need, a National Solid Waste Management Strategy was developed in 2017 to ensure that future regulations, directions, funding and action plans are all geared towards improving solid waste management. During the drafting of the strategy, stakeholder's consultation workshops were heard to involve all relevant stakeholders. The strategy aimed at making Namibia a leading country in Africa concerning the standard of solid waste management by 2028.

Previous studies done in Namibia concerning heavy metal concentrations in soil, water, fish and vegetation indicated the presence of various types and concentrations of heavy metals. A study done in Gruben River found higher levels of copper, zinc and nickel in sediments, which was attributed to the Khan copper mines (Taylor & Kesterton, 2002) while in Northern Benguela, Cape monkfish (*Lophius vomerinus*) were found to contain mercury, though below the WHO limit (Erasmus, Hamutenya, Itembu, & Gamatham, 2018). Similarly, in Katima Mulilo an assessment made on pasture grass growing around the disposal site found the presence of heavy metals such as Pb, Cr, Cd, As, Ni, Co, Cu and Mn, with Mn showing the highest mean concentrations and Co the lowest. However, all metals were within the acceptable regulatory limit (Abah, Mashebe, & Onjefu, 2017). The presence of heavy metals in pasture grass was attributed to the incineration happening at Katima Mulilo disposal site. This provides evidence to conclude that open waste disposal contaminates disposal site soil, which in turn potentially pollutes soils adjacent to these sites. Okpoveta, Osakwe, Okoh, and Otuya (2010) in Nigeria and Sruti, Anju, Sunil, and Shrihari (2014) in India made a similar conclusion.

2.4 Sources of heavy metals

Human existence has been troubled by environmental pollution ever since early times and this challenge is still growing today mainly due to population progression and economic expansion (Ali et al., 2014; Hasheela, 2009). The integrity of the environment is threatened by ineffective and unsafe waste dumping (Sankoh et al., 2013). In most states in the world, the knowledge and techniques to manage MSW are often poor, which in most cases has led to detrimental damage to the environment. Over the years, soils in the disposal site have become contaminated with the accumulation of toxic heavy metals. Toxic heavy metals occur naturally in soil crust at a rarely toxic amount, less than 1000 mg/kg (Wuana & Okieimen, 2011). Due to activities performed by man, soil in both rural and urban areas are now contaminated with different heavy metals, that are above the tolerable limit in some areas (Mageswari, Iyappan, Aravind, Sameer, Vignesh & Kumar, 2017; Rajkumar, Subramani & Elango, 2010). Table 1 below summarises the main sources of eight pollutants. Information contained in this table was derived from Agency for Toxic Substances and Diseases Registry [ATSDR], 2002, 2004, 2008; Department of Environmental Affairs [DEA] RSA, 2010; Su, Jiang, & Zhang, 2014; U.S. Department of Health and Human Services [DHHS], 2005; Wuana and Okieimen, 2011.

Table 1: Sources of heavy metals

POLLUTANT	*Sources*
LEAD	Batteries, paints, cable sheeting, rolled/extruded lead (mainly sheets), ammunition, alloys, Lead compounds, Petrol additives, balance weights for vehicles, plating of gasoline tanks, solders, pottery glazes, leaded crystal glassware, cosmetics, hair dyes, jewellery, gunshot, relic fishing sinkers, tire weights, and imported children's toys, traditional or folk remedies, and candy/food packaging.
CADMIUM	Ni-Cd batteries pigments, PVC Stabilisers, plating, alloys, semi-conductor, photo-conductor in solar cells, electronic devices, steel coatings, pigments for plastics, glass, ceramics and has minor application in photography, photocopying, dyeing and printing.
MANGANESE	Manufacturing of alloys, steel and iron products, mining operation, production and use of fertilisers, fungicides, synthetic manganese oxide, dry cell batteries and organomanganese fuel additives.
ARSENIC	Mining and smelting operations, agricultural applications, lead-acid batteries, light-emitting diodes, paints, dyes, metals, pharmaceuticals, pesticides, herbicides, soaps, and semiconductors.
NICKEL	Mining and smelting, alloys including stainless steel, nickel plating, batteries, welding electrodes, manufacturing of pigments.
CHROMIUM	Leather tanning, metal plating and metal surface treatment, raw materials for synthesis, pigments, dyes for plastics, cement, textiles, paints, printing ink, cutting oils, photographic materials, detergents, wood preservatives.
ZINC	Zinc mining and smelting, galvanizing processes, alloys including brass and bronze, electrical components, paint pigments, cosmetics and in the manufacture of pharmaceuticals, dyes and insecticides.
COPPER	Smelters and refiners, electrical industry, production of metal alloys, some water pipes, penny, paints, electrical wiring, pigments and plumbing systems.

2.5 Impacts of heavy metals contamination in soils

Heavy metals are contained in waste. When waste is disposed of, these metals are transferred into the soil where they alter the physical and chemical properties of the soil (Su, Jiang, & Zhang, 2014). The soil has been a basic utility for life existence on earth and continues to be so until today. Soil characteristics and productivities are negatively influenced by heavy metal contamination. Heavy metal contamination refers to the excess accumulation of heavy metals in the soil as a result of human activities (Bansal, 2018; Su et al., 2014). It is difficult to recognise contamination by heavy metals as it is odourless and pale. Besides, its impact is only seen after a long period and its extremely difficult to remedy contaminated soils (Su et al., 2014). Dumping of waste at the disposal site has led to soil contamination in these sites. Areas adjacent to the disposal site could similarly be contaminated with heavy metals from the disposal site with the aid of water and wind (EC, 2002).

After percolating the soil, heavy metals undergo several chemical reactions ranging from quick adsorption to slow adsorption, oxidation-reduction reactions, ionic exchange reactions, and desorption (Gil, Ramos-Miras, Roca-Pérez, & Boluda, 2010). Thereafter, heavy metals get restructured into various chemical forms which will determine the nature of their bioaccumulative, bioavailability, toxicity and mobility (Ma & Rao, 1997; Su et al., 2014). The chemical reaction occurring in heavy metals influences soil properties and activities, and one such activity is microbial. Microbes, such as bacteria and fungi serve as good indicators for soil health and can be used to determine the severity of contamination (Wuana & Okieimen, 2011). Research has shown that due to heavy metal contamination, microbial number, diversity and activities have decreased considerably (Bansal, 2018; Su et al., 2014; Wuana & Okieimen, 2011). Correspondingly, Bansal and Mishra (2012) concluded from their study of estimation of microbial count that where there are excess heavy metals concentrations, microorganism's diversity decreases significantly. This decrease harms ecosystem functions as it affects decomposition and nutrient cycle in soils. Cadmium and zinc were reported to disrupt the biological balance and physiological functions of soil, while lead influences soil chemical properties and disturbs the activities of a certain bacterial family (Bansal, 2018). Besides lead, cadmium and zinc, copper was also reported to impact soil microbes, thereby disturbing soil fertility and decomposition rate (Bansal & Mishra, 2012).

In addition to microbial activity, heavy metals contamination also affects soil enzymatic activities. Enzyme activities are essential for normal functioning of soil biota, assisting in decomposition of organic matter as well as nutrient recycling. It was observed that activities of enzymes significantly reduce with increased heavy metal concentrations (Su et al., 2014). The reduction was attributed to the interaction between heavy metals and enzymes. Nonetheless, some toxic heavy metals such as zinc are useful in forming essential structural part of some enzymes (Yu & Cheng, 2015).

Heavy metal contamination also affects soil physicochemical properties. Toxic metals influence pH, available organic matter, water holding capacity, infiltration, porosity and permeability (Li et al., 2018). Ali et al. (2014) found soil quality at disposal sites in Islamabad city to be deteriorating due to high pH level, electrical conductivity, total dissolved solids (TDS) and heavy metals concentration such as lead, nickel, zinc, and chromium. Some researchers further stated that long term dumping of municipal solid waste in an open disposal site impact soil property, which further translates into the contamination of surface and groundwater as well as influence land productivity (Kirunda, 2009; Anikwe & Nwobodo, 2002).

In soil, heavy metals tend to interact with each other and with other soil properties. These interactions are highly influenced by soil physicochemical properties (Tripathi & Misra, 2012). Dawki, Dikko, Noma, and Aliu (2013) found chromium, zinc and lead to be positively correlated with cation exchange capacity, total nitrogen, phosphorus, calcium, potassium, sodium and organic carbon, but copper and nickel did not show any correlation. Similarly, Tripathi and Misra (2012) found a positive association between chromium, nickel and lead while copper associated strongly with nickel and zinc. Moreover, lead and zinc also showed a significant positive association. The associations observed between heavy metals is an indication that they originated from the same source.

Waldo Tobler’s first law of Geography state that "everything is related to everything else, but near things are more related than distant things"(Tobler, 1990). Given spatial variability of heavy metals, the fundamental law implies that high metal concentrations are expected in soil nearer to the disposal site and decreases further with increased distance. Several studies have agreed with this law such as Zabir et al. (2016) who studied spatial dissemination of some heavy metals in Bangladesh and concluded that Cr, Pb, Cu, Zn, Fe & Mn concentrations decrease with increased distance from the waste discharging canal. Similarly, Yan et al. (2013) also found metal concentrations decreasing exponentially with increased roadside distance in China. All these studies attributed the presence and concentrations of heavy metals in adjacent soils to waste dumping in the disposal sites.

On the contrary, Sakawi, Ariffin, Mastura, and Jali (2013) in their study of the analysis of heavy metals concentration per distance and depth around the vicinity of open landfill found heavy metal concentrations around the landfill site vicinity to vary with distance. The finding was attributed to viscosity, as there was less water near the landfill as opposed to more water furthest.

2.6 Heavy metals property, impacts and standard limits

Vegetation diversity is also highly influenced by soil heavy metal contamination. Even though some metals (copper, manganese, zinc and nickel) are vital to biological systems, others (cadmium, lead and arsenic) are extremely hazardous to biota (Bansal, 2018). Many studies indicated a strong correlation between disposal sites contamination and low vegetation diversity (Ali et al., 2014; Bansal, 2018; Ideriah et al., 2010; Sawyerr et al., 2017). Evidence from these studied showed that waste dumping transfers toxic metals such as lead, mercury, nickel, aluminium and zinc into the soil, which negatively impacts biodiversity. Heavy metals accumulate in the soil, from which they percolate and get absorbed by plant roots. Research has shown that urban soils are heavily accumulated with heavy metals, which could get into humans via the skin, inhalation and absorption (Sawyerr et al., 2017; Su et al., 2014). Since humans derive their food from soil, the effects of heavy metals contamination from soil to human cannot be ignored. Some authors have established that residents living nearby open disposal sites showed high cases of chronic diseases such as Tuberculosis than those living furthest (Roht et al., 1985; Sankoh et al., 2013).

Many countries in the world including international bodies (WHO and Food and Agriculture Organisation [FAO]) have set standards for the permissible limit of heavy metals in the soil, Namibia, however, has no standards concerning soil and thus uses South Africa's standards. This study has therefore referred to SA standards.

Lead: Is a soft bluish-grey metal discovered by the ancient Romans and Greeks. Lead is non-essential to plant and animal biological functions but it has been widely used due to its unique properties of resisting corrosion, low melting point and pliability (Sherene, 2010). Lead remains locked up in different chemical forms within the environment especially in soils because it does not degrade (U.S DHHS, 2005).

Humans obtain lead through dermal, inhalation and ingestion. Upon entering the body via respiratory and digestive systems, lead gets into the blood which circulates it to all body parts. From the blood, lead enters the bones where it can stay for ages. In children, lead poisoning results in infant mortality, paralysis, blindness, severe mental retardation, seizures and even death while in adults, it causes chronic neuropathy, anaemia, peripheral nerve dysfunction and elevated blood pressure (U.S DHHS), 2005). Prolonged exposure to lead affects the renal, cardiovascular, haematological, immunological and reproductive systems and causes cancer. The maximum allowable limit for lead in SA is 20 mg/kg (DEF, 2010) whereas for WHO is 100mg/kg (Chiroma, et al., 2014).

Cadmium: Is a soft, silver-white heavy metal, highly toxic even in a small dose. It is water-soluble, more mobile in soil and non-essential to plant and animal life (Sherene, 2010). Cd arises from smelters, incineration of municipal waste, nickel-cadmium batteries and iron steel production facilities which then released it into the atmosphere. It then falls back to earth on its own or comes back with rainwater. Once in the soil, it seeps into different horizons of the soil, gets in groundwater and plants, from which it enters the food chain (Pamela & Tuckey, 2008). Cadmium is therefore found in livers, kidneys, fish and vegetables as a result of food chains and food webs. Cadmium exposure is due to inhalation, dermal, ingestion and smoking as a small dose of cadmium is also found in cigarette smoking. Cadmium is bio cumulative, hence magnifies along the food chains. It targets the kidneys, bones and lungs causing bronchitis, pneumonitis, pulmonary oedema, intra-alveolar haemorrhage, thrombosis of small blood vessels, nausea, vomiting, abdominal cramps and pain as well as diarrhoea (Chindo, 2016; DHHS, 2005). The standard limit for cadmium is 7.5mg/kg in SA (DEF, 2010) and 3 mg/kg by WHO (Chiroma, et al., 2014).

Manganese: Is a brittle white grey element forming parts of the transition metals after iron and titanium. Manganese is hard but can easily react with air to form oxides. It is also one of the most occurring metals on earth, widely distributed in air, soil, rocks, sediments, water, food products and biological matters (ATSDR, 2008). Just like copper, manganese is essential to plants, animals and humans as it plays an important role in bone and connective tissue formation, lipid and carbohydrates metabolism, embryonic development, reproductive functions as well as the synthesis of cartilage mucopolysaccharides. Human exposure is possible via dermal, ingestion and inhalation (Miller, Pallan, Gangji, Lukic, & Clase, 2013). Chronic manganese poisoning could occur in mining areas and industries that process manganese ore, alloys and dry cell batteries. Acute poisoning leads to a condition known as manganism, associated with psychological and neurological symptoms (Alessio, Campagna, & Lucchini, 2007).

The permissible limit for manganese in soil by WHO is 2000 mg/kg (Chiroma et al., 2014) while South Africa set it far below that of WHO at 740 mg/kg (DEA, 2010).

***Arsenic*:** Is a grey, most abundant and toxic metalloid to humans and the environment. It exists in pure crystals or mixed with other minerals. Humans exposure is through inhaling atmospheric dust, ingestion of especially the leafy vegetables and drinking contaminated water (Patel et al., 2005). Continuous exposure to arsenic causes pulmonary diseases, diabetes mellitus, skin lesion, skin cancer, cancer of the bladder, kidney and lungs, neurological effects, hypertension and cardiovascular diseases (Smith, Lingas, & Rahman, 2000). The standard limit for arsenic in SA stands at 5.8mg/kg while WHO placed it at 20mg/kg (Kamunda et al., 2016).

***Nickel*:** Is a hard, ductile, malleable and silvery-white metal that has a slight golden shade (ATSDR, 2004). It is the second most abundant element in the earth's crust but it's usually inaccessible as it's locked up in the planets iron-nickel core. It has been used since ancient times due to its unique and special properties of magnetic shielding and corrosion-resistant. It exists in a combined form with other elements such as sulphur and arsenic (Feder et al., 1996).

Nickel is naturally present in food and water. Chocolate and fats contain very high concentrations of nickel than other food although it could also be highly concentrated in vegetables from polluted soils. Humans get exposed to nickel through inhalation, ingestion, dermal.

Nickel is essential in small quantity in humans as prebiotics, however, too large concentrations could lead to higher chances of developing cancer of the lungs, nose, larynx and prostate. It is also responsible for general sicknesses, dizziness, lung embolism, respiratory failure, asthma, chronic bronchitis, birth defects, heart disorder and allergic reactions such as skin rashes, mainly from jewellery (Grimsrud & Adersen, 2012). In South Africa, the allowable limit for Ni in the soil is 91 mg/kg while the WHO placed it at 50 mg/kg (Kamunda et al., 2016).

Chromium*:* Is a hard, brittle and silvery metal. It occurs in many forms (chromium VI & III) which are extremely colourful. Human exposure to Cr is via inhalation, ingestion and dermal. WHO reported that chromium is a carcinogen when inhaled and is responsible for lung, nasal and sinus cancer. Other human risks associated with Cr includes skin irritation, eczema, dermatitis, nasal irritation, asthma and rhinitis, nose bleeding, respiratory irritation, eye irritation and damage, perforated eardrums, kidney damage, liver damage, pulmonary congestion and oedema, epigastric pain as well as discoloration of teeth (West, 2019; Adeleken & Abegunde, 2011). The soil maximum allowable limit for Cr set by WHO is 100mg/kg while in SA it stands at 6.5 mg/kg much lower than WHO standards (Kamunda et al., 2016).

Zinc: Is a slightly brittle metal which appears blue silvery. Second, to iron, zinc is one of the most essential elements of human. It has a lot of nutritional requirement vital during antenatal and postnatal development (Hambidge & Krebs, 2007). Although zinc is vital to human health, a high quantity of zinc compounds could irritate the gastrointestinal tract, acute renal tubular necrosis and intestinal nephritis. Inhaling of zinc chloride causes pneumonitis and adult respiratory distress syndrome while inhalation of zinc oxides leads to fatigue, thirst chills, fever, cough, leucocytosis dyspnoea, metallic taste, salivation and myalgias (Barceloux & Barceloux, 1999).

Zinc enters the human body through the skin, ingestion and inhalation where different body parts behave differently to each exposure route (Plum, Rink & Haase, 2010). WHO permissible limit for zinc in the soil is quite high (300 mg/kg) compared to SA (240 mg/kg) (Kamunda et al., 2016).

***Copper**:* Is a reddish metal naturally occurring in soil, water, rocks, sediments, air, plants and animals. Just like iron and Zinc, copper is essential for human and animal health but in low concentration, as at high concentration, it can be toxic (ATSDR, 2002). It enters the environment through mining, waste dump, burning of fossil fuels as well as agriculture. Humans get exposed to copper via ingestion, inhalation and dermal.

High doses of copper irritate nose, mouth, and eyes and cause headaches, dizziness, nausea, as well as diarrhoea. Drinking water with high levels of copper than normal leads to nausea, vomiting, stomach cramps and diarrhoea (ATSDR, 2002; Georgopoulos, Wang, Georgopoulos, Yonone-Lioy, & Lioy, 2006). Acute intake of copper due to occupational exposure can be fatal as it damages the liver and kidneys and may even cause death (ATSDR, 2002). The maximum allowable limit for copper in the soil is 16 mg/kg in SA and 100mg/kg by WHO.

Several studies have been carried out in several countries to assess the impacts of waste dumping on soil (Ideriah et al., 2010; Chindo, 2016; Kamunda et al., 2016; Shi, Lou, Zhang, Xia & Cai, 2013), however in Namibia, information regarding the assessment of the spatial distribution of heavy metals in the soil adjacent to disposal sites are quite limited, therefore this study embarked upon assessing spatial variability of heavy metal concentrations in the soil adjacent to Oshakati disposal site. The result will provide baseline knowledge vital for setting up minimum standards for disposal sites establishment and soil quality monitoring control.

2.7 Study area and study site

2.7.1 Oshakati town

The study was conducted in the vicinity of Oshakati disposal site situated in Oshakati town (figure 3). Oshakati town is located at 17. 7895° S, 15. 7058° E and it serves as the regional capital of the Oshana region. The town is divided into two electoral constituencies, namely, Oshakati West and Oshakati East. It was officially founded in July 1966 with 36 541 inhabitants and 0.9 % annual growth rate (NSA, 2011). Oshakati town is known for hosting the Annual Totem Expo, which celebrates a mixture of local traditions and modern business exhibition. There are several developments observed in the town, which resulted in people migrating from elsewhere for employment opportunities, business, work, and shopping. The following are some of the noticeable developments seen in the town: Oshana Regional Study and Resource Centre, three main shopping Centres (Yetu, Game and Etango), the newly opened Dr Aupa Indongo open market, Oshakati Independence Stadium, University of Namibia Northern Campus, many primary and secondary schools as well as large commercial enterprises such as Meatco, Namibian Breweries and Coca Cola (Oshakati Town Council, 2018).

The average size of people per household is 3.85 inhabitants and every household generate approximately 0.11kg/cap/day of waste daily, whereas monthly, the amount of waste generated in Oshakati totals to 740 000 tons/month of which 50 % is recyclables (Xisi & Peuya, 2014).

Oshakati town uses contactors, hired each year to collect and transport waste to the open disposal site (Haukena, 2017). The disposal site covers an area of approximately 62 000 square kilometres and is situated in Othingo village, four kilometres west of the town centre (Bennett et al., 2017). The disposal site is surrounded by farm fields (situated less than five meters from the site boundary) where different crops mainly Mahangu are grown each year. The site is also surrounded by Oshana on the western part and partly on the northwestern side (appendix 10). Besides being an international business hub in northern Namibia, Oshakati also houses Small and Medium Enterprises (SME) which renders services such as welding, metal & woodwork, painting, electrical, mechanical and the alike to the inhabitants. Moreover, several petrol stations, garages, scrap metal shops and tailoring businesses exist in town. All these progressions contribute to the sources of heavy metals which find their ways to the disposal site.

Recycling efforts are carried out by the informal waste collectors who collect at the disposal site, although there are a few that collect at households (Haukena, 2017). Bennett et al. (2017) described Oshakati disposal site as chaotic and disorganized because there are no directions or regulations regarding where to dump waste (appendix 7 and 8).

Oshakati's climate is semi-arid, with hot summers (average day temperature could rise above 33°C) and mild winters (average night temperatures can be as low as 6°C). Rain falls mainly during summer between seasons (November – March) with an average annual precipitation of 472 mm (Oshakati Town Council, 2018). The town is surrounded by Palm trees, farmlands and settlements.

2.7.2 Othingo village

The study location was an area around Oshakati disposal site. The disposal site is located in a village called Othingo, which is situated within the boundaries of Oshakati town in Oshana region (figure 3). Othingo village is four Kilometre west of Oshakati town centre, located at S 17° 46. 561°, E 015° 40.103°

on the Global Positioning System (GPS) geographical information and approximately 1093 m above the sea level (recorded at the site on 27/02/2019). The village is headed by a headwoman and houses approximately 120 residents. The disposal site covers an area of approximately 62000 square metres (Bennett et al., 2017) is set exactly in the middle of the village.

Three sampling locations were demarcated, the first one was the disposal site vicinity and the other two were control sites (figure 3). The first control site (referred to control site 1) was an open area located about 700m away from the disposal site and it consisted of short thorn bushes and shrubs. The second control site (referred to control site 2) was an independent farm furthest (about 2 km) from the disposal site, which was a homestead where crops were grown and animal such as cattle and goats reared. The two control sites served as a comparison to contrast soil quality from the disposal site vicinity while the disposal site served as a reference site to compare metals concentration to the three-study sites. All three sites had comparable soil properties except for contamination caused by the disposal site.

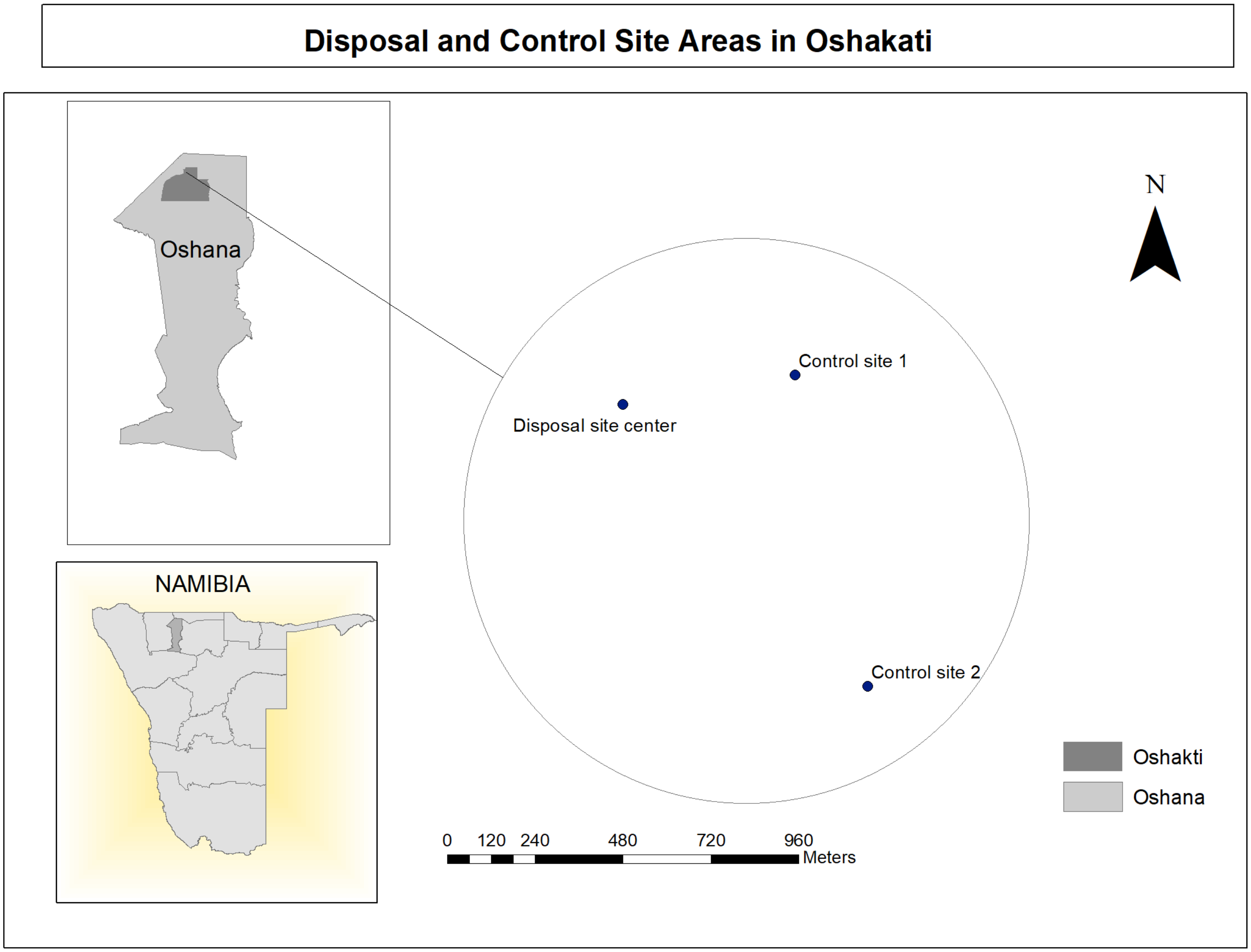


Figure 3: Map of Namibia showing Oshakati town in Oshana region. Oshakati map further indicates the three sampling locations which were disposal site vicinity, control site 1 and control site 2.

2.8 Soil sampling methods and materials

2.8.1 Scoping assessment

In August 2018, a scoping assessment was done in three disposal sites of the following towns: Oshakati, Ondangwa and Outapi. The assessment aimed at evaluating the presence and concentrations of heavy metals at these sites and to determine whether their concentrations were within the standard limit for heavy metals in soils. This was necessary for determining the heavy metals and site the study should focus on. During scoping, topsoil (30 cm) samples were collected from all three disposal sites, their vicinity and control site, using a 30 cm soil auger. From the disposal sites, five soil samples were randomly (Chiromo,

2009) collected at clear points where there were no piles of waste whilst at disposal site vicinity, 15 soil samples were collected two metres away from the site boundary. Similarly, five soil samples were taken from the control site which was situated furthest from the disposal site. Before collection surface debris was removed. After collection, soils samples were sealed in plastic bags and transported to Namibia University of Science and Technology (NUST) laboratory for heavy metal analysis using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The following 12 heavy metals were analysed for their presence and concentrations: chromium (Cr), manganese (Mn), calcium (Ca), iron (Fe), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), magnesium (Mg), lead (Pb), mercury (Hg) and arsenic (As). Based on the scoping results, Oshakati disposal site was selected as the study area with a total of eight heavy metals identified for analysis. The heavy metals were chosen on the basis that they either exceeded the standard limits for SA and WHO or they had high environmental impacts. The chosen metals were Pb, Cd, Mn, As, Ni, Cr, Zn and Cu. Oshakati disposal site was then used as a reference site in understanding spatial variability of heavy metals from the site to adjacent areas.

2.8.2 Sampling design

The study collected a total of 95 topsoil samples from the vicinity of Oshakati disposal site and two control sites using a 30 cm soil auger (Ideriah et al., 2010). A total of 56 soil samples were collected from Oshakati disposal site vicinity, 28 from control site 1 and 11 from control site 2. Surface debris was removed before sampling and the soil auger was wiped and dried before the next use. At all sampling sites, four transects were laid (figure 4) according to the cardinal direction and topsoil samples were taken at the intervals of 10 metres[m], 20m, 30m, 40m, 50m, 100m and 150m in February 2019 (adopted from Ideriah et al., 2010). At each interval, five soil samples were taken and mixed to form a representative sample. After collection, all soil samples were placed in clear polyethene bags, sealed and sent to NUST laboratory in Windhoek for acid digestion and analysis of physicochemical properties (pH, EC, texture and particle size distribution) and heavy metal concentrations (lead, cadmium, manganese, arsenic, nickel, chromium, zinc, copper).

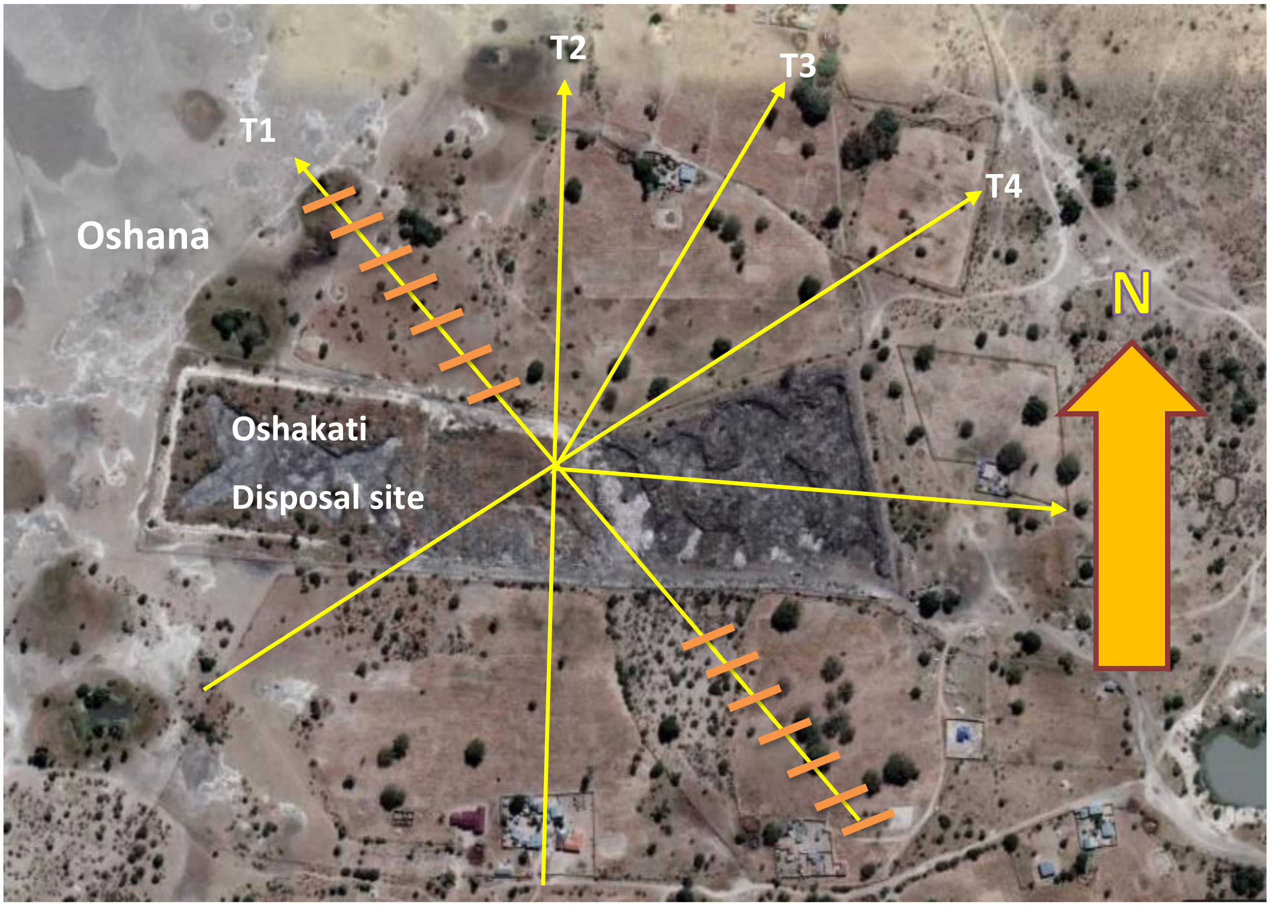


Figure 4. A diagrammatic representation of how the transects were laid during the soil sampling period. The yellow lines represent the four transects and the orange lines across the yellow lines represent the intervals of 10m, 20m, 30m, 40m, 50m, 100m and 150m where soil samples were collected.

2.9 Soil analysis

2.9.1 Soil physical analysis

Particle size analysis and soil texture

Was measured using a pipette method (Day, 1965). Firstly, soil samples were air-dried and grounded to pass a 2 mm sieve. After sieving, 20 g of each soil sample was placed in 250 ml polyethene bottle, including a blank. An amount of 20 ml dispersing agent followed by 100 ml of de-ionised water was added to the soil in the bottles. The polyethene bottles were then shaken for two separates 30-minute periods at 180 oscillations per minute. The solutions were allowed to stand overnight and then shaken again the following morning. Approximately 80 ml of water was added to the bottles, which were then allowed to stand in a vibration-free and constant temperature location. The polyethene bottles were shaken again for 30 seconds by hands and immediately placed on the flat bench. The bottles inner lid was carefully removed for sedimentation to settle. The bottles were left to stand overnight. Soil samples in the bottles were placed in three aluminium dishes each representing a soil fraction (clay, silt and sand), which were then placed in an oven and heat dried at 100 °C for 3 hours. The dishes containing clay and silt fractions were weighted after drying while sand fraction was separated by washing the content with several portions of water and allowing them to pass through a 53 µ sieve. A fine jet of water was placed over the sieve to wash silt, clay and dispersing solution off the sand for approximately 60 seconds. Finally, the clean sand was placed into weighted aluminium dish and dried at 100 °C overnight after which the sand fraction was determined. Soil textural class was then determined using the United State Department of Agriculture classification system.

Electrical conductivity

Electrical Conductivity was measured using a conductivity meter in the supernatant of the 1:2.5 soil: water suspension before measurement of pH (Bower & Wilcox, 1965). Soil samples were air-dried and ground to pass a 2mm mesh sieve. About 20 g of air-dried soil was placed in a 100 ml beaker where 50 ml of distilled water added. The solution was stirred three times for one hour. To finish off, a conductivity cell was inserted into the extract upon which electrical conductivity was determined.

2.9.2 Soil chemical analysis

Soil pH

Soil pH was measured using a pH meter in the supernatant suspension of a 1:2.5 soil: water ratio suspension (Hendershot, Lalande, & Duquette, 1993). Initially, soil samples were air-dried and grounded to pass a 2mm mesh sieve. Approximately 20 g of soil was placed in a 100 ml beaker where 50 ml de-ionised water was added and the solution was stirred for about 20 seconds three times for one hour. Lastly, an electrode was introduced into the suspension, awaiting reading to stabilise. Soil pH was then recorded to an accuracy of 0.01 unit.

Heavy metals

In the laboratory, soil samples were prepared for acid digestion method 3050B hot plate. At the beginning, soil samples were mixed to homogeneity, weighted in the range of 0.90 – 1.05 g and placed in conical flasks.

A 10m of 1:1 Nitric acid (HNO_3) was added and the sample digest was mixed slurry, covered with a watch glass and heated to 95°C for 10 -15 minutes. The digest was allowed to cool, then 5 ml of concentrated HNO_3 was added and refluxed for 5 minutes. This step was repeated for 2 hours to allow the solution to evaporate to 5 ml. After cooling, 2 ml of water and 3 ml of 30% Hydrogen peroxide (H_2O_2) were added to the sample digest. The sample digest was further heated and 1 ml of H_2O_2 aliquots was added until the effervescence subsidised and volume reduced to 5 ml. The vessels were allowed to cool again and after cooling, 10 ml of concentrated Hydrochloric acid (HCL) was added. The conical flasks were covered, placed on a hot plate at 95°C to allow reflux for 15 minutes. Finally, the digestate was filtered through a Whatman No. 41 paper, collected in a 100 ml volumetric flask and refrigerated at 5°C. The ICP-OES analysis followed the next day.

2.10 Statistical analysis

All data were entered in Statistical Package for the Social Sciences (SPSS) IBM SPSS statistics version 26 were all statistical analysis was done. Means and standard deviation were computed to understand the descriptive statistics of soil physicochemical properties and heavy metals concentration in all study sites, whereas the multivariate analysis of variance (MANOVA) was used to test for statistical significance in mean metal levels in all study sites and distance. Furthermore, Tukey Post Hoc test was performed to determine significant differences in mean metal values at all sites. Pearson's correlation coefficient test and regression were calculated to assess the spatial variability of heavy metals concentration from the disposal site to adjacent areas. Tables and graphs were further generated to present results. All tests used a statistical significance value of $\alpha = 0.05$.

2.11 Limitations

The study was faced with some limitations. Initially, the study intended to collect over 300 soil samples, including soil profiles in both dry and wet seasons, but due to ICP-OES malfunction that took over 6 months to be fixed (as repair was to be done by an international technician); the study could only analyse few samples (95) in the wet season. Another hindrance was the lack of technical support personnel in the laboratory to supervise the researcher during analysis, as analysis could only be done in the presence of a trained personnel. This has also led to the 135 soil samples collected not to be all analysed.

Chapter 3: Results

3.1 Results overview

A total of 95 topsoil samples from a depth of 30 cm were collected from Oshakati disposal site vicinity and two control sites (control site 1 and control site 2). At each site, four transects were laid and soil samples were collected at intervals of 10m, 20m, 30m, 40m, 50m, 100m, and 150m along the transects. Soil sampling was done in February 2019. Results are presented below.

3.2 Soil physicochemical properties

Table 2 presents the descriptive statistics of soil samples taken from the disposal site vicinity and two control sites. Soil pH in the disposal site vicinity ranged from a minimum of 6.2 to a maximum of 6.9 with a mean value of 6.7, which indicated a slightly acidic soil. Results from control site 1 showed pH ranging from a minimum of 5.4 to a maximum of 6.0 with a mean value of 5.7, demonstrating a moderately acidic soil. Whereas at control site 2, pH ranged from a minimum of 6.1 to a maximum of 6.8 with a mean value of 6.4 specifying a slightly acidic soil. Statistically, there was no significant difference in pH observed in all three study sites.

Electrical conductivity shown in Table 2, shows very high mean values (71.1 µS/cm) at the disposal site vicinity and low at both control sites, where it measured mean value of 62.5 µS/cm at control site 1 and 51.0 µS/cm at control site 2. There was no significant difference in electrical conductivity in all sites.
Regarding particle size distribution calculated by mode, all three sites were predominated by sand fraction ranging from as low as 92.2% recorded at control site1 to 93.4% at control site 2. As a result, the textural class in all three sites was determined as sand. The sand loamy texture was however observed along some transects at the disposal vicinity and control site 2 (Appendix 3). Furthermore, control site 2 had a higher sand fraction and low silt and clay portions compared to the other sites.

Table 2: Descriptive statistics of physicochemical parameters (pH, EC and texture) of topsoil (30 cm) samples taken from the disposal site vicinity and two control sites within a distance of 0 to 150 metres.

Distance (m)	**Physicochemical parameters**	**Statistical Measure**	**Sites**		
	Variable	**Variable**	**Disposal vicinity**	**Control site 1**	**Control site 2**
0 - 150	**pH** (n = 95)	Mean	6.7	5.7	6.4
		SD	0.5	0.2	0.3
		P-value	0.2	0.8	0.2
0 - 150	**EC** (µS/cm) (n = 95)	Mean	71.1	62.5	51.0
		SD	18.0	20.0	17.5
		P-value	0.6	0.2	0.3
0 - 150	**Texture** (n = 95)	Sand %	93.0±2.2	92.2±1.3	93.4±4.1
		Silt %	3.4±1.6	3.4±0.9	3.3±3.9
		Clay %	3.6±0.7	4.3±0.7	3.4±0.8
		Modal texture	Sand	Sand	Sand

Statistical significance (*P<0.05*)

3.3 Heavy metals occurrence and concentration

The results revealed that heavy metals were present in varying concentrations within the disposal site vicinity and both control sites. Of the eight heavy metals studied, only cadmium was not detected within the disposal site vicinity, all other metals (chromium, manganese, nickel, copper, zinc, arsenic and lead) were found in all three study sites as shown in Table 3.

Results of soil samples collected from the disposal site vicinity indicated that manganese recorded the highest mean concentration of 13.687 mg/kg while arsenic recorded the lowest of 0.003 mg/kg. The remaining heavy metals recorded the following in descending order: Zn > Cr > Pb > Cu > Ni (Table 3).

Results from control site 1 also indicated that manganese recorded the highest mean value of 23.011 mg/kg while arsenic was the least with 0.016 mg/kg. All other metals were in descending order: Zn > Cr > Cu > Ni > Pb > Cd (Table 3). Comparable to the disposal site vicinity and control site 1, the results from control site 2 also showed that manganese recorded the highest mean value (25.096 mg/kg) and arsenic the lowest (0.012mg/kg). The remaining heavy metal values were Zn > Cr > Ni > Cu > Pb > Cd (Table 3).

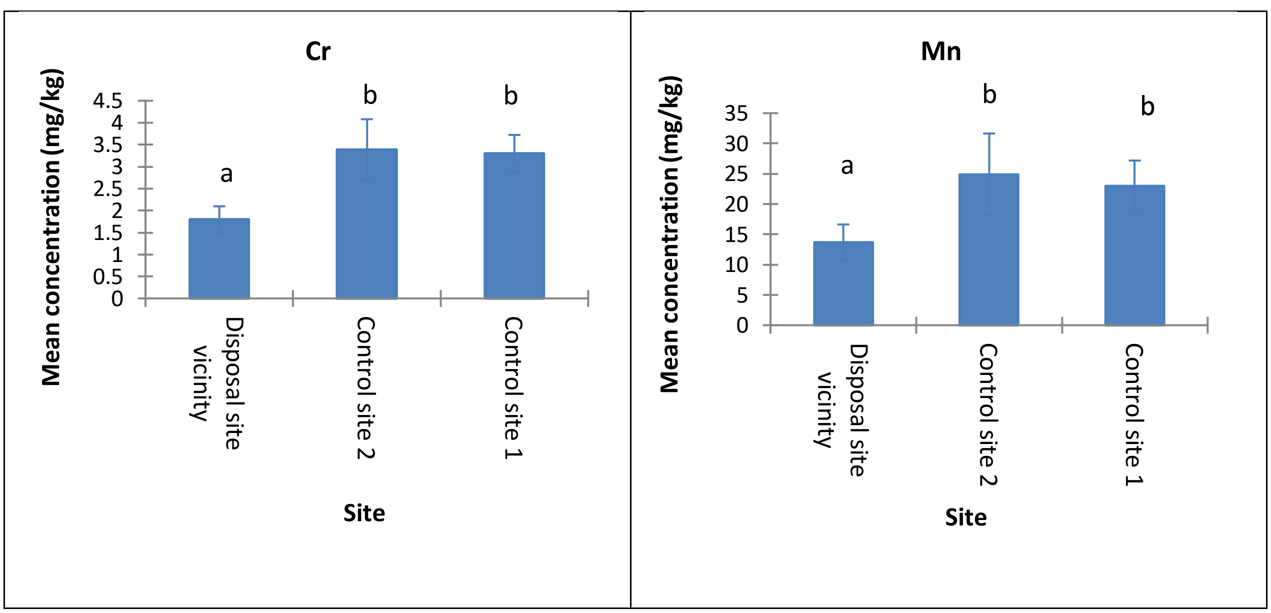
Table 3: Comparison of mean heavy metal concentration (mg/kg) in top soil (30 cm) from the disposal site vicinity (n = 56), control site 1 (n = 28) and control site 2 (n = 11) (mean ± SD)

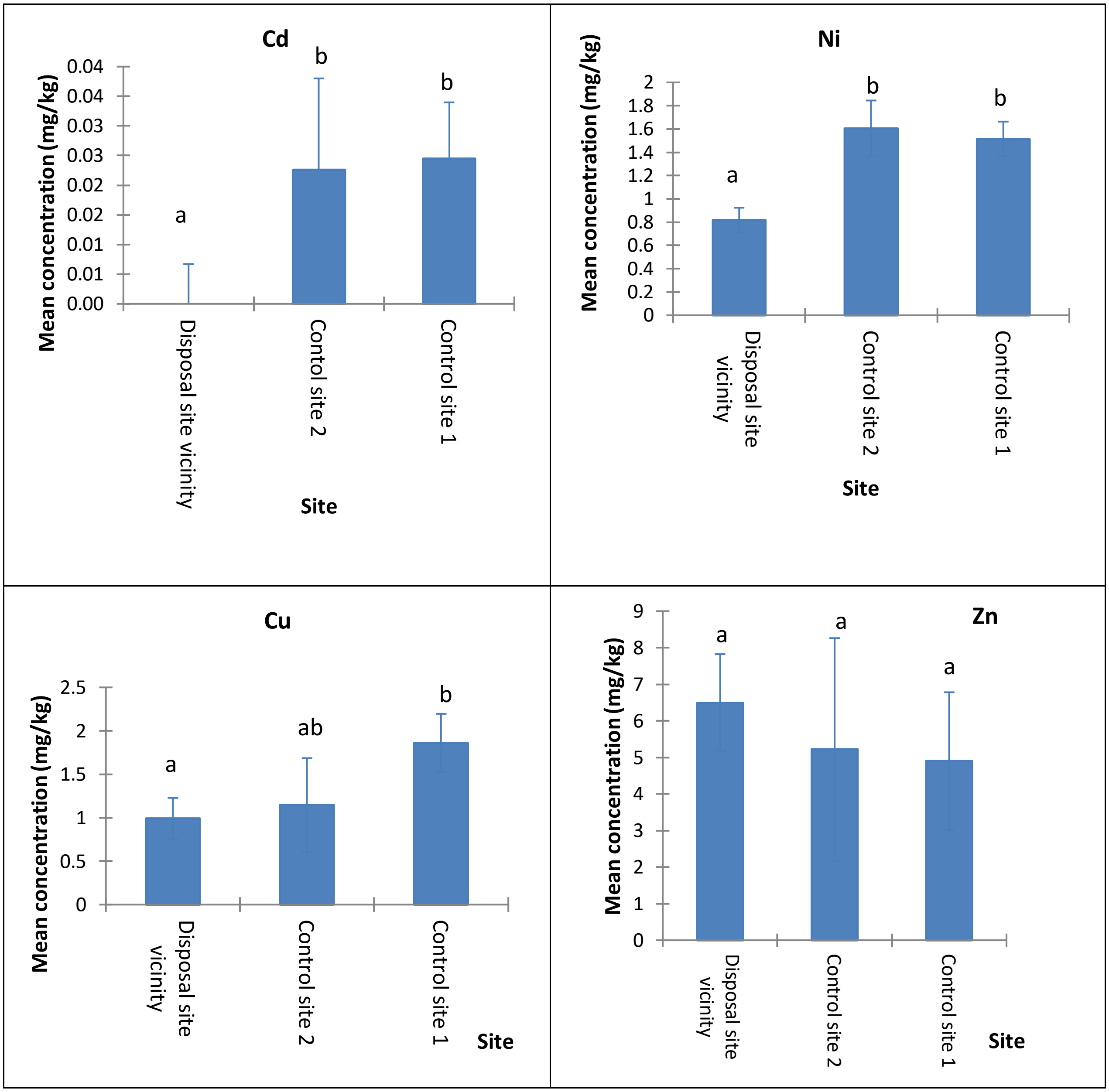
Site	Chromium	Manganese	Cadmium	Nickel	Copper	Zinc	Arsenic	Lead
Disposal vicinity	1.795 ± 1.281^{a}	13.687 ± 10.199^{a}	-	0.818 ± 0.386^{a}	0.991 ± 0.931^{a}	6.491 ± 6.285^{a}	0.003 ± 0.014^{a}	1.391 ± 2.202^{a}
Control site 1	3.294 ± 0.868^{b}	23.011 ± 9.837^{b}	0.024 ± 0.030^{b}	1.514 ± 0.407^{b}	1.860 ± 0.938^{b}	4.899 ± 2.493^{a}	0.016 ± 0.061^{a}	0.539 ± 0.339^{a}
Control site 2	3.382 ± 0.860^{b}	25.096 ± 15.930^{b}	0.023 ± 0.061^{b}	1.620 ± 0.372^{b}	$1.170 \pm 0.434a^{ab}$	5.489 ± 1.487^{a}	0.012 ± 0.041^{a}	0.803 ± 0.285^{a}

Superscripts indicate a significant difference in means at 5% level of significance (α=0.05).

A MANOVA was used to compare heavy metal concentrations between the disposal site vicinity and both control sites. The multivariate result was significant between all three study sites, Pillai's Trace = .845, F = 6.35, df = (16.000), p = .000. A Tukey Post Hoc test was further performed to ascertain for particular significance differences in heavy metal values from all study sites.

The test result (figure 5) showed a significant difference in mean heavy metal concentrations between the disposal site vicinity and both control sites, and no significant difference in heavy metals concentration between the disposal site vicinity and distance. To determine the exact differences in means metal concentration from the three study sites, a Tukey Post Hoc test was performed. Results in figure 5 showed a statistically significant difference in mean concentrations of chromium ($p = 0.0001$), manganese ($p = 0.002$), cadmium ($p = 0.0001$) and nickel ($p = 0.0001$) between the disposal site vicinity and both control sites and no significant difference in mean values of zinc, arsenic and lead. However, it was noted that copper was statistically significant at disposal site vicinity and control site 1 but insignificant between disposal site vicinity and control site 2.
Moreover, there was no significant difference observed in all mean metal concentrations at both control sites ($p > 0.05$). Importantly, it was observed that besides zinc and lead, mean metal values of other heavy metals were significantly high at both control sites than at disposal site vicinity.




Cd
Mean concentration (mg/kg)
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
a
b
b
Disposal site vicinity
Contol site 2
Control site 1
Site
Ni
Mean concentration (mg/kg)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
a
b
b
Disposal site vicinity
Control site 2
Control site 1
Site
Cu
Mean concentration (mg/kg)
2.5
2
1.5
1
0.5
0
a
ab
b
Disposal site vicinity
Control site 2
Control site 1
Site
Zn
Mean concentration (mg/kg)
9
8
7
6
5
4
3
2
1
0
a
a
a
Disposal site vicinity
Control site 2
Control site 1
Site

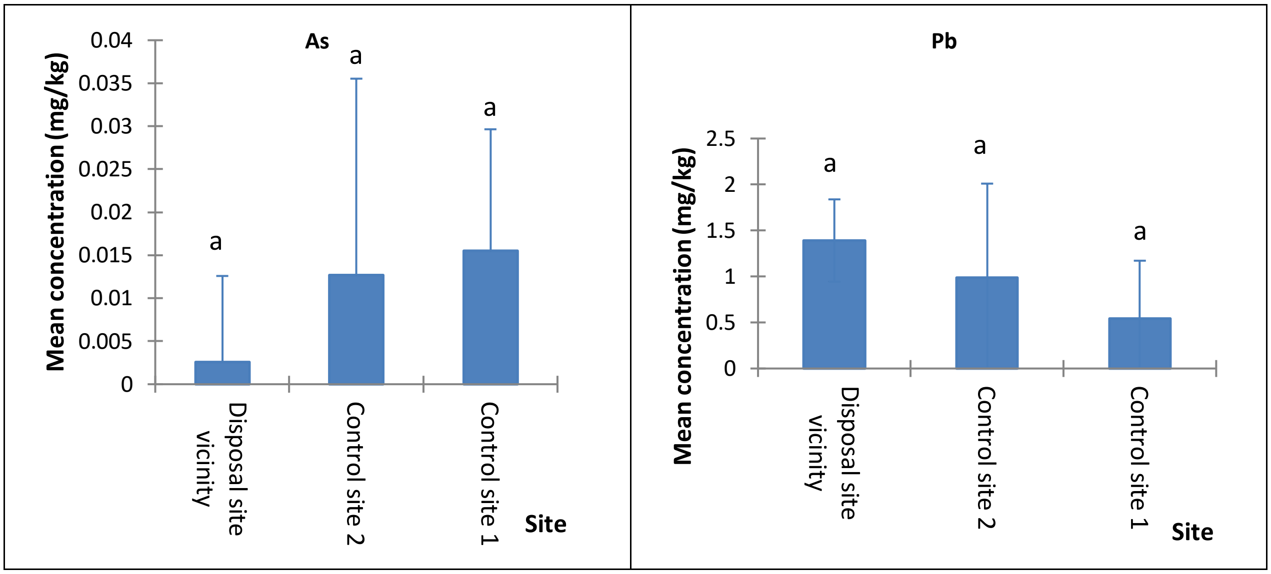


Figure 5: Variations of mean heavy metal concentrations of topsoil samples taken at a depth of 30 cm from the disposal site vicinity and control sites (n = 95).

Superscripts indicate a significant difference in means at 5% level of significance (α=0.05).

Oshakati disposal site was used as a reference site in this study to compare the heavy metal values to the three study sites (disposal site vicinity, control site 1 and control site 2). The scoping results from the disposal site showed high mean concentrations of all heavy metals (except cadmium which was not detected) as compared to all study sites (disposal site vicinity, control site 1 and control site 2) indicated in table 4.

Table 4: A comparison of the mean heavy metal concentration of topsoil samples at 30 cm from the three-study sites and disposal site. The results for the disposal site were obtained in August 2018 from Oshakati during scoping assessment (mean ± Sd).

Site	Chromium	Manganese	Cadmium	Nickel	Copper	Zinc	Arsenic	Lead
Disposal site vicinity (n = 56)	1.795±1.281[a]	13.687±10.199[a]	-	0.818±0.386[a]	0.991±0.931[a]	6.491±6.285[a]	0.003±0.014[a]	1.391±2.202[a]
Control site 1 (n = 28)	3.294±0.868[b]	23.011±9.837[b]	0.024±0.030[a]	1.514±0.407[b]	1.860±0.938[b]	4.899±2.493[a]	0.016±0.061[a]	0.539±0.339[a]
Control site 2 (n = 11)	3.382±0.860[b]	25.096±15.930[b]	0.023±0.061[a]	1.620±0.372[b]	1.170±0.434[ab]	5.489±1.487[a]	0.012±0.041[a]	0.803±0.285[a]
Disposal site (n = 5)	98.400±79.529	165.600±122.052	-	275.060±260.492	56.800±48.561	211.60±118.6690	14.000±6.164	31.200±31.689

3.4 Comparison of soil test results to the standard limits of heavy metals in soil

To ensure healthy environments and protect diverse ecosystems, the mean heavy metal concentrations obtained from the three study sites were compared to the recommended standard limits of heavy metals in soils by WHO and SA, as Namibia has no limits of its own. Table 5 shows that all metals studied in all the three sites (disposal site vicinity, control site 1 and control site 2) were below the tolerable limits recommended by WHO and SA.

Table 5: A comparison of mean heavy metal concentration (mg/kg) in topsoil samples (30 cm) from the disposal site vicinity, control site 1 and control site 2 to the standard limits set by SA and WHO (mean ±SD).

Site	Chromium	Manganese	Cadmium	Nickel	Copper	Zinc	Arsenic	Lead
Disposal vicinity (n = 56)	1.795±1.281	13.687±10.199	0.000±0.000	0.818±0.386	0.991±0.931	6.491±6.285	0.003±0.014	1.391±2.202
Control 1 (n = 28)	3.294±0.868	23.011±9.837	0.024±0.030	1.514±0.407	1.860±0.938	4.899±2.493	0.016±0.061	0.539±0.339
Control 2 (n = 11)	3.382±0.860	25.096±15.930	0.023±0.061	1.620±0.372	1.170±0.434a	5.489±1.487	0.012±0.041	0.803±0.285
SA guidelines	**6.5**	**740**	**7.5**	**91**	**16**	**240**	**5.8**	**20**
WHO guidelines	**100**	**2000**	**3**	**50**	**100**	**300**	**20**	**100**

However, the scoping results of topsoil samples taken from the disposal site disclosed that chromium, nickel, copper, arsenic and lead were many times above the tolerable limits for SA than other metals (Mn, Cd and Zn), and below WHO standard limits (Table 6). Furthermore, nickel was extremely far above both SA and WHO standard limits for heavy metals in soil.

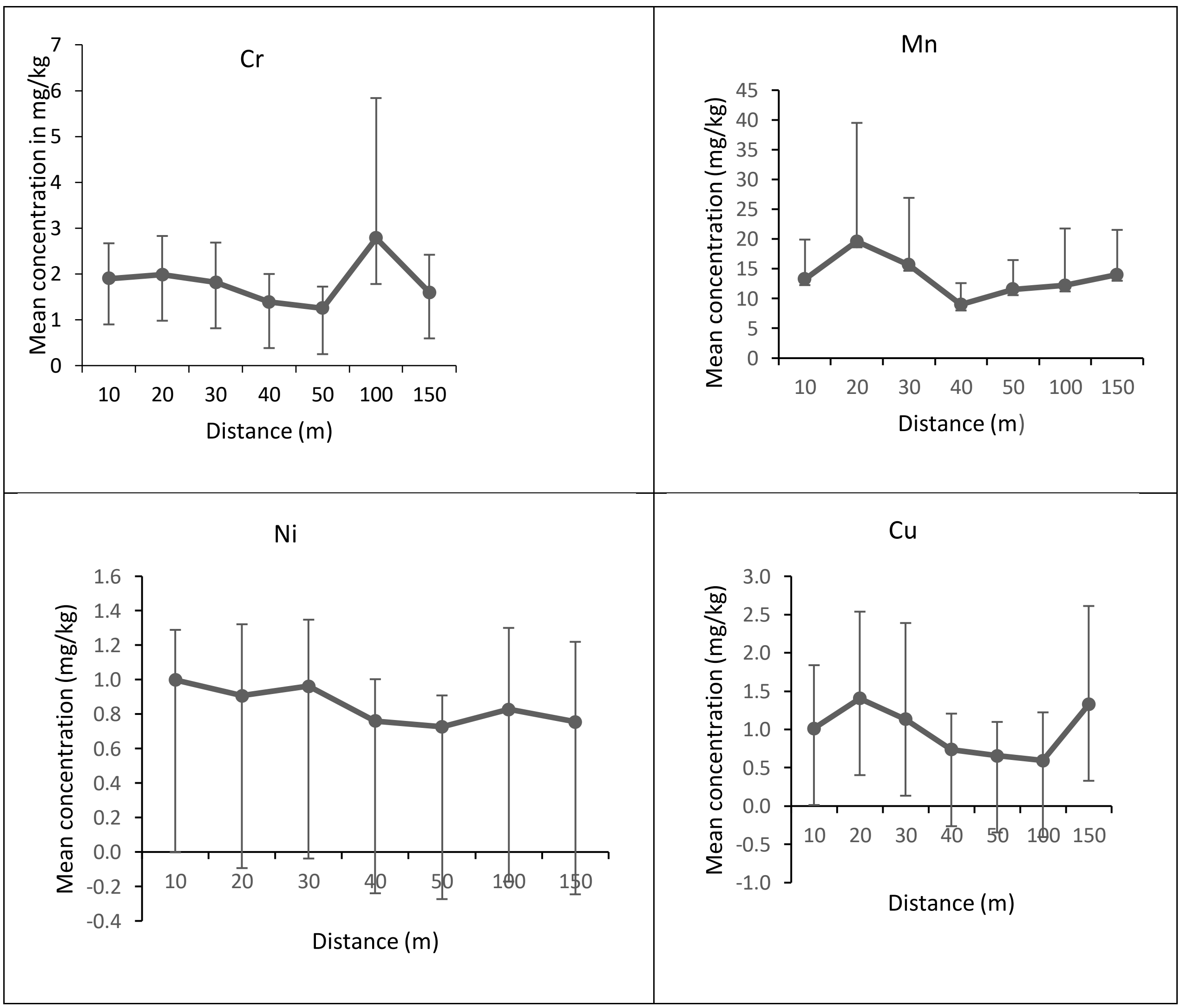
Table 6: A comparison of mean concentrations (mg/kg) of heavy metals in topsoil (30 cm) from the disposal site during scoping compared to SA and WHO guidelines for heavy metals in soil. The metals indicated in **bold** were above the standard limits for SA and only Ni was found above limits for both SA and WHO.

Site	Cr	Mn	Cd	Ni	Cu	Zn	As	Pb
Disposal site	**98.400**	165.600	nd	**275.060**	**56.800**	211.600	**14.000**	**31.200**
WHO guidelines	100	2000	3	50	100	300	20	100
SA guidelines	6.5	740	7.5	91	16	240	5.8	20

Nd = Not detected

3.5 Spatial variability of heavy metals

The study investigated the spatial distribution of heavy metals from the disposal site to its vicinity. This was necessary to understand whether metals do disperse from the disposal site to nearby areas. Figure 6 shows the spatial variability of mean metals values from the disposal site vicinity to its vicinity, from a distance from 10m to 150m. As shown in figure 6, it was only zinc that showed slight trends between the distance of 20m and 100m, where the mean value was high from the distance of 20m and decreases toward 100m away from the disposal site. From 100m, zinc means value increased slightly, but still lower than at 20m. All other metals did not show a consistent pattern, they fluctuated between distances.



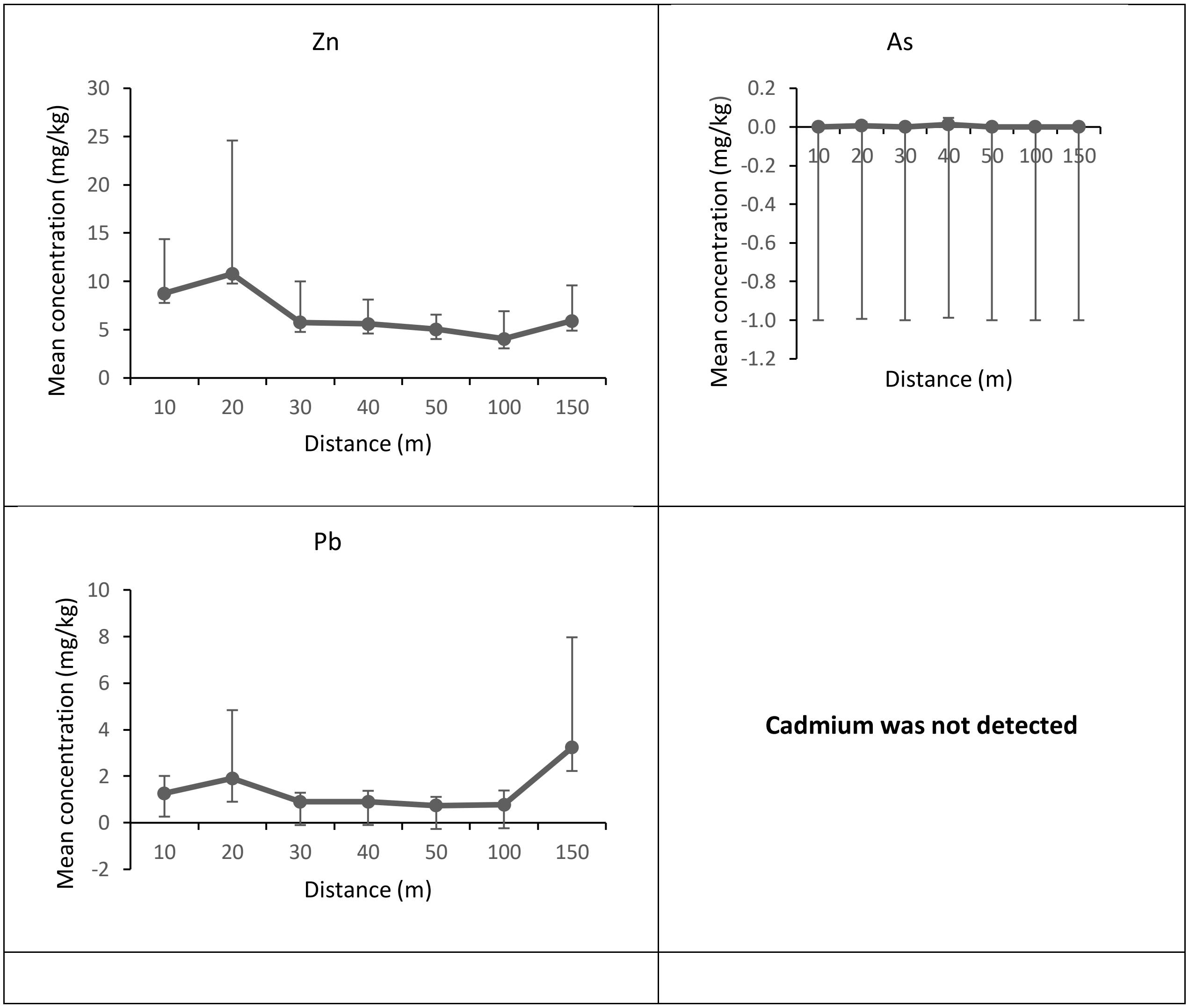
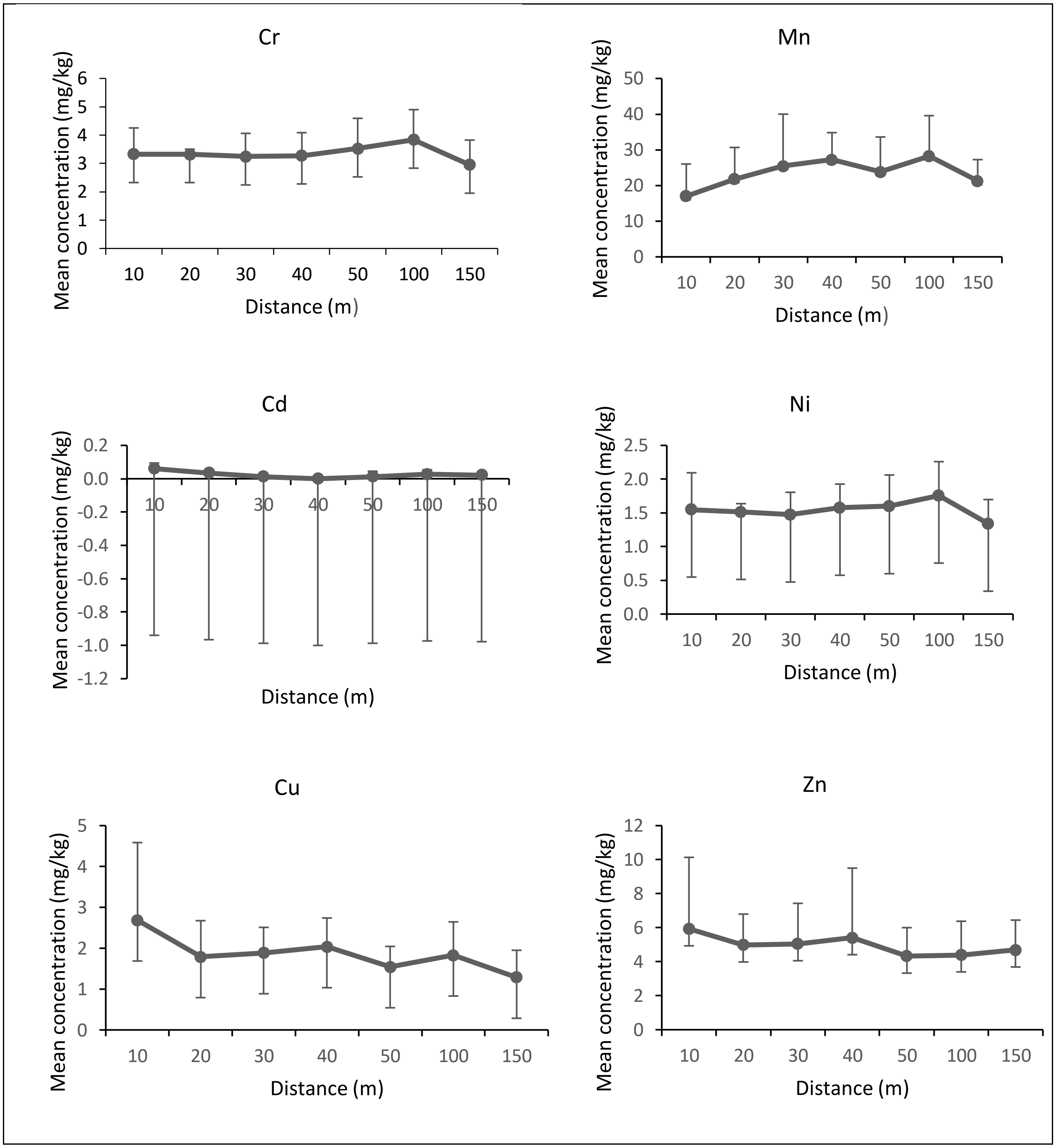


Figure 6: Variation of mean metal concentration in topsoil samples taken at the depth of 30cm from the vicinity of the disposal site at varying distances (n= 56)

At control site 1 (figure 7) heavy metal concentrations showed a similar fluctuating trend to the vicinity of the disposal site. Cadmium and arsenic values were very low as they were only detected at few distances along the transects.


Cr
Mean concentration (mg/kg)
Distance (m)
Mn
Mean concentration (mg/kg)
Distance (m)
Cd
Mean concentration (mg/kg)
Distance (m)
Ni
Mean concentration (mg/kg)
Distance (m)
Cu
Mean concentration (mg/kg)
Distance (m)
Zn
Mean concentration (mg/kg)
Distance (m)

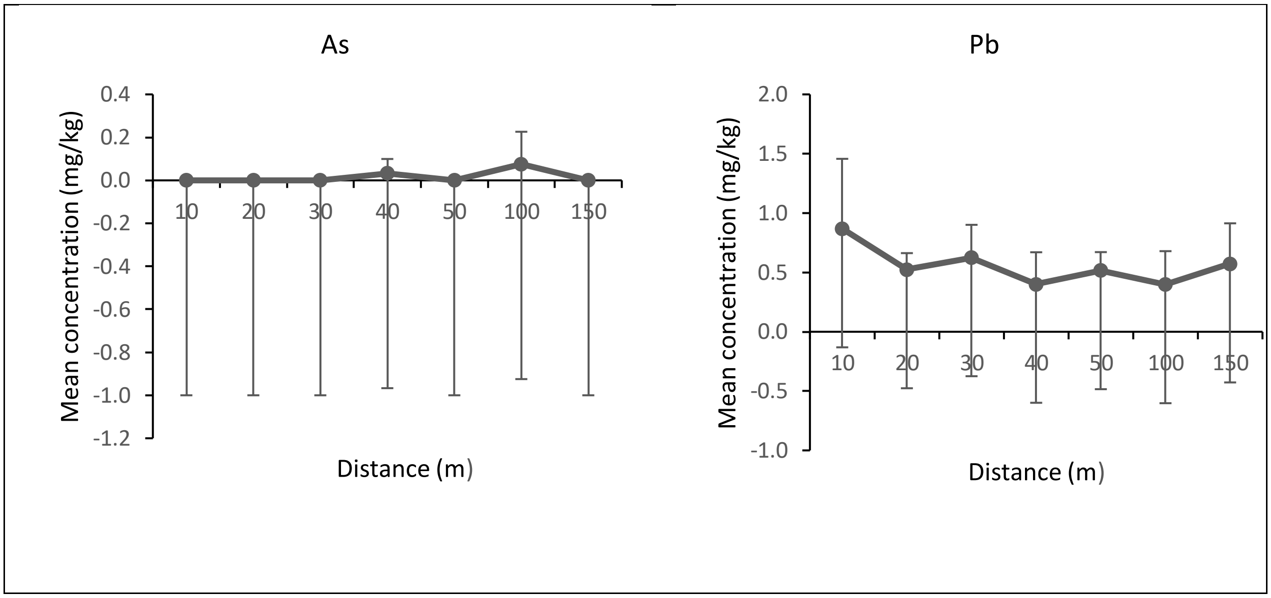
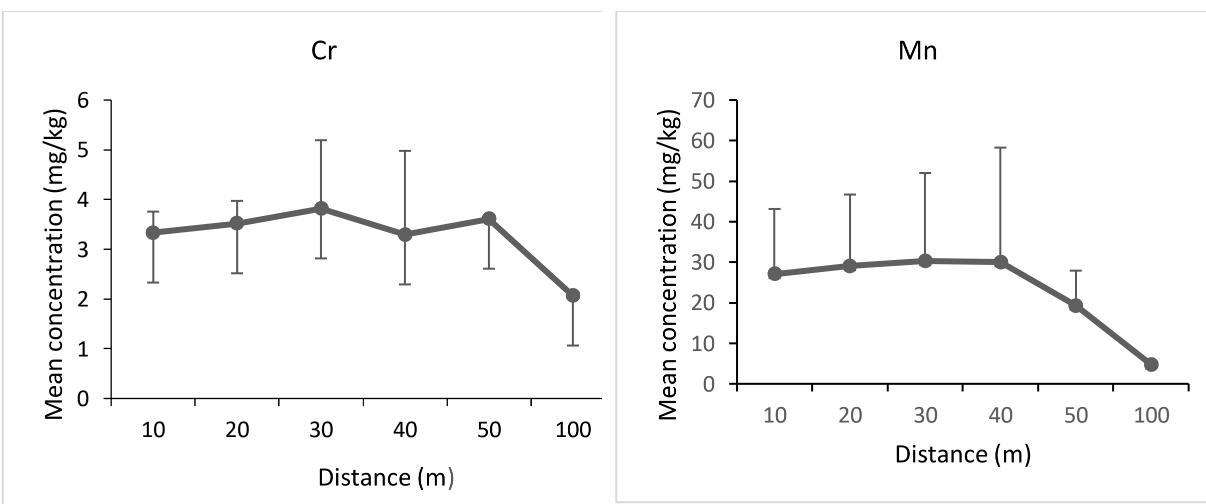


Figure 7: Variation of mean metal concentration in topsoil samples taken at the depth of 30cm from control site 1 at varying distances (n= 28)

At control site 2, it was only arsenic and cadmium that recorded very low mean values and also showed no trends with distance (figure 8). All other metals indicated a slight association between mean metals concentration and distance. As distance increases, mean metal values of Cr, Mn, Cu, Zn and Pb decreased.



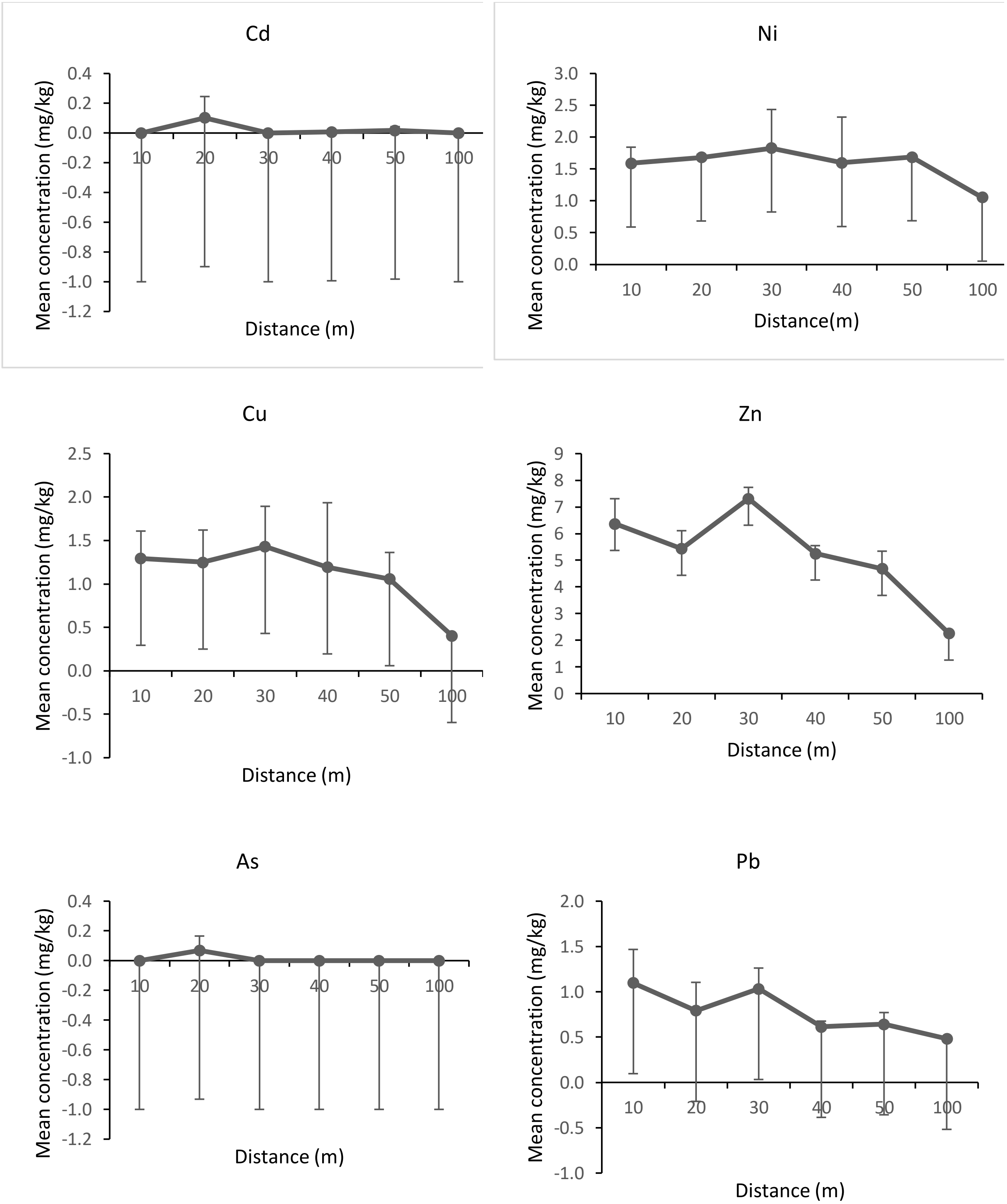
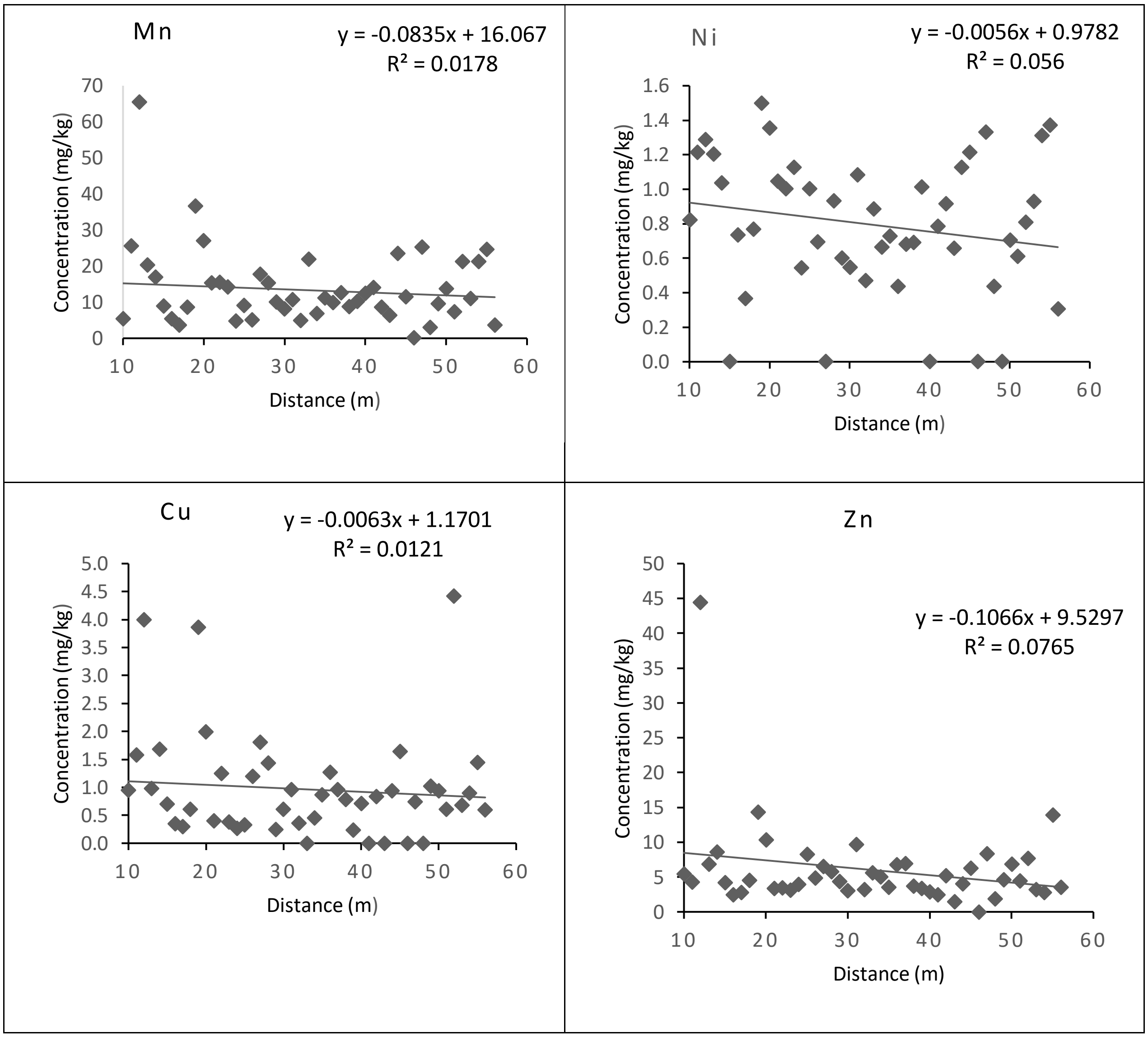


Figure 8: Variation of mean metal concentration in topsoil samples taken at the depth of 30cm from the control site 2 at varying distances (n= 11).

To ascertain for significance in the association, a Pearson product-moment correlation was computed to determine the relationship between heavy metal concentrations at various distances. Results from the disposal vicinity shown in figure 9 showed that there was no significant linear relationship observed between distance away from the disposal site and metal concentrations. Arsenic traces were recorded only at some distances while cadmium was not detected at all in the vicinity of the disposal site.



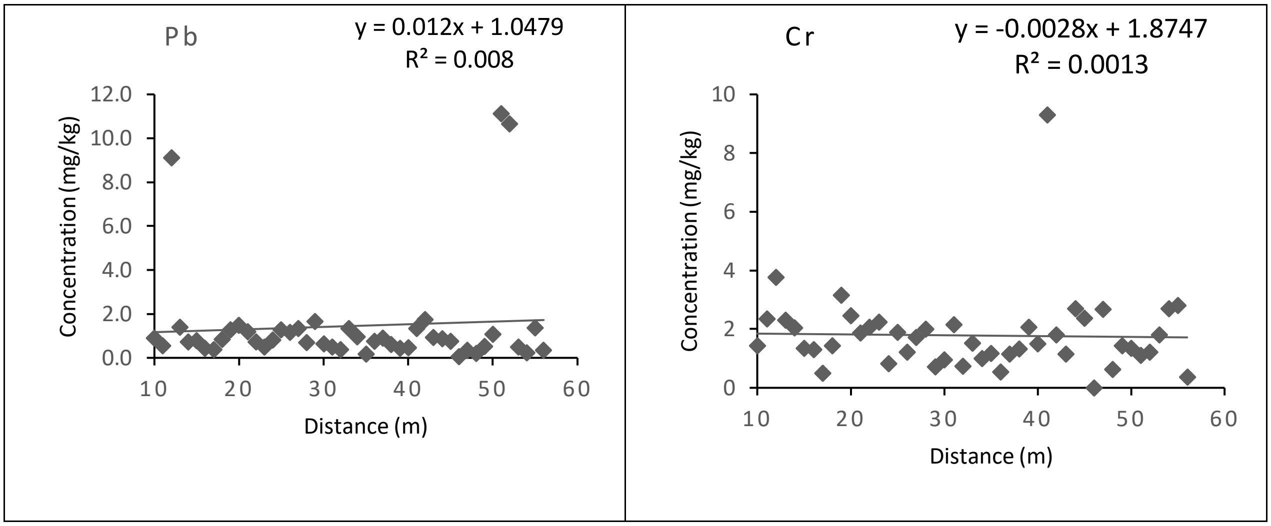
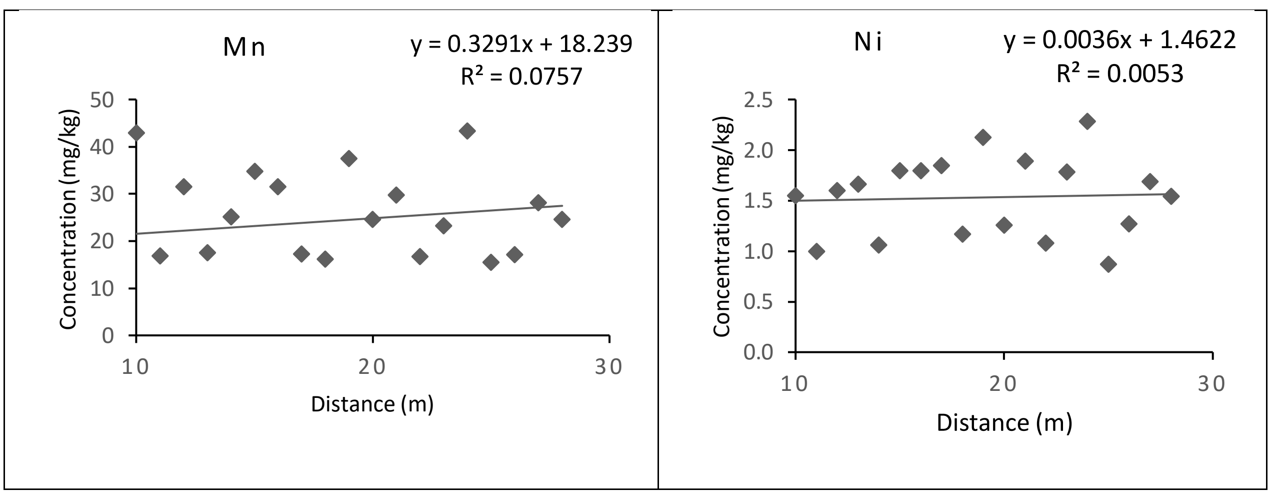


Figure 9: Results from disposal site vicinity showing a correlation in metal concentration with distance.

Results from control site 1 in figure 10 showed a similar trend to the vicinity of the disposal site. There was no association of metal concentrations with distance. Similarly, arsenic and cadmium traces were observed at some distances along the sampling transects.



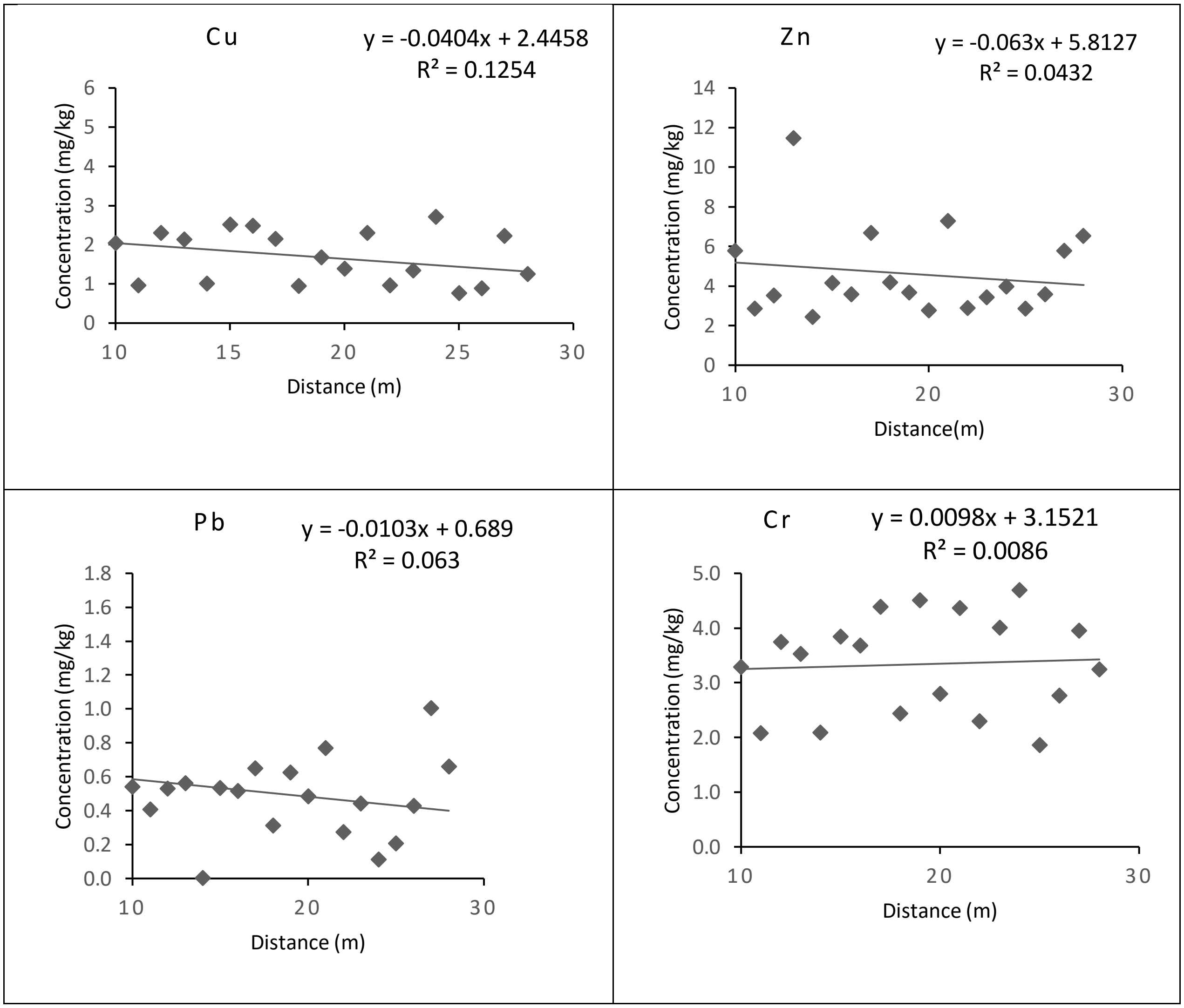


Figure 10: Results from control site 1 indicating a correlation between metal concentration and distance.

On the contrary, results for control site 2 in figure 11 were different from those of disposal site vicinity and control site 1. It was only Ni and Cr where no significant correlation was observed. Copper, zinc and manganese showed a very weak negative correlation with distance while lead showed a weak negative association with distance.

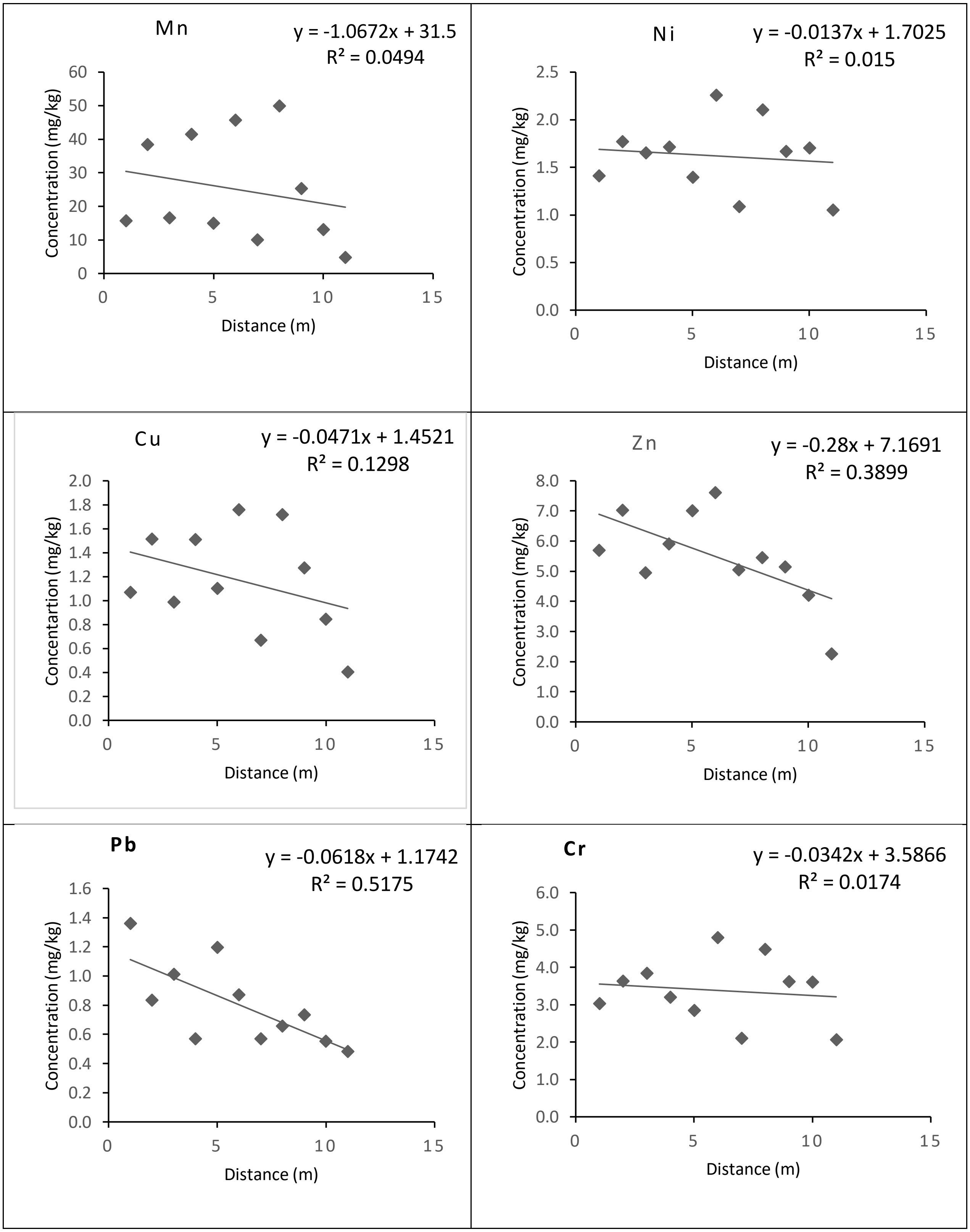


Figure 11: Results from control site 2 indicating how metal concentration correlated at various distances along the sampling transects.

3.6 Metals interaction at various distances

A Pearson's correlation matrix was calculated to understand how heavy metals interact with each other at various distances at the disposal site vicinity and both control sites. Results in table 7 indicated that it was only at 100m distance were significant linear relationship existed in mean metal concentration and distance, which were statistically significant ($p < 0.05$). There were no linear associations observed at 10m, 20m, 30m, 40m, 50m, and 150m distance. The results indicated that manganese positively correlated strongly with nickel, copper and arsenic ($r = 0.9046$, $r = 0.8283$, $r = 0.6563$, $p > 0.05$) while nickel values correlated strongly with those of manganese, copper, zinc and arsenic ($r = 0.9046$, $r = 0.8686$, $r = 0.6015$, $r = 0.5704$, $p = 0.05$). Moreover, copper strongly correlated with Mn, Ni, Zn and As ($r = 0.8283$, $r = 0.8989$, $r = 0.5874$, $r = 0.6067$) while arsenic associated strongly with Mn, Ni and Cu ($r = 0.6563$, $r = 0.5704$, $r = 0.6067$) as indicated in table 7.

Table 7: Pearson's correlation matrix showing group association in metal concentrations at a distance of 100m.

Variables	Cr	Mn	Cd	Ni	Cu	Zn	As	Pb
Cr	**1**	0.4904	0.0760	0.4372	0.2504	0.1989	0.2241	0.3405
Mn	0.4904	**1**	0.1597	**0.9046**	**0.8283**	0.5517	**0.6563**	-0.1576
Cd	0.0760	0.1597	**1**	0.2734	0.1379	-0.1070	-0.1194	-0.2302
Ni	0.4372	**0.9046**	0.2734	**1**	**0.8989**	**0.6015**	**0.5704**	-0.0892
Cu	0.2504	**0.8283**	0.1379	**0.8989**	**1**	**0.5874**	**0.6067**	-0.1365
Zn	0.1989	0.5517	-0.1070	**0.6015**	**0.5874**	**1**	0.0171	0.2092
As	0.2241	**0.6563**	-0.1194	**0.5704**	**0.6067**	0.0171	**1**	-0.3197
Pb	0.3405	-0.1576	-0.2302	-0.0892	-0.1365	0.2092	-0.3197	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Chapter 4: Discussion

4.1 Soil Physicochemical parameters

One of the properties that affect concentration, dispersion and solubility of nutrients including heavy metals in soil is pH. Soil pH is influenced by several factors including among other parent materials, soil organisms, temperature, rainfall, land use and its management (United States Department of Agriculture [USDA], n.d.). The very slightly acidic pH detected at the disposal site vicinity could be attributed to land use factors and sorption process. Different kinds of waste from various sources get dumped at the disposal site and change in temperature could affect the weathering and sorption of heavy metals which could greatly influence pH (Chindo, 2016). Ideriah et al. (2010) reported that metals are greatly bioavailable at high pH and low at low pH, this was true for this study as low mean metal values were detected in soil at disposal site vicinity. Similarly, Chindo (2016) further indicated that slightly acidic pH was suitable for crops as most nutrients are soluble thus available to crops. The disposal site vicinity comprises of crop farms where various crops mainly mahangu, maize, beans and groundnuts are grown each year, this could pose a great danger to humans as at this low pH, crops would absorb high concentrations of toxic heavy metals via their root hair cells from contaminated soil. The pH results obtained in this study were similar to the findings of other researchers such as Ideriah et al. (2010), Pillai et al. (2014) and Chindo (2016), however, this comparison is quite delicate as context are completely different in terms of waste types, sources, level of development in an area and population size.

According to other studies, the recommended pH suitable for disposal site soils should not be strongly acidic nor alkaline (Weiss, 1974; Bonarius, 1975, as cited in Ogbonna, Igbenijie & Isirimah, 2007). This thus implies that the mean pH value obtained in this study was suitable for disposal site soil.
At both control sites, pH ranged between slightly to moderately acidic values possibly due to land use activities taking place at these sites.

Electrical conductivity determines and measures the salinity of the soil, high EC recorded at disposal site vicinity could be attributed to high soluble salts which may have leached from the disposal site as the two are close. Amongst the waste dumped at the disposal site are deposits containing acids such as waste from garage scraps and batteries from various sources. During rainfall, these acids containing waste could be washed into nearby areas influencing soil pH there (Chindo, 2016).

Soil texture plays a vital role in soil management as it determines water holding capacity, aeration and drainage. The study wanted to understand whether the Oshakati disposal site was sitting on a suitable soil for landfill. Results obtained from the disposal site classified soil as sandy possibly due to lack of humus formation as topsoil was constantly cleared to make space for new waste (Ideriah et al., 2010). Many researchers have done assessment studies on the subject of suitable soil texture for disposal sites (Fijalkowski, Kacprzak, Grobelak, & Placek, 2012; Nwosu & Pepple, 2016; Sherene, 2010). Fijalkowski et al. (2012) indicated that soil with high sand fraction disadvantage disposal site as it has a poor holding capacity, great porosity thus encourages quick penetration and seepage of heavy metals to underground resources resulting in water contamination. This was contrary to the reference made by Uba et al (2008, as cited in Chindo, 2016) who found sandy soil to be good for the disposal site. Other researchers found clay soil to be the best for sitting disposal sites, as it is impermeable to water and chemicals as well as compacting fairly well (Indian University Northwest [IUN], n.d; Nwosu & Pepple, 2016). Correspondingly Sherene (2010) found clay soil to be good at retaining metals compared to sandy soil as Pb was found in high concentration in fine-textured soil compared to course textured one. In support of Sherene (2010), Wisomski, Stepniewski, and Musz-Pomorska (2018) also found clay substrate to be the best liner for disposal and landfill sites. On the contrary, Loughry (1974, as cited in Chindo, 2016) recommended loamy soil to be the best due to its properties of great permeability. Nevertheless, Ogbonna et al. (2007) indicated that a good soil texture for waste dumps are those possessing more than 40% sand fraction and less than 31% clay fraction, as less sand has low filtration rate while less clay discourages surface flooding. High permeability soils have advantages and disadvantages depending on-site location, judging from all these deliberations, the sandy soil recorded at Oshakati disposal site may not be a good soil for this site. High permeability would mean heavy metals will penetrate and accumulate in soil within and adjacent to the site. Since the site is surrounded by farmlands and Oshana, these metals could disperse into soil, water and vegetation which could lead to environmental pollution and health risks (Su et al., 2014).

4.2 Metal presence, concentration and comparison to the standard limits

The topic of heavy metal occurrence, concentration and dispersion has received great attention from researchers all over the world in recent years. Many studies conducted at disposal sites and disposal site adjoining areas in various countries revealed that heavy metals were indeed present at these sites in varying concentrations (Adelekan & Alawode, 2011; Ali et al., 2014; Amadi, 2011; Ideriah et al., 2010;

Opaluwa et al., 2012; Pillai et al., 2014). The outcome of this study also found similar results. Cadmium was the only heavy metal not detected in the vicinity of the disposal site, all other metals (chromium, manganese, nickel, copper, zinc, arsenic and lead) were present in varying amount. The scoping assessment results also indicated that cadmium was the only heavy metal not detected in the disposal site, all others were present. The absence of cadmium in the vicinity of the disposal site may imply that waste disposed of does not contain enough concentration to be detected or it may mean that cadmium may have escaped into atmospheric air and dust, as dumped waste is treated by burning. This was supported by Wuana and Okieimen (2011) who indicated that cadmium usually reaches the disposal site incombustible form which is why it is mostly found in fly ash and atmospheric particulates. This may explain the reason for the lack of cadmium in Oshakati disposal site. Studies done by Abah et al. (2017); Tripathi and Misra (2012) also did not find cadmium in soils adjacent to disposal sites.

The occurrence of heavy metals in the disposal site vicinity was not surprising as it was in close range to the disposal site. Heavy metals may have slowly dispersed from the disposal site into these nearby areas through water and wind or it may be due to natural occurrence. Waste that reaches Oshakati disposal site is not segregated except for a few IWC who sort out recyclables for selling (Haukena, 2017). Furthermore, all waste collected from Oshakati town irrespective of the source whether household, hospital, garage, metal scraps, industries, agriculture, electronics are all disposed at the site with no proper treatment except burning. Thus, this practice could justify the occurrence of heavy metals in the disposal site vicinity. Opaluwa et al. (2012) and Abah et al. (2017) also found heavy metals in areas adjoining disposal sites. Besides the translocation from the disposal site, the occurrence of heavy metals in disposal site vicinity may also be attributed the activities taking place in these areas such as applications of fertilisers, pesticides and illegal waste dumping. It was observed that waste generated in these areas is not disposed in the disposal site but within the farm fields.

At control site 1 and control site 2, all eight heavy metals: cadmium, chromium, manganese, nickel, copper, zinc, arsenic and lead were all detected. This may be attributed to activities taking place in those areas and not due to the disposal site.

Generally, there were low metal concentrations at the disposal site vicinity compared to both control sites except for zinc and lead, as result showed a significant difference in Cr, Mn, Cd and Ni at disposal site vicinity versus both control sites. This difference indicated that heavy metals may have originated from different sources (Salah, Turki, and & Mahal, 2015). The low metal values recorded at disposal site vicinity showed that the disposal site has less impact on soil adjacent to the site as there was slow dispersion of these metals from the disposal site to surrounding areas. This was supported by Srivastava et al. (2017) who argued that metals have low mobility in soil.

The results may also be influenced by sampling season as sampling was done in the wet season, it could be that metals have seeped underground away from the topsoil. The high concentration of lead in the disposal site vicinity compared to control sites could be due to the application of pesticides and atmospheric deposit from the disposal site and Okahao road that is close by. While a high concentration of zinc may be linked to agricultural activities occurring in these farms.

Furthermore, manganese recorded the highest mean value in disposal site vicinity compared to other metals. This may be due to natural occurrence, as manganese is one of the most abundant metals in the earth crust. It may also be originating from the application of fertilisers which is a common practice in these farmlands or it may be seeping from industrial waste dumped at the site. Kabata-Pendias (2010) attributed the high levels of manganese to soils that are rich in organic matter or iron as well as soils from semiarid to arid regions. This may be true for this study as Namibia is an arid country.

Opaluwa et al. (2012); Abah et al. (2017) & Papaioannou, Kalavrouziotis, Koukoulakis, and Papadopoulos (2015) also found high levels of manganese in soils adjacent to disposal sites and control sites.

The insignificant differences observed in heavy metal concentrations between control site 1 and 2 suggested that these sites have common sources of anthropogenic input. Both control sites formed boundaries with Oshana channels on one side. Oshana gets flooded with water from Angola during rainy seasons and this could bring contaminated water to these sites during flooding seasons. Another reason for high metals values may be attributed to the history of these sites particularly land-use factors.

Cadmium was detected at both control sites but not at the disposal site vicinity, this implies that the presence of cadmium at control sites was not linked to the disposal site but other anthropogenic factors. However, an interview held with one of the villagers revealed that control site 1 chosen for this study was indeed a secret military base where the SA army used to keep their military weapons and ammunition. The villager further indicated that there were still weapons buried at the site and it was not safe for sampling. Therefore, based on the interview, the presence of cadmium at control site 1 could be linked to this as the literature indicates that cadmium coating has been widely used in air and military industries to protect against corrosion (Jovanovic, Jankovic Radovanovic, & Duric, 2018).

There was no significant difference in copper value from the disposal site vicinity and control site 2. This may be attributed to that these areas shared similar features. They were both farmlands with homesteads who disposed their households waste within the farmland, creating patch point of contamination. An interview held with one of the farm owners indicated that households waste is not disposed at the disposal site but within the farmland. Heaps of waste were observed across the farmland which has resulted in illegal dumping. This has further provided answers to the patch occurrence of arsenic at some distances along some transects but not in the entire control site areas.

The high concentrations of heavy metals in both control sites reflected soil contamination caused by different anthropogenic sources other than the disposal site. Duressa and Lata (2015) made a similar conclusion in their study of the determination of Levels of As, Cd, Cr, Hg and Pb in Soils. Therefore, continuous monitoring is required to prevent further soil pollution and other environmental impacts.

Metals occur naturally in the soil layers, usually at low bearable quantities (Ideriah et al., 2010), however as a result of anthropogenic activities, these low amounts have in recent years increased beyond tolerable limits. Metals such as cadmium and lead are not normally found on the upper layer of the soil, their occurrence in topsoil is due to the external intervention (Al-Turki & Helal, 2004). In this study, lead was detected in all three study sites in topsoil at 30cm. Furthermore, results from an earlier scoping done at the disposal site recorded a high mean value of lead, which was about two times above the permissible limits for SA. These high concentrations could be attributed to the leaded waste that is dumped at the disposal site such as batteries, paints, alloys, petroleum-related waste and vehicles that enter the site to dispose of waste. Therefore, an area in such proximity to the disposal site may equally become polluted with pollutants originating from decomposition, leaching and incineration happening in the disposal site. The high level of lead found in this study was supported by Adelekan and Abegynde (2011), Adelekan and Alawode (2011), Amadi (2011), Duressa and Leta (2015) as well as Neto, Crapez, McAlister and Vilela (2005) in their studies.

Lead and other heavy metals accumulate in the soil, affecting its activities such as microbial, enzymatic and phytochemical properties. Plants would absorb these potentially toxic heavy metals from contaminated soil, which will bioaccumulate in animal and human food chains (Adelekan & Alawode, 2011). Lead plays no biological role in human bodies instead it is extremely toxic to humans. Since the disposal site is close to the crop farms, toxic heavy metals could leach into these farm plants, get absorbed via roots and enter the food chain as well as food webs and subsequently into humans, resulting in healthy implications of the villagers (Adeleken & Abegunde, 2011; DHHS, 2005; Georgopoulos et al., 2006; Patel et al., 2005; West, 2019). Moreover, heavy metals are non-biodegradable and persistent, once present in the environment, they keep magnifying along the food chains affecting many organisms in the food webs (Duressa & Letta, 2015).

In addition to lead, the presence of Cr, Cu, As, Ni, Mn, and Zn at the disposal vicinity cannot be overlooked. The fact that these metals are present, with time they would accumulate in the soil. The accumulation could be worsened by continuous dumping of waste containing these heavy metals such as paints, printing inks, electronics, pigments, lead-acid batteries and stainless-steel. This raises a need for improvement in waste management strategies as once heavy metals are present in an ecosystem, they become persistent, bioaccumulative and non-biodegradable (ATSDR, 2004). Immediate intervention to heavy metals occurrence needs to be addressed accordingly to prevent soil pollution in the long run.

Importantly, the present levels of heavy metal obtained in this study from the disposal vicinity and both control sites were all below the standard limits for soil set by SA and WHO. Abah et al. (2017) in their study of assessment of heavy metals pollution status of the pasture grass around Katima Mulilo Municipal Solid Wastes Dumpsite, Namibia also found heavy metal values below standard limits. Correspondingly, Tripathi and Misra (2012) made a similar conclusion in their study of physicochemical properties and heavy metals in contaminated soils of municipal waste dumpsites at Allahabad, India. Although the levels are low and do not constitute hazard at the moment, worries are that with time, toxic heavy metals will continue to accumulate in soil due to continuous and open waste dumping. Heavy metals accumulation will negatively affect soil physicochemical properties, microbial activities, enzyme activities and fertility (Tipathi & Misra, 2012).

4.3 Spatial variability of heavy metals

Waldo Tobler's first law of Geography states that near things are more related than distant things (Tobler, 1990). According to Tobler's law, heavy metal concentrations were projected to be high few metres away from the disposal site vicinity and gradually decreases with increased distance.

The results of this study did not support Tobler's law of Geography, as Pearson's correlation showed no correlation in mean metals values with distance away from the site. The lack of associated may be attributed to land-use factors. One major activity taking place in these areas is ploughing of farm fields, the ridges, curves and dents made by plough could explain the fluctuation tendencies observed. Moreover, the application of fertiliser was done in an old manner, where farmers placed heaps of fertilisers far apart from each other around the farmland that was not evenly spread. In addition, households waste was observed disposed of in these farmlands. These heaps created patch point of contamination as they were also unevenly disposed of. Another factor that could have influenced the spatial distribution of heavy metals from the disposal site could be the slope. The slope tends to influence leaching and runoff (Nabulo, Oryem-Origa, & Diamond, 2006). The finding of this study was similar to other researchers such as Zhang et al. (2012) who found no exponential association in the metal distribution in farmlands as a result of agricultural activities happening as well as metals resources in these farmlands, and Abah et al. (2017) who found low mean metal concentrations (below standard limit) in pasture grass growing near Katima Mulilo municipal waste dump, which he attributed to the incineration and emission from the waste dumpsite. The results of Nabulo et al. (2006); Zehetner, Rosenfellner, Mentler, and Gerzabek (2009); Opaluwa et al. (2012) contradict the outcome of this study, as they found metals concentration decreasing with increasing distance due to leaching and runoff from the disposal site.

In addition to Tobler's law, expectations were that high metal values would be found in the vicinity of the disposal site as compared to control site 2 (both shared similar land use activities). This was because, during incineration, runoff and infiltration, heavy metals could translocate to nearby areas thereby contaminating soils there. However, the results of this study revealed the contrary. Chromium, manganese, nickel and arsenic were comparatively high in control site 2 than disposal site vicinity. These variations point out that these high metal levels were not due to the disposal site but other factors performed in these farmlands such as application of fertiliser and insecticides, livestock dips, proximity to roads, types of waste disposed and types of activities done amongst other (Sherene, 2010).

Another factor that could explain these high metal values at control site 2 could be attributed to illegal dumping of domestic waste as waste is dumped within the farm field. It may also be related to seasonal flooding which might bring in contaminated water from elsewhere as control site 2 form borders with Oshana on the northern side (appendix 11).

4.4 Metals interaction at various distances

Metals tend to interact with each other in soils. The correlation matrix in this study revealed that Mn positively correlated strongly with Ni and Cu while Ni correlated well with Mn, Cu and As. On the other hand, chromium, cadmium and lead did not correlate with any metals. The positive correlations observed may be attributed to soil physicochemical properties as Rieuwerts, Thornton, Farago, and Ashmore (1998) indicated that pH, electrical conductivity, water holding capacity, bulk density, organic matter content, texture and cation exchange capacity influence heavy metal interaction. On the other hand, Tripathi and

Misra (2012) indicated that metal interaction specifies that heavy metals were coming from the same source. The lack of correlation for Cr, Cd and Pb may be influenced by high pH recorded in this study. Rieuwerts et al. (1998) discovered that metal adsorption is significant for Pb at pH 3 – 5 and Cd between pH 3 – 6.5.

Other researchers such as Dauwea, Janssensa, Bervoetsb, Blustb, and Eens, (2004); Luo and Rimmer (1995); Tripathi and Misra (2012) also found a strong correlation between copper, nickel, and zinc. However, Tripathi and Misra (2012) further found lead correlating with other metals such as nickel and chromium, which was not the case in this study.

Chapter 5: Conclusion and recommendations

5.1 Conclusion

The study aimed at investigating spatial variability of eight heavy metal (Pb, Cd, Mn, As, Ni, Cr, Zn & Cu) concentrations in soils adjacent to Oshakati solid waste disposal site in Namibia. The outcome revealed that heavy metals were indeed present at Oshakati disposal site vicinity and both control sites at levels below the standard limits for heavy metals in soil established by SA and WHO. However, cadmium was not detected in the disposal site vicinity.

The study further concluded that low metal concentrations existed at disposal site vicinity compared to control sites. All study sites were predominated by manganese and arsenic the least.

Another outcome ascended from this study was that the distance from the disposal site did not influence the spatial variability of heavy metals. Moreover, only at 100m distance were positive associations were observed between Mn, As, Ni, Zn and Cu. Chromium, cadmium and lead did not interact with other metals. The detection of heavy metals in the disposal site vicinity although in low amounts cannot be ignored as the site boundary is less the two metres away from the farm fields. Continuous dumping of waste in the disposal site will continue to spread contaminants to these nearby farm soil. Contaminants will accumulate in these soils and disturb the soil properties. Contaminated soil poses a threat to organisms inhabiting these soils.

5.2 Recommendations

The outcome of this study has led to the following recommendations:

To researchers

1. There is a need to asses other risks related to disposal sites such as groundwater contamination and potential health hazards emerging from direct exposure of nearby villagers and IWC.
2. To fully understand spatial variability of heavy metals to nearby areas, soil profile study and terrain analysis in both wet and dry seasons are essential.

To local authorities

1. There is a need to develop and implement a monitoring system of heavy metals in soil, water and vegetation especially in areas adjacent to disposal sites.
2. Community members should be sensitised regarding waste separation at source.
3. Relocation of the disposal site to safer grounds to prevent further dispersion of heavy metals not only to nearby soils but to Oshana water channels.

To regulators

1. Namibia has no standard limits for heavy metals in soils; therefore, the study recommends that the line ministry urgently consider working on standards.
2. Develop a periodic soil quality monitoring system that will be used by all local authorities in ensuring healthy environments.

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Appendices

Appendix 1 Raw data showing heavy metal concentrations from disposal site vicinity

Sample Id	Cr (mg/kg)	RSD	Mn (mg/kg)	RSD	Cd (mg/kg)	RSD	Ni (mg/kg)	RSD	Cu (mg/kg)	RSD	Zn (mg/kg)	RSD	As (mg/kg)	RSD	Pb (mg/kg)	RSD
DT1 @10 osh	0.973	4.6%	9.52	1.9%	nd		0.815	2.4%	nd		7.18	1.1%	nd		1.79	5.6%
DT1 @20 osh	1.28	4.8%	9.17	1.9%	nd		0.961	10.4%	0.961	1.7%	9.78	0.4%	nd		1.32	2.9%
DT1 @30 osh	0.502	3.8%	3.56	3.2%	nd		0.366	13.8%	0.306	1.0%	2.78	0.7%	nd		0.363	3.0%
DT1 @40 osh	1.89	2.2%	9.02	2.2%	nd		1.00	13.3%	0.334	5.0%	8.29	0.6%	nd		1.29	6.6%
DT1 @50 osh	1.51	6.0%	21.9	2.6%	nd		0.883	7.0%	nd		5.67	2.3%	nd		1.34	1.4%
DT1 @100 OSH	9.30	2.2%	14.0	1.2%	nd		0.785	2.9%	nd		2.48	3.2%	nd		1.35	8.0%
DT1 @150 OSH	1.43	4.5%	9.50	0.4%	nd		nd		1.03	2.2%	4.61	1.6%	nd		0.516	1.6%
DT1 @10 MA	2.55	2.8%	8.06	3.0%	nd		1.18	2.0%	0.582	1.2%	5.25	1.0%	nd		0.669	1.0%
DT1 @20 MA	1.43	6.2%	5.38	1.0%	nd		0.820	12.4%	0.956	2.1%	5.48	1.1%	nd		0.901	6.0%
DT1 @30 MA	1.43	5.5%	8.62	2.7%	nd		0.765	10.9%	0.609	3.9%	4.58	1.2%	nd		0.843	2.1%
DT1 @40 MA	1.22	3.1%	5.00	3.5%	nd		0.694	5.3%	1.20	1.0%	4.87	0.6%	0.090	35.5%	1.148	5.5%
DT1 @50 MA	0.994	4.2%	6.71	0.5%	nd		0.662	5.5%	0.461	4.0%	5.05	0.3%	nd		0.958	6.0%
DT1 @100 MA	1.81	1.0%	8.48	0.5%	nd		0.913	37.9%	0.840	3.2%	5.26	1.2%	nd		1.75	2.1%
DT1 @150 MA	1.34	3.4%	13.7	1.8%	nd		0.705	5.5%	0.943	0.7%	6.85	1.9%	nd		1.09	2.1%
DT2 @10 MAHA	1.52	1.7%	9.98	1.4%	nd		0.785	10.7%	1.66	0.7%	5.63	1.5%	nd		0.341	2.6%
DT2 @20 MAHA	2.34	4.0%	25.5	0.6%	nd		1.21	3.5%	1.58	0.6%	4.30	0.9%	nd		0.542	2.3%
DT2 @30 MAHA	3.15	3.1%	36.6	1.7%	nd		1.50	0.7%	3.87	0.9%	14.3	0.7%	nd		1.28	26.1%
DT2 @40 MAHA	1.71	2.8%	17.8	2.2%	nd		nd		1.81	1.1%	6.52	1.0%	nd		1.34	14.2%
DT2 @50 MAHA	1.17	3.0%	11.2	1.0%	nd		0.726	24.1%	0.871	0.6%	3.54	0.8%	nd		0.172	2.2%
DT2 @100 MAHA	1.15	5.6%	6.32	0.9%	nd		0.657	6.9%	nd		1.50	0.9%	nd		0.927	2.6%
DT2 @150 MAHA	1.10	4.5%	7.27	0.5%	nd		0.611	3.0%	0.612	1.1%	4.45	0.6%	nd		11.1	1.3%
DT2 @10 MASHA	2.64	2.2%	19.9	1.1%	nd		1.30	3.4%	1.72	1.3%	12.0	0.9%	nd		1.39	16.6%
DT2 @20 MASHA	3.76	0.6%	65.4	0.6%	nd		1.29	2.3%	4.00	1.2%	44.5	0.3%	0.055	18.9%	9.12	3.2%
DT2 @30 MASHA	2.45	3.9%	26.9	1.3%	nd		1.35	6.4%	1.99	2.7%	10.4	0.5%	nd		1.49	2.6%
DT2 @40 MASHA	2.00	4.6%	15.3	2.0%	nd		0.931	24.4%	1.44	1.2%	5.76	0.7%	nd		0.708	6.6%
DT2 @50 MASHA	0.54	8.4%	9.89	1.2%	nd		0.434	5.8%	1.27	0.8%	6.83	0.3%	nd		0.741	3.6%
DT2 @100 MASHA	2.69	2.8%	23.5	1.1%	nd		1.12	7.4%	0.937	3.3%	4.08	1.4%	nd		0.882	9.9%
DT2 @150 MASHA	1.21	1.0%	21.3	1.5%	nd		0.808	7.1%	4.43	0.8%	7.71	1.7%	nd		10.6	1.8%
DT3 @10 OP	0.852	3.6%	17.7	0.9%	nd		0.569	4.5%	0.786	3.1%	8.79	0.3%	nd		0.978	8.6%
DT3 @20 OP	2.30	5.0%	20.3	1.2%	nd		1.20	31.3%	0.981	2.1%	6.85	1.0%	nd		1.40	1.9%
DT3 @30 OP	1.86	4.1%	15.3	3.2%	nd		1.05	4.4%	0.403	6.2%	3.42	1.7%	nd		1.18	4.5%
DT3 @40 OP	0.720	8.1%	10.1	1.5%	nd		0.600	0.6%	0.245	4.6%	4.36	1.5%	nd		1.66	2.1%
DT3 @50 OP	1.14	1.3%	12.6	0.6%	nd		0.680	22.9%	0.960	0.9%	6.98	0.5%	nd		0.889	5.1%
DT3 @100 OP	2.37	3.0%	11.4	0.7%	nd		1.21	3.0%	1.65	0.7%	6.30	1.0%	nd		0.755	7.1%
DT3 @150 OP	1.80	0.7%	10.9	0.8%	nd		0.928	8.4%	0.682	4.1%	3.22	2.2%	nd		0.505	1.4%
DT3 @10 THO	2.19	1.4%	9.99	3.2%	nd		1.11	4.1%	1.10	2.3%	7.08	0.2%	nd		2.15	3.5%
DT3 @20 THO	2.05	1.2%	16.9	1.8%	nd		1.03	3.2%	1.69	1.1%	8.58	0.4%	nd		0.727	6.6%
DT3 @30 THO	2.06	3.0%	15.4	1.1%	nd		1.00	3.5%	1.25	2.4%	3.49	0.8%	nd		0.729	1.3%
DT3 @40 THO	0.950	2.9%	8.09	0.8%	nd		0.546	28.2%	0.614	3.1%	3.07	1.2%	nd		0.645	2.7%
DT3 @50 THO	1.33	1.9%	8.68	0.8%	nd		0.691	4.7%	0.785	3.0%	3.77	1.3%	nd		0.603	6.8%
DT3 @150 THO	2.70	2.7%	21.2	0.4%	nd		1.31	0.8%	0.898	1.6%	2.82	0.8%	nd		0.221	4.4%
DT4 @10 MA	2.85	2.2%	24.8	1.3%	nd		1.40	0.9%	2.26	0.8%	21.1	1.0%	nd		2.26	0.2%
DT4 @20 MA	1.34	1.7%	8.83	0.5%	nd		nd		0.705	1.8%	4.26	1.5%	nd		0.792	5.3%
DT4 @30 MA	2.25	3.7%	14.1	0.6%	nd		1.12	7.7%	0.389	3.6%	3.15	1.2%	nd		0.503	2.5%
DT4 @40 MA	2.14	1.7%	10.6	1.4%	nd		1.08	3.9%	0.967	1.2%	9.66	0.5%	nd		0.494	4.8%
DT4 @50 MA	2.07	3.7%	10.2	0.1%	nd		1.01	5.9%	0.235	8.5%	3.38	1.0%	nd		0.441	5.0%
DT4 @100 MA	2.67	1.6%	25.2	0.5%	nd		1.33	3.2%	0.745	1.9%	8.40	0.4%	nd		0.344	2.1%
DT4 @150 MA	2.81	1.9%	24.5	2.4%	nd		1.37	2.5%	1.45	1.2%	14.0	0.6%	nd		1.37	2.8%
DT4 @10 OP	1.61	2.6%	6.20	3.8%	nd		0.826	10.3%	nd		3.18	0.2%	nd		0.525	2.2%
DT4 @20 OP	1.31	3.2%	5.34	2.6%	nd		0.735	33.4%	0.358	2.4%	2.52	2.1%	nd		0.434	4.6%
DT4 @30 OP	0.823	4.9%	4.77	2.5%	nd		0.544	6.8%	0.270	5.3%	4.00	0.6%	nd		0.808	2.3%
DT4 @40 OP	0.746	5.0%	4.92	0.8%	nd		0.468	2.7%	0.359	4.0%	3.21	1.4%	nd		0.386	3.1%
DT4 @50 OP	1.49	2.8%	12.5	1.8%	nd		nd		0.711	1.7%	2.93	1.1%	nd		0.470	2.1%
DT4 @100 OP	0.623	5.8%	2.93	0.6%	nd		0.434	4.4%	nd		1.93	1.9%	nd		0.213	2.1%
DT4 @150 OP	0.362	7.7%	3.59	2.8%	nd		0.304	0.9%	0.603	4.6%	3.56	0.7%	nd		0.340	2.7%

Appendix 2 Raw data showing heavy metal concentrations from control sites

Sample Id	Cr (mg/kg)	RSD	Mn (mg/kg)	RSD	Cd (mg/kg)	RSD	Ni (mg/kg)	RSD	Cu (mg/kg)	RSD	Zn (mg/kg)	RSD	As (mg/kg)	RSD	Pb (mg/kg)	RSD
CT1 @10 OS	4.35	2.6%	26.7	2.6%	nd		2.27	0.3%	5.52	0.2%	12.2	0.2%	nd		1.66	2.6%
CT1 @20 OS	3.30	2.7%	27.9	1.1%	nd		1.61	0.8%	2.53	0.4%	7.08	0.8%	nd		0.679	4.7%
CT1 @30 OS	3.88	2.5%	10.7	1.1%	0.013	11.5%	1.76	1.6%	2.22	1.0%	8.09	0.5%	nd		1.03	3.8%
CT1 @40 OS	3.52	2.9%	17.5	0.9%	nd		1.66	1.8%	2.13	0.8%	11.5	1.0%	nd		0.559	8.7%
CT1 @50 OS	4.38	1.8%	17.3	1.4%	0.031	8.8%	1.85	0.9%	2.14	0.9%	6.68	0.5%	nd		0.647	4.9%
CT1 @100 OS	4.36	2.5%	29.7	1.4%	nd		1.88	1.0%	2.30	0.4%	7.30	1.4%	nd		0.769	1.2%
CT1 @150 OS	1.86	2.7%	15.5	1.1%	0.017	15.3%	0.867	3.6%	0.772	0.6%	2.85	1.0%	nd		0.204	16.5%
CT1 @10 MA	2.72	1.6%	8.60	2.8%	0.094	1.5%	1.21	1.3%	1.58	0.4%	3.87	0.7%	nd		0.940	1.8%
CT1 @20 MA	3.16	3.4%	11.6	2.2%	0.068	4.6%	1.37	2.5%	0.815	0.1%	3.95	1.2%	nd		0.413	2.2%
CT1 @30 MA	3.28	1.5%	42.9	1.6%	nd		1.55	0.8%	2.05	0.5%	5.77	0.9%	nd		0.538	14.6%
CT1 @40 MA	2.08	1.3%	25.0	1.5%	nd		1.06	1.4%	1.01	0.7%	2.44	0.3%	0.133	22.9%	nd	
CT1 @50 MA	2.43	2.2%	16.2	1.8%	nd		1.17	1.4%	0.948	0.8%	4.17	0.9%	nd		0.309	6.4%
CT1 @100 MA	2.29	3.5%	16.7	1.2%	0.041	4.5%	1.08	1.7%	0.959	0.7%	2.90	0.9%	nd		0.273	17.1%
CT1 @150 MA	2.76	2.9%	17.1	1.2%	0.010	17.0%	1.27	0.8%	0.883	0.5%	3.58	0.6%	nd		0.427	6.8%
CONTROL CENTER	2.69	2.9%	13.2	2.2%	0.040	6.4%	1.17	0.7%	1.87	0.7%	11.7	0.7%	nd		0.373	8.0%
CT3 @10 HO	2.38	2.6%	10.1	0.9%	0.081	3.8%	1.06	1.3%	1.66	0.5%	3.94	1.6%	nd		0.299	9.5%
CT3 @20 HO	1.64	2.8%	6.96	1.0%	0.044	6.8%	0.700	1.2%	1.66	0.8%	2.94	0.7%	nd		nd	
CT3 @30 HO	2.08	2.6%	16.8	1.1%	nd		0.997	2.5%	0.964	0.3%	2.85	0.8%	nd		0.404	4.1%
CT3 @40 HO	3.84	2.6%	34.8	0.5%	nd		1.79	1.6%	2.51	0.3%	4.16	0.8%	nd		0.532	9.8%
CT3 @50 HO	4.50	3.1%	37.4	0.3%	0.020	12.5%	2.12	2.8%	1.68	0.6%	3.68	0.7%	nd		0.623	8.2%
CT3 @100 HO	4.00	2.3%	23.2	1.0%	0.065	17.6%	1.78	2.3%	1.35	1.2%	3.43	1.4%	nd		0.439	4.3%
CT3 @150 HO	3.94	2.4%	28.0	2.0%	0.062	7.3%	1.68	1.2%	2.23	0.4%	5.78	0.4%	nd		1.00	1.8%
CT3 @10 OK	3.86	2.9%	22.6	2.1%	0.067	11.6%	1.65	1.1%	1.99	1.0%	3.68	1.2%	nd		0.578	7.2%
CT3 @20 OK	3.51	2.7%	25.9	0.6%	0.035	4.6%	1.55	1.1%	2.02	0.4%	3.92	0.7%	nd		0.479	6.7%
CT3 @30 OK	3.74	2.2%	31.5	1.3%	0.037	9.5%	1.60	0.8%	2.31	1.6%	3.53	0.1%	nd		0.529	6.7%
CT3 @40 OK	3.68	3.7%	31.4	1.4%	nd		1.79	1.1%	2.49	1.1%	3.59	1.5%	nd		0.515	2.1%
CT3 @50 OK	2.79	3.2%	24.5	0.1%	nd		1.26	1.0%	1.40	0.9%	2.78	0.7%	nd		0.484	11.1%
CT3 @100 OK	4.68	2.4%	43.3	1.4%	nd		2.28	2.0%	2.71	0.3%	3.97	0.4%	0.302	10.6%	0.110	39.1%
CT3 @150 OK	3.24	2.7%	24.5	2.3%	nd		1.54	2.1%	1.26	1.2%	6.54	1.6%	nd		0.659	8.0%
FT1 @10 OS	3.03	4.2%	15.7	1.2%	nd		1.41	1.2%	1.07	1.0%	5.70	0.7%	nd		1.36	4.5%
FT1 @20 OS	3.84	2.3%	16.5	0.3%	0.203	27.1%	1.65	1.0%	0.988	0.7%	4.96	1.4%	nd		1.01	2.9%
FT1 @30 OS	2.84	3.4%	15.0	2.2%	nd		1.40	0.5%	1.10	0.8%	7.02	0.2%	nd		1.19	5.6%
FT1 @40 OS	2.10	4.2%	10.0	0.8%	nd		1.09	3.5%	0.672	1.1%	5.05	0.7%	nd		0.571	9.8%
FT1 @50 OS	3.61	2.6%	25.4	1.1%	nd		1.67	0.8%	1.27	0.7%	5.15	0.7%	nd		0.733	5.2%
FT1 @100 OS	2.06	2.0%	4.78	1.4%	nd		1.05	3.4%	0.406	0.3%	2.26	1.4%	nd		0.482	3.7%
FT1 @10 PO	3.63	4.3%	38.4	0.6%	nd		1.77	0.7%	1.52	0.9%	7.03	1.1%	nd		0.835	5.0%
FT1 @20 PO	3.20	2.0%	41.5	0.7%	nd		1.72	0.3%	1.51	0.8%	5.91	0.3%	0.137	37.4%	0.570	3.3%
FT1 @30 PO	4.79	2.6%	45.6	0.7%	nd		2.26	0.8%	1.76	0.9%	7.61	0.5%	nd		0.870	2.7%
FT1 @40 PO	4.48	2.5%	50.0	1.4%	0.013	26.1%	2.11	0.5%	1.72	0.5%	5.46	1.1%	nd		0.658	9.4%
FT1 @50 PO	3.61	3.9%	13.1	1.1%	0.035	10.4%	1.71	2.5%	0.845	0.8%	4.22	0.2%	nd		0.552	3.6%
FARM CENTER	3.63	3.1%	22.8	2.0%	0.114	1.7%	1.63	1.0%	1.19	0.8%	5.14	0.5%	nd		1.19	3.5%

Nd: not detected; CT: Control site 1; and FT: Control site 2.

Appendix 3 Raw data of soil physicochemical parameters from disposal site vicinity

Sample ID	pH	EC	Texture	Sand	Silt	Clay
		µS/cm		%	%	%
DT1, 10 OS	6.08	42.7	Sand	94.3	2.5	3.2
DT1, 20 OS	6.07	27.7	Loamy sand	79.5	14.2	6.3
DT1, 30 OS	6.11	28.1	Sand	95.5	1.2	3.2
DT1, 40 OS	6.05	38.6	Sand	94.3	2.7	3
DT1, 50 OS	6.13	37.6	Sand	93.8	2.5	3.7
DT1, 100 OS	6.13	76.8	Sand	95.2	1.4	3.4
DT1, 150 OS	5.4	23.2	Sand	94.4	2.9	2.7
DT1, 10 MA	7.22	96.5	Sand	91.6	4.6	3.8
DT1, 20 MA	7.2	149.9	Sand	92.5	4	3.4
DT1, 30 MA	6.64	118.6	Sand	92.4	4.8	2.8
DT1, 40 MA	6.5	20.5	Sand	97.4	0.1	2.5
DT1, 50 MA	5.98	47	Sand	91.8	5.6	2.6
DT1, 100 MA	6.52	70.6	Sand	96.8	1	2.2
DT1, 150 MA	7.04	97.5	Sand	95.6	1.3	3.1
DT2, 10 MA	6.31	43.7	Sand	95.4	1.8	2.8
DT2, 20 MA	6.93	77.7	Loamy sand	83.6	11	5.4
DT2, 30 MA	6.92	52.8	Sand	93.7	2.1	4.2
DT2, 40 MA	6.53	102.8	Sand	93.8	2	4.2
DT2, 50 MA	7.1	157.7	Sand	93.4	3.9	2.7
DT2, 100 MA	6.73	68.5	Sand	95.5	2.9	1.6
DT2, 150 MA	7.52	136.8	Sand	97	0.5	2.5
DT2, 10 MASH	7.2	73	Sand	95.4	1	3.6
DT2, 20 MASH	6.97	114.6	Sand	93.6	1.2	5.2

DT2, 30 MASH	6.85	68.7	Sand	93	2.6	4.3
DT2, 40 MASH	6.77	57.3	Sand	94.1	2.7	3.1
DT2, 50 MASH	6.6	95.3	Sand	94.1	3.1	2.9
DT2, 100 MASH	5.9	62.2	Sand	93.2	2.9	4
DT2, 150 MASH	6.36	84.8	Sand	93.6	2.7	3.7
DT3, 10 OP	6.99	157.6	Sand	92.6	3.7	3.7
DT3, 20 OP	5.98	101.2	Sand	88.9	4.7	6.3
DT3, 30 OP	6.41	76.3	Sand	92.4	3.6	4
DT3, 40 OP	6.61	22.9	Sand	96	1.3	2.7
DT3, 50 OP	6.73	29	Sand	95.6	1.2	3.2
DT3, 100 OP	5.74	107.8	Sand	93.5	2.9	3.6
DT3, 150 OP	6.16	39.7	Sand	88.3	7.8	3.9
DT3, 10 THO	7.3	85.5	Sand	93.1	4	2.9
DT3, 20 THO	6.87	146.8	Sand	91	4.2	4.8
DT3, 30 THO	6.59	71.2	Sand	94	2.2	3.7
DT3, 40 THO	6.84	46.1	Sand	95.3	1.4	3.3
DT3, 50 THO	6.44	64.6	Sand	95.7	1.5	2.8
DT3, 100 THO	5.97	72.1	Sand	95.6	1.1	3.3
DT3, 150 THO	5.55	60.3	Sand	92.7	1.5	5.8
DT4, 10 MA	7.2	163.8	Sand	90.9	4.4	4.7
DT4, 20 MA	6.23	76.6	Sand	93.7	2.7	3.6
DT4, 30 MA	6.42	65.5	Sand	96	0.6	3.4
DT4, 40 MA	5.95	44.1	Sand	94.6	2.6	2.8
DT4, 50 MA	6.26	85.7	Sand	93.6	3.6	2.9
DT4, 100 MA	7.19	134.7	Sand	93.7	3.2	3.1
DT4, 150 MA	8.25	57.8	Sand	93.9	3	3.1

DT4, 10 OP	7.08	58.5	Sand	93.7	3.7	2.7
DT4, 20 OP	7.12	87.1	Sand	95.1	2.9	2
DT4, 30 OP	6.38	47.3	Sand	96.6	1	2.4
DT4, 40 OP	5.96	45.6	Sand	96.8	0.6	2.6
DT4, 50 OP	5.85	65.6	Sand	95.2	2	2.7
DT4, 100 OP	5.57	15.94	Sand	95.7	1.8	2.5
DT4, 150 OP	5.95	72.5	Sand	93.8	2.7	3.5
Disposal centre	7.8	45.9	Sand	88.9	6.4	4.8

Appendix 4 Raw data of soil physicochemical parameters from control site 1

Sample ID	**pH**	**EC**	**Texture**	**Sand**	**Silt**	**Clay**
		µS/cm		**%**	**%**	**%**
CT1,20 OS	6.05	58.8	Sand	93.7	1.7	4.6
CT1,30 OS	5.79	63.5	Sand	95.3	1.7	2.9
CT1,40 OS	5.58	54.4	Sand	93	2.4	4.6
CT1,50 OS	5.92	23.6	Sand	94.6	1.5	3.9
CT1,100 OS	5.75	77.2	Sand	91.7	3.3	5
CT1,150 OS	5.6	50.2	Sand	91.3	2.9	5.8
CT1,10 MQ	5.79	40.2	Sand	95.6	1.8	2.6
CT1,20 MQ	5.5	41.6	Sand	93.9	2.8	3.3
CT1,30 MQ	6.21	61.7	Sand	89.3	4.4	6.3
CT1,40 MQ	5.83	71.2	Sand	89.1	4.7	6.3
CT1,50 MQ	5.59	101.1	Sand	90.3	6.2	3.5
CT1,100 MQ	5.72	55.9	Sand	95.6	0.6	3.8
CT1,150 MQ	5.67	68.7	Sand	90.3	5.6	4.1
Control centre	5.38	35.1	Sand	92	4.4	3.6
CT3,10 HO	5.43	66.8	Sand	95.5	0.8	3.7
CT3,20 HO	5.38	25.6	Sand	94.6	1.7	3.7

CT3,30 HO	5.79	64.5	Sand	88.6	7.6	3.7
CT3,40 HO	5.56	64	Sand	89.8	5.2	5
CT3,50 HO	5.29	75	Sand	93.4	2	4.6
CT3,100 HO	6.11	70.2	Sand	92.2	3.7	4
CT3,150 HO	5.38	50.6	Sand	92.9	2.8	4.4
CT3,10 OK	5.65	70	Sand	94.1	2.5	3.4
CT3,20 OK	6.02	27.2	Sand	91.4	4.2	4.5
CT3,30 OK	6.04	47.8	Sand	89.4	5.4	5.2
CT3,40 OK	6.1	126.6	Sand	93.1	2.9	3.9
CT3,50 OK	5.88	71.2	Sand	93.8	2.5	3.7
CT3,100 OK	5.79	178.2	Loamy sand	87.1	3.8	9
CT3,150 OK	6.12	104.1	Sand	91.5	4.3	4.2

Appendix 5 Raw data of soil physicochemical parameters from control site 2

Sample ID	**pH**	**EC**	**Texture**	**Sand**	**Silt**	**Clay**
		μS/cm		**%**	**%**	**%**
Farm centre	6.44	26.8	Sand	96.2	1.7	2
FT1,10 OS	6.45	62.4	Sand	94.1	3.2	2.8
FT1,20 OS	6.39	77	Loamy sand	81.5	16.9	1.6
FT1,30 OS	6.43	63.4	Sand	94.6	2.7	2.7
FT1,40 OS	6.14	30.4	Sand	97.1	0.1	2.8
FT1,50 OS	6.02	69	Sand	91.9	4.4	3.7
FT1,100 OS	7.2	80.8	Sand	99.4	0.2	0.3
FT1,10 PO	6.55	56.9	Sand	94.1	0.8	5.1
FT1,20 PO	7.25	73.2	Sand	88.9	5.3	5.9
FT1,30 PO	7	51.5	Sand	93.4	1.6	4.9
FT1,40 PO	6.13	40.5	Sand	94.5	0.6	4.9
FT1,50 PO	6.09	34.2	Sand	97.8	0.4	1.8

Appendix 6 GPS coordinates for the transects laid at all study sites

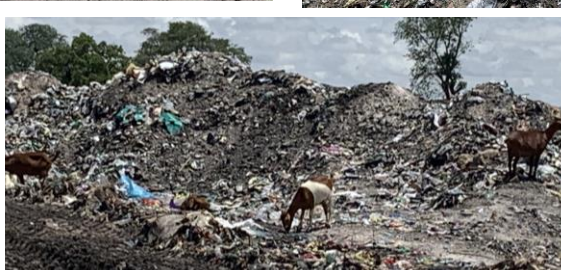
SITE	Sample ID	LATITUDE	LONGITUDE
DISPOSAL SITE TRANSECTS	**DT 1**		
	DT1 @ 10 OSH	S17.46488	E015.40030
	DT1 @ 20 OSH	S17.46482	E015.40027
	DT1 @ 30 OSH	S17.46478	E015.40024
	DT1 @ 40 OSH	S17.46474	E015.40020
	DT1 @ 50 OSH	S17.46469	E015.40108
	DT1 @ 100 OSH	S17.46446	E015.40005
	DT1 @ 150 OSH	S17.46420	E015.39997
	DT1 @ 10 MA	S17.46561	E015.40103
	DT1 @ 20 MA	S17.46565	E015.40113
	DT1 @30 MA	S17.46566	E015.40115
	DT1 @ 40 MA	S17.46569	E015.40118
	DT1 @ 50 MA	S17.46571	E015.40124
	DT1 @ 100 MA	S17.46585	E015.40148
	DT1 @ 150 MA	S17.46600	E015.40173
	DT 2		
	DT2 @ 10 MAHA	S17.46562	E015.40101
	DT2 @ 20 MAHA	S17.46570	E015.40103
	DT2 @ 30 MAHA	S17.46574	E015.40103
	DT2 @ 40 MAHA	S17.46579	E015.40101
	DT2 @ 50 MAHA	S17.46584	E015.40103
	DT2 @ 100 MAHA	S17.46613	E015.40105
	DT2 @ 150 MAHA	S17.46640	E015.40106
	DT2 @ 10 MASHA	S17.46488	E015.40035
	DT2 @ 20 MASHA	S17.46483	E015.40037
	DT2 @ 30 MASHA	S17.46477	E015.40039
	DT2 @ 40 MASHA	S17.46473	E015.40039

	DT2 @ 50 MASHA	S17.46468	E015.40040
	DT2 @ 100 MASHA	S17.46441	E015.40044
	DT2 @ 150 MASHA	S17.46413	E015.40046
	DT 3		
	DT3 @ 10 OP	S17.46462	E015.40141
	DT3 @ 20 OP	S17.46461	E015.40149
	DT3 @ 30 OP	S17.46459	E015.40153
	DT3 @ 40 OP	S17.46458	E015.40157
	DT3 @ 50 OP	S17.46455	E015.40163
	DT3 @ 100 OP	S17.46447	E015.40189
	DT3 @ 150 OP	S17.46434	E015.40208
	DT3 @ 10 THO	S17.46559	E015.40093
	DT3 @ 20 THO	S17.46563	E015.40091
	DT3 @ 30 THO	S17.46566	E015.40087
	DT3 @ 40 THO	S17.46568	E015.40082
	DT3 @ 50 THO	S17.46573	E015.40078
	DT3 @ 100 THO	S17.46593	E015.40065
	DT3 @ 150 THO	S17.46621	E015.40057
	DT 4		
	DT4 @ 10 MA	S17.46461	E015.40121
	DT4 @ 20 MA	S17.46458	E015.40112
	DT4 @ 30 MA	S17.46452	E015.40111
	DT4 @ 40 MA	S17.46447	E015.40110
	DT4 @ 50 MA	S17.46441	E015.40108
	DT4 @ 100 MA	S17.46415	E015.40102
	DT4 @ 150 MA	S17.46392	E015.40087
	DT4 @ 10 OP	S17.46511	E015.40153
	DT4 @ 20 OP	S17.46512	E015.40156
	DT4 @ 30 OP	S17.46514	E015.40162
	DT4 @ 40 OP	S17.46517	E015.40167
	DT4 @ 50 OP	S17.46520	E015.40171

	DT4 @ 100 OP	S17.46531	E015.40195
	DT4 @ 150 OP	S17.46539	E015.40223
	DUMPSITE CENTER	S17.77524	E015.66735
COTROL SITE TRNSECTS	**CT 1**		
	CT1 @ 10 OS	S17.46336	E015.40311
	CT1 @ 20 OS	S17.46333	E015.40307
	CT1 @ 30 OS	S17.46329	E015.40305
	CT1 @ 40 OS	S17.46324	E015.40302
	CT1 @ 50 OS	S17.46320	E015.40298
	CT1 @ 100 OS	S17.46293	E015.40280
	CT1 @ 150 OS	S17.46273	E015.40271
	CT1 @ 10 MA	S17.46348	E015.40324
	CT1 @ 20 MA	S17.46354	E015.40328
	CT1 @ 30 MA	S17.46358	E015.40330
	CT1 @ 40 MA	S17.46366	E015.40366
	CT1 @ 50 MA	S17.46360	E015.40332
	CT1 @ 100 MA	S17.46384	E015.40349
	CT1 @ 150 MA	S17.46408	E015.40363
	CONTROL CENTER	S17.46340	E015.40316
	CT 3		
	CT3 @ 10 HO	S17.46342	E015.40312
	CT3 @ 20 HO	S17.46342	E015.40307
	CT3 @ 30 HO	S17.46344	E015.40301
	CT3 @ 40 HO	S17.46346	E015.40297
	CT3 @ 50 HO	S17.46347	E015.40290
	CT3 @ 100 HO	S17.46355	E015.40262
	CT3 @ 150 HO	S17.46363	E015.40238
	CT3 @ 10 OK	S17.46337	E015.40321
	CT3 @ 20 OK	S17.46334	E015.40325
	CT3 @ 30 OK	S17.46331	E015.40330
	CT3 @ 40 OK	S17.46328	E015.40335

	CT3 @ 50 OK	S17.46325	E015.40339
	CT3 @ 100 OK	S17.46311	E015.40362
	CT3 @ 150 OK	S17.46305	E015.40390
	FT1		
FARM CONTROL TRANSECTS	FT1 @ 10 OS	S17.46954	E015.40391
	FT1 @ 20 OS	S17.46953	E015.40392
	FT1 @ 30 OS	S17.46955	E015.40404
	FT1 @ 40 OS	S17.46955	E015.40405
	FT1 @ 50 OS	S17.46955	E015.40414
	FT1 @ 100 OS	S17.46955	E015.40415
	FT1 @ 10 PO	S17.46954	E015.40381
	FT1 @ 20 PO	S17.46958	E015.40378
	FT1 @ 30 PO	S17.46955	E015.40371
	FT1 @ 40 PO	S17.46955	E015.40369
	FT1 @ 50 PO	S17.46955	E015.40361
	FARM CENTER	S17.46953	E015.40387

Appendix 7 Vandalised fence and Goats feeding on waste in the disposal site



Appendix 8 Organisation and arrangement of the disposal site

Appendix 9 Topsoil layer cleared for new waste in the disposal site

Appendix 10 Crop farm and Oshana surrounding the disposal site