ORIGINAL RESEARCH ARTICLE

Environmental analysis of heavy metal pollution in Mtondia dumpsite, Kilifi County, Kenya.

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Abstract
Dumping and open burning of waste with no regard to environmental implications is a common occurrence in Kenya. In several health surveys in communities close to dump sites, a wide range of human health problems, such as respiratory symptoms, allergies, irritation of the skin, and gastrointestinal problems, have been reported. The issue of heavy metal pollution brought about by the dump sites has become of concern in recent studies. Heavy metal contamination occurs when their concentrations exceed the recommended limits in the soil, water, or plant resources and have negative effects on humans or animals. The accumulation of heavy metals in agricultural soils is of great concern due to food safety issues, potential health risks, and detrimental effects on the soil's ecosystems. The samples were obtained through random sampling and analysed in the laboratory using the Energy Dispersive X-ray Fluorescence (EDXRF) technique. The EDXRF technique software was used to calculate the qualitative and quantitative aspects of the heavy metals. SPSS version 22 was used to calculate Pearson's correlation coefficient. It was observed that the soil and plants sampled from the dumpsite recorded higher levels of heavy metals than the control samples. This showed that the soils at the dumpsite were more polluted with heavy metals as compared to those at the farms. The mean concentrations of the heavy metals in soil during the dry season followed the trend Zn>Mn>Pb>Cu>Ni>Co>Cr>As. In conclusion, it was observed that the resources (soil, plants, water, and fish) were indeed polluted with various heavy metals. However, the levels do not exceed the permissible limits set by the WHO and FAO.

Keywords: Dumpsites, heavy metals, pollution, accumulation, open burning, solid wastes

1.0 Introduction
Solid waste dumping is the most common method of solid waste disposal in Kenya. In Kilifi County, large amounts of solid waste produced within the county are dumped at the Mtondia dump site. Moreover, dumpsite waste is commonly burned, adding to the additional problems of air pollution. Open dumpsites like Mtondia are unsightly, unsanitary, and generally smelly. They attract scavenging animals, rats, insects, pigs, and other pests. Surface water percolating through the trash can also dissolve or leach harmful chemicals that are then carried away from the dumpsites in surface or subsurface runoff (Naubwani *et al.,* 2015).

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Among these chemicals, heavy metals are particularly toxic and lead to bioaccumulation and biomagnification in plant and animal tissues. The bioaccumulation of the trace metals is aided by their capacity to bind with clay particles and organic matter, forming strong complexes that are more stable and long-lasting (Thelma *et al.,* 2020). These heavy metals may constitute an environmental problem if the leachate migrates into the soil, groundwater, and finally the plants.

This study investigated the levels of heavy metals in soils, plants, water, and fish in and around the dumpsite at Mtondia. According to Andy (2005), the reality is that incineration and burning don't eliminate toxic substances; they concentrate them. The burning of waste gets rid of the combustible materials and oxidises the metals, leaving the ash richer in heavy metals. After the process of oxidation and corrosion, these metals dissolve in rainwater and leach into the soil, where they are picked up by growing plants, thereby entering the food chain. Heavy metals such as mercury, lead, and cadmium are not destroyed by burning (Andy, 2005).

According to Keith (2008), incineration and burning of waste emit toxic air pollutants including dioxins and furans, heavy metals (such as lead, mercury, and cadmium), particulate matter, acid gases (hydrogen chloride and sulphur dioxide), carbon monoxide, and nitrogen oxides. These emissions have serious adverse consequences for the environment and human health. Dioxins, for example, have been linked to cancer, immune system disorders, diabetes, birth defects, and other health effects. The international convention on the elimination of persistent organic pollutants (POPs) lists medical waste incinerators among the main dioxin and heavy metal pollution sources in the environment (Sunday *et al.,* 2009). The public's concern for a clean environment and increasing community opposition to open burning and dumping should be paramount factors in ensuring generated waste is well disposed of in accordance with the regulations.

Residents around the dump site are perceived to be at a considerable risk of exposure to the toxic metals because they use the soil resources to grow their crops, and animals also feed on the plants growing in the dumpsite areas, leading to bioaccumulation in the food chain. There is therefore a need to assess the pollution risks posed by the continued dumping of waste in the environment and call for action to make informed decisions, policies, and enforcement of laws to minimise heavy metal contamination in the county and country at large. Due to the increase in population and decreasing land space, there is a huge amount of solid waste generated every year from multiple sources across the county, which is a cause for concern for its disposal at the dumpsites. For instance, municipal waste and toxic ash disposal in the environment are problematic and expensive, and if handled improperly, they pose human health and environmental dangers. According to Sunday *et al.* (2009) and Neil (2003), a hundred times more dioxin and heavy metals may enter the environment through activities like waste dumping, waste incineration, and burning, hence the need to ensure disposal is controlled to prevent release to the environment.

The most common heavy metals include copper, nickel, chromium, lead, cadmium, mercury, and iron. Some elements, such as iron and nickel, are essential to the survival of all forms of life if they are low in concentration. Elements like Pb, Cd, and Hg are toxic to living organisms even in low concentrations, and they cause anomalies in the metabolic functions of the organism, especially in greater concentrations (Thelma *et al.,* 2020). The accumulation of heavy metals in agricultural soils is

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of great concern due to food safety issues, potential health risks, and detrimental effects on the soil's ecosystems (Chindo *et al*., 2016). Hence, most heavy metals are extremely toxic because of their solubility in water, where they are known to accumulate in living organisms, and even at low levels, they can result in long-term cumulative health effects, which are among the leading health concerns all over the world.

Hg can enter and accumulate in the food chain. The form of mercury that accumulates in the food chain is methylmercury, and this accumulation leads to symptoms such as permanent damage to the brain and kidneys, personality traits, changes in vision, muscle coordination, loss of sensation, and difficulties with memory. According to Chukwuocha *et al.* (2015), heavy metals such as Pb, Zn, Cu, Cd, As, Hg, and Ni play a disruptive role when they enter the body system in higher concentrations than the required amount. It has been reported that human exposure to toxic metals via the food chain causes blood and bone disorders, kidney damage, decreased mental capacity, and neurological damage (Chukwuocha *et al.,* 2015; Seema and Rubab, 2019). This often leads to anaemia, brain damage, anorexia, convulsions, vomiting, and death. According to Dirisu *et al.* (2019), exposure to toxic heavy metals like lead and cadmium has been reported to cause blood and brain disorders, kidney and liver damage, and a myriad of neurological disorders. This study added value by showing seasonal variations in heavy metals and trying to establish a correlation between the concentrations in the soils and those in the plants at different seasons.

This study investigated the levels of concentration of heavy metals in soils, plants, water, and fish in and around the dumpsite at Mtondia. This helped to assess the degree of risk to individuals and households closely associated with the dumpsite. Hence, the results of this study were very useful in determining the levels of heavy metal pollution in the soil at the dumpsite and the plants grown in the surrounding area. The study also determined the correlation between concentrations of heavy metal pollution and concentrations in plants in different seasons. This information would be very useful to policymakers, such as relevant government agencies, in providing information on the profile of the heavy metal pollution of soil at dumpsites. Heavy metal element risk assessment in the soil found at the Mtondia dumpsite was done using the contamination factor (CF) and geo-accumulation index (I-geo) of heavy metals. The contamination factor was obtained from the expression.

$$\mathrm{C_f} = \frac{\mathrm{C_m}}{\mathrm{B_m}} \qquad 1$$

Where Cm is the mean concentration of metal M in soil and Bm is the background concentration (value) of metal M, taken from literature. Where Cf < 1 indicates low contamination; 1 < Cf < 3 indicates moderate contamination; 3 < Cf < 6 indicates considerable contamination; and Cf> 6 indicates very high contamination (Isaac et al., 2018). A low contamination factor is indicative of a low accumulation of elements, while a high contamination factor indicates active uptake.

The geo-accumulation index (I-geo) for the soil was also calculated to evaluate the degree of heavy metal contamination at the Mtondia dumpsite using the formula below: (Isaac et al., 2018) and Chindo et al. (2016).

$$\mathrm{Igeo} = \mathrm{Log2}\left(\frac{\mathrm{Cm}}{1.5}\,\mathrm{x}\,\mathrm{Bm}\right) \qquad 2$$

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where,

Cm = the mean concentration of heavy metals in soil.

Bm = background concentration of heavy metal, and 1.5 is a factor for possible variation in the background concentration due to lithological differences. I-geo is classified into seven descriptive classes as follows:

0 = unpolluted; 0-1 = from unpolluted to moderately polluted.
1-2 = moderately polluted.
2-3 = from moderately to strongly polluted.
3-4 = strongly polluted.
4-5 = from strongly to extremely polluted.
>6 = extremely polluted.

2.0 Materials & methods

2.1 Study site

The study was conducted at the Mtondia dumpsite, which is located 4km away from Kilifi town and lies at a latitude of -3.566546 and a longitude of 39.871435. There are communities living around the dumpsite who depend on the dumpsite for their livelihood by foraging through the waste to look for valuables and other scraps to sell for money. In addition, there were five water pans from which they got fish to supplement their dietary proteins. The same water is also used by their cattle and goats as their drinking water. The area surrounding the dumpsite has many limestone quarries, from which construction materials are extracted and sold for economic gain. The limestone miners also use the water pans for bathing. The communities living around the dumpsite use the edible green vegetables and crops growing around the dumpsite, such as *Amaranthus spp.* and *Zea mays,* as food. It was found out that the herbivore such as goats and cows also feed on *Amaranthus spp.* and other vegetative materials growing at the dumpsite.

2.2 Study design

The study adopted an experimental design where field sampling of soil, plants, water, and fish was done. Analysis was performed in the laboratories of the Kenya Marine and Fisheries Research Institute (KMFRI) using the Energy Dispersive X-ray Fluorescence (EDXRF) technique. Soil and plant samples were sampled during both the dry and rainy seasons in order to assess seasonal variations of heavy metals and establish whether there was a correlation of heavy metals between soil and plants. Control samples were picked from agricultural farms 5 kilometres away from the dumpsite.

2.3 Fundamentals of X-Ray fluorescence (XRF)

The fundamental principle of X-ray fluorescence (XRF) is the detection and measurement of X-rays emitted from excited atoms in a sample. X-ray fluorescence is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays (Asma, 2011; Fredrick *et al.*, 2020). The EDXRF technique is a non-destructive method and has the ability to perform simultaneous multi-elemental determinations; hence, it is extensively applied in industrial and research laboratories because of its accuracy, precision, and high sensitivity (Antoaneta et al., 2009).

EDXRF involves the use of ionising radiation to excite the sample. This excitation ejects electrons from the atomic shells of the elements in the sample. When a given atom replaces the ejected electron by

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taking another electron from an outer atomic shell, x-ray energies are emitted. Since each element generates a specific energy level in this replacement process, these energies are known as characteristic x-rays (Asma, 2011). Some of the merits of EDXRF are that the spectra are simple to interpret and are almost independent of the chemical state of the analyte. The sample preparation is also minimal and the method does not lead to destruction of the sample. This method also gives good precision and accuracy and can be used on a wide range of samples, whether solid, powdered, or liquid. The main disadvantage of this method is that the instrumentation is expensive and requires trained and skilled manpower (Raquel et al., 2006).

2.4 Target population

The target population for this study was the dumpsites in Kilifi County, with a specific focus on the Mtondia dumpsite.

2.5 Data collection

Laboratory analysis was the main source of data collection, where the various samples were analysed and the data gathered was used to process results and findings. Data was collected from primary and secondary data sources. The primary source of information was the sampling and laboratory analysis of various samples of interest at the dumpsite. Secondary data was gathered from the library and internet to provide additional information on research in the thematic area.

2.6 Sampling procedures

This study used simple random sampling for the soil, water, plant, and fish samples. All statistical tests were done at a 95% confidence interval with an estimated sampling error (e) of 5%. The main advantage of random sampling was that each item in the population had an equal chance of being included in the sample.

2.6.1 Soil samples

Portions of 100g of soil sample from identified points were collected through a random sampling method at a depth of 10 cm from the topsoil using a stainless-steel hand auger, where 0.5 cm of surface soil was removed before the samples were taken. The representative samples were then put into the sterilised polyethylene bags, labelled with the required sample information, and taken to the laboratory for analysis. A control plant sample of the same species was collected from a farm site approximately 5 km away from the study site to serve as the basis of comparison from a non-polluted source (Olumuyiwa et al., 2015).

2.6.2 Plant samples

Amaranthus Spp. plant samples were collected at different distances. A random sampling technique was used to collect the plant species. The plants picked were those growing within two metres of the point where the soil sample was picked. The plant parts, including the leaves and stem, were collected. The samples were mixed to form a composite of the plant, stored, and transported in a plastic bag to the laboratory for analysis. A control plant sample of the same species was collected from a farm site approximately 5 km away from the study site to serve as the basis of comparison from a non-polluted source (Chukwuocha et al., 2015)

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2.6.3 Water samples

Water sample points were selected from the vicinity of the dumpsite at different distances from the dumpsite. Water samples were taken by the random sampling technique from the water pans, and samples were obtained at a depth of 10–15 cm below the surface water to avoid floating debris. The water samples collected were kept in 50-ml polyethylene bottles, which were pretreated and sterilised with nitric acid. The water samples were acidified after collection into the bottles to keep the pH low and to prevent precipitation of the heavy metals *(*Besufekad et al., 2020*).*

2.6.4 Fish samples

Fresh fish samples from nearby water pans were collected using a net, stored in ice, packed in clean, sterile sample containers, and transported to the lab for analysis.

2.7 Sample analysis

2.7.1 Soil samples

Samples were mixed thoroughly to achieve homogeneity. 100g of each sampled soil was weighed using the Sartorius analytical balance model and the wet weights recorded, after which the samples were oven-dried at 50 ˚C till constant weight to obtain dry weights, then transferred and pre-heated in a muffle furnace for 3 hours at 450 ˚C to determine the carbon content using the Loss of Ignition Technique. The resultant samples were then crushed and ground using a mortar and pestle, sieved in a 2 mm sieve, and stored in labelled polythene bags at ambient temperature. The soil powder was pelletized with binding agent using a manual press at 15 tonnes for analysis with an Energy Dispersive X-Ray Fluorescence (EDXRF) analyzer in the laboratory (Asghar et al., 2021).

2.7.2 Plant samples

The plant samples were washed three times with tap water and rinsed with distilled water to remove soil and airborne pollutants. The surface water was absorbed through Whatman filter paper no. 42. The plant tissues, stems, and leaves were oven-dried at 70°C for 24 hours to remove moisture content. Through an electric grinder, the plant tissues were ground into a fine powder. A composite sample of the stem and leaves was then prepared. About 300 mg of each sample was pelletized using a press with a pressure of about 2 tonnes/cm^2 to produce a thick pellet sample. The pellets produced were kept in a desiccator to get rid of the moisture content. The samples were then analysed for heavy metals in the laboratory using an EDXRF analyzer. (Agbo et al., 2021; Carlos et al., 2015)

2.7.3 Water samples

The water samples collected were preserved by adding 1.0 M of concentration HNO_3 and stored in the refrigerator in preparation for the heavy metal analysis. To 100 mL of acidified water sample, 10% of ADPC (Ammonium Pyrrolidine Dithiocarbamate, $C_6H_{12}N_2S_2$) was added, and the contents were allowed to stand for 15-20 min. The samples were then filtered using a Millipore membrane filter in a filtration unit with the aid of a vacuum pump. The precipitate on the filter was then measured for heavy metals in the laboratory using an EDXRF analyzer (Obaroh et al., 2015).

2.7.4 Fish samples

The fish samples were dissected for their different organs, which were then digested in a kjeldhal flask using 8 ml of concentrated sulfuric acid and 2 ml of concentrated nitric acid. The samples were

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then digested using the following reagents: nitric acid, sulfuric acid, silicon anti-foaming agent (30% and hydrogen peroxide (30% (v/v). The digestion was achieved using a modified aluminium hot block where all the fish parts were digested and about 5g was mixed with 4ml of conc nitric acid and one drop of 30% (w/v) silicone anti-foaming reagent was added, and the mixture was allowed to react for three and a half hours at 60 degrees Celsius. The final sample digests were transferred into 50-ml calibrated volumetric flasks and topped up with double-deionized water. To the solution, 10 ml of freshly prepared 2% NADDTC (Sodium Diethyl Dithio Carbonate) was added, and the solution was allowed to stand for about 20 minutes before being analysed using an EDXRF analyzer (Samson, 2005; Jonathan & Maina, 2012).

3.0 Results and discussion

3.1 Grain size distribution of soil

The soil grain size distribution in Figure 1 is useful in showing the percentage distribution of gravel, sand, silt, and clay in a soil sample. This helps determine the ability of soil to retain surface water or drain it. The soil was found to have a high percentage of clay using the textural analysis triangle in figure 1.

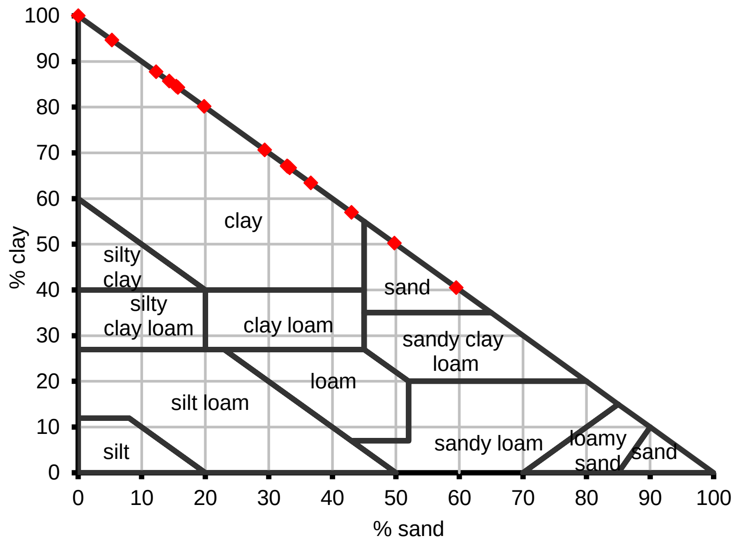

Figure 1: General Soil Classification from % soil grain size contribution in Mtondia dumpsite

The study showed the soil to be characterised as clay soil (72.9%) and sand soil (27.1%) from the textural analysis triangle. The grain size was determined using the Mastersizer 3000 Powerful Particle Analyzer.

3.2 Heavy metal levels in soil samples

This section shows the seasonal variation of heavy metal levels in the soil samples analyzed. Tables 1 and 2 represent the levels of the various metals during the dry and wet seasons when samples were taken and help to compare the levels during the two seasons. The mean concentration of heavy metals during the dry season was found to be higher than the mean concentration of heavy metals

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during the wet season, as shown in the tables.

Table 1: Concentration of heavy metals in the soil during the dry season in mg/Kg

	As	Co	Cu	Mn	Ni	Pb	Zn	Cr
S1	1.5	8.2	4.2	49.1	3.3	3.2	14.3	7.5
S2	2.9	5.2	21.8	36.9	3.5	37.5	121.6	6.8
S3	3.6	< LOD	27.1	95	3.7	99.1	179.4	13.3
S4	< LOD	< LOD	0.4	6.2	< LOD	1.3	2.2	3.7
S5	< LOD	< LOD	< LOD	< LOD	1.1	1.6	59.7	< LOD
S6	< LOD	< LOD	< LOD	< LOD	1.3	< LOD	5.4	< LOD
S7	< LOD	< LOD	< LOD	< LOD	1.6	1.2	4.9	< LOD
S8	0.4	< LOD	3.5	8.8	1.6	1.8	17.9	3
S9	< LOD	< LOD	16.6	23	3.4	10.5	29.1	< LOD
S10	1	< LOD	6.8	29.7	2.6	6.7	20.9	4.2
S11	< LOD	8	1.7	28.5	2.7	3.7	12.9	3.9
S12	< LOD	< LOD	0.7	< LOD	1.1	1.1	3.3	< LOD
S13	< LOD	< LOD	< LOD	< LOD	< LOD	1.2	41.8	< LOD
S14	1	4.5	5.5	18.2	2.5	7.1	20.1	< LOD
S15	2.2	10.7	6.8	33.2	4.1	14.7	31.1	4

Limit of Detection (LOD) = 0.05 mg/kg and a standard deviation of ±0.01

Table 2: Concentration of heavy metals in the soil during the wet season in mg/Kg

	As	Co	Cu	Mn	Ni	Pb	Zn	Cr
S1	< LOD	< LOD	0.9	< LOD	2.6	< LOD	4.4	< LOD
S2	< LOD	< LOD	< LOD	< LOD	< LOD	1.2	15.9	< LOD
S3	1	< LOD	4.3	18.1	3.6	6.3	15.6	< LOD
S4	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	4	< LOD
S5	0.7	8.9	3.2	36.3	4.6	5.4	15.1	< LOD
S6	< LOD	< LOD	< LOD	< LOD	1.1	1.1	4	< LOD
S7	< LOD	9	4.1	48.6	4.7	61.4	16.6	6.3
S8	< LOD	7.9	1	46.5	3.9	1.2	10.5	3.1
S9	0.9	< LOD	9	33.7	2.2	8.3	31.8	3.9
S10	3.4	7.8	5.4	35.1	3.8	72.7	75.3	< LOD
S11	0.8	4.3	1.8	10.7	3.2	2.2	31.6	< LOD
S12	< LOD	< LOD	< LOD	< LOD	1.6	< LOD	3.8	< LOD
S13	< LOD	< LOD	< LOD	< LOD	1.2	0.8	7.9	< LOD
S14	< LOD	< LOD	< LOD	< LOD	1.6	1.1	3.1	< LOD
S15	6.8	< LOD	< LOD	< LOD	1.3	1	10.7	< LOD

LOD = 0.05 mg/kg and a standard deviation of ±0.01

As shown in tables 1 and 2 and figure 2 above, the concentration of heavy metals was higher during the dry season than during the wet season. Zinc had higher concentrations during both seasons and

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was followed by manganese and then lead. Hazardous metals like arsenic and lead were also detected in the soil samples, though in small concentrations.

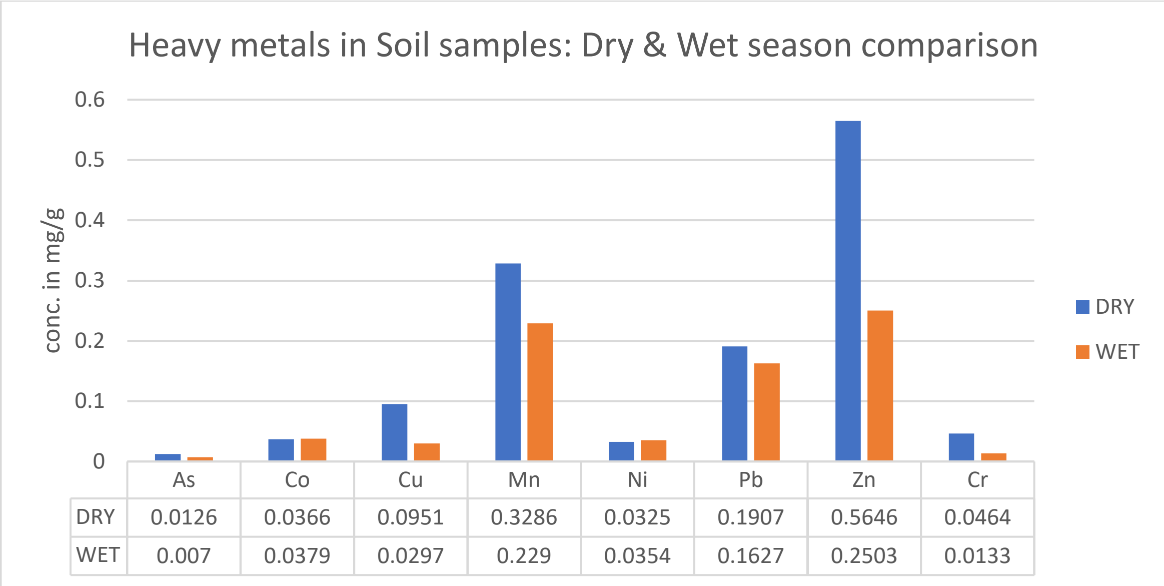

Figure 2: Comparison graph of As, Co, Cu, Mn, Ni, Pb, Zn, and Cr concentrations between the control site and sampling stations during the dry and wet sampling seasons

3.3 Heavy metals risk assessment in the soil at the Mtondia dumpsite

The contamination factor (C_f) was obtained from the expression.

$$C_f = \frac{C_m}{B_m} \qquad 3$$

Where Cm is the mean concentration of metal M in soil and Bm is the background concentration (value) of metal M, taken from literature. Where Cf < 1 indicates low contamination; 1 < Cf < 3 indicates moderate contamination; 3 < Cf < 6 indicates considerable contamination; and Cf> 6 indicates very high contamination (Isaac et al., 2018). A low contamination factor is indicative of a low accumulation of elements, while a high contamination factor indicates active uptake. During both the dry and wet seasons, lead (pb) metal was found to have the highest contamination factor of 0.01167 and 0.00957, while the lowest contaminant was manganese (Mn) at 0.000047 and 0.00029, respectively. The contamination sequence was as follows:

Dry season (Pb> Zn > Cu >As >Co > Ni > Mn)

Wet season (Pb > Zn > Co > As > Cu > Ni > Mn)

The overall observation was that the soil had low contamination (Cf < 1).

where; Cf < 1 indicates low contamination; 1 < Cf < 3 indicates moderate contamination; 3 < Cf < 6 indicates considerable contamination; and Cf> 6 indicates very high contamination (Isaac et al., 2018; Chindo et al., 2016).

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The geo-accumulation index (I-geo) for the soil was also calculated to evaluate the degree of heavy metal contamination at the Mtondia dumpsite using the formula below: Isaac et al. (2018) and Chindo et al. (2016).

$$\mathrm{Igeo} = \mathrm{Log2}\left(\frac{\mathrm{Cm}}{1.5}\,\mathrm{x}\,\mathrm{Bm}\right) \qquad 4$$

where;
Cm = the mean concentration of heavy metals in soil.
Bm = background concentration of heavy metal, and 1.5 is a factor for possible variation in the background concentration due to lithological differences. I-geo is classified into seven descriptive classes as follows:

0 = unpolluted.
0-1= from unpolluted to moderately polluted.
1-2 = moderately polluted.
2-3 = from moderately to strongly polluted.
3–4 = strongly polluted.
4-5 = from strongly to extremely polluted.
>6 = extremely polluted

Table 3: Calculated contamination factor (CF) and geo-accumulation index (I-geo) of heavy metals in Mtondia dumpsite soils during dry and wet seasons in mg/kg and standard deviation of ±0.01

	Contamination Factor (CF).		Geo-accumulation Index (I-geo)		Geochemical background (mg/kg)	UCC
	Dry	Wet	Dry	Wet		
As	2.86	1.4	0.574	0.281	5	
Co	2.19	2.23	0.439	0.447	17	
Cu	3.62	1.06	0.726	0.213	28	
Mn	0.47	0.3	0.094	0.059	775	
Ni	0.76	0.79	0.152	0.158	47	
Pb	11.67	9.57	2.342	1.921	17	
Zn	8.88	3.77	1.782	0.756	67	

The geo-accumulation index (I-geo) for the soil was also calculated to evaluate the degree of heavy metal contamination at the Mtondia dumpsite using the formula below: (Isaac et al., 2018; Chindo et al., 2016).

The geo-accumulation index trend observed for the dumpsite soil was as shown below.

Dry season: Pb>Zn>Cu>As>Co>Ni>Mn
Wet season: Pb>Zn>Co>As>Cu>Ni>Mn

From the calculations for the geo-accumulation index, it was found out that the geo-accumulation index for all heavy metals analysed during both the dry and wet seasons for the soil was more than

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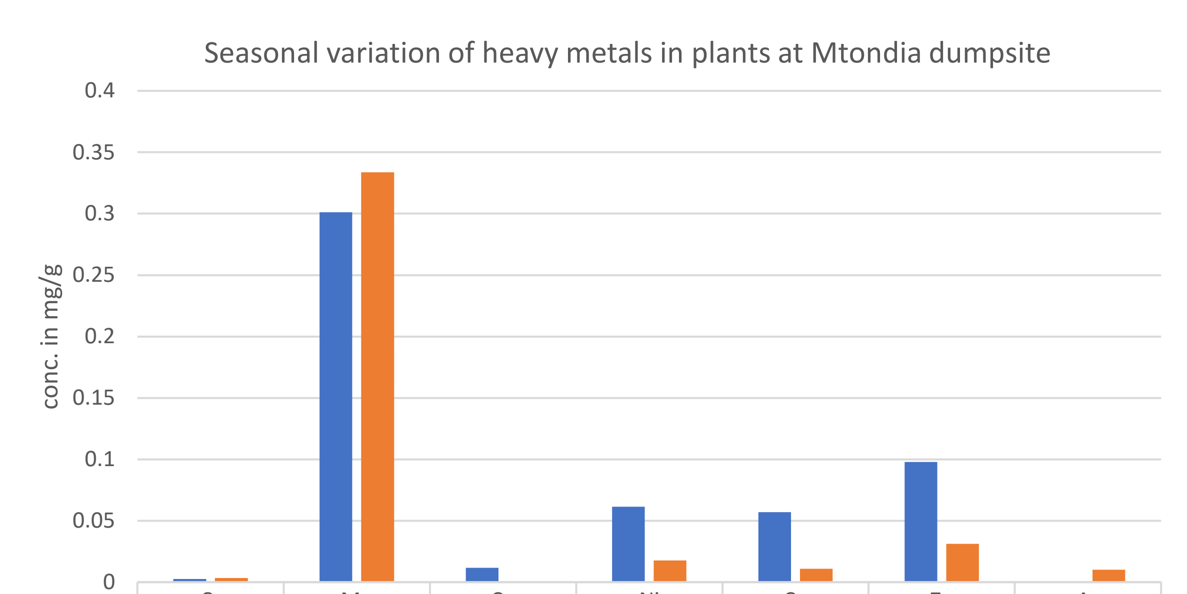
zero but below one, hence it fell in the category of 0–1, meaning it fell from unpolluted to moderately polluted. The geo-accumulation index and contamination factor for lead (Pb) were found to be higher than those of manganese in both seasons, as shown in the sequence above.



	Cr	Mn	Co	Ni	Cu	Zn	As
DRY	0.0026	0.3012	0.0118	0.0614	0.0569	0.0979	0
WET	0.0033	0.3336	0	0.0176	0.0109	0.0313	0.0101

Figure 3: Comparison graph of Cr, Mn, Co, Ni, Cu, and Zn concentrations during the dry and wet sampling seasons.

3.4 Transfer factors (TF) of heavy metals from soils to *Amaranthus spp* plants

In order to understand more about the contamination of sampled plants from the dumpsite by heavy metals, the transfer factor for each of the samples was calculated. Transfer Factor (TF) is the ratio of the concentration of heavy metals in a plant in mg/kg to their respective concentrations in mg/kg in the soil. It showed the amount of heavy metal in the soil that ended up in the plants sampled from the site (Joan et al., 2016).

where

$$Transfer\ Factor = \frac{Metal\ content\ in\ plant\ (mg/kg)}{Metal\ content\ in\ soil\ (mg/kg)} \qquad 5$$

The calculated TFs are shown in the table below. It was observed that the calculated transfer factors for heavy metals from the soil to the plants were higher during the wet season as compared to the dry season for manganese and arsenic and lower during the wet season as compared to the dry season for cobalt, copper, nickel, and zinc.

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Table 4: Transfer factor of heavy metals from soil to plants during the dry season

	Co	Cu	Mn	Ni	Zn
Soil	1.982± 0.01	7.477± 0.01	25.214± 0.01	2.259± 0.01	42.573± 0.01
Plant	1.105± 0.01	5.173± 0.01	27.382± 0.01	5.582± 0.01	8.9± 0.01
TF	0.5575± 0.01	0.6919± 0.01	1.086± 0.01	2.471± 0.01	0.2091± 0.01

Table 5: Transfer factor of heavy metals from soil to plants during the wet season

	As	Cu	Mn	Ni	Zn	Pb
Soil	0.0664± 0.01	2.714± 0.01	20.836± 0.01	2.709± 0.01	20.436± 0.01	14.536± 0.01
Plant	0.0918± 0.01	0.0991± 0.01	30.327± 0.01	1.6± 0.01	2.845± 0.01	0.273± 0.01
TF	1.3825± 0.01	0.03651± 0.01	1.4555± 0.01	0.5906± 0.01	0.1392± 0.01	0.0188± 0.01

Tables 4 and 5 below show the calculated transfer factor for each of the heavy metals during the dry and wet seasons, which helped the researcher determine if the plants found at the dumpsite were capable of transferring the heavy metals to the food chain through the various paths found, such as the human populations and the grazing animals around the dumpsite

3.5 Correlation between heavy metals in soil and plants in the Mtondia dumpsite.

The heavy metal concentrations were observed to be higher in soils during the dry season than the wet season, whereas they were higher in plant tissues during the wet season than the dry season.

Table 6: Pearson's moment coefficient of relationship between levels of heavy metals in soil and plants during the dry season

	As	Co	Cu	Mn	Ni	Pb	Zn
As	1						
Co	0.183226	1					
Cu	0.825557	0.011135	1				
Mn	0.86474	0.272268	0.776297	1			
Ni	0.676203	0.413132	0.74649	0.770314	1		
Pb	0.858528	-0.05823	0.861826	0.849885	0.544346	1	
Zn	0.867494	-0.01899	0.859986	0.743138	0.531284	0.934939	1

Inter-elemental analysis of the metals in both soil and plants showed several positive correlations, as shown in Table 6 above. Positive correlations of heavy metals in soil and plants were observed for all metals except cobalt, which had some negative correlations.

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3.6 Concentration levels of heavy metals in the fish sampled from water pools at the Mtondia dumpsite

Table 7: Comparison graph of concentrations of Mn, Co, Ni, Cu, Zn, As, and Pb in fish samples

	Pool 1	Pool 2	Pool 3	Pool 4	Pool 5
Cr	2.0 ± 0.01	2.4± 0.01	2.1± 0.01	2.7± 0.01	2.5± 0.01
Co	3.3± 0.01	< LOD	4.2± 0.01	6± 0.01	4.5± 0.01
Ni	5.2 ± 0.01	3.4± 0.01	< LOD	4.5± 0.01	6.6± 0.01
Cu	5.7± 0.01	4.9± 0.01	6.3± 0.01	3.9± 0.01	4.6± 0.01
Zn	9.2± 0.01	9.1± 0.01	10± 0.01	5.4± 0.01	5.6± 0.01
Ag	< LOD	17.2± 0.01	< LOD	< LOD	< LOD
Cd	< LOD	< LOD	< LOD	< LOD	< LOD

LOD = 0.05 mg/kg and a standard deviation of ±0.01

The levels of concentration of heavy metals in the fish samples found in the water pools around Mtondia dumpsite in the dry season were higher in pool five as compared to the other pools. Pool five had the highest manganese concentration levels for all the fish samples analysed.

3.7 Mean elemental concentration in pool water during the dry season

Table 8: Comparison Table of Mn, Co, Ni, Cu, Zn, and Pb Concentrations in Dumpsite Pool Water Samples (mg/kg) During the Dry Sampling Season

	Pool 1	Pool 2	Pool 3	Pool 4	Pool 5
Mn	34 ± 0.01	< LOD	< LOD	< LOD	< LOD
Co	9.3 ± 0.01	< LOD	< LOD	< LOD	< LOD
Ni	5.6 ± 0.01	< LOD	< LOD	< LOD	< LOD
Cu	4.5 ± 0.01	< LOD	< LOD	< LOD	< LOD
Zn	5.6 ± 0.01	< LOD	< LOD	< LOD	< LOD
Pb	7 ± 0.01	< LOD	< LOD	< LOD	< LOD

LOD = 0.05 mg/kg and a standard deviation of ±0.01

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3.8 Mean elemental concentration in pool water during the wet season

Table 9: Comparison Table of As, Co, Cr, Cu, Mn, Ni, Pb, and Zinc Concentrations in Dumpsite Pool Water Samples (mg/g) During the Wet Sampling Season

	Pool 1	Pool 2	Pool 3	Pool 4	Pool 5
As	2.7±0.001	1.6±0.001	< LOD	< LOD	< LOD
Co	< LOD	< LOD	< LOD	< LOD	< LOD
Cr	5.3±0.001	7.8±0.001	< LOD	< LOD	4.4±0.001
Cu	2.7±0.001	11.1±0.001	< LOD	< LOD	20.4±0.001
Mn	50.3±0.001	51.8±0.001	22.6±0.001	< LOD	31.2±0.001
Ni	3.9±0.001	3.7±0.001	1.1±0.001	< LOD	4.1±0.001
Pb	8.3±0.001	8.4±0.001	0.9±0.001	2.4±0.001	29±0.001
Zn	22.5±0.001	87.4±0.001	2.6±0.001	67.4±0.001	160.5±0.001

LOD = 0.05 mg/kg and a standard deviation of ±0.001

As shown in Tables 8 and 9 above, the levels of concentration of heavy metals in water sampled from the water pools around the dumpsite showed that concentration levels were higher during the wet season as compared to the concentration during the dry season. The concentration of manganese was observed to be higher during the dry season compared to other heavy metals detected in the sample. The concentration of manganese was observed to be higher than that of zinc during the wet season. The presence of lead was detected during the wet season in all the pools, though at low concentration levels, while the presence of arsenic was detected in all the pools except in pools three, four, and five, where its concentration was below the limit of detection. Arsenic and chromium were detected, though at very low levels. The levels of concentration of heavy metals in water sampled from the water pools around the dumpsite showed that concentration levels were higher during the wet season as compared to the concentration during the dry season. This showed that the potential impact of the onset of the rains around the dumpsite and its surroundings increased concentrations of heavy metal ions in the water pans. This showed that during the wet season there were heavy metals that dissolved in rainwater and were transported to the various water pools found around the dumpsite, and that some of this may have its source in the run-off water from the dumpsite topsoil. However, none of the concentrations were above the WHO/FAO (1996) limits.

4.0 Discussion based on the observations, findings, and objectives of the study

4.1 Particle size characterization

As per Figure 1, the soil at the dumpsite was characterised as predominantly clay particles at 72.9%. The clay fraction was generally higher compared to the other fractions of soil particles. A high percentage of clay soil particles on the topsoil would lead to the soil retaining water for a longer time and therefore increase the sorption of heavy metal ions and subsequent leaching in the soil (Chindo et al., 2016; Nkop et al., 2016). This would ultimately lead to pollution of the groundwater when the dissolved metals seep into the lower layers of the soil.

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4.2 Concentrations of heavy metals in soil, plants, fish, and water

The heavy metals detected in the resources analysed were arsenic, cobalt, copper, manganese, nickel, lead, chromium, silver, and cadmium. However, the most abundant heavy metals in the samples analysed were zinc (Zn), manganese (Mn), and lead (Pb), where Zn>Mn>Pb.

4.2.1 Concentrations of zinc in soil, plants, fish, and water samples

Zinc was the most abundant heavy metal found in the soil samples during the dry and wet seasons, as shown in figure 2. However, the concentration levels were higher during the dry season than during the wet season. A similar study by Oladunni et al. (2013) in Nigeria found that heavy metal concentrations from dumpsite soil samples were generally lower during the wet season due to increased aeration and dilution from rainfall. This finding agreed with the studies of Olayiwola and Onwordi (2015), Anyiam (2020), and Adeola et al. (2015), where concentrations of zinc were found to be consistently higher in soil samples as compared to other heavy metals detected in the soil sample. The results, however, disagreed with a similar study by Tariwari et al. (2016) and Isaac et al. (2018), where iron and copper were found to be higher than zinc in soil samples compared to other heavy metals analysed in the samples. Hence, the soil was found to be polluted with zinc, although not beyond the permissible limit by WHO/FAO, contrary to the study by Oladunni et al. (2013).

Zinc was found to have the second highest contamination factor and geo-accumulation index after lead metal, as shown in Table 3. This showed that zinc had a higher potential to cause pollution in the dumpsite soils as compared to other heavy metals like manganese and copper. This finding was in line with that of Isaac et al. (2018) and Chindo et al. (2016), where zinc was found to have moderately contaminated the dumpsite soils together with iron. In plants, as shown in Figure 3, zinc was found to be more abundant during the dry season than during the wet season. This showed that the zinc ions were not affected by dilution from the rainwater, and high levels during the dry season may be influenced by other factors such as atmospheric deposition. This finding was not in agreement with that of Joan et al. (2016), where concentration levels of Zinc, Fe, Mn, and Cu were lower in vegetables grown at the dumpsite compared to other heavy metals analysed, such as Ni and Co. However, the results agreed with those of a study done by Chen et al. (2021), where zinc levels in fodder grass grown on dumpsite soil were found to be within the permissible limit set by WHO/FAO.

In a study carried out by Kebir (2011) in Algeria, the transfer factor of zinc was found to be higher than that of all other heavy metals analyzed. This disagreed with the findings of this study, where the transfer factor of zinc was the lowest in both the dry and wet seasons, as shown in figure 4. Zinc had strong positive correlation coefficients with all other heavy metals except cobalt, as shown in Table 6. This showed that the source of zinc pollution and that of these metals may be of a similar origin. The water samples had higher zinc concentration levels during the wet season as compared to the dry season, as shown in tables 8 and 9. This shows that surface runoff and leaching may have played a role in depositing the ions from the dumpsite soils into the water pools and ultimately into the fish sampled from the pools. According to Kebir (2011), zinc pollution results mostly from anthropogenic activities. Pollution by zinc potentially results from industrial waste in textiles and paint, and the negative impact may include killing soil microbial organisms and reducing the organic matter mineralization that is essential for plant growth (Chen et al., 2021; Raymond and Felix, 2011).

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4.2.2 Concentrations of manganese in soil, plants, fish, and water

Manganese was the second most abundant heavy metal in the dumpsite soil in both dry and wet seasons, after zinc. Although the concentration levels of manganese were high in both seasons in soil, plant, fish, and water resources, they were within the WHO/FAO permissible threshold limits. This finding agrees with that of Obi et al. (2017) and Solomon (2019) on studies on heavy metals in dumpsite soils and Tariwari et al. (2016) on heavy metals in vegetation grown in dumpsites, where the levels of manganese were found to be low and within tolerable limits and therefore did not pose any risk to human health and ecology. Manganese can have hazardous effects, and according to Joan et al. (2016), chronic overexposure to manganese can lead to permanent neurodegenerative disorders in human beings.

Manganese was more abundant in the plants during the wet season than during the dry season, as shown in figure 2. This showed the ability of manganese to transfer from the soil to the plants during the wet season. This is reflected by a higher transfer factor of manganese in wet season than any other metal, as shown in figure 4. These results agreed closely with those of Rasaq et al. (2015) and Nwogo et al. (2017). This high transfer factor during the wet season showed that a high risk of exposure to manganese for humans and animals through phytoaccumulation in plants existed, Zakka et al. (2014), because it's during the wet season that many vegetation growing on the dumpsite gets to develop and is therefore available to be fed on by the animals and humans in the form of vegetables.

Manganese had a positive correlation with nickel and lead, as shown in Table 6, indicating that the sources of pollution by these heavy metals could have been a common one. Manganese was present in water pools, mostly in concentrations that were below the limit of detection during the dry season, except for pool 1, as shown in Table 5. However, during the wet season, the levels increased, as shown in Table 6. Contamination factor analysis and geo-accumulation indexes, as shown in Table 3, found that Manganese had the least contamination potential and geo-accumulation indexes in both seasons. This showed that although manganese was abundant, it had a low potential for reaching poisoning levels compared to other heavy metals detected in the soil samples.

According to Halina (2011), most toxic metals, when released into the environment, even in low concentrations, will accumulate and exert their toxic effects on living organisms over a long period of time and therefore should never be ignored. Manganese gets into the body through inhalation or ingestion, affects the central nervous system, and leads to other neurological disorders in the body (Obi et al., 2017). In general, manganese was found to be the most abundant heavy metal present in all the resources (soil, plants, water, and fish) analysed at the dumpsite. However, the levels were within the threshold limits of WHO/FAO and therefore did not pose any risk to human health. However, the presence of manganese in all these resources indicated a gradual accumulation and potential risk of contamination for the resources at the dumpsite and surrounding communities.

4.2.3 Concentrations of lead in soil, plants, fish, and water

The concentration levels of lead were the third most abundant in the soil samples from the dumpsite, as shown in figure 2. The concentration levels in both soil and plants were higher than the concentration levels for the samples collected from the farmlands. This agreed with a similar study

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done by Leah and Johnny (2014) in the Philippines, which showed that the concentration levels of lead were higher in the dumpsite than in the farmlands where the control samples were obtained. This showed that the dumpsite soils were polluted with lead metal, although the pollution level was not above the threshold limit set by WHO/FAO.

This finding agreed with that of a study done by Olayiwola and Onwordi (2015) in Nigeria and Riziki (2010) in Tanzania. However, this finding disagreed with that of Omaka et al. (2020), Afolayan & Hassan (2017), and Henry et al. (2017), where the levels of lead were found to be higher and above the WHO threshold limits. An analysis of the contamination factor (CF) and geo-accumulation index (I-geo) of heavy metals, as shown in Table 3, showed that lead had the highest contamination factor and geo-accumulation index in soil in both dry and wet seasons. This showed that lead metal had the greatest potential among the heavy metals analysed to pollute the resources at the dumpsite. This finding agreed with that of Chindo et al. (2016) and Adedotun (2018), where similar findings were made that lead had a higher contamination factor than other heavy metal pollutants.

Although lead metal levels were present in the soil during dry and wet seasons, their respective concentrations in plant samples were not detected during both dry and wet seasons. This showed that there was severe leaching of lead metal ions in the soil to lower depths where plant roots would not absorb the ions. The concentration levels of lead in the water samples were mostly below the limit of detection in the dry season, as shown in Table 5. However, during the wet season, there were increased levels of lead metal in the water samples, as shown in Table 6. The levels of lead were detected in the fish samples during the wet season, as shown in figure 5. This showed the potential for surface runoff during the wet season and its impact on contaminating the water and fish found around the dumpsite.

4.2.4 Concentrations of arsenic in soil, plants, fish, and water samples

Arsenic was found to be present in soil during the dry season and also in the wet season at concentration levels either higher or lower than those of the control sample, and in some instances, the level was below the limit of detection as shown in the figures. However, it was not anywhere near the WHO/FAO limit of 0.02 mg/g. This showed that arsenic was not abundant in the soil samples compared to other heavy metals. This finding agreed closely with that of Solomon (2019) and Hammed et al. (2017) in studies carried out in Nigeria, where they found that arsenic concentrations were within tolerable limits in soil samples from dumpsites and therefore posed no risk. The low concentration levels of arsenic in both seasons showed that arsenic buildup in the dumpsite soil was slow. However, a gradual buildup of toxic metals in the dumpsite should not be ignored since the buildup results from both natural and anthropogenic activities.

No arsenic levels were detected in plants during the dry season. However, during the wet season, arsenic was detected in the plant samples, but in low concentrations. The transfer factors calculated to find out the potential for exposure from the soil to human beings and animals through the plants showed a high factor for arsenic and manganese. Hence, although arsenic at the dumpsite is gradually building up, the high transfer factor shows it has the potential to contaminate the food crops grown at the dumpsite and thereby poison human beings and animals that feed on them. The fish samples were found to have low levels of arsenic during the wet season. This shows the potential for surface

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runoff from the dumpsite to contaminate the water pools with dissolved arsenic ions, where the fish were able to ingest the metal from the water. Thus, the potential for pollution of surrounding water pools by surface runoff from the dumpsite is imminent.

According to Nrashant et al. (2007), in a study carried out in India, communities are exposed to arsenic through ingestion, inhalation, or skin contact, where ingestion of food or water contaminated with arsenic is the most common exposure method. Arsenic exposure to humans is hazardous and leads to health problems such as vascular disease, including arteriosclerosis, peripheral vascular disease, and ischemic heart disease (ISHD), renal disease, neurological effects, cardiovascular disease, chronic lung disease, cerebrovascular disease, reproductive effects, and cancers of the skin, lungs, liver, kidney, and bladder (Sadguru & Ashok, 2021). Hence, measures should be taken to create more awareness and to monitor and control the disposal of waste at the dumpsite.

4.2.5 Concentrations of cadmium and silver in fish samples

The fish samples analysed during the dry season showed very low concentrations of silver and cadmium, which were all below the limit of detection. There were no concentration levels of silver and cadmium detected during the wet season in both fish and water samples or in soil during the dry or wet seasons. This showed that the likely source of these traces was through atmospheric deposition. According to Köck and Hofer (1998), atmospheric deposition occurs in aquatic ecosystems, and hence trace levels of heavy metals like cadmium and lead could be found even in areas with no pollution with such heavy metals.

This argument was supported by a study by James et al. (1982), where atmospheric concentrations and known temporal trends in deposition were shown to follow the trend of Ag, Cd, Cu, Pb, Sb, Se, and Zn in that order. Hence, atmospheric deposition of heavy metals should not be taken lightly, as it was found to be connected to ecological and health impacts in a study carried out by Wenli et al. (2019) on the deposition of heavy metal traces in grains of rice and fish. It shows that food resources obtained from resources in open spaces, such as fish and vegetables from water pools and dumpsites, are prone to contamination with trace metals from atmospheric deposition. A study by Hadrup et al. (2018) found that silver has the potential to cause eye irritation and allergic contact dermatitis. Other reported impacts were toxicities of the hepatic, renal, neurological, and haematological systems in the body. However, no data has shown its carcinogenic potential.

A study by Hans (1999) showed that the bioaccumulation of silver in soil is rather low. However, the study showed that in water systems, the highest reported bioconcentration factors (BCFs) were observed in algae, and the lowest BCF was found in fish, with no indication of biomagnification. According to Genchi et al. (2020), cadmium poses a health risk for both humans and animals and is an environmental pollutant that is derived from agricultural and industrial sources. Some of the toxic effects of cadmium exposure include various types of cancer, such as breast, lung, prostate, nasopharynx, pancreas, and kidney (Yingying et al., 2017). Cadmium, even in very low amounts, has the potential to bioaccumulate, causing damage to the kidney, reproductive, respiratory, and skeletal systems, Godt et al. (2006). Hence, although at very low concentration levels, these two heavy metals are toxic and should be given the attention that they deserve.

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4.2.6 Levels of concentration of the identified heavy metals in the soil at the dumpsite as compared to the WHO guidelines

In general, it was observed that the soil and plants sampled from the dumpsite recorded a higher level of heavy metal concentration when compared with those from the control site, and this agreed with the findings of Hammed et al. (2017), Amusan et al. (1999), and Ebong et al. (2009). They found out that for a polluted dumpsite, the levels of concentration of detected heavy metals would be higher than the levels of concentration of a control soil sample from a farm in a faraway area from the dumpsite.

The concentration levels of heavy metals at the dumpsite during both the dry and wet seasons were higher than the concentration levels of heavy metals in the control sample. This showed that the soils at the dumpsite were more polluted with heavy metals as compared to those at the farms where the control sample was picked. It further showed that there was an impact of anthropogenic activities like dumping and waste from factories, incinerators, and homes at the dumpsite.

4.2.7 Impacts of dry and wet seasons on heavy metal soil pollution at the dumpsite

Figure 2 on the seasonal comparison of heavy metals in soil samples shows that the concentration levels of detected heavy metals in the soil samples analysed were higher in the dry season as compared to the wet season. It showed that the rains did have an impact on reducing the concentration levels of available heavy metal ions in the soil through the leaching of the ions to the lower depths of the soil stratum. This may have happened because the soluble metal ions were dissolved and leached to regions where they were available during the sampling or were diluted by rain to levels below detection during the analysis in the lab. This may be why, during the wet season, some detected heavy metals had their concentration levels below the limit of detection, as shown in Table 2.

4.2.8 Contamination of plants growing around the dumpsite with the identified heavy metals

During the wet season, the concentration levels of heavy metals in the plant samples analysed were higher for some heavy metals and lower for others. As shown in Figure 3, the mean concentration levels of manganese during the dry and wet seasons were found to be higher compared to all other heavy metal elements detected in the plant tissue samples analysed in the laboratory. This showed that there were increased levels of manganese in the soil at the dumpsite during the wet season and therefore a higher likelihood of manganese toxicity. As shown in Figure 3, the concentration of heavy metals in plants was higher during the wet season and lower during the dry season. This compares closely with the findings in this study that the heavy metal concentration in soil during the dry and wet seasons was high during the dry season and lower during the wet season, showing that there was potential uptake by plants of the heavy metal ions dissolved in the soil during the wet season. According to Isaac et al. (2018) and Chindo et al. (2016), who studied metal uptake, translocation, and effects in plants growing on naturally polluted and unpolluted sediments, plants may facilitate the transportation of metals from sediments up into shoots.

These metals would then be made available to grazing animals and then reintroduced into the food web via fish, birds, and humans. During both the dry and wet seasons, lead (pb) metal was found to have the highest contamination factor of 0.01167 and 0.00957, while the lowest contaminant was

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manganese (Mn) at 0.000047 and 0.00029, respectively, as shown in Table 3. This meant that the soil at the dumpsite would, in the future, be more polluted with lead and manganese. The transfer factor for arsenic was higher during the wet season at 1.382 and for manganese at 1.455, as shown in Table 5, where the factor was more than one. TF is one of the key components of human exposure to heavy metals through the food chain (Joan et al., 2016). The prolonged human consumption of *Amaranthus spp* grown on this dumpsite and the transfer of these heavy metals into the human body system could pose serious human health problems. This meant that the plants at the dumpsite were more likely to be polluted with the two metals since their uptake was higher.

According to Annalisa et al. (2012), manganese is considered an emerging environmental contaminant because it is a perceived or real threat to human health and the environment. A study in Namibia (Ebong et al., 2009) established that pasture grass that was obtained from around waste dumpsites had higher levels of heavy metals. It is possible for heavy metals to accumulate in the tissues and organs of domestic animals that become exposed to contaminated environments, materials, and fodder. Hence, herbivores, like the goats and cattle found at the dumpsite, that browse and feed on vegetation from the dumpsite may act as a possible pathway for passage of the heavy metals to the food chain and ultimate bioaccumulation in the trophic levels.

4.2.9 Correlation between heavy metals present in the soil and their concentration in the plants found at the dumpsite

The heavy metal concentrations were higher in soils during the dry season than the wet season, whereas they were higher in plant tissues during the wet season than the dry season. This showed that the metal ions were dissolved by the rains and taken to the lower levels of the topsoil, where the plant roots could pick them up while growing during the wet season. Manganese and zinc levels were found to be higher than those of other heavy metals detected. This showed an increased uptake of manganese by plants during the wet season compared to the dry season. Inter-elemental analysis of the metals in both soil and plants showed several positive correlations, as shown in Table 4.

The positive correlations observed indicated that increasing levels of heavy metals in the dumpsite soils would result in an increased concentration of heavy metal levels in the *Amaranthus spp plants.* Similar observations were made by Rasaq et al. (2015), Ojebah & Uwague (2018), Nwogo et al. (2017), and Chindo et al. (2016) of the positive correlation of heavy metal levels in soil with those of the vegetables in their studies. These positive correlations suggested that these metals were from a common source, most likely the industries whose wastes were disposed of at the dump site. The presence of herbivores like goats and cows grazing at the dumpsite, as shown on plates 3 and 4, suggested a likely pathway through which the heavy metal contaminants could eventually find their way into the food chain and to humans. This explanation is in line with previous studies carried out in Kenya by Geoffrey et al. (2020) and in Nigeria by Chikere et al. (2021), where they found concentrations of heavy metals in plants where animals graze or scavenge would offer a possible pathway for bioaccumulation and biomagnification. The accumulation of metals in edible vegetables such as *Amaranth spp* is capable of poisoning communities that collect and eat these vegetables as food.

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5.0 Conclusions

From the analysis results of heavy metal contamination of the various resources at the Mtondia dumpsite, it was observed that the resources (soil, plants, water, and fish) were indeed polluted by various heavy metals at different levels of concentration.

The heavy metal levels of concentration in soil and plant samples from the dumpsite were found to be generally higher than the samples taken from the control site in farmlands. This showed that the dumpsite soil was polluted with heavy metals as compared to the soil from the farms, probably from the impact of anthropogenic activities such as burning and dumping of waste from industries, factories, homesteads, and incinerators.

The levels of concentrations of heavy metals in the soil samples were found to be higher during the dry season as compared to the wet season and followed the trend Zn>Mn>Pb>Cu>Co>. As in mg/g, while in plants, water, and fish samples, the levels of concentration of heavy metals were found to be generally higher during the wet season as compared to the dry season and varied between different resources.

Manganese, zinc, and lead were found to be the most common heavy metals detected in the samples analysed during dry and wet seasons. However, manganese was higher than all the other detected heavy metal concentration levels. This showed a potential for manganese toxicity in the resources at the dumpsite.

The calculated contamination factors (CF) and geo-accumulation index (I-geo) for heavy metals in the soil samples showed that lead (Pb) had the highest potential to pollute the dumpsite, while manganese had the lowest potential. The overall observation from the contamination factor analysis was that the soil had low contamination at ($Cf < 1$), while from the geo-accumulation index analysis, the observation of the geo-accumulation index (I-geo) at 0–1 was indicative of pollution status, ranging from unpolluted to moderately polluted.

The presence of hazardous heavy metals such as arsenic and lead was detected in soil, plants, and fish samples, although at lower levels of concentration. This showed that there was a gradual buildup of hazardous heavy metal pollution at the dumpsite resources.

Transfer factors (TF) of the heavy metals from soils to *Amaranthus spp* plants were found to be increased during the wet season, with arsenic and manganese having a higher transfer factor. This meant that there was a gradual accumulation of hazardous heavy metals within the plants growing at the dumpsite.

All individual heavy metal concentrations in soil, water, fish, and plant samples analysed were found to be within permissible limits by WHO/FAO (1996).

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6.3 Conflict of interest

None.

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8.0 APPENDIX I:

WHO/FAO LIMITS FOR HEAVY METALS

	Heavy Metal concentration (mg/kg) Cr Cu Mn Ni Pb Zn V Fe									
Heavy Metal	As	Co	Cr	Cu	Mn	Ni	Pb	Zn	V	Fe
WHO/FAO Limits	20	50	100	100	740	50	100	300	2	5000

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