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The Impacts of Landfill Management Site A on Grass, Soil, and Surface Water: A Preliminary Study in KwaZulu-Natal, South Africa

A dissertation submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science

School of Animal, Plant, and Environmental Sciences

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Declaration

I declare that this dissertation "The Impacts of Landfill Management Site A on Grass, Soil, and Surface Water: A Preliminary Study in KwaZulu-Natal, South Africa", is my own, unaided work. It is being submitted for the Degree of Masters of Science at the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

F.N. Ndobe

11 June 2023

Abstract

Environmental pollution is a major global challenge, and the prime pollution source is anthropogenic activities, including industrial and waste management activities amongst others. Heavy metals are known pollutants released due to landfill operations and pose a problem in the terrestrial ecosystem, aquatic ecosystem, and human health through exposure. There are well-documented studies of heavy metal contamination and its impact on soil, groundwater, and surface water, and plants in general, yet the characteristics of contamination can be unique to each landfill site. This study aimed to investigate the potential impacts of toxic waste leachate from a landfill site in KwaZulu-Natal on the surrounding grasses, soil, and surface water. The methodology involved two broad approaches to data collection, a quantitative approach which entailed collecting grass, soil, and surface water samples near the landfill site to determine the levels of heavy metals (As, Cd, Cr, Cu, Pb, and Zn) and their potential impacts, and a qualitative approach which entailed interviews with nearby residents to investigate the community's perception and awareness of health and environmental risks associated with living close to the landfill site. Three sampling sites downhill from the landfill site were sampled, namely the central stream site (adjacent to the leachate/storm water dam one, downstream site (storm water dam two), and control site-upstream (northbound), and heavy metals concentration varied significantly between sample types and sites. In almost all cases, the heavy metals exceeded WHO permissible limits. Contamination factor (C*f*), pollution load index (PLI), and ecological risk index (R*i*) were also calculated and based on these, in grass Cr, Cu, Pb, and Zn contributed to very high contamination in the central stream area, whereas downstream, Cd showed very high contamination, suggesting a very high ecological risk. In soil, contamination levels and risk were mostly moderate to low. In surface water, Pb contributed to high contamination while downstream water was mostly moderately contaminated. The most common challenge highlighted by community members during interviews were air pollution, water pollution, dust, and noise nuisance. For all communities, headaches are the most commonly reported, followed by asthmatic conditions and respiratory-related distress. The results indicated that people living 1-2km away from the landfill site were likely more exposed to health and environmental-related risk than people living 3-5km away from the potential polluting sources.

In conclusion, high heavy metal contamination in soil, surface water, and grass suggests a likely leachate leakage and/or the dispersion of other related pollutants in the surrounding environment, which requires a further in-depth investigation to find the signature source of pollution.

Key Words: Leachate, Heavy Metals, Contamination, Toxicity, Health, and Environmental Impacts.

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Abbreviations

As- Arsenic

Cd- Cadmium

Cr- Chromium

Cu – Copper

DWAF- Department of Water Affairs and Forestry

EC – Electrical conductivity

FAO- United Nations Food and Agricultural Organization

GNR- Government Notice Regulation (South Africa)

H_2O_2- Hydrogen Peroxide

HCL-Hydrochloric acid

HF- Hydrofluoric acid

HNO_3- Nitric acid

HMs- Heavy metals

ICP-OES- Inductively Coupled Plasma Optical Emission Spectroscopy

IWMP- Integrated waste management plan

NEM: WA- National Environmental Management: Waste Act (No.59 of 2008)

NNS- National norms and standards

NWMS- National waste management system

Pb- Lead

PTFE-Polytetra-fluoro-ethylene

SP1-SP9- Grass samples 1 to 9

SPSS- Statistical Package for the Social Science

SS1-SS9- Soil samples1 to 9

SW1-SW9- Water samples 1 to 9

TDS-Total Dissolved Solids

WHO- World Health Organization

WML- Waste Management License

Chapter 1: Introduction and Rationale

Globally and locally, waste production has greatly increased due to improved social conditions and better living standards, exponential growth in technology, industrial development and activities, and the steady rise in population growth, and all these subsequently contributed to a significant waste management burden (Miller, 2007; Roberts, 2013; Vaverkova, 2019). With the increased waste production and management burden, landfilling has become the dominant solution to waste management in South Africa as it is the environmentally acceptable method of disposing waste, with approximately 90% of waste materials being disposed of into landfill sites and 10% being recycled (Godfrey and Oelofse, 2017). The landfilling method has proven to be the most cost-effective method of waste management in both developed and developing countries (Yang *et al.* 2018). Landfilling can be defined as a controlled operation of disposal, compression, and burial of waste materials at an authorised landfill site (DWAF,1998; Vaverkova, 2019), for waste to be safely isolated from the surrounding environment. However, due to management failures, landfilling has been associated with environmental pollution, as landfills are known sources of pollutants that are likely to contaminate soil, vegetation, and water resources, and result in health-related problems in the surrounding communities through pollution plumes from the site operations (Kjeldsen *et al.* 2002; Miller, 2007). Due to the potential impact associated with landfilling operations, it is necessary to explore and investigate the possible effects of Landfill Site A on the surrounding environment. The landfill site is in the province of KwaZulu-Natal, South Africa, and receives hazardous and non-hazardous waste on a daily basis. For this study, the name of the company and the surrounding communities are intentionally anonymised for ethical, and security reasons. The name of the company and the site throughout the study are referred to as "Landfill Site A, the local streams as Stream A and Stream B, and the local communities, which is Community A, located (1-2km away) and Community B (3-5km away)".

Landfill site A has been making headlines in the newspapers and other related social media platforms due to persistent complaints from the local residents and eventually, the matter was brought to court (African News Agency, 2019). In 2019, local traditional healers and churches raised concerns about water pollution in the surrounding environment, and the pollutants were alleged to be emanating from landfill site A's storm water runoff, which contaminated water systems and subsequently posed a risk to human and livestock health (African News Agency, 2019). Other complaints were about air pollution allegedly being emitted from the site. The influx of complaints subsequently led to the suspension of the site's Waste Management License (WML) as the company was alleged to be in contravention of the National Environmental Management: Air Quality Act (39 of 2004) (African News Agency, 2019). The surrounding area has a high concentration of people living nearby the landfill site and some members of the community have animals grazing in the vicinity as the site's location is not far from the residential areas. The site was developed upslope from two streams (stream A and stream B) and fertile agricultural land, with sugar cane farms in close proximity. The site is on an elevated geological formation with stream A running just below the sloped site. Generally, mismanagement of landfill sites and/or dumping sites does not only affect human health and the environment but also the economy, as it is likely to hinder progress towards sustainable development (Adelson *et al.* 2008). For a city and the surrounding environment to be considered sustainable, the interaction between people and the environment requires integration to bring balance between the natural environment and society, without overutilisation of resources and/or excessive environmental pollution (Science for Environment Policy, 2018). The landfilling of waste potentially has short-and long-term adverse impacts on the environment due to poor practices. Short-term impacts may include dust, noise, and flies among others, whereas long-term impacts include environmental degradation and water resource pollution due to leachate generation and its migration into the environment, and these may be persistent even after closure (DWAF,1998).

Pollutants or contaminants leaching from the landfill site include carbon dioxide, ammonia/ammonium, methane, a variety of heavy metals and organic compounds (Kjeldsen *et al.* 2002). Pollutants have the potential to create a high biological oxygen demand, resulting in the deoxygenation of water, which could threaten and even kill aquatic life (Newtown, 2018). Landfill leachate linked to waste disposal processes is the major source of environmental pollution and it can be formed in various ways: (1) through moisture in the disposed waste materials, (2) through rainfall, (3) landfill surface conditions, (4) the prevailing climate and underlying soil conditions. Leachate is produced when liquids or rainwater percolate through the layers of decomposed waste at the base of the landfill site, migrating and spreading either transversely or vertically and collecting various contaminants along the way (Mahurpawar, 2015; Wijngaard *et al.* 2017; Vaverkova, 2019). Landfill leachate has a great potential to pollute the environment and threaten human health when leaching into the neighbouring land (Giang *et al.* 2018). The best optimum strategy to minimise excess liquid at the base of waste pits includes the use of dense clay deposits and a geomembrane lining system among others, as it prevents infiltration into the surrounding soil (Alam and Ahmade, 2013).

1.1. Research gap

There are well-documented scientific research studies of heavy metal contamination and its impact on soil, ground and surface water, and plants in general, yet each landfill site has its own unique characteristics when it comes to pollution, based on topography, surrounding vegetation, proximity to surface water, etc. Given the concerns and complaints raised by the surrounding community, the potential impacts of this landfill site's pollution on the surrounding grasses, soils, and surface water need to be quantified and assessed.

1.2.Aim and objectives

This study's aim was to investigate the potential impacts of toxic waste leachate from the landfill site on grass, soil, and surface water. The investigation of toxic waste leachate was conducted with the objectives

(1) to determine the potential impact of the leachate plume from the landfill site through sampling

(2) to determine the level of heavy metal (arsenic, chromium, cadmium, copper, lead, and zinc) contamination of grass, soil, and surface water at various distances from the landfill site;

(3) to investigate the community's awareness and perception of the possible environmental and health-related impacts of toxic substances leaching from landfill site A.

1.3. Dissertation layout

The dissertation comprises five chapters. Chapter 1 provides an introduction and rationale, the research gap, and the aim and objectives of the research study. Chapter 2 provides the literature review related to landfill contamination, as well as a description of the study area and receiving environment. Chapter 3 describes the methodology used for the assessment. Chapter 4 presents the findings of the research study. Chapter 5 discusses the findings context of other literature, the implications of the study findings in the surrounding environment, along with limitations of the study. References and appendices are found at the end of the report.

Chapter 2: Literature Review

Globally, various types and dimensions of waste create significant socioeconomic costs, and have human and environmental health impacts (Oyedotun *et al.* 2021). The exponential growth of waste production is adding pressure to the existing environmental issues with observable effects on the environment and human health. In 2012, globally, the municipal solid waste production specifically was estimated to be approximately 1.3 billion tonnes per annum. With the exponential population growth, the predictions were that by the year 2025, the production of waste would be at an estimated 2.2 billion tonnes per year (Rodríguez-Eugenio *et al.* 2018). South Africa is estimated to generate approximately 12.7 million tonnes of municipal solid waste annually and approximately 90% is landfilled (Oelofse *et al.* 2020). Common methods of waste disposal include landfilling, incinerators, composting, recycling, re-use of by-products from industrial processes and burial in underground caverns (Miller, 2007; Yang *et al*. 2018). Composting is one of the best methods of biologically recycling degradable waste. Incineration is another costly alternative method for waste disposal, however, the ash material from the incineration process ultimately finds its way to the landfill for final disposal as hazardous waste (Vaverkova, 2019; NWMS, 2020). The incineration of municipal waste is also known to generate significant concentrations of zinc, lead, copper, aluminium, and iron, among others (Nagajyoti *et al.* 2010). The National Waste Management Strategy (2020) revealed that South Africa generated approximately a 67 million tonnes of hazardous waste in 2017, of which 93% was deposited at landfill sites, with the biggest contributor to hazardous waste being fly and residual ash (NWMS, 2020). The landfilling method remains an integrated waste disposal method as it is considered the most cost-effective alternative with low technical barriers worldwide (Vaverkova, 2019).

For the location of landfill sites, there are criteria to be followed which influence the decision on site selection during an environmental impact assessment (EIA) where public participation processes are also considered. The public participation process and acceptance are important, especially when there are potential impacts due to locating the landfill site in close proximity to a residential community, with the likelihood to affect their quality of life, land and property values, and health (DWAF,1998). With regard to the waste disposal sites and their location, the economic pillar focuses more on the cost of transporting waste from waste generators to the landfill site among other things. If the landfill site is located too far from the public (considering acceptable buffer zones), the transport costs and collection tariffs will be higher due to the distance travelled from the waste generators (public) to the disposal site, resulting in financial constraints for the service users (DWAF, 1998).

The location of the landfill site must be environmentally and socially acceptable, at an acceptable buffer zone to conform with section 24 of The Constitution of South Africa, which stipulates that "everyone has the right to an environment that is not harmful to their health and or well-being". The constitutional rights of the people must not be violated. Regarding the landfill location in particular, the environmental focus is on the potential threats to the environment, e.g. water resources among others, if the landfill site is not located adjacent to the water bodies; or is well-built and properly managed to reduce water pollution risks and other related effects (Miller, 2007; Adelson *et al.* 2008).

There are different types of landfill sites as they accept different types of waste according to classification (A, B, C, and D) (see Table 1) and each type is determined by the waste to be deposited, the size of the operations and waste stream, possible leachate generation, and the potential environmental impact it poses (DWAF, 1998).

Table 1: Landfill classification and various types of waste (NEM: Waste Act, 59 of 2008)

Landfill class	**Waste type**	**Examples**
Class A	Type 1	Hazardous waste (H: H and H: h ratings): asbestos waste, spoilt, or expired waste.
Class B	Type 2	General waste such as garden waste, business waste not containing chemicals (e.g. cardboard, and office furniture), and domestic waste.
Class C	Type 3	Post-consumer packaging; waste tyres.
Class D	Type 4	Building and demolition waste.

Landfill sites are used for the deposition of various waste products (as per NEM: Waste Act, 59 of 2008):

(1) General waste which includes but is not limited to domestic and garden waste not containing hazardous or chemical waste and commercial waste. It can be characterised as generic waste as it does not constitute a great threat to the environment and public health, however, this type of waste must be properly managed and disposed of in an acceptable manner as required by the waste management legislation and related policies.

(2) Hazardous waste which includes inorganic and organic waste, animal carcasses, waste tyres, asbestos waste, spoilt and unusable hazardous and industrial waste containing hazardous or chemical substances, and health care risk-related waste (DWAF, 1998; Miller, 2007). Hazardous waste can be characterised as corrosive, carcinogenic, or toxic even at low levels due to the significant threats it poses and adverse effects it has on people and the environment when improperly managed and disposed. The disposal of hazardous waste is classified in accordance with its toxicological properties and the risk impact probability to the surrounding environment, e.g. hazardous waste with ratings 1 and 2 is classified as extremely to highly hazardous, whereas hazardous waste with ratings 3 and 4 is classified as moderately to low hazardous (DWAF, 1998).

There are several critical components that are needed for landfill sites to be secured which include cells with engineered liners (design), leachate collection systems, storm-water drainage, groundwater monitoring systems, and methane/gas collection systems as shown in Figure 1 (Vesilind *et al*. 2002; NEM: Waste Act, 59 of 2008; Naveen *et al.* 2018).

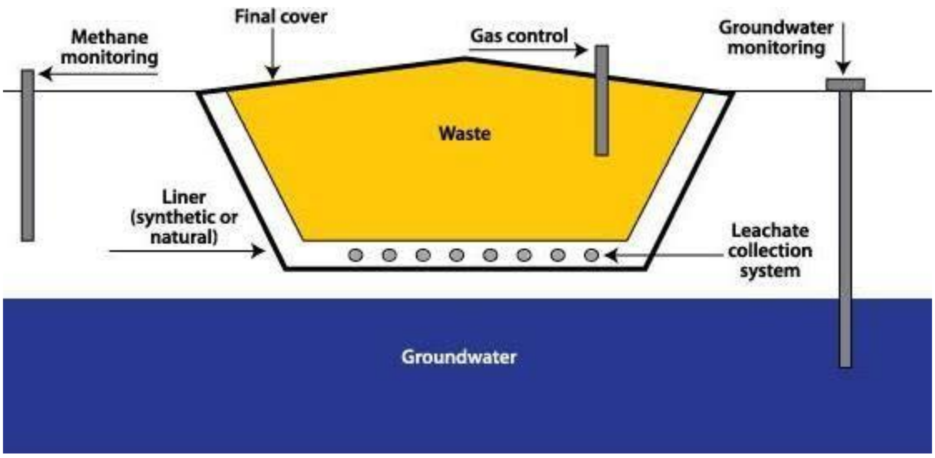

Figure 1: Critical components of a landfill site (Vesilind *et al*. 2002)

The landfill site must be designed by a registered professional engineer and be constructed in accordance with the plan, and the design plan shall be approved by the Director of the Licensing Department (Department of Environment Forestry and Fisheries) as per national norms and standards of the waste management and licensing regulation (NEM: Waste Act, 59 of 2008-GNR 634, 2013). Cells are the main component of the landfill, as these are specific areas used to deposit or bury waste. A cell in use must be covered with specific material (cap/cover) at the end of the working day to prevent rain water intrusion which could result in more or rapid leachate generation, and to reduce vermin, fly and vector infestation, odours and other related nuisances that may arise. When a cell is at full capacity or no longer in use, it must be rehabilitated, or a temporal cap must be installed (DWAF, 1998; Ferronato and Torretta, 2019). The compaction of waste in the cell-in-use is encouraged as it reduces the amount of capping cover needed, and also minimises fire risks, reduces possible rapid migration of leachate due to channels, and increases the longevity of a site (DWAF, 1998).

The disposal of waste in an un-engineered or improperly built landfill site has a potential impact of contaminating soil and groundwater, hence this raised serious concerns about the public health and environmental pollution. Health-related studies revealed that there are increased health risks resulting from exposure to toxic heavy metals from landfill sites (Ferronato and Torretta, 2019). For example, poorly implemented laws and regulations and the lack of proper waste management practices led to massive environmental pollution in New York, Niagara Falls approximately seven decades ago after a chemical company dumped steel drums containing at least 200 toxic chemicals in the Love Canal Site and covered chemical hazardous waste with loose clay and topsoil. The area where toxic chemicals were discovered was declared a disaster area (Philips *et al.* 2007). It can be concluded that chemicals and heavy metals pollution become the pollution sink of the environment since their removal is difficult once they have invaded the environment. Heavy metals and other related toxic chemicals are non-biodegradable hence there are likely to continue to pollute the surrounding environment even after the site has ceased operations without proper and effective rehabilitation processes in place (Makuleke and Ngole-Jeme, 2020).

2.1. Landfill leachate and its formation

Leachate is the liquid generated in the waste cells, its formation begins immediately once a cell receives its first batch of waste. This liquid is generated by moisture that exists in the waste itself through the degradation of putrefiable waste and rainwater among others (Vaverkova and Adamcova, 2014). Normally, the leachate concentration is higher when the waste biodegradation occurs more rapidly. The leachate produced from landfill sites consists of heterogeneous mixtures of heavy metals, high nitrogen concentrations, dissolved organic matter, inorganic compounds, fulvic acids, and a wide range of xenobiotic organic compounds (Turki and Bouzid, 2017; Vaverkova, 2019). Leachate generation and migration are highly dependent on soil types (Vaverkova and Adamcova, 2014) and the physical properties of soil contribute to the migration of leachate to the surrounding environment and their extent of movement. The soil texture, porosity, and permeability determine the speed at which leachate will infiltrate into the environment (Figure 2) (Makuleke and Ngole-Jeme, 2020).

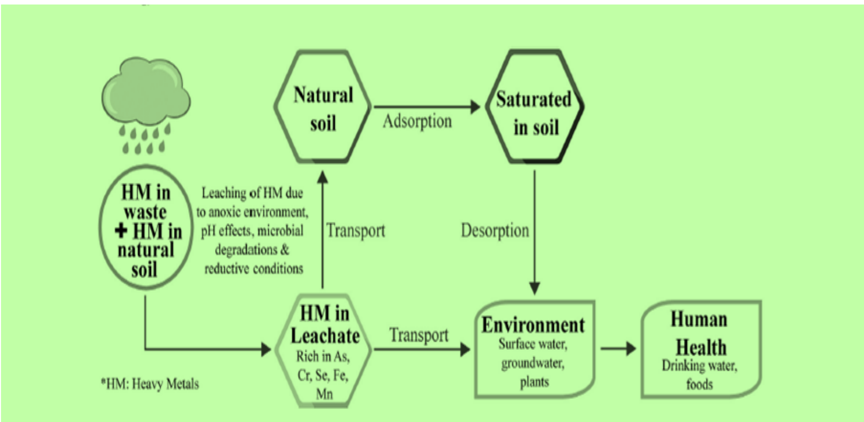

Figure 2. The transportation process of heavy metals from the landfill leachate to the environment and human health (Hussein *et al.* 2020)

The quality of leachate produced can be influenced by various factors such as the type of deposited waste and moisture content, age of the site and its composition, seasonal weather variation, water permeation, transpiration and evaporation, hydrogeological conditions in the vicinity, waste density, chemical and biological activities and total precipitation amount (Vaverkova, 2019). Excessive leachate formation is likely to spiral out of control by seeping into the nearest water resource (Wijngaard *et al.* 2017; Newton, 2018). Kjeldsen *et al.* (2002) indicated that the effects of leachate in surface water include oxygen depletion and changes to the stream's bottom fauna and flora (Kjeldsen *et al.* 2002). Minimum standard requirements were developed to ensure that sites are properly built and engineered and lined with sheet layers of absorbent material, to minimise risks of leakages and inhibit pollutants from moving into water resources and soil (Miller, 2007; Adamcova *et al.* 2016). Waterproof covers, insulation layers and geotextile membranes are common methods of landfilling that help to control the amount of water reaching the upper level of the landfill (Vaverkova, 2019). However, with the common methods used to inhibit leachate migration, manufacturing and construction defects are likely to occur and leachate can penetrate through the geo-membranes and seep through to contaminate soil and groundwater respectively (Boateng *et al.* 2019). Some landfill sites use clay soils as barrier liners to curtail leachate migration due to its ability to absorb and contain liquids, however, during the dry season, clay soil releases the contained liquids and small cracks can form in the soil, allowing leachate to escape and pollute water bodies, especially when not discovered and adequately managed on time (Mavimbela *et al.* 2019). The aim behind a properly designed landfill site is to minimise environmental pollution by avoiding any hydrological connections between the deposited waste and the environment, groundwater in particular (Xu *et al.* 2018), and minimise health-related impacts.

2.2. Heavy metals and their impacts

Heavy metals can be defined as metallic chemical elements and metalloids that have an atomic number >20 and are relatively high in density (> 5g/cm^3) or with high atomic weight/molecular mass which can result in toxicity problems even at low concentrations (Sharma and Agrawal, 2005; Nagajyoti *et al.* 2010; Rodríguez-Eugenio *et al.* 2018; Ali *et al.* 2019; Briffa, *et al.* 2020; Iyama *et al.* 2022). Heavy metals are more dominant in the terrestrial and aquatic ecosystem compared to the atmosphere and their leaching processes and dispersal mode contribute to their dominance in soil and water sources (Sharma and Agrawal, 2005; Nagajyoti *et al.* 2010). Generally, many heavy metals and metalloids occur naturally in the earth's system, however, the prime source of pollution is due to anthropogenic activities which include industrial activities, mine tailings, disposal of waste containing heavy metals and domestic effluent, coal combustion residues, sewage sludge, wastewater irrigation, leaded gasoline and paints among others (Onder *et al.* 2007; Rodríguez-Eugenio *et al.* 2018; Briffa *et al.* 2020; Iyama *et al.* 2022). The secondary source of heavy metals is from agricultural activities which include *inter alia* the use of agrochemicals such as pesticides, fertilisers, and insecticides (Briffa *et al.* 2020).

Anthropogenic activities such as agricultural and industrial activities tend to produce significant amounts of toxic waste containing heavy metals which eventually find their way to the landfill site for safe disposal. Landfill leachate is known to contain organic and inorganic contaminants (toxic heavy metals) due to the decomposed waste, with the potential to seep through into the surrounding environment (Essien *et al*. 2022). The potential mobilisation of landfill leachate containing heavy metals can be influenced by a number of factors which include the type of waste deposited, the topography of the landfill site, and runoff (Olayiwola *et al.* 2017). Heavy rainfall and runoff accelerate leachate transportation via hydrological pathways and are likely to take shortcut pathways to the surface and groundwater (Wijngaard *et al.* 2017; Vaverkova, 2019).

Heavy metal uptake in the environment can be influenced by various factors which include soil moisture and pH, root system characteristics, type and size of plant species, and the oxidation-reduction potential (Eh) conditions of the aquatic environment (Sharma and Agrawal, 2005; Nagajyoti *et al.* 2010). The excessive release of heavy metals due to landfill operations poses a problem in terrestrial and aquatic ecosystems and to human health, due to their high degree of toxicity, even at low concentrations (Briffa *et al.* 2020). Heavy metal contaminants gradually accumulate in the environment and often take years to exhibit effects (Philips *et al.* 2007). Heavy metal exposures can have deleterious effects on human health which could subsequently affect socioeconomic life (Martin and Griswold, 2009). As heavy metals bio-accumulate in the human system (Briffa *et al.* 2020), their health effects are linked to numerous medical conditions which include but are not limited to nervous system disorders, kidney and lung diseases, gastro-intestinal dysfunction, skin lesions, and reproductive defects (Makuleke and Ngole-Jeme, 2020), however, the severity of the effect depends on the metal concentration, route of exposure, individual susceptibility and the duration of exposure (Akinbile, 2012; Vongdala *et al.* 2019).

Landfill site leachate can include any number of these heavy metals, however previous studies linked to landfill sites in Kwazulu-Natal (the location of landfill site A) have identified arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) as those commonly found in higher concentrations in developing leachate (see Giang *et al.* 2018)

2.2.1. Arsenic (As)

Arsenic is a greyish metalloid element that occurs naturally in the earth's crust, due to volcanic eruptions and weathering of arsenic-containing rocks and natural waters, at a low concentration of approximately 2mg/kg and 1-2µg/l respectively (FAO, 1995; DWAF, 1996; Finnegan and Chen, 2012; WHO, 2017; Rodríguez-Eugenio *et al.* 2018). However, elevated concentrations are due to anthropogenic activities including mining, disposal of industrial or related waste containing arsenic and various industrial manufacturing processes (FAO, 1995; DWAF, 1996; Jain and Chandramani, 2018; Green-Facts, 2022). Arsenic has both organic and inorganic forms (DWAF, 1996; Jain and Chandramani, 2018). The main arsenic contamination sources of water, soil and air are the smelting of non-ferrous metals, mining, and burning of fossil fuels (Green-Facts, 2022).

Arsenic can be transported and released into the atmosphere through the burning of fossil fuels, vegetation, and volcanic eruptions among other things and return as a wet deposition or dry deposition on earth. Arsenic may accumulate in terrestrial plants through root uptake from the contaminated or polluted soil or through leaves via airborne arsenic deposition, with the potential to reduce plant growth and development among other things (Green-Facts, 2022). It is also an element that is insoluble in water, with the potential to exert lethality on the aquatic ecosystems, however, some of the arsenic compounds can dissolve (DWAF, 1996). Humans exposed to elevated concentrations of As metal are likely to suffer from skin cancer, diabetes, and pulmonary nervous system damage as clinical effects of As are linked to cancer and neuropathy, whereas low exposure is linked to reduced red and white blood cell production (Mahurpawar, 2015; Balali-Mood *et al*. 2021).

2.2.2. Cadmium (Cd)

Cadmium is a highly toxic soft silver-like metal, which rarely exists in the natural environment (FAO, 1995; Balali-Mood *et al.* 2021), however, the possible natural release of cadmium can occur due to volcanic eruptions and weathering of rocks. The main existence of cadmium in the environment is due to anthropogenic activities such as the disposal of waste products containing cadmium and industrial manufacturing (FAO, 1995; Green-Facts, 2015; Balali-Mood *et al.* 2021). Cadmium particle forms are likely to move from one place to another by either wind or can be washed away by water, and can reside in the environment for many years as Cd is insoluble and also non-biodegradable. Cadmium also has the potential to accumulate in human vital organs and subsequently cause harm (Effendi *et al.* 2016). A human exposed to Cd is at risk of suffering from emphysema/lung and kidney diseases. It is also linked to liver damage and degenerative bone diseases (Mahurpawar, 2015; Balali-Mood *et al*. 2021). In the environment, Cd effects are linked to the inhibition, and abnormalities in plant growth by interfering with nutrients needed by plants for development (Rodríguez-Eugenio *et al.* 2018).

2.2.3. Chromium (Cr)

Chromium is a silver-like metal with a blue tinge and naturally exists in the earth's crust such as rocks, and volcanic dust at a low concentration level (Sharma *et al.* 2020). Chromium varies in oxidation forms from Cr (II), Cr (III) to Cr (VI), with trivalent (Cr III) and hexavalent (Cr VI) being the most common forms of chromium. The levels of toxicity and chemical properties vary, with Cr (II and III) being less toxic than Cr (VI) (Singh and Kalamdhad, 2011; Oliveira, 2012; Sharma *et al.* 2020). The effects depend on the oxidation state, duration of exposure, and uptake levels and are highly detrimental to living organisms (Oliveira, 2012). Cr (III) is a macronutrient and is listed as one of the essential trace elements as it is used in brewer's yeast, grain, and wheat germ at a safe allowable concentration, however, it can be poisonous at elevated concentrations. Cr (VI) is highly soluble in water, and very mobile in the environment as it has the potential to move through the soil profile to contaminate groundwater and subsequently food chains (DWAF, 1996; Shanker *et al.* 2005; Sharma *et al.* 2020). Apart from its natural existence, chromium is released through anthropogenic activities such as solid waste deposition containing by-products, and it is widely used in industrial processes (DWAF, 1996; Oliveira, 2012; Balali-Mood *et al.* 2021). Chromium exposure in humans could be through breathing air containing chromium dust /vapours and the ingestion of food and water containing chromium (Balali-Mood *et al.* 2021). Human exposure to Cr is linked to skin ulcers and other dermal-related conditions, respiratory conditions such as asthma, shortness of breath, liver and kidney damage (Mahurpawar, 2015; Balali-Mood *et al*. 2021). In the environment, Cr effects are associated with the suppression of root, stem, and leaf growth and are also associated with biochemical and physiological disorders in plants (Oliveira, 2012).

2.2.4. Copper (Cu)

Copper is a reddish essential element, which exists naturally in the environment due to decaying vegetation and forest fires among others. Cu exists in various oxidation forms such as metallic copper, cuprous copper and cupric copper. Cu is known to be a good conductor of electricity and heat, with a low chemical reactivity (DWAF, 1996; Lenntech, 2022). Copper's oxidation form depends highly on pH. Cu is categorised as an essential element as it is one of the vital micronutrients needed by plants for growth by supplying nutrients and also assists in enzymatic activities, seed and chlorophyll production, assimilation of carbon dioxide and adenosine triphosphate (ATP) synthesis (DWAF, 1996; Nagajyoti *et al.* 2010; Asati *et al.* 2016; Gawryluk *et al.* 2020; Liu *et al.* 2021; Lenntech, 2022). Excessive sources of Cu pollutants in the environment can be due to a number of anthropogenic activities such as sewage effluent treatment plants, waste disposal sites, agricultural products, and fertilisers (DWAF, 1996; Lenntech, 2022). Exposure to excessive levels of Cu in humans is associated with carcinogenicity, liver and kidney damage, gastrointestinal distress, and red blood cell disorder amongst others (Mahurpawar, 2015). In the environment, soil in particular, Cu effects are linked with the reduced absorption of water and essential nutrients needed by plants for growth (Shabbir *et al.* 2020).

2.2.5. Lead (Pb)

Lead is a soft blueish-white metal, which is likely to be toxic to both human health and the environment, even at low concentrations. Lead exists in various oxidation forms and is highly ductile (DWAF, 1996, Balali-Mood *et al.* 2021). Lead metal uptake by plants normally occurs through the soil and is retained in roots, however, the uptake can be minimised by calcium and phosphorus application in soil (Asati *et al.* 2016). Pb is used in the manufacturing of batteries, paint, gasoline, and water pipes. Sources of lead are mainly anthropogenic and these include mining combustion of fossil fuels, milling and smelting of lead-containing metals, municipal and industrial wastewater discharge (DWAF, 1996, Balali-Mood *et al.* 2021). Lead tends to accumulate in air, sediments, soil, and water to subsequently contaminate/pollute (DWAF, 1996; Balali-Mood *et al.* 2021; Lenntech, 2022). Human exposure effects are linked to lung dysfunction, central nervous system damage, and anaemic conditions (Mahurpawar, 2015; Balali-Mood *et al*. 2021). In the environment, Pb exposure is linked to neurological effects in vertebrates and are also associated with reduced growth and reproduction in plants (DWAF, 1996; Nagajyoti *et al.* 2010; Asati *et al.* 2016; Rodríguez-Eugenio *et al.* 2018).

2.2.6. Zinc (Zn)

Zinc is a bluish-white essential element that is naturally present in the environment but at low concentrations (DWAF, 1996; Guarino *et al.* 2020; Lenntech, 2022). Zinc is categorised as an essential micronutrient that plays a significant role in human health and growth hence it is contained in some food sources, however, it must be at favourable limits (Nagajyoti *et al.* 2010; Singh and Kalamdhad, 2011; Lenntech, 2022). Zinc also plays an essential role in the environment by supplying nutritional proteins in soils, and also in plant growth and development (Gawryluk *et al.* 2020), as it is an enzyme cofactor (Nagajyoti *et al.* 2010; Asati *et al.* 2016; Guarino *et al.* 2020). Zinc is also known to stimulate plants to produce chlorophyll (Nagajyoti *et al.* 2010; Asati *et al.* 2016). A deficiency of zinc can have serious health effects on humans and plants, conversely, excessive zinc can have adverse effects (Asati *et al.* 2016). Anthropogenic activities are the main sources of unnaturally high zinc concentrations in the environment, including smelting processes and steel production, mining activities, waste containing zinc metal, and other industrial activities (DWAF, 1996). In soil, Zn is not highly mobile and can be easily absorbed and contained in the environment (Lenntech, 2022). Exposure to excessive levels of Zn metal in humans is associated with liver and kidney failure, enhanced Alzheimer symptoms, bloodstained urine, and gastrointestinal condition (Sharma and Agrawal, 2005; Singh and Kalamdhad, 2011). Excessive Zn in the environment may increase acidity in water, with the potential to pose a threat to aquatic ecosystems (Lenntech, 2022).

2.3. Heavy metal impact on grass

Heavy metals (HMs) are naturally present in the earth's crust at low favourable levels and their presence plays a significant role in plant growth, however, excessive availability can exert harmful effects on plants (Sharma and Agrawal, 2005; Rodríguez-Eugenio *et al.* 2018; Ali *et al*. 2019). The disposal and decomposition of waste materials in waste disposal sites release toxic substances that change the natural balance of nutrients in the soil which is needed for plant growth and development, then subsequently impact plant health and species diversity.

Plants and crops grown near waste disposal sites are potentially exposed to heavy metal pollution in the form of mobile ions through the roots or by absorbing heavy metals through the stomata of the leaves via foliar absorption (Olayiwola *et al.* 2017). The toxic and deadly effects of heavy metals vary with heavy metal content, plant species, type and the size of the plant, soil composition, and plant pH (Nagajyoti *et al.* 2010).

Syeda *et al.* (2014) studied the contribution of open waste dumping sites to decreased vegetation and its effects on plant diversity in Pakistan and found all analysed metals to be significantly high in the vegetation. Traditional herbs have been widely used worldwide, especially in Africa, for various purposes from diagnosis to curing diseases and these are mainly used by traditional doctors (Mahomoodally, 2013). Natural herbs are likely to grow anywhere, even near a landfill or dumping sites, and these medicinal plants are likely to accumulate heavy metals when grown in polluted land/soils (Okem *et al.* 2014). Humans using natural herbs as a medicinal remedy are also likely to be exposed to health risks when consuming potentially contaminated herbs (Okem *et al.* 2014; Zuma *et al.* 2016). With various forms of human exposure to heavy metal contamination or pollution, the food chain is considered a great risk to human health through the consumption of contaminated food or water. Food crops that are grown near closed or active landfill sites are likely exposed to heavy metals and other related contaminants from contaminated soil, and the ingestion of such food crops can significantly affect the consumer's health (Makuleke and Ngole-Jeme, 2020). Vongdala *et al.* (2019) assessed the accumulation of heavy metals in various plant species in and around a landfill site and found excessive heavy metal concentrations which exceeded the World Health Organisation (WHO) standards.

2.4. Heavy metals impact on soil quality

Soil is an integral part of the ecosystem (Nyika *et al.* 2020) and one of the crucial resources needed to sustain the environment, life and the well-being of humans and other organisms through food production and supply (Miller, 2007; Nyika *et al.* 2020). Soil pollution can occur through natural and/or anthropogenic processes. Landfill operations in particular are likely to result in soil pollution and degradation, whereby the services offered by soil will be compromised (Vaverkova *et al.* 2017). Soils are highly susceptible to the accumulation of heavy metals (Nyika *et al.* 2020) and are considered to be the ultimate sink for heavy metals that are discharged to the environment through landfilling and other related activities (Kanmani and Gandhimathi, 2013; Nyika *et al.* 2020). Kanmani and Gandhimathi (2013) assessed heavy metal contamination in soil due to leachate migrating from an Ariyamangalam open dump site in Tiruchirappalli, India, and found that the concentrations of several heavy metals in the soil exceeded acceptable standard limits. Vandana *et al.* (2011) also assessed heavy metal contamination (Ni, Cu, Zn, Pb, Cr, and As) in soil, near the hazardous waste disposal site in Hyderabad, India. The results showed high concentrations for all assessed metals in the soil and all exceeded the standard limits (Vandana *et al.* 2011), suggesting the probabilities of leachate migration or contaminated runoff from the landfill site into the soil.

Generally, soils are able to naturally break down most organic compounds found in waste and convert them into harmless substances, however, with inorganic compounds and their inability to break down, these subsequently accumulate in soil over time (Liu *et al.* 2013; Olayiwola *et al.* 2017; Altarez and Sedigo, 2019). Heavy metals can be naturally present in soils as some metals are part of the soil but at an optimal level, however, their excess concentrations can be considered toxic and likely to pose a significant threat to the soil in particular (Osmani *et al.* 2015). Heavy metal contamination is known to alter the soil microbial community composition and population activities (Singh and Kalamdhad, 2011). Soil microbes play a crucial role in nutrient cycling for crops and plants; they detoxify crop residues and injurious chemicals; and they replenish soil structures (Singh and Kalamdhad, 2011).

Healthy soil is a prerequisite for food chain security; once a pollution plume enters the agricultural or fertile soil, it pollutes/contaminates and subsequently threatens food production for animals and humans (Liu *et al.* 2013; Rodríguez-Eugenio *et al.* 2018). Soil contamination can be defined by the presence of chemical concentrations or any related substances in soil which is out of place at a level higher than natural existence, with the prospect to exert adverse effects on human health and the environment (Rodríguez-Eugenio *et al.* 2018). Soil is the most common pathway of heavy metal contamination to plants and eventually to humans through the food chain (Rodríguez-Eugenio *et al.* 2018).

2.5. Heavy metals impact on surface water quality

Anthropogenic activities are known dominant sources of pollution in the environment specifically in water resources (Miller, 2007; Vongdala *et al.* 2019). Stream health is likely to deteriorate due to changes caused by physical, biological, and chemical stressors and these stressors are mainly induced by industrialisation, waste disposal-related activities and exponential population growth (Miller, 2007), however, it should be noted that there are naturally induced water quality challenges as well. Streams and rivers are challenged by uncontrolled exposures to micro-pollutants and pollutants which may enter through accidental spillages and storm water runoff during heavy rainfalls (Wijngaard *et al.* 2017; Vaverkova, 2019). The deposition of heavy metals into streams and rivers also involves leaching into groundwater, moving along water pathways and or being washed away by water run-off into the streams and rivers during heavy rainfalls (Mahurpawar, 2015). Heavy metals move as dissolved species or as part of suspended sediments in rivers and streams (Nagajyoti *et al.* 2010), unlike other aquatic environments, streams and rivers are likely to naturally recover from pollution at certain limits and the self-recovery can be influenced by the river flow velocity, water volume, and the amount of pollution content among other things (Miller, 2007; Zubaidah *et al.* 2019). Water pollution due to pollutants emanating from the hazardous and non-hazardous waste has been a serious issue in developing countries, as most of these countries lack proper waste management technologies and other appropriate expertise to prevent the contamination of streams, rivers, and /or groundwater (Miller, 2007). An investigative study conducted in Nigeria to determine the environmental impacts of landfill site operations on groundwater quality revealed that the dumpsite systematically pollutes or contaminates groundwater. However, the levels of contamination were solely dependent on the proximity to the dumpsite, leached doses, and duration of exposure (Akinbile, 2012; Vongdala *et al.* 2019). In surface water, heavy metals can adsorb to sediments (Singh and Kalamdhad, 2011) and the non-biodegradability of heavy metals worsens the devastating effects in the aquatic environment as they remain in the environment for a longer period (Singh and Kalamdhad, 2011). Worldwide, including South Africa, stringent waste management measures were developed to minimise possible environmental pollution from waste disposal sites through waste legislation, regulations, and policies (DWAF, 1998; Godfrey and Oelofse, 2017; Vaverkova *et al.* 2017).

2.6. South Africa's legal framework on waste management

In the past, there were no laws and regulations on proper waste management, and no stringent measures were in place for waste disposal and burial, hence landfills were built without engineered liners or leachate collection systems. Historically in South Africa, the implementation of waste management began with the Environment Conservation Act (No.73 of 1989), which legally defined waste and the promulgation of the legislation focused mainly on the requirements of waste management which included the permitting, control, and managing of waste disposal sites to ensure that any waste disposal operations were permitted and adhered to stipulated conditions.

In 1994, the Department of Water Affairs and Forestry (DWAF) developed the minimum requirements documents with the technical guidance of handling, classification and disposal of waste, and these were later replaced by the National Norms and Standards for the assessment and disposal of waste for landfill sites (DWAF, 1998; Godfrey and Oelofse, 2017). The Constitution of the Republic of South Africa (Act No.108 of 1996) under environmental rights, Section 24, includes two components which stipulate the following: - (a) "everyone has the right –to an environment that is not harmful to their health or well-being” and (b) “to have an environment protected for the benefit of present and future generations through reasonable legislative and other measures that prevent pollution and ecological degradation, and promote conservation".

In the year 2000, The White Paper on Integrated Pollution and Waste Management was also developed, with integrated waste management focussing on three components, namely reuse, reduction and recovery of waste (Godfrey and Oelofse, 2017). In 2008, the National Environmental Management: Waste Act (59 of 2008) was developed and promulgated, later amended in 2014. NEM: Waste Act, 59 of 2008 was developed as a proactive tool to achieve integrated waste management which aimed at protecting human health and the environment by providing practicable and reasonable measures to prevent pollution and environmental degradation while ensuring sustainability [NEM: WA (No.59 of 2008)]. In 2012, the National Waste Management Strategies (NWMS) were developed to achieve the objectives of the Waste Act by encouraging the minimisation of waste generation and environmental impacts associated with improper waste management (Bosch Munitech, 2016; Godfrey and Oelofse, 2017).

The National Norms and Standards (NNS) for waste management were developed to guide licensing, control measures on waste management activities and to ensure compliance with the relevant legislation (NEM: Waste Act, 59 of 2008). In South Africa, the responsibility for waste management was assigned to the local government (municipalities), which is also responsible for monitoring the waste management activities and operations to ensure compliance with the relevant legislation (Roberts, 2013).

2.7. Status quo of landfill sites in KwaZulu-Natal

Although South Africa's waste legislation is in line with global waste management trends, the monitoring and enforcement processes have been difficult due to a lack of suitable waste skills, and practices. In 2004, a survey was conducted in the province of KwaZulu-Natal, to assess the status quo of waste disposal sites and the assessment revealed that there were then approximately 99 waste disposal sites, both legal and illegal, in all 10 districts of the province (Muswema, 2004). Generally, the majority of waste disposal sites in KwaZulu-Natal are not appropriately located as most are located near residential areas, high water tables, and/or adjacent to streams. There were many unregistered sites in the province with common problems such as non-compliance with waste management laws and regulations (Muswema, 2004). Some sites were improperly built and poorly managed because of poorly implemented policies, lack of resources, and technical expertise (DWAF, 1998; Godfrey and Oelofse, 2017; Ferronato and Torretta, 2019).

The latest 2021 report on the status quo of waste management in the province revealed that the number of waste disposal sites has tripled since 2004, with minimal compliance or improvements, as there are a total of 339 sites in KwaZulu-Natal with only 107 legally registered sites and 232 illegal dump sites (Magubane, 2021).

2.8. Landfill Site A–Case Study Description

The study area experiences mostly humid, warm, and sunny weather with light rain throughout the year and summer being the wettest season. Temperatures in winter range approximately from 16°C to 23° C and in summer from 28°C to 33° C (IDP, 2019/2020). The study area is rich in biodiversity, ranging from the coastal ecosystem to the valleys covered mostly by grasslands and dense forests, hence the importance of safe-guarding the environment from any effects of pollution (Bosch Munitech, 2016). The main vegetation found near the site includes shrubs, grasses, forests, and sugarcane fields along the northern side of the landfill site. The landfill site is approximately 1km away from the nearest residential area and there is a high concentration of people living in the area, specifically along the eastern and southern sides of the site, with low income and insufficient employment opportunities (Kruger, 2010; Bosch Munitech, 2016; IDP, 2019/2020). The area is characterised by different socio-economic conditions and various communities' expectations when it comes to the environment and its safety. It also has rich agricultural land and most people who reside in the area are dependent on agricultural and other related activities for income. The consequences of pollution do not only affect the surrounding environment but also the social life and economy of the local residents (Bosch Munitech, 2016; IDP, 2019/2020).

The topography of Landfill Site A comprises of a wide valley, steep and sloping southwards (sloped surface), with the site draining towards stream A. There are streams near the landfill site (upstream and downstream), a dam, and nature reserve which are approximately 5km away from the site. The landfill site has been operating for more than three decades and is permitted to accept various waste types, from type one to type four (as per the National Waste Act, No. 36 of 2008).

Chapter 3: Methodology

The chosen methodology involved two broad approaches to data collection, a quantitative approach, which entailed collecting grass, soil, and surface water samples near Landfill Site A, to determine the levels of heavy metals and potential impact, and a qualitative approach which entailed interviews with local residents to investigate the community's perception and awareness of health and the environmental-related risks associated with living in close proximity to the landfill site.

3.1. Pollutant selection

The leachate produced from landfill sites contains several dissolved heavy metals such as antimony, arsenic, lead, nickel, calcium, cadmium, iron, barium, mercury, manganese, potassium, magnesium, nitrite, cyanide (total), and chromium (total and VI) among others (see Giang *et al.* 2018). However, only six heavy metals, namely arsenic (As), chromium (Cr), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn), were selected for analysis, as leachate produced from the landfill site contain these metals amongst others. The chosen metals are considered the main toxic metallic elements as their presence is difficult to detoxify once they have entered the environment (Mahurpawar, 2015). Metallic elements also exert toxic and harmful effects on human health and the environment when in elevated concentrations such as Cu and Zn, whereas As, Cd, Cr, and Pb are toxic even at low concentrations (Hussein *et al.* 2020), with the potential to result in death. Previous studies indicated that these are the most environmentally relevant hazardous heavy metals (Ali *et al*.2019) and the most toxic metallic elements which induce human poisoning (Jaishankar *et al*. 2014; Balali-Mood *et al*. 2021).

3.2. Site selection and sample collection

The selected heavy metals were measured in surface water, soil, and grass samples at several sampling points to determine heavy metal content/concentration. The following sampling points (Figure 3) were identified for data collection, namely the stream A (below the landfill site), the grazing land (surrounding the site as local livestock was observed grazing), and the stream above the landfill site (upstream). Sampling point 1 was just below and adjacent to leachate/ storm water dam one (central stream) and sampling point 2 was identified adjacent to the leachate/ storm water dam two (downstream). Sampling point 3 was identified on the northern side of the landfill site (upstream), which was accessible since it is not privately owned and there was no leachate dam or any waste burial activities taking place. The upstream (control site), was located at an elevation of 542m, above the elevation of the landfill site, while central and downstream sampling points were located at an elevation of 424m and 339m respectively, lying lower than the landfill site. A handheld E-trex GPS was also used for geographical location recordings for all sampling points. Sampling was done at various sites approximately 50m apart downhill and uphill from the landfill site, and to determine levels of heavy metals and their potential impact. All samples were taken outside the landfill site as access to the site was denied, however, accessing the sampling sites was a challenge due to the dense growth of bushes and trees (thick vegetation).

A total of 27 (n=27) samples was taken across all three sampling points (central stream site, downstream site, and control site upstream), and were coded SS1-SS9 (soil samples); SW1-SW9 (surface water samples); and SP1-SP9 (grass samples). All sample analysis was done by Mintek, which is a SANAS-accredited laboratory, and ISO 17025 compliant for testing laboratories.

All solid samples were taken using non-metallic equipment to avoid sample contamination with metallic equipment. Soil and grass samples were stored in sampling paper bags to avoid plastic moisture during transit. Glass bottles with tightly sealed lids were used for surface water samples. Sample bottles and equipment used were washed thoroughly with distilled water before use, and this process minimises the likelihood of biased science experiment outcomes, as distilled water is pure and free from contaminants (Wong and Xiangdong, 2003; Hoenig and de Kersabiec, 1996). A weather forecast was considered for the days of sample collection as samples were taken on days when it had not rained for at least 4 days, because wet soil, in particular, is difficult to collect and mix and for surface water, to give a true reflection of a sample, rather than being diluted by rainwater. Samples were collected for two consecutive days (10-11 January 2022), due to distances apart, from sampling point 1 to sampling points 2 and 3 respectively. All samples were transported to Johannesburg for analysis.

Figure 3: Sampling points (source: Google Earth, 2023)

Physiochemical parameters (EC, TDS, and pH) were measured *in situ*, using calibrated hand held Smart Technologies meters (as per Adesewa and Morenikeji, 2017). The meters were submerged at approximately 10cm into the surface water, to take the readings and recorded accordingly for each and every liquid sample. Measuring these properties at the time of sampling was effective and accurate as they are likely to change during transit and storage.

Precautionary measures were taken during the sampling activity, to prevent any form of contamination from the outside and possible deterioration of samples before and while in transit to the laboratory. The inadequacy or ineffectiveness of precautionary measures may result in the deterioration and spoilage of samples; and other errors in sampling analysis can be associated with the pre-treatment stages of samples (Hoenig and de Kersabiec, 1996), hence the importance of precautionary measures throughout, from the sampling process to analysis.

3.2.1. Grass sampling

Grass was selected as the growth type for analysis, as livestock were observed grazing near the landfill site. A total of nine grass samples were extracted, with three samples collected per site. All grass samples (leaves and roots) were collected with a thoroughly cleaned plastic shovel, and a ceramic knife. Soils and other related debris were removed from the grass samples, and the grass was stored in a labelled paper bag [description (SP) and location (1)] (as per Mylavarapu *et al.* 1993). The paper bags were left open overnight in a cool room for air drying purposes, to minimise possible microbial growth (degradation) before transportation to the laboratory.

In the laboratory, samples were oven-dried at 70°C for five days. The drying process was done to minimise or limit the changes in the grass sample condition due to microbial activity. Once grass samples were completely dried, they were pulverized (ground into a fine powder) with a pestle/ mortar. A mass of 0.25g was weighed using an analytical balance instrument and transferred into a pressure-resistant reaction Teflon vessel (PTFE-TFM liners), onto which 6 ml HNO_3 and 2 ml H_2O_2 were added. The vessels were allowed to react for approximately 15 minutes prior to sealing (to avoid pressure build-up), placed inside the rotor, then into a Multiwave Go digester. The digester was set at 120 °C to decompose and dissolute until dissolved (grass matrix into solution form), and the purpose of adding drops of nitric acid in conjunction with a digester was for the decomposition of grass and dissolution of heavy metals. The vessels were then removed and vented carefully in a fume hood after cooling to room temperature. The solutions were transferred into 50 mL volumetric flasks and diluted with deionized water to the mark. The solutions were filtered through 0.22 µm PTFE syringe filters prior to analysis. The analysis was conducted through the ICP-OES (as per Wong and Xiangdong, 2003; Hussein *et al.* 2020). The levels of contaminants were determined by juxtaposing the results obtained from the laboratory with the WHO limit values.

3. 2.2. Soil Sampling

The soils collected had a loamy texture. A plastic shovel was used to prepare the soil sampling spots. A total of nine soil samples was taken in three different sampling points with three soil samples collected per site. The following thoroughly cleaned equipment was used: plastic shovel, plastic hand trowel, plastic measuring ruler, 5L plastic bucket, and sampling paper bags. Samples were taken at a 0-30cm depth to avoid natural contaminants in the topsoil layer e.g. from debris and animal dung etc. Soils were scooped and mixed (homogenized) in a bucket with a plastic hand trowel before they were transferred to a labelled paper bag [description (SS), and location (1)]. A mass of 50-100g of soil was collected at each sampling point; should there have been a need for reanalysis, sufficient soil was easily available.

In the laboratory, samples were oven dried at 70°C for five days, to remove moisture, and to speed up the drying process to limit changes in the soil sample condition due to microbial activities. Once soil samples were completely dried, they were finely ground (pulverised) using an agate mortar and pestle to break down larger particles (to increase homogeneity), filtered through a 2mm stainless steel sieve mesh to remove coarse debris and other unwanted materials, then stored in a sealed container for further processing (as per Mylavarapu *et al.* 1993; Wong and Xiangdong, 2003; Vandana *et al.* 2011; Ololade *et al.* 2019). A mass of 0.25g was weighed using an analytical balance instrument and transferred into a pressure-resistant reaction Teflon vessel (PTFE-TFM liners), to which 6 ml HNO_3, 2ml HCL, 1 ml HF (10% of the concentrated), and 0.5 ml H_2O_2 were added. The vessels were allowed to react for approximately 30 minutes prior to sealing (to avoid pressure build-up), placed inside the rotor then into a Multiwave Go digester. The digester was set at 180 °C to decompose and dissolute until dissolved. The vessels were then removed and vented carefully in a fume hood after cooling to room temperature. The solutions were transferred into 50 mL volumetric flasks and diluted with deionized water to the mark. The solutions were filtered through 0.45 µm then 0.22 µm PTFE syringe filters and diluted further (to reduce TDS) prior to analysis. The analysis was conducted through ICP-OES (as per Hussein *et al.* 2020; Wong and Xiangdong, 2003).

3.2.3. Surface water sampling

Stream A, downstream, and Stream B, upstream were identified for surface water analysis, since the location of the landfill site A is in a steep slope topography, sloping southwards surface towards the stream. Water quality was assessed along the central stream (adjacent to the leachate and storm water dam), downstream from the landfill site (also adjacent to the storm water dam), and the above stream from the landfill site. Livestock was also observed drinking water from the stream. The physical and aesthetic appearance of both the upstream and downstream sections of the river was fair. A total of nine surface water samples were collected, with three water samples per site (SW1-SW9), using new clean sampling glass bottles (250ml), rinsed with distilled water, and a triple rinse process was also performed where sampling bottles were triple rinsed with the water to be sampled. Standing downstream, the sampling bottle was held firmly with one hand near its base, the bottle opening was facing upstream to avoid any risks of hand contamination or any surface scum and debris, then quickly plunged into the water up to full capacity. A few drops of nitric acid were added (1:1) using a Pasteur pipette (as per Hoenig and de Kersabiec, 1996), then the bottle was tightly sealed with the bottle cap (as per SABS 241-1971). The acidification of water samples with nitric acid was done immediately to keep the $pH < 2$, and this process was done to prevent the adsorption of trace elements on the walls of sampling bottles for a relatively longer period (Hoenig and de Kersabiec, 1996). The samples were labelled [description (SW), location (1)], and stored in a cooler box with icepacks for rapid cooling and preservation during transit to the laboratory.

In the laboratory, the water samples were kept in the refrigerator for a few days while waiting for sample preparation. For analysis, samples were digested by adding a few drops of nitric acid, because of its oxidizing nature. Once the digestion process was completed, the solutions were filtered through 0.45 µm PTFE syringe filters and prepared for analysis. The analysis was done through the ICP-OES (Wong and Xiangdong, 2003; Hussein *et al.* 2020). For the results, the levels of contaminants were determined by juxtaposing the results obtained from the laboratory with the WHO limit values. It must be noted that ppm is equivalent to mg/l (e.g. 1ppm=1mg/l).

3.3. Community interviews

Fifteen questions were prepared for interviews (see Appendix 1) with local community members living near the landfill site, to investigate the community's awareness and perception of the environmental and health-related impacts of living near the landfill site. Both open-ended and closed-ended questions were used to collect the interview data. Participants included both males and females who were 18years of age and above, with all research ethics protocols observed (see Appendix 2 and Appendix 3). Participants from different households were randomly selected through a voluntary response as the researcher was knocking randomly on doors, seeing who opens the door and their willingness to participate in the survey. Only one member per household was interviewed to cover a bigger area in the targeted communities. Initially, there were twenty-three households targeted randomly in close proximity (1-2km away) to the site and twenty-three households furthest from the site (3-5km away), however, due to limitations and challenges that were anticipated, thirty participants were secured closer to the site (1-2km) and fifteen participants from further away (3-5km), totalling forty-five participants. Ethics clearance for human participants (non-medical) was obtained from Wits University's human (non-medical) ethics committee (protocol number: H22/06/30).

3.4. Data analysis

All samples were quantified using ICP-OES as it is one of the best methods to analyse heavy metals and most researchers use ICP-OES. It was chosen because it is able to measure a relatively large number of elements, from a very small sample (Hussein *et al.* 2020; Wong and Xiangdong, 2003). There were detection limits of <0.02ppm for lower limits and >100ppm for upper limits for all elements analysed. Statistical analysis was performed using Statistica Version. 14.0 and SPSS. The data gathered for the grass, soil, and water samples were assessed using an ANOVA. A one-way ANOVA with a Tukey post-hoc test was used to determine statistical significance between sites and the significance level was set at $p<0.05$. Primary data findings were compared to South African and WHO standard limits for heavy metal content (As, Cd, Cr, Cu, Pb, and Zn) in grass, soil, and surface water, to determine whether levels exceeded permissible limits. SPSS was employed for processing and analysing interview data. The interview data were coded and recorded on an excel spreadsheet and analysed through SPSS. There were separate codes assigned for participants living at 1-2km and 3-5km away respectively, to distinguish between the interview responses from both areas in terms of their awareness and perception of environmental and health-related issues associated with living near the landfill site. The data generated by the SPSS programme were graphically presented in the form of a clustered column, and clustered bar.

3.5. Pollution indices

Pollution indices were created as tools to guide, assess and evaluate comprehensive pollution risks in the environment (Kowalska *et al.* 2018), with the potential to determine whether contamination or pollution was induced by natural processes or human-related activities (Kowalska *et al.* 2018). For all calculations breakdown (see Appendix 4 and Appendix 5). Contamination factor (C_f) is an evaluation tool that can be used to determine the degree of individual heavy metal contamination and its toxicity in the environment. The contamination factor is determined as:

$$C_f = \frac{Cn}{Cb} \qquad (1)$$

Where Hakanson (1980), proposed the following:

C_f - represents the contamination factor (coefficient)

C_n – represents the heavy metal concentration of a sample

C_b – represents the natural background of each metal (reference value), which was obtained in the control site upstream.

Table 2 summarises the various Cf classifications based on the above calculation

Table 2: Contamination factors (C_f) for each single element (Hakanson, 1980).

Index values	Contamination Status
$C_f < 1$	Low contamination factor
$1 \leq C_f < 3$	Moderate contamination factor
$3 \leq C_f < 6$	Considerable contamination factor
$C_f \geq 6$	Very high contamination factor

Pollution load index(PLI) assesses the overall levels of measured metals and determines the degree of pollution in the environment, with PLI > 1 indicating “Pollution”; PLI < 1 indicating “No Pollution”. The Pollution Load Index is calculated as:

$$PLI = \sqrt[n]{Cf_{As} \times Cf_{Cd} \times Cf_{Cr} \times Cf_{Cu} \times Cf_{Pb} \times Cf_{Zn}} \quad (2)$$

Where, Hakanson (1980), proposed the following:

C_f - represents the contamination factor of the individual heavy metal

n- represents the number of measured metals (As, Cd, Cr, Cu, Pb, and Zn)

PLI- represents the pollution load index

Risk index (R*i*) is a tool to assess the potential risk of contamination and evaluate the potential ecological risks to the environment (Hakanson, 1980; Kowalska *et al.* 2018; Rostami *et al.* 2020). The ***Ri*** is calculated as:

$$Er = Tr \times Cf \quad (3)$$

$$R_I = \sum E_r \quad (4)$$

Where, Hakanson (1980), proposed the following:

C_f - represents the contamination factor (coefficient)

E_r - represents the potential ecological risk factor

R_I – represents the ecological risk index

T_r - represents the toxic response factor of a given substance (Hakanson, 1980)

Table 3 provides details on the potential ecological risk of contamination and ecological risk to the environment based on the above calculations

Table 3: Potential ecological risk (E_r) and ecological risk factor (R*i*) / index as proposed by Hakanson (1980).

E*r* class	E_r index	R*i* class	R*i* index
1	E*r* < 40 = low potential ecological risk	1	R*i* < 150 = low ecological risk
2	40 ≤ E*r* < 80 =moderate ecological potential risk	2	150 ≤ R*i* < 300 =moderate ecological risk
3	80 ≤ E*r* < 160=considerable potential ecological risk	3	300 ≤ R*i* < 600=considerable ecological risk
4	160 ≤ E*r* < 320 = high potential ecological risk	4	R*i* ≥ 600= very high ecological risk factor
5	E*r* ≥ 320= very high ecological risk		

Chapter 4: Results

To understand the potential impacts of toxic waste leachate on the surrounding environment, twenty-seven samples of grass, soil, and surface water were collected from three sites around the landfill site to test for heavy metals. Three samples of each were collected at each site for replication. As expected, heavy metal concentrations varied significantly between sample types and sites ($F_{156} = 55.8$; $p<0.001$). For the grass and surface water, it must be noted that South African standard limits were not available and it is for this reason that the World Health Organization (WHO) guideline limits for all the parameters were adopted in this study.

4.1.The concentration of heavy metals in grass samples

Of all analysed heavy metals (As, Cd, Cr, Cu, Pb, and Zn) in grass, As, Cu, and Zn showed the highest concentrations compared to the other heavy metals (Table 4). The arsenic (As) in grass appeared at high concentrations across all three sites, with a higher concentration mean of 1188mg/kg in the central stream sites and a lower mean of 1017mg/kg in the control sites, with no significant differences noted ($p>0.05$), however, concentrations levels exceeded WHO permissible limits of 0.2mg/kg (WHO, 2007). Cadmium (Cd) was only detected downstream (SP4), with a concentration mean of 2mg/kg across all downstream sites, whereas Cd was below detectable levels in the central and control sites. Cd concentration levels exceeded WHO permissible limits of 0.02mg/kg (WHO, 2010) and the results indicated that the downstream site was most affected by Cd contamination. Chromium (Cr) was only detected in the central stream area, at the highest mean concentration of 46mg/kg. Cr was significantly higher in SP1 and SP3 (central site; $p<0.001$) than in other sites, as it was below detectable levels (BDL) at both the downstream and control sites. The Cr concentration across the central stream sites exceeded WHO permissible limits of 1.3mg/kg (WHO, 2010) and the results indicated that the central stream was most affected by Cr contamination.

Copper (Cu) concentration was higher at the central stream sites (119mg/kg) than at the downstream (43mg/kg) and control sites (21mg/kg). Cu was significantly higher in SP2 (central stream; $p<0.05$) than in other sites. Cu concentrations across all sites exceeded WHO permissible limits of 10mg/kg (WHO, 2010), and the results indicated that the central stream was most affected by Cu contamination.

Lead (Pb) concentration was higher at the central stream sites (26mg/kg) than at the control sites (4mg/kg). Pb was significantly higher in SP2 (central upstream; $p<0.05$) than in other sites, however, Pb concentration also exceeded WHO permissible limits of 2mg/kg (WHO, 2010) across all sites and the results indicated that the central stream was most affected by Pb contamination.

Zinc (Zn) concentration was higher at the central stream sites (205mg/kg) than at the downstream (51mg/kg) and control sites (13mg/kg). Zn was significantly higher in SP1-SP6 (central and downstream sites; $p<0.01$) compared to other sites. Zn concentrations in the central stream sites exceeded the WHO permissible limits of 60mg/kg, whereas both the downstream and control sites were within the WHO permissible limits and the results indicated that the central stream was most affected by Zn contamination.

Table 4: Heavy metal concentration of grass (Mean± Std.-Dev) and WHO permissible limits (WHO, 1996; WHO, 1998; WHO, 2007; WHO, 2010; Osmani *et al.* 2015).

Location	**Site**	**As (mg/kg)**	**Cd (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
Central site	SP1,SP2,SP3	**1188**±177	<0.02	**46**±47.0	**119**±118.0	**26**±23	**205**±259
Downstream	SP4,SP5,SP6	**1107**±15	**2.0**±3.46	<0.02	**43**±47	<0.02	51±12
Control site	SP7,SP8,SP9	**1017**±185	<0.02	<0.02	**21**±11	**4.0**±6.9	13±13
Permissible limits(mg/kg)	WHO	0.2	0.02	1.3	10	2	60

4.1.1 Indices of heavy metal pollution and the extent of pollution in grass

To assess the degree of contamination due to heavy metal accumulation in the grass, the contamination factor (C_f) and pollution load index (PLI) were calculated. The control site values were used as background values (Cb) as pre-industrial values were not available. In the central stream area, the contamination status results indicated that Cr, Cu, Pb, and Zn contributed to very high contamination, whereas downstream, Cd showed very high contamination. For both central and downstream sites, the pollution load index showed high pollution in grass.

Table 5: Contamination factor (C_f) and Pollution load index (PLI) with ecological risk index (R*i*) in grass

Grass	Central grass			Downstream		
	C_f	T*r*	E*r*	C_f	T*r*	E*r*
As	1	10	12	1	10	10
Cd	1	30	30	100	30	3000
Cr	2300	2	4600	1	2	0
Cu	6	5	29	2	5	10
Pb	7	5	33	0.05	5	0.3
Zn	16	1	17	4	1	4
PLI	7459			38		
R*i*	4721 Very High Ecological Risk			3024 Very High Ecological Risk		

Contamination status				
Low	Moderate	High	PLI values >1-Pollution	High ecological risk

The potential ecological risk factor ($\mathbf{E}_r$) values for Cr (central stream) and Cd (downstream) showed significantly high potential ecological risk, with $\mathbf{E}_r \geq 4600$ and $\mathbf{E}_r \geq 3000$ respectively, whereas the $\mathbf{E}_r$ for all other metals (As, Cu, Pb, and Zn) across the sites indicated a low potential ecological risk (Table 5). The **R*i*** values, both central and downstream, displayed a significantly high ecological risk (Table 5).

4.2.The concentration of heavy metals in soil samples

Of all the heavy metals (As, Cd, Cr, Cu, Pb, and Zn) tested for in soil, As and Cu showed the highest concentrations compared to other metals (Table 6) across all 3 sampling areas, including the control site (upstream). The concentration levels exceeded the recommended South African standard limits (as per NEM: Waste Act, 59 of 2008), and WHO permissible limits (Table 6) (Lee and Lee, 2011; Chiroma *et al.* 2014). Cadmium (Cd) was omitted from the data table as it was below detectable levels.

At the depth of 0-30cm, the arsenic (As) in soil appeared at high concentration across all three sites, with a higher concentration mean of 1734mg/kg in the control sites and a lower concentration mean of 1605mg/kg in the downstream sites, with no significant differences noted ($p>0.05$), however, concentration levels exceeded SA's soil screening values of 5mg/kg (as per NEM: Waste Act, 59 of 2008) and WHO permissible limits of 20mg/kg (Lee and Lee, 2011; Chiroma *et al*. 2014) and the results indicated that As contamination affected all sites. Copper (Cu) concentration was higher in the central stream sites (310mg/kg) than in the downstream (218mg/kg) and control sites (211mg/kg). Cu was significantly higher in SS1-SS3 (central stream; $p<0.05$) than in other sites. Cu concentrations across all sites exceeded SA's soil screening values of 16mg/kg and WHO permissible limits of 100mg/kg (NEM: Waste Act, 59 of 2008; Lee and Lee, 2011; Chiroma *et al.* 2014) and the results indicated that the central stream was most affected by Cu contamination.

Chromium (Cr) concentration was higher in the control site (119mg/kg) than in the central stream (26mg/kg) and downstream sites (12mg/kg). Cr concentration was significantly higher in SS7–SS9 (control site) than in other sites. Cr concentration across the sites exceeded SA's soil screening values of 6.5mg/kg (as per NEM: Waste Act, 59 of 2008), whereas only the control site exceeded WHO permissible limits of 100mg/kg (Lee and Lee, 2011; Chiroma *et al.* 2014) and the results indicated that the control site was most affected by Cr contamination. Lead (Pb) concentration was higher in the downstream sites (61mg/kg) than in control sites (47mg/kg) and central stream sites (45mg/kg). Pb concentration was significantly higher in SS4-SS5 (downstream; $p<0.05$) than in other sites. Pb concentration across all the sites exceeded SA's soil screening values of 20mg/kg (as per NEM: Waste Act, 59 of 2008), whereas it was within WHO permissible limits of 100mg/kg (Lee and Lee, 2011; Chiroma *et al.* 2014) and the results indicated that the downstream was most affected by Pb contamination.

Zinc (Zn) showed a higher concentration in the central stream (113mg/kg) than in the downstream (78mg/kg) and control sites (13mg/kg). Zn concentration was significantly higher in SS1-SS3 (central stream) and SS4-SS6 (downstream; $p<0.01$) than in the control sites. Zn concentration across all sites was within SA's soil screening values of 240mg/kg (as per NEM: Waste Act, 59 of 2008) and WHO permissible limits of 300mg/kg (Lee and Lee, 2011; Chiroma *et al.* 2014), however, the results indicated that the central stream and downstream sites were most affected by Zn.

Table 6: Mean (± S.D.) heavy metal concentrations in soil and standard limits for different countries (mg/kg) Lee and Lee, 2011; Chiroma *et al.* 2014; Rodríguez- Eugenio *et al.* 2018; SA (NEM: Waste Act, 59 of 2008).

Location	**Site**	**As (mg/kg)**	**Cr (mg/kg)**	**Cu (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
Central site	SSI,SS2,SS3	**1657**±147	**26.6**±25	**310**±45	**44**.6±48	113.0±77
Downstream	SS4,SS5,SS6	**1605**.±130	**12**.0±21	**218**.6±112	**60.6**±24	78.0±54
Control site	SS7,SS8,SS9	**1734**±288	**119**±115	**211**±80	**47**±57	13.6±15
Permissible limits (mg/kg)	SA	5.8	6.5	16	20	240
	WHO	20	100	100	100	300

4.2.1. Indices of heavy metal pollution and the extent of pollution in soils

Both at the central stream and downstream sites, the contamination status indicated that Zn contributed to very high contamination; As, Cu and Pb contributed to moderate contamination, and Cr showed low contamination (Table 7). The overall pollution load index suggested that the central stream was severely polluted compared to the downstream, with a central stream PLI of 7.4 and downstream PLI of 4.

Table 7: Contamination factor (C_f) and pollution load index (PLI) with the ecological risk index (R_I) in soil

Soil	Central Soil			Downstream		
	C_f	Tr	Er	C_f	Tr	Er
As	1	10	10	1	10	9.1
Cr	0.2	2	0.4	0.1	2	0.2
Cu	1.4	5	8	1	5	5
Pb	1	5	5	1.2	5	7
Zn	8			6	1	6
PLI	7.4			4		
R_I	31.3 Low Ecological Risk			27.3 Low Ecological Risk		

Contamination status				
Low	Moderate	High	PLI values >1-Pollution	Low ecological risk

To further assess the potential and ecological risk of contamination in the soil, the potential ecological risk factor (**E_r**) and risk index (**R_I**) were calculated. The **E_r** values for all metals across the sites displayed a low potential risk (Table 7), therefore, the overall **R_I** indicated low ecological risk across all sites, which suggests minimal impact or risk in the surrounding soils.

4.3. Surface water characteristics and heavy metal concentrations

Surface water samples taken varied in pH, T°, TDS, and EC. The pH values ranged from 6.5 to 7.12 in all three sampling points (control site, central stream, and downstream), with a pH <7 for samples taken in the control site, which was more acidic than the samples taken in the central and downstream. The TDS and EC values were lowest at the control site. Surface water temperature ranged from 21-23°C (Table 8) and all physiochemical properties were within WHO standards across all sites. In surface water, the overall heavy metal concentration of As, Cr, Cu, and Pb varied per site, with As showing the highest concentration than other heavy metals. The arsenic (As) appeared at high concentrations across all three sites, with a higher concentration mean of 5.85ppm in the control stream and a lower concentration mean of 5.04ppm in the central stream, with no significant differences noted ($p>0.05$), however, concentration levels exceeded the WHO permissible limits of 0.01ppm (WHO, 2008; WHO 2017) and the results indicated that As contamination affected the streams across sites.

Chromium (Cr) concentration was higher in the control stream (0.32ppm) than in the central stream (0.1ppm) and downstream (0.04ppm). Cr was significantly higher in the control stream; $p<0.05$) than in the other sites. Cr concentration in the control stream and central stream exceeded the WHO permissible limit of 0.05ppm, whereas the downstream was within limits (WHO, 2008; WHO, 2011) and the results indicated that the control stream was most affected by Cr contamination. Copper (Cu) concentration was higher in the central stream and downstream than in the control site, however, no significant differences were noted and exceeded the WHO permissible limits of 0.1ppm across all sites (WHO, 2008; WHO, 2011). Lead (Pb) concentration was higher in the central stream than in the downstream and control sites. Pb concentrations were significantly higher in the central stream ($p<0.05$), however, concentrations exceeded the WHO permissible limits of 0.01ppm across all sites (WHO, 2008; WHO,2011) and the results indicated that the central stream was most affected by Pb contamination.

Table 8: Mean (± Std.-Dev) metal concentrations of surface water, physiochemical properties measurement in situ, and WHO permissible limits (WHO, 2008; WHO, 2011; Meride and Ayenew, 2016; WHO, 2017).

Site	**As (mg/l)**	**Cr (mg/l)**	**Cu (mg/l)**	**Pb (mg/l)**	**pH**	**TDS ppm**	**EC µS/cm**	**T° °C**
Central site	**5.04;** ±0.9	**0.1**; ±0.19	**0.33**, ±0.2	**0.32**, ±0.56	7.12	0.188	0.375	23
Downstream	**5.38**; ±0.19	0.04; ±0.06	**0.32**, ±0.10	**0.04**, ±0.07	7.02	0.176	0.354	21
Control site	**5.85**, ±0.44	**0.32**, ±0.30	**0.18**, ±0.08	**0.05**, ±0.08	6.5	0.081	0.166	22
Permissible limits)	0.01	0.05	0.1	0.01	6.5-8.5	500	400	30

4.3.1. Indices of heavy metal pollution and the extent of pollution in surface water

The heavy metal accumulation in surface water was calculated based on the CF and PLI. The control stream values were used as background values (C_b). At the central stream site, contamination status indicated that Pb contributed to high contamination; As and Cu contributed to moderate contamination, and Cr showed low contamination, whereas downstream, As, Cu, and Pb contributed to moderate contamination, and Cr showed low contamination. The overall pollution status in stream A suggests that the central stream site is severely polluted (PLI = 8) compared to downstream (PLI = 2).

Table 9: Contamination factor (C_f) and Pollution load index (PLI) with the ecological risk index (R_I) in surface water.

Surface water	Central stream			Downstream		
	C_f	Tr	Er	C_f	Tr	Er
As	1	10	9.2	1	10	9.2
Cr	0.3	2	0.6	0.1	2	0.2
Cu	2	5	9	2	5	9
Pb	6	5	32	1	5	4
PLI	**8**			**2**		
R_I	51 Low Ecological Risk			22 Low Ecological Risk		

Contamination status				
Low	Moderate	High	PLI values >1-Pollution	Low ecological risk

The potential ecological risk factor (**E_r**) and risk index (**R*i***) indicators were also calculated to assess the potential and ecological risk of contamination in the surface water. The **E_r** values of As, Cr, Cu, and Pb across the sites showed low potential ecological risk, as all metals displayed **E_r** < 40 (Table 9). Therefore, the risk index **(R*i)*** suggested a low ecological risk (R_i <150).

4.4. The community's awareness and perception of the possible environmental and health-related issues

For this study, to investigate the community's awareness and perception of the possible environmental and health impact of toxic substances leaching from landfill site A, a set of interview questions was formulated to investigate communities living in close proximity to the landfill site. Only two communities were interviewed for the survey, which are Community A (1-2km away) and Community B (3-5km away). Community A is located on the eastern and southern sides of the landfill site, and the downstream site is closer to the community with easy access, especially to the stream.

4.4.1. Demographic data

A total of 45 participants (n) were interviewed, with 24% males and 76% females. The study survey targeted all within South Africa's legal age group (18+), however, the majority of participants were 36 years of age and above (Figure 4).

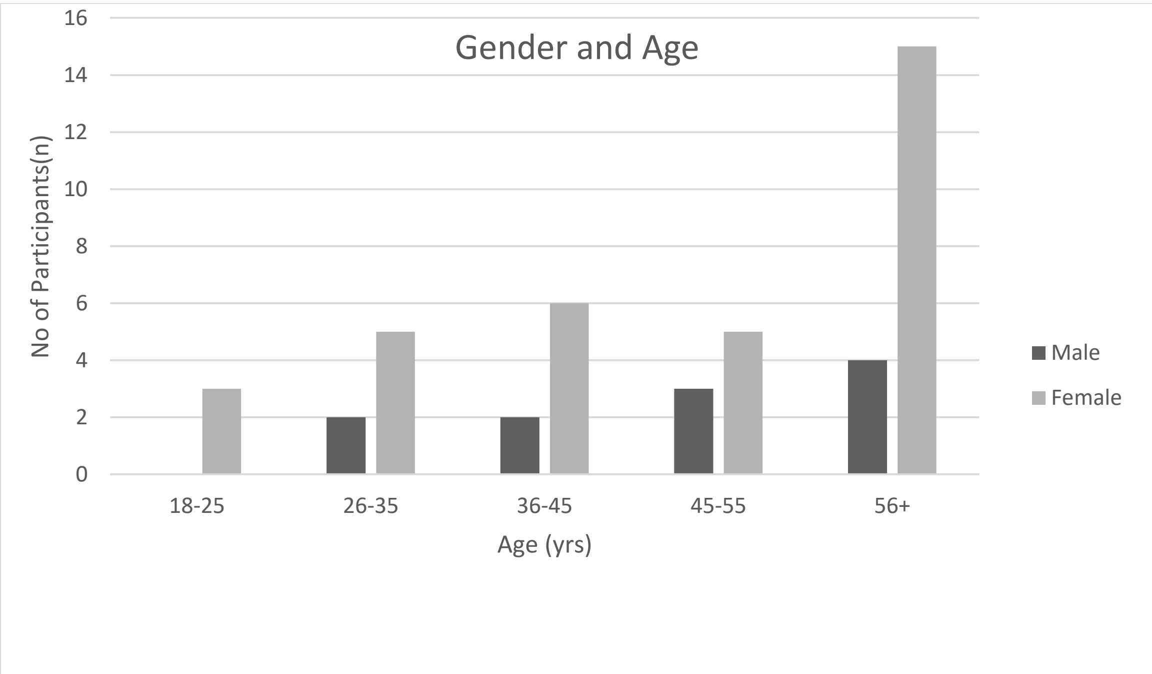

Figure 4: Gender and age groups

A total of 40% of the participants was unemployed, 29% were pensioners, 11% were doing temporary jobs as they indicated that they relied on callouts, 16% were full-time employed and 4% were self-employed as they had small businesses that were operating locally.

The majority of participants in both communities (51%) had attained the secondary level of education, (9%) had not attained any form of education, and this group was unable to read and write, (22%) participants have completed a tertiary level of education / still at the tertiary institution and the last group, (18%) only reached a primary level of education and they were able to read and understand the content of the project.

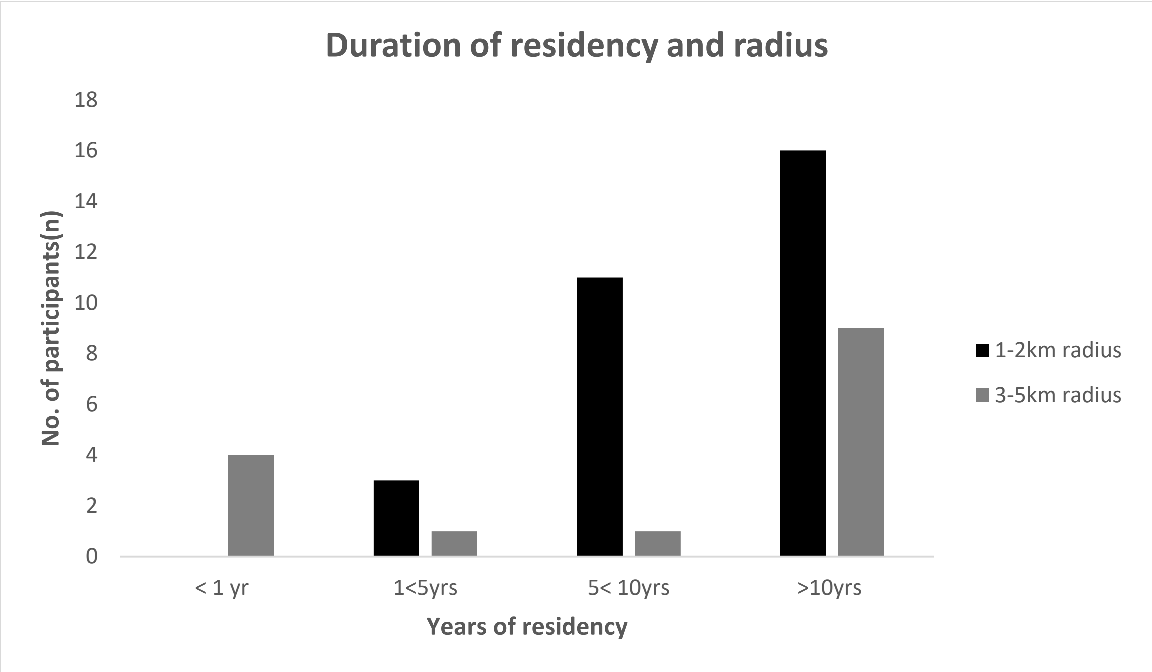

Figure 5: Duration of residency in proximity to the landfill site

Of all participants, 33% resided in a radius of 3-5km around the landfill site, while 67% resided within a radius of 1-2km; the duration of residency varied (Figure 5).

4.4.2. Environmental impact and related problems

About 57% of residents living within a 1-2km radius around landfill site A indicated that the major challenge was air pollution due to offensive odour from the landfill, whereas 87% of the participants living between 3-5km away also highlighted the same odour issue which dates back decades ago, although the odour intensity varied from time to time to both communities as prevailing winds are the contributing factor to odour intensity.

Another participant was quoted as,

"***the nightmare is far from over, as there is another proposed landfill site in the surrounding area. We saw on local papers and social media outlets that it was approved. With the new landfill proposal in the pipeline, it is evident that there won't be any break for residents as the municipality will be adding to the existing problem, and our rights to a clean and healthy environment are violated*".**

About 30% of participants living 1-2km away complained about water pollution, whereas 13% of participants living further away (3-5km) also indicated the same water pollution issues. Participants living closer to the site further revealed that from time to time, especially when taps run dry, they are using stream water for washing, cleaning, and other related purposes since there are water shortage issues in the area. They also highlighted that during the catastrophic floods in KwaZulu-Natal (April 2022), the situation worsened due to the burst pipes, damaged roads, and other damaged infrastructures which also contributed to the interrupted water supply service by the local municipality, as water tankers were unable to reach their communities to deliver water. They had no options but to consume stream water as the local municipality was busy fixing burst pipes that were destroyed by floods, which took longer than anticipated, with on and off supply from the taps. Participants living within 1-2km further highlighted that their livestock was also affected due to grazing in the landfill surroundings and drinking water from the stream, and one participant was quoted as,

"***Our livestock have been drinking water from the streams for years, some mystery dies, and no one knows the cause of death*".**

About 10% of participants living 1-2km away reported noise nuisance issues, whereas no noise issues were reported by participants between 3-5km away. Only 3 % within 1-2km complained about dust and other related nuisance due to the underway construction at the site, whereas participants who live further away had no dust or related nuisance issues. In both radius groups, the majority of participants indicated that they were not aware of any pollution measures in place to curb emissions and other related pollution, however, only one participant indicated that during the legal dispute between Community B residents, the landfill site, and authorizing departments, she saw on a local newspaper that local authorities are monitoring the landfill site operations. The participant further explained that the newspaper article reported that there were air emission monitoring stations at the south east of the site and northern side of the site, yet there was still an offensive odour in the surrounding area. For community involvement and information sharing regarding emission levels, all participants indicated that they do not know anything about emissions levels, and none of the participants has ever attended environmental monitoring meetings.

4.4.3. Perceived health impacts

In both communities A (1-2km away) and B (3-5km away), headaches are the most common complaint, followed by asthmatic conditions and respiratory-related conditions. Other ailments that were highlighted included fatigue, eye irritation, sinusitis, and dizziness due to the stench emanating from the site. Some participants indicated that their health conditions are deteriorating due to the conditions they live in. A participant from community A (1-2km) further highlighted that in the year (2021) there was a massive fire, as they saw a massive flame from a distance, and further explained that the fire brigade was all over the site trying to extinguish the fire. It was also highlighted that they do not feel safe, with the fear that maybe one day they will be forced to evacuate their homes because there are hazardous and flammable chemicals dumped at that site.

In both communities, on swimming and fishing activities in stream A and the river where the stream drains, only (15%) indicated that as much as they cannot guarantee that children do not swim in the stream, however, they have seen local children going to the river for fishing and playing by the river /stream, whereas the other 85% have never seen children swimming, fishing or playing by the stream. It was further highlighted that they were not aware of any health-related issues due to swimming/playing as to their knowledge, none of their children have played or swim by the stream. On hunting and related activities, of 45 participants, only 2% indicated partaking in non-professional hunting activities and the other (98%) do not partake in hunting activities or consume hunted meat. Hunters indicated that they had no issues and that their hunting dogs are healthy as they have been hunting for years and consume wild meat without any health-related issues.

Chapter 5: Discussion

Anthropogenic activities have been a significant concern in the environment and public health globally as they release toxic heavy metals and other related pollutants into the environment. Several studies suggest that landfills remain a major source of pollution in the surrounding environment through leachate seepage containing heavy metals and organic compounds amongst other things (Makuleke and Ngole-Jeme, 2020). This study aimed to investigate the potential impacts of toxic waste leachate from the landfill site on grass, soil, and surface water in its vicinity. This was achieved by assessing heavy metal concentrations in grass, soil, and surface water samples in the vicinity of the landfill site. The study was further extended to the local residential areas to investigate the community's awareness and perception of the environmental and health-related impacts of living near the landfill site.

5.1.Heavy metals in soils and grass

Heavy metals have been considered the most significant pollutants in the environment due to their toxicity, persistence, bio-accumulativeness in nature, and inability to bio-degrade easily (Sharma and Agrawal, 2005; Singh and Kalamdhad, 2011; Ali *et al.* 2019). In the biological system, some metals such as As, Cd, Cr, and Pb are categorised as "threat metals" due to their non-beneficial effects in living organisms, and a high degree of toxicity even at low concentrations (Ali *et al.* 2019; Briffa *et al.* 2020; Hussein *et al.* 2020), whereas metals such as Zn and Cu are categorised as "essential metals" as they have beneficial effects to living organisms, to human health and certain plants at an optimal level; however, studies also indicated that even essential metals can be harmful in excess levels (Asati *et al.* 2016).

The heavy metals contamination found in soil and grass at three sampling sites around the landfill site accumulated in the following order: soil -Zn>Cu>Pb>As>Cr, with Cd below detectable levels; and grass - Cr>Cd>Zn>Pb>Cu>As. Arsenic (As) showed no significant differences in soils and grasses across all sites as it showed high content across sites, including the control site, which also exceeded WHO limits, suggesting another potential pollution source in the vicinity, other than the landfill site. The arsenic (As) metalloid element is known to occur naturally at a low concentration of approximately 2mg/kg, however, the content found in grass and soil was above 1000mg/kg, and based on the results, this was not an indication of the natural sources but anthropogenic activities. The overall contamination status in both soil and grass indicated that central and downstream areas were more contaminated with heavy metals than the upstream control, strongly suggesting that the additional contamination does in fact originate from the landfill site. In nearly all cases, the heavy metal concentrations exceeded the South African limits and WHO permissible limits, which was an indication of potential toxicity exposure to human health and the environment in the surroundings. The collected soil had a loamy texture and this texture is characterised by high porosity and permeability, with the potential to influence leachate mobilisation into the surroundings (Makuleke and Ngole-Jeme, 2020). Zn was the main contamination factor in soil, whereas Cu, Pb, As, and Cr displayed moderate to low contamination in both central and downstream soils.

This study shows similarities with other studies which have reported significantly high levels of Zn, Cr, Pb, As, and Cu in soil, compared to the control site in the vicinity of Round Hill Landfill, in Eastern Cape and another study that reported high levels of Zn in soil within the landfill area (Vongdala *et al*. 2019). The contamination levels of Cr, Cu, Pb, and Zn in particular were also comparable to the study done in Laos (Vongdala *et al*. 2019). Cu concentrations found in soil exceeded South African standards and WHO permissible limits across sites, while Cr concentrations only exceeded South African standards, and these show similarities with a previous study in Zimbabwe which also found high levels of Cr and Cu in the soil around the landfill (Makuleke and Ngole-Jeme, 2020). All these metals are commonly found in the industrial activities, and the industrial waste is ultimately deposited in the landfill site (DWAF, 1996).

Compared to soils, grass samples contained higher levels of contamination, with Cd, Cr, Cu, Pb, and Zn contributing significantly to high contamination, and central and downstream sites being extremely polluted (PLI=7459 and PLI=37 respectively), suggesting a very high ecological risk in the surrounding grasses in the vicinity of the landfill site. This study showed a similar pattern to the study previously conducted by Olowoyo *et al*. 2011, in the waste dump site in Pretoria, South Africa, which reported high levels of Cr in edible plants (medicinal) within the landfill site, however, Cu, Zn, and Pb reported low levels, which were also within WHO permissible limits (Olowoyo *et al*. 2011). Okem *et al*. (2014) also reported levels of Cd, As, and Pb in South African medicinal plants, even though Pb and Cd were lower than As (Okem *et al*. 2014), however, they are known to exert toxicity even at low concentrations (Hussein *et al.* 2020).

The high presence of these metals in soil and grasses possibly exists due to their ability to absorb and retain pollutants over a long period (Asati *et al.* 2016; Vongdala *et al*. 2019). The studied pollutants are known to alter soil properties with the likelihood to affect plant processes, crop production, and eventually human health through the food chain (Nagajyoti *et al.* 2010; Singh and Kalamdhad, 2011; Asati *et al.* 2016; Gawryluk *et al.* 2020). Heavy metals exert toxic effects on soil biota and affect microbial processes, which play a key role in maintaining soil structure and quality, recycling nutrients needed by plants, and also controlling plant pests (Singh and Kalamdhad, 2011). Previous studies found that in soil, Cr, Pb, and Zn alter the composition of soil microbial communities, reduce soil productivity by inhibiting nutrient uptake needed by plants for development/growth, and form insoluble compounds to exert detrimental effects on microbial cell metabolism (Nagajyoti *et al.* 2010; Asati *et al.* 2016; Gawryluk *et al.* 2020).

With the landfill site located approximately 1km away from the nearest residential area, livestock was also observed grazing in the central and downstream sites where significant levels of Cr, Cd, Cu, and Pb were found. Heavy metal pollution is known to pose a serious threat to livestock and other wildlife grazing on contaminated or polluted land and previous studies suggested that livestock grazing on highly contaminated land were likely to suffer acute and chronic effects of exposure, which include haemorrhagic diarrhoea, severe stomach inflammation, and intestinal tissue damage (DWAF, 1996; Green-Facts, 2015; Lenntech, 2022). In this regard, some interview participants highlighted that their livestock has been grazing in its vicinity and died without any obvious cause.

Heavy metals contamination is known to be more dominant in aquatic and terrestrial ecosystems than in the atmosphere as it disperses as particulates or vapour form, which ultimately returns to land either as dry or wet deposits to contaminate and pollute (Sharma and Agrawal, 2005; Asati *et al.* 2016; Ali *et al.* 2019); it stands to reason that the significant high levels of Cu, Pb, and Zn in soil and Cd, Cr, Cu, Pb, and Zn in grass found in the central and downstream sites may have been influenced by the high presence of these metals in the terrestrial ecosystem and their ability to absorb them. The central and the downstream sites were close to the leachate pond and storm water dam, with the central stream located at an elevation of 424m and downstream at 339m. It should be noted that the soil texture in the landfill area and the topography of the landfill site are among the characteristics that influence the migration and the speed at which leachate infiltrates into the surroundings (Makuleke and Ngole-Jeme, 2020). Soils are known to be highly susceptible to the accumulation of heavy metals (Kanmani and Gandhimathi, 2013; Nyika *et al.* 2020) and are the most common pathway of metals concentration to plants and the food chain (Rodríguez-Eugenio *et al.* 2018). However, in this study, grasses in particular accumulated more metals compared to the soils, and this may be due to their ability to absorb and retain them in the roots for a longer period (Asati *et al.* 2016; Vongdala *et al*. 2019). Therefore, it must be considered that potential toxicity exposure and risks are monitored to minimise further pollution in the ecological community.

5.2.Heavy metals in surface water

Water resource pollution has been a critical environmental issue globally, due to the ecological risk pollution poses to the aquatic ecosystem and human health (Ali *et al.* 2019). Water has the potential to dissolve various organic and inorganic particles and other related pollutants as it is considered the universal solvent (Miller, 2007; WHO,2011). Rivers and streams are known to self-recover from pollution, however, the natural recovery process can be influenced by the amount of pollutants and the stream or river flow velocity among other things (Zubaidah *et al.* 2019). In this study, the heavy metals contamination found in the surface water accumulated in the following order -Pb>Cu>As>Cr, with Cd and Zn below detectable levels. The overall contamination status indicated that the central stream and downstream stream water were more contaminated than the upstream control. Cr, Cu, and Pb concentrations exceeded WHO permissible limits in the central stream area, with Pb showing higher contamination than other metals.

The findings of this study show similar patterns to those of previous studies which have reported significantly high levels of Pb and As in the vicinity of the Roundhill Landfill in the Eastern Cape-South Africa, which also poses harmful effects on the environment and human health (Mepaiyeda *et al*. 2020). The excessive presence of Pb in surface water can be linked to high quantities of Pb containing waste material such as batteries and paint which are ultimately deposited into the landfill site (Balali-Mood *et al.* 2021) and the results may suggest that there is a high presence of these metals in the landfill leachate, and potentially seeping or being washed away into the stream. In this study, the streams are located just below the steeply sloped landfill site, and the central and downstream sites are close to the leachate pond and storm water dam, where the polluted water potentially flowed to and contaminated surface water and the surroundings. Previous studies also indicated that heavy metals deposition into streams and rivers involves moving along water pathways or being washed away by water run-off into the stream or rivers during heavy rainfall (Mahurpawar, 2015; Wijngaard *et al.* 2017;

Vaverkova, 2019) and that the topography of the landfill site is also known to influence the mobilisation of landfill leachate containing metals into the nearby water sources (Olayiwola *et al*. 2017).

The accumulation of significant levels of Pb in the surface water presents significant problems to aquatic life and adverse health effects to people living in the vicinity of the potentially polluting source and consuming water from the untreated source. In this regard, interview participants in the surrounding area indicated that they were consuming water from the stream during catastrophic floods in April 2022, and these results suggest that the stream is in fact unsafe for consumption. Livestock was also observed drinking water from the stream, with the potential exposure to Pb, Cu, and Cr which are linked to haemorrhagic diarrhoea, abdominal pain, severe inflammation of the stomach, and intestinal tissues in animals/livestock, however, the severity of these conditions differs between species and their system as the threshold limits differ from poultry to cattle (DWAF, 1996). Therefore, this study suggests that the significant heavy metal contamination found in the stream may exist due to the landfill site operation and leachate seepage since leachate is known to migrate through the layers of soil to enter and contaminate the surface water. The heavy metal contamination may have then escalated further in the landfill and the surroundings due to heavy rainfall and a large released volume of water, which was triggered by the tripping of a few hydro-plus fuse gates of dam A, which is a safety mechanism or feature, designed to release excess water in order to prevent overflow of the dam when the water reaches a certain level. The hydro-plus fuse gates tripped due to the intensity of heavy rain in the surroundings, as the western side of Durban in KwaZulu-Natal was severely affected by the catastrophic floods.

5.3.Community perception of health effects

Living in close proximity to landfills has been a great concern due to health and environmental risks linked to various pollutants emanating from landfills (Njoku *et al.* 2019). There is a high concentration of people living in the surrounding residential areas, specifically on the eastern and southern sides of Landfill A, and the area was frequented by people who are affected by poverty due to insufficient job opportunities and/or low income. In the survey conducted on the surrounding communities (Communities A and Community B, located 1-2km and 3-5km away respectively), their awareness and perception of the risks of living near the landfill site indicated that people living in close proximity to the landfill were likely more exposed to health and environment-related risk than people living further away from the potential polluting source. The results on health and environmental-related issues from the community's perception revealed that their major concerns were air pollution and water pollution, followed by noise and dust nuisance, however, the mostly affected participants were those living within a 1-2km radius, compared to participants living between 3-5km radius; their concerns were mainly air pollution. The respondents of those living within 1-2km (57%) indicated serious concerns of air pollution, with malodour/odour problems, whereas 87% of respondents living between 3-5km also indicated the same problem, and all associated these problems with their deteriorating health condition. This study suggests that they might be other pollutants as well in the surrounding environment, however, the lived experiences of residents specifically link their pollution problems to the existing landfill site as they highlighted that specifically air and water quality has changed over the years due to the existence of Landfill Site A in the vicinity.

The noise and dust nuisance concerns were frequently reported by respondents living closer to the landfill site due to the construction underway as there is a landfill site extension, whereas respondents living further away did not report any noise and dust issues. In this regard, headaches, followed by asthmatic and respiratory distress, were most frequently reported by both community participants, whereas those living within 1-2km further highlighted ailments which included fatigue, eye irritation, sinusitis, and dizziness. Therefore, this study shows similarities with the previous study done in the Limpopo Province, South Africa (Njoku *et al*. 2019) and another done in Vietnam (Phan *et al*. 2021), which reported that people living closer to the site were likely more exposed to adverse health effects of air pollution, including dust.

Water pollution concerns were more common among participants living closer (30%) to the site and those living on the eastern side of the site, whereas only 13% of respondents living further away also indicated the same problem. Heavy metals exposure through food and water consumption is known to impact human health (Rodríguez-Eugenio *et al.* 2018). The significantly high levels of lead (Pb) contamination found in the surface water suggest that the stream's water was in fact unsafe for human consumption. Similarly, significantly high levels of Pb and As detected in the vicinity of the Roundhill landfill in the Eastern Cape resulted in human health impacts through the consumption of polluted water (Mepaiyeda *et al*. 2020). People were also exposed to heavy metals contamination through the food chain due to edible plants absorbing heavy metals, as plants are known to absorb and retain pollutants through the soil and/or water (Asati *et al.* 2016; Rodríguez-Eugenio *et al.* 2018; Vongdala *et al*. 2019) and adversely affecting their health through consumption. The high levels of Pb, Cu, and Cr found in a sloping landfill area pose a risk of contaminating downslope vegetation, soil, and water which is ingested by humans. High doses of Pb, Cu, and Cr poisoning are linked to gastrointestinal dysfunction, anaemia, kidney and liver damage, abdominal discomfort, and bloody diarrhoea (Balali-Mood *et al*. 2021). Some participants living within a 1-2km radius of the landfill site highlighted that they have seen children swimming in the river, where the stream drains, and other participants indicated that they had consumed fish from the same river, while a small number of participants in the 1-2km radius also indicated that they have been hunting and consuming wild meat (non-professional hunters). Another form of exposure for humans, children, and hunters in particular, could be by coming into contact with contaminated soil and grass when en route to hunting, swimming, or playing by the stream or river, as the stream is located within dense growth and thick bushes/vegetation. In this regard, previous studies reported that the deposition of heavy metals in the form of dust /vapour can travel over a long distance with significant effects on human health (Sharma and Agrawal, 2005; Asati *et al.* 2016; Kowalska *et al.* 2018; Ali *et al.* 2019) and risks linked to Pb, Cr, Cu, and As found in soil and grass include dermatological issues (Balali-Mood *et al*. 2021). Other health studies found that As, Cr, Cd, and Pb poisoning are linked to cancer, kidney damage, central nervous system damage, respiratory discomfort, headache, dizziness, diarrhoea, and nose irritation among others however, the impact was dependent on exposure levels, duration of exposure, and its magnitude (Green-Facts,2015; Effendi *et al.* 2016; Tchounwou *et al.* 2012; Ali *et al.* 2019; Balali-Mood *et al.*2021). With the high levels of contamination found in grass, soil, and surface water in the vicinity of the landfill site, humans were highly exposed to the adverse health effects of heavy metals contamination. In this regard, previous studies have indicated that heavy metal exposure through food and water consumption can be the greatest health risk for humans (Balali-Mood *et al.* 2021).

6. Conclusions

Pollution load suggests that soil in the surrounding area is not safe for crop production and other related activities, as the land was heavily contaminated with heavy metals which poses a risk to both human health and the environment. High contamination in the central stream and downstream suggested a possible leachate seepage and or other related pollutants in the surrounding environment. It should be noted that the results show a glance at heavy metal contamination status in the surrounding area as it was a once-off sampling event with a limited number of samples taken for analysis. A further in-depth effective modelling study should be considered in future research with more samples, to identify the signature of heavy metals pollution found in abundance in the surrounding grass, soil, and surface water, relating to anthropogenic activities taking place in the vicinity, and also the core of environmental factors in the landfill site and the surroundings. Therefore, it is recommended that grasses, soils, and surface water be monitored closely to minimise health risks in the surrounding community and the environment while preserving the environment. Local authorities to ensure regular monitoring and law enforcement. Regularly raise awareness in local communities on pollution and associated risks.

6.1. Limitations of the study

-Statistical analysis of samples: natural background values (B_n) for metals were not available as pre-industrial concentrations were not obtained, however, for this study, upstream/control site concentrations were obtained as natural background values and their values were compared to Hakanson’s (1980) proposed approach.

-Only a limited number of samples was taken for analysis, as sites were very difficult to access. A once-off sample event was conducted.

-There were difficulties in administering interviews, as some of the residents were reluctant to participate, whereas others did not allow access due to safety and other related reasons, more especially in a 3-5km radius, hence only 15 participants were secured for the survey in the area.

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Appendix 1

Interview schedule

Social and demography characteristics

1. Gender and age
2. Employment status and educational attainment
3. Duration of residency closer to the landfill site

Health impact characteristics

4. Are there any environmental and health-related issues have you encountered as you reside closer to the landfill?
5. Perception of most reported health-related illnesses encountered.
6. Do children swim instream A -stream below the landfill site?
7. Have children ever had any skin irritation or health-related problems due to swimming in the stream?

Environmental impact characteristics

8. What type of pollution have you encountered in the area (air, water, noise, dust, etc.)?
9. Do you have any livestock grazing near the landfill site and drinking water from stream A (stream below the landfill site)?
10. Has your livestock suffered from any health-related issues due to grazing near the site according to your knowledge?
11. Have you ever consumed any plants growing near the landfill site including sugar cane?
12. Are there any hunting activities taking place in the area that you take part in or are you aware of?
13. Has anything being done in the area to curb pollution that you are aware of?
14. Do you attend environmental monitoring committee meetings in the area?
15. Is information regarding emission levels available and easily accessible to the public?

The End

Thank you for your participation is highly appreciated

Appendix 2

The Impacts of Landfill Management Site A on Grass, Soil, and Surface Water: A Preliminary Study in KwaZulu- Natal, South Africa

CONSENT FORM

I………………………………………………………………… agree to participate in this research project and also agree to the following, by ticking the relevant options:

- The research study was explained to me and I understand what the study is about.

Yes		No	

- I understand that I can volunteer to take part in the study.

Yes		No	

- I agree that direct quotations from my interview may be used by the researcher in the research report

Yes		No	

- I agree that the interview may be audio-recorded.

Yes		No	

- I agree that the researcher may use the information I provide in the interview but my participation will remain anonymous; my name and any personal information will not be used or passed on.

Yes		No	

Name of the participant: ………………….

Signature: ……..………………………………….

Date: …………………………

Name of the researcher: …………….

Signature: ……..………………………………….

Date: …………………………

Appendix 3

The Impacts of Landfill Management Site A on Grass, Soil, and Surface Water: A Preliminary Study in KwaZulu- Natal, South Africa

Participant Information Sheet

Good day Sir/ Madam

My name is Nonhlanhla Ndobe, a Masters student in the School of Animal, Plant and Environmental Science at the University of the Witwatersrand in Johannesburg. As part of my studies, I am conducting a research project about the community's perception and awareness of health and the environmental risk of living in the close proximity to the landfill site and the study title is "The Impacts of Landfill Management Site A on Grass, Soil, and Surface Water: A Preliminary Study in KwaZulu- Natal, South Africa". I am inviting you to take part in an interview, if you decide to take part, your participation in this research study will take approximately 45 minutes. With your permission, I would like to audio-record the interview. This data will be held securely on a password-protected server and not disclosed to anyone else. Only the researcher will have access to the data. During the research activity, I will need to ask for some personal information about you, and your experiences of living in close proximity to the landfill site. The interview will be confidential and anonymous. When I share the results of the research study, I will not include your name or anything else that could identify you. With your permission, other researchers may use the data collected from this research study, but your name and any personal information will not be used or passed on.

Please note that you will not receive any direct benefits from participating in this research, and there are no disadvantages or penalties for not participating. You may withdraw at any time or not answer any question if you are uncomfortable. The interview will be completely confidential and anonymous as I will not be using your name or any identifying information in my data analysis and dissertation, and the information provided If you experience any distress or discomfort at any point in this process, we will stop the interview or resume another time. This research study will be written up as a research report. If you have any questions about this research at any point during the research process, feel free to contact me, or my supervisor, on the details listed below. If you wish to receive a summary of this report, I will be happy to send it to you. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za.

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Supervisor: Dr Ute Schwaibold -Ute.Schwaibold@wits.ac.za

Yours sincerely,

Nonhlanhla Ndobe

Appendix 4 (calculations)

Contamination factor (Cf) and pollution load index (PLI)

Formula 1 and Formula 2

	Central soil	**Cf values**	**Downstream**	**Cf values**
Heavy metals Cf	As	1	As	1
	Cr	0.2	Cr	0.1
	Cu	1.4	Cu	1
	Pb	1	Pb	1.2
	Zn	8	Zn	6
PLI		**7.4**		**4**
Low contamination	**Moderate contamination**	**Considerable contamination**	**High contamination**	**PLI >1 Pollution**

	Central water	Cf values	Downstream	Cf values
Metals Cf	As	1	As	1
	Cr	0.3	Cr	0.1
	Cu	2	Cu	2
	Pb	6	Pb	1
PLI		**8**		**2**
Low contamination	**Moderate contamination**	**Considerable contamination**	**High contamination**	**PLI >1 Pollution**

	Central grass	Cf values	Downstream	Cf values
Metals Cf	As	1	As	1
	Cd	1		100
	Cr	2300	Cr	1
	Cu	6	Cu	2
	Pb	7	Pb	0.05
	Zn	16	Zn	4
PLI		**7459**		**37**
Low contamination	**Moderate contamination**	**Considerable contamination**	**High contamination**	**PLI >1 Pollution**

Appendix 5

Toxic response factors (T_r) (Hakanson, 1980) and natural background values(C_b) for heavy metals-soil (NEM: Waste Act, 59 of 2008).

Formula 3 and Formula 4

	As	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**
C_b(mg/kg).	1734	0	119	211	47	14
T_r	10	30	2	5	5	1

Ecological risk index (Hakanson, 1980).

Sampling point (soil)	**E_r**	**E_r**	**E_r**	**E_r**	**E_r**	**Ri= ($\sum E_r$)**	**Ri Class Index**
Mg/kg	**As**	**Cr**	**Cu**	**Pb**	**Zn**		
Central	10	0.4	8	5	8	31.3	**Low ecological risk**
Downstream	9.1	0.2	5	7	6	27.3	**Low ecological risk**

Toxic response factors (T_r) (Hakanson, 1980) and natural background values(Cb) for heavy metals in water (WHO, 2008; WHO, 2017).

	As	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**
C_b(mg/kg).	5.85	-	0.32	0.18	0.05	-
T_r	10	30	2	5	5	1

Sampling point (water)	**E_r**	**E_r**	**E_r**	**E_r**	**Ri= $(\sum E_r)$**	**Ri Class Index**
Mg/L or ppm	**As**	**Cr**	**Cu**	**Pb**		
Central	9.2	0.6	9	32	51	**Low ecological risk for the stream**
Downstream	9.2	0.2	9	4	22	**Low ecological risk for the stream**

	As	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**
C_b(mg/kg).	1017	0.02	0.02	21	4	13
T_r	10	30	2	5	5	1

Sampling point (grass)	**E_r**	**E_r**	**E_r**	**E_r**	**E_r**	**E_r**	**Ri= $(\sum E_r)$**	**Ri Class Index**
Mg/kg	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**		
Central	12	30	4600	29	33	17	4721	**Very high ecological risk**
Downstream	10	3000	0	10	0.3	4	3024	**Very high ecological risk**