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Studies on the Possible Bioaccumulation of Heavy Metals in Soil Samples Dumped With Faecal Sludge

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ABSTRACT

Heavy metal pollution has become a growing environmental concern primarily due to human activities. While it is found in soils naturally through processes of weathering of parent materials, it is the anthropogenic activities that create the greatest threat. This study was carried out to determine the possible bioaccumulation of heavy metals in faecal sludge, soil and maize grown on faecal dumped farm. The samples (faecal sludge, soil and maize) were obtained from University of Maiduguri Farm, Borno State, at three different depths (0cm, 10cm, 20cm and 30cm). Heavy metals were analyzed using standard method. In this study, spatial variations were observed for all metals across the depth. The results of the pH of the soil in this study ranged from 5.78 to 7.54. The results showed that heavy metals are more concentrated at 10cm and 20cm depth of the test soil with pH values of 5.78 and 5.92 respectively. The concentration of heavy metals at 0cm depth were Nickel (2.17 mg/kg), Cobalt (1.11mg/kg), Selenium (0.81mg/kg), Arsenic (0.21mg/kg), Lead (2.19mg/kg), Cadmium (5.61mg/kg), Mercury (0.70mg/kg), Chromium (8.72mg/kg), Zinc (5.48mg/kg) and Iron (13.03mg/kg) having the lowest concentration of metals. The concentration of heavy metals determined in faecal sludge in this study were in the sequence Cr>Zn>Pb>Ni>Cd>Fe>Se>As>Co>Hg. Selenium and Cadmium content of the test soil were above the recommended WHO limit of 0.3mg/kg for selenium and 0.5mg/kg for cadmium at all depths. The level of Cr and Hg were above permissible limit only at depth 10cm, surpassing the permissible limit set by WHO 2021 of 30-50 mg/kg and 0.3 mg/kg for Cr and Hg respectively for soil's maximum heavy metals limit. Nickel, Cobalt, Arsenic, Lead, Zinc and Iron of the test soil were within the permissible limit. Selenium at all depths 0cm (0.7 mg/kg), 10cm (1.33 mg/kg), 20cm (0.63 mg/kg), 30cm (0.50 mg/kg) and Cd 0cm (4.91 mg/kg), 10cm (6.56 mg/kg), 20cm (15.31 mg/kg), 30cm (8.40 mg/kg) at the control soil were above the permissible limit of 0.3mg/kg for Se and 2.0mg/kg for Cd in the soil while Ni, As, Pb, Hg, Cr, Zn and Fe were also within the permissible limit. In conclusion, regular monitoring and testing of soil, water and crops should be conducted to ensure compliance with safety standards and prevent heavy metal contamination.

Keywords: Sludge, Heavy Metals, Bioaccumulations, Faecal Sludge.

INTRODUCTION

The increasing global population and rising demand for food are placing immense pressure on already limited agricultural resources essential for crop production (Ngo *et al.,* 2021). A major concern is the lack of crop rotation practices among farmers, leading to soil fertility depletion, which is a critical limiting factor for crop yields. Additionally, water scarcity poses another significant challenge, contributing to low and unpredictable harvests (Hashimoto, 2020). Climate change has further exacerbated these issues by causing prolonged droughts that negatively impact crop size and yield (Shen and Graedel, 2020).

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The high cost of inorganic fertilizers makes them unaffordable for many small-scale farmers who rely on fertilizers to maintain soil fertility. These challenges have prompted farmers to seek alternative, cost-effective ways to enhance agricultural productivity (Liang *et al.,* 2020). One such alternative is sludge, which consists of solid deposits or sediments resulting from water treatment, wastewater management, and sanitation processes (Samal *et al.,* 2022).

Faecal sludge, specifically, originates from human waste, including solid and liquid excreta from toilets, septic tanks, grey water, and hygiene products (Mahapatra *et al.,* 2022). While it is rich in organic matter, it also contains harmful pathogens, making it potentially hazardous to human health, particularly when used for irrigation (Samal *et al.,* 2022). A significant concern with faecal sludge is the presence of heavy metals such as chromium (Cr), arsenic (As), lead (Pb), copper (Cu), iron (Fe), cadmium (Cd), mercury (Hg), and nickel (Ni) (Ekiyor *et al.,* 2019). At low concentrations, these metals play beneficial roles in certain biological processes. However, excessive exposure can lead to severe health complications, including gastrointestinal disorders, kidney damage, nervous system impairments, birth defects, and even cancer (Ohiagu *et al.,* 2020; Eze and Enyoh, 2020). The accumulation of heavy metals in the human body occurs through various mechanisms, primarily oxidative stress and enzyme inactivation, resulting in toxic effects on multiple organs (Kormoker *et al.,* 2019).

Soil is a crucial natural resource that directly influences food safety, quantity, and quality, while also playing a vital role in ecological and environmental sustainability. When crops are cultivated in fields irrigated with faecal sludge, they absorb heavy metals through their roots and leaves. These metals accumulate in different plant parts, including stems, grains, fruits, and leaves, posing significant health risks to consumers (Huang *et al.,* 2020). Given that even slight variations in heavy metal concentrations beyond safe limits can cause severe environmental and health issues, it is essential to investigate their presence in agricultural soil and crops (Enyoh *et al.,* 2020).

MATERIALS AND METHODS

Sample Collection

Sludge and maize samples were obtained from the University of Maiduguri Agricultural farm at random and kept in airtight containers for further analysis (Figure 1). Soil samples were collected using soil auger; the soil auger was positioned vertically at the desired sampling location (Figure 2), then pushed and rotated into the ground until it reaches the desired depth. Once at the depth, the auger was carefully pulled out and the soil samples were collected in a clean container. Soil samples were obtained from four different depths: 0 cm, 10 cm, 20 cm, and 30 cm.

Soil Sample Processing

Soil was sorted mechanically to get rid of foreign material and then sun dried for at least six (6) hours, the dried soil samples was then crushed and sieved using 2mm sieve. The fine soil obtained was stored in an air tight container for analysis (AOAC, 2020)

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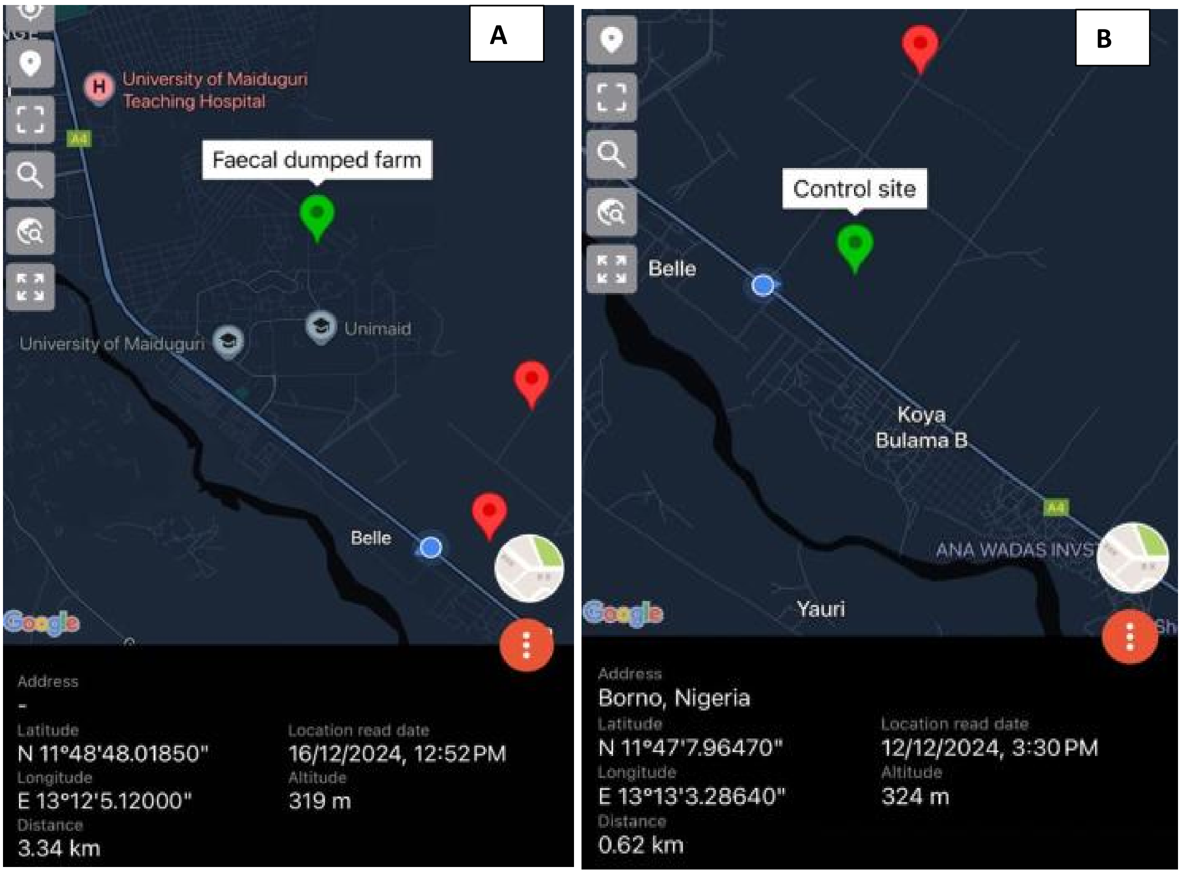

Figure 1: A- GPS Coordinate of control site. **B-** GPS Coordinate of faecal dumped farm site.

Source: Field survey (2024)
Location: University of Maiduguri Farm

MATERIALS AND METHODS

Sample Digestion

Two grams of each soil sample was weighed into a crucible and incinerated at **600°C** for three hours using a Carbolite muffle furnace. The resulting ash was treated with 10.0 mL of 6M HCl and boiled in a water bath for **10 minutes**. The mixture was filtered into a 100 mL volumetric flask, and the filter paper was washed to ensure complete transfer. The final volume was adjusted to **100 mL** with deionized water. A **10 mL** aliquot of the digested sample was transferred into a sample container and aspirated into the AAS for measurement, with results recorded in **ppm** (AOAC, 2010). To ensure analytical quality, blank samples were included in each batch to check for potential contamination from heavy metals or metalloids in the chemicals used during digestion.

Determination of Heavy Metals

The concentrations of heavy metals, Ni, Co, Se, As, Pb, Cd, Hg, Cr, Zn, and Fe, were determined using Atomic Absorption Spectrophotometer (AAS) Buck scientific model 210GP AA 6800 series (Shimazocorp). This was done according to method described by (AOAC, 2021).

Ten millilitres of the digested sample were transferred to the sample container and aspirated to the AAS; reading was recorded in ppm/mg/kg (AOAC, 2020).

Data Analysis

The Data was obtained in triplicate, and data collected was subjected to Analysis of Variance (ANOVA) and student's t-test using SPSS version 23.0. Duncan multiple range was used to compare the mean and the result were considered significant at $p<0.05$.

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RESULTS

Heavy Metal Concentrations in Faecal-Contaminated Soils at the Various Depths

The heavy metal concentrations in faecal-contaminated soil samples are presented in Table 1. Nickel levels varied significantly (p<0.05) across samples A to D, with the highest concentration recorded in sample D (12.57 mg/kg), while sample C had the lowest (10.32 mg/kg) compared to the control (A). A significant increase (p>0.05) in Nickel levels was observed in samples B, C, and D.

Cobalt concentrations were lowest in sample A (0 cm depth) at 1.11 mg/kg, increasing progressively with depth: sample B (10 cm depth – 2.59 mg/kg), sample C (20 cm depth – 2.58 mg/kg), and sample D (30 cm depth – 4.03 mg/kg). No significant difference (p<0.05) was observed between the Cobalt content of sample B and sample C, while sample D had the highest concentration.

Selenium concentrations differed significantly (p<0.05) among the samples: sample A (0 cm depth – 0.8 mg/kg), sample B (10 cm depth – 6.56 mg/kg), and sample C (20 cm depth – 5.16 mg/kg), and sample D (30 cm depth – 8.11 mg/kg). The highest Selenium concentration was recorded in sample D, while sample A had the lowest.

A significant (p<0.05) decrease in Arsenic concentration was observed in sample A (0 cm depth – 0.21 mg/kg) compared to the other samples. The highest Arsenic concentration was found in sample B (10 cm depth – 8.37 mg/kg), followed by sample D (5.04 mg/kg), while sample C recorded the lowest value (4.54 mg/kg).

Lead concentrations varied significantly (p<0.05) across the samples, with a marked reduction from sample B to sample D. Sample B had the highest Lead concentration (26.07 mg/kg), while sample A recorded the lowest (2.19 mg/kg). A significant reduction (p<0.05) in Lead levels was observed in sample A compared to samples B, C, and D.

Cadmium concentrations showed a significant (p<0.05) difference among the samples: sample A (0 cm depth – 5.61 mg/kg), sample B (10 cm depth – 54.85 mg/kg), sample C (20 cm depth – 25.91 mg/kg), and sample D (30 cm depth – 17.23 mg/kg). The highest Cadmium level was recorded in sample B, followed by sample C and sample D, while sample A had the lowest concentration.

Mercury concentrations varied significantly (p<0.05), with sample A (0 cm depth) recording 0.70 mg/kg, sample B (10 cm depth – 1.74 mg/kg), and sample C (20 cm depth – 0.60 mg/kg). The highest Mercury concentration was observed in sample B, and Mercury was detected in sample D (30 cm depth).

Chromium levels showed a significant (p<0.05) increase, with sample A (0 cm depth) recording the lowest concentration (8.72 mg/kg), followed by sample D (30 cm depth – 14.18 mg/kg). A significant increase (p<0.05) in Chromium levels was observed in sample C (20 cm depth – 39.26 mg/kg), while the highest concentration was recorded in sample B (10 cm depth – 55.79 mg/kg).

Zinc concentrations varied significantly across the samples. The lowest Zinc level was recorded in sample A (0 cm depth – 5.48 mg/kg), while the highest was observed in sample B (10 cm depth – 37.02 mg/kg), followed by sample C (20 cm depth – 18.5 mg/kg) and sample D (30 cm depth – 13.22 mg/kg).

Iron concentrations showed significant (p<0.05) differences among the samples. The highest Iron content was observed in sample B (26.15 mg/kg), while sample D recorded the lowest (9.47 mg/kg). The Iron concentration in sample A (13.03 mg/kg) was significantly higher than that of sample

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D but significantly lower than those of samples B and C.

Heavy metal concentrations in soil contaminated with faecal matter at depths 0cm, 10 cm, 20 cm, and 30 cm were detected for all analyzed metals, except Mercury (Hg) which was not detected at a depth 30 cm. The levels of Nickel, Cobalt, and Selenium in this study align with findings from Ye *et al.* (2022), which reported an increase in heavy metal concentration with soil depth. The distribution of these metals varies depending on the specific element and soil type. Lower concentrations were observed at the surface level (0 cm), possibly due to factors such as surface runoff, erosion, or leaching, as suggested by Sankhla and Kumar (2020).

Research by Guo *et al.* (2013) indicated that Zn, Pb, Cd, Cr, and Hg were more concentrated at the surface level (0 cm) compared to deeper layers. However, the current study contradicts this by showing higher concentrations of these metals with increasing soil depth, particularly at 10 cm and 20 cm. The Cadmium concentrations found exceeded the Nigerian soil target value set by the Department of Petroleum Resources (DPR) at 0.8 mg/kg and the World Health Organization (WHO) permissible limit of 2.0 mg/kg (2021). These findings are comparable to those reported by Odukoya *et al.* (2011) and Ogbe Media and Mbong (2013), as well as studies conducted in Onitsha (Nwajei *et al.,* 2007), Akure (Oviasogie *et al.,* 2011), and Port Harcourt (Akpoveta *et al.,* 2010; Ogbonna *et al.,* 2009).

The levels of Lead detected in this study were below the WHO (2021) permissible range of 20–50 mg/kg. Additionally, the concentrations were lower than those reported by Amusan *et al.* (2005), Adefeni and Awokumi (2009), Adelekan and Alawode (2011), and Odukoya *et al.* (2011). Chromium levels, with the exception of the 10 cm depth measurement (55.79 mg/kg), were all within the WHO acceptable limit (2021). A lower concentration of Chromium in soil contaminated with fecal matter was also reported by Amadi (2011) at the Aladima dumpsite.

Nickel concentrations at all depths were within the WHO permissible limits, though higher than those reported by Adefemi and Awokunmi (2009), Oviasogie *et al.* (2009), and Akpoveta *et al.* (2010). Zinc levels in this study remained below the WHO (2021) permissible limit at all depths but were lower than values reported by Ogmedia and Mbong (2013) while being comparable to those found by Adelekan *et al.* (2011b). Iron concentrations, ranging between 13.03 mg/kg and 9.47 mg/kg, were below the WHO (2021) limit and lower than those documented by Adefemi and Awokunmi (2009).

Table 1: Heavy metal concentration levels in faecal dumped soils at Different depths.

Metals (mg/kg)	A (0cm)	B (10cm)	C (20cm)	D (30cm)	WHO Limits (mg/kg)
Ni	2.17 +0.05^{d}	12.57 +0.15^{b}	10.32 +0.10^{c}	16.21 +0.15^{a}	30-50
Co	1.11 +0.00^{c}	2.59 +0.08^{b}	2.58 +0.01^{d}	4.03 +0.09^{a}	5.0
Se	0.81 +0.01^{d}	6.56 +0.22^{b}	5.16 +0.15^{c}	8.11 +0.24^{a}	0.3-1.0
As	0.21 +0.01^{d}	8.37 +0.10^{a}	4.54 +0.05^{c}	5.04 +0.05^{b}	20-40
Pb	2.19 +0.11^{d}	26.70 +0.70^{a}	11.57 +0.25^{b}	5.78 +0.12^{c}	20.50
Cd	5.61 +0.05^{d}	54.85 +0.38^{a}	25.91+0.18^{b}	17.23 +0.12^{c}	0.5-2.0
Hg	0.70 +0.01^{c}	1.74 +0.06^{a}	0.60 +0.02^{b}	ND	0.3-1.0
Cr	8.72 +0.12^{d}	55.79 +2.25^{a}	39.26 +0.15^{b}	14.18 +0.18^{c}	30-50
Zn	5.48 +0.50^{d}	37.02 +1.01^{a}	18.5 +0.42^{b}	13.22 +0.25^{c}	300
Fe	13.03 +0.05^{c}	26.15 +0.29^{a}	24.27 +0.93^{b}	9.47 +0.08^{d}	500

Values are presented as mean + SEM, n=3

Values with different super-scripts along the row are significantly different at P value < 0.05

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Keys

A- Soil sample at 0cm depth, B- Soil sample at 10cm depth, C- Soil sample at 20cm depth, D- Soils sample at 30cm depth, ND=not detected

Heavy Metal Concentrations in Control Soils at Different Depths

The heavy metal concentrations in the control soil samples are presented in Table 2.

A significant decrease ($p<0.05$) in Nickel concentration was observed in samples B, C, and D, with sample B exhibiting the highest concentration and sample D the lowest. The Nickel levels in samples B, C, and D were significantly ($p<0.05$) higher than in sample A.

Cobalt concentrations in samples D and C showed no significant difference ($p<0.05$), whereas a significant difference ($p<0.05$) was noted between sample B and the control sample A.

For Selenium, sample B recorded a significantly ($p<0.05$) higher concentration compared to samples C and D. The Selenium content in sample D was significantly ($p<0.05$) higher than in sample A, whereas the concentrations in samples D and C were significantly ($p<0.05$) lower than in sample A.

Arsenic concentrations in samples B, C, and D showed significant differences ($p<0.05$). Sample A had the highest Arsenic concentration compared to samples B and D but was lower than sample C.

Lead concentration was highest in sample B compared to samples C and D. Sample A recorded a Lead concentration of 2.18 mg/kg, which was lower than that of samples C and D.

Cadmium concentrations varied significantly ($p<0.05$) among the samples: sample A (0 cm depth – 4.91 mg/kg), sample B (10 cm depth – 6.56 mg/kg), sample C (20 cm depth – 15.31 mg/kg), and sample D (30 cm depth – 8.40 mg/kg). The highest Cadmium concentration was recorded in sample C (20 cm depth – 15.31 mg/kg), while the lowest was found in sample A (0 cm depth – 4.91 mg/kg).

The lowest Mercury concentration was observed in sample B (0.05 mg/kg), followed by sample D (0.06 mg/kg) and sample C (0.15 mg/kg). However, the Mercury levels in samples B and D showed no significant difference ($p<0.05$).

Chromium concentration was lowest in sample A (4.47 mg/kg) compared to sample B (34.66 mg/kg), sample C (16.53 mg/kg), and sample D (12.91 mg/kg). Sample B exhibited the highest Chromium concentration among all samples.

Zinc concentration in sample A differed significantly ($p<0.05$) when compared to samples B, C, and D. A notable reduction ($p<0.05$) in Zinc levels was observed in sample D compared to samples B and C, with sample B having the highest Zinc concentration.

Iron concentrations in sample C (20 cm depth – 10.23 mg/kg) and sample D (30 cm depth – 10.51 mg/kg) showed no significant ($p>0.05$) difference. However, a reduction in Iron concentration was observed in sample A (0 cm depth – 3.27 mg/kg) compared to sample B (10 cm depth – 8.38 mg/kg).

Soil contaminated with heavy metals significantly impacts soil quality and biodiversity, as these metals accumulate in surface layers and enter the food chain (Hong *et al.,* 2022). The control site at the University of Maiduguri Farm showed elevated levels of heavy metals, particularly Selenium at 10cm, exceeded the WHO permissible limit. Cadmium accumulation at all depths also surpassed the WHO limit for unpolluted heavy metal soil. Compared to studies by Chandra and Kumar (2017), the Cadmium concentration in this study was

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higher, likely due to discarded batteries or runoff from nearby roads (Agoro *et al.,* 2020; Shamuyarira and Gumbo, 2014). Research indicates that 77% of Maiduguri's agricultural land has a history of fecal sludge disposal, contributing to persistent soil contamination (Sankhla and Kumar, 2020).

Table 2: Heavy metals concentration in control soils at different depths.

Metals (mg/kg)	A (0cm)	B (10cm)	C (20cm)	D (30cm)	WHO Limits (mg/kg)
Ni	2.89 +0.03[d]	5.62 +0.05[a]	3.78 +0.04[b]	3.34 +0.03[c]	30-50
Co	1.91 +0.02[a]	0.75 +0.02[c]	0.96 +0.04[b]	0.99 +0.04[b]	5.0
Se	0.71 +0.02[b]	1.33 +0.02[a]	0.63 +0.04[d]	0.50 +0.01[c]	0.3-1.0
As	1.42 +0.01[b]	0.74 +0.01[d]	2.20 +0.02[a]	1.27 +0.01[c]	20-40
Pb	2.18 +0.03[d]	12.30 +0.13[a]	7.47 +0.15[b]	3.93 +0.01[c]	20.50
Cd	4.91 +0.03[d]	6.56 +0.04[c]	15.31+0.11[a]	8.40 +0.05[b]	0.5-2.0
Hg	ND	0.05 +0.00[b]	0.15 +0.01[a]	0.06 +0.00[b]	0.3-1.0
Cr	4.74 +0.05[d]	34.66 +0.27[a]	16.53 +0.54[b]	12.91 +0.39[c]	30-50
Zn	2.48 +0.04[d]	10.38 +0.49[a]	5.59 +0.19[b]	3.47 +0.13[c]	300
Fe	3.27 +0.39[c]	8.38 +0.02[b]	10.23 +0.08[a]	10.51 +0.22[a]	500

Values are presented as mean + SEM, n=3

Values with different super scripts along the row are significantly different at P value < 0.05

Keys

A=Control soil sample at 0cm depth
B= Control soil sample at 10cm depth
C=Control soil sample at 20cm depth
D=Control soil sample at 30cm depth
ND=not detected

Heavy Metal Content of Faecal Sludge

The Concentration of heavy metal determined in faecal sludge were in the sequence.

Cr > Zn > Pb > Ni > Cd > Fe > Fe > Se > As > Co > Hg >

The Concentration of Chromium (Cr) was found to be highest in the faecal sludge having (129mg/kg) which is followed by Zinc (Zn) having (77mg/kg) while the lowest concentration was observed in Mercury (Hg) having (0.52mg/kg).

Heavy metal concentrations in fecal sludge analyzed in this study were higher than those in similar studies (Afolabi and Sohil, 2017). A decreasing trend in heavy metal concentration was observed, consistent with the findings of Manga *et al.* (2022) and Ahmed *et al.* (2019). The levels of Cr, Zn, Pb, Ni, and Cd exceeded WHO and FAO (2021) guidelines for alternative fertilizers. Previous studies from Ghana, South Africa, and Uganda also reported high Zinc content in fecal sludge (Appiah-Effah *et al.,* 2015; Shamuyarira and Gumbo, 2014; Manga *et al.,* 2020; Ahmed *et al.,* 2019). The variance in metal concentrations may stem from the chemicals used in fecal decomposition and the nature of waste disposal in pit latrines.

Table 3: Heavy Metal concentration of Faecal Sludge (mg/kg)

Parameters	Mean Conc.
Ni	31.57 +0.27
Co	1.86+0.08
Se	15.17 +0.28
As	2.75 +0.02
Pb	47.01 +0.59
Cd	20.64 +0.14
Hg	0.52 +0.01
Cr	129.92 +1.21
Zn	77.54 +3.44
Fe	20.51 +0.10

Values are Mean + SEM, n= 3

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CONCLUSION

In conclusion, dumping of faecal sludge has led to bioaccumulation of faecal sludge in the soil which can be taken up by crops, based on fact obtained from this study, we suggest official body (ies) to take necessary precaution measures to ensure the good treatment and safer method of faecal sludge use on farm lands.

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