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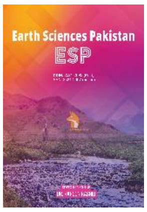

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RESEARCH ARTICLE

ANALYSIS OF BIOACCUMULATION OF HEAVY METALS IN WATER, CABBAGE (*BRASSICA OLERACEA VAR. CAPITATA*) AND TILAPIA FISH (*OREOCHROMIS NILOTICUS*) FROM UNRECLAIMED MINING PITS

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ABSTRACT

The study investigated the levels of specific heavy metals in water, tilapia, and vegetables grown in abandoned mining pits in Bukuru, Jos South. Control point was set up in Riyom while five sampling points were chosen throughout Bukuru town. 32 water samples as well as 8 samples of fish and cabbage were gathered. Eight (8) heavy metals, including cadmium, manganese, mercury, copper, nickel, lead, uranium, and zinc, were examined in the samples. The findings demonstrated that the dry season comparison with control did not reveal a statistical difference at $\rho > 0.05$, d = 0.06, but the comparison of mean seasonal levels of heavy metal levels in water samples with control shows a statistical difference in concentration levels between mean concentration and trend observed at control point at $\rho < 0.05$, d = 0.02. Nevertheless, compared to the control sample, Cd, Mn, Cu, Ni, Pb, and Zn was higher in cabbage. For both seasons, the maximum allowable limit for fish consumption was exceeded by all investigated heavy metals except for Ur, which was not found. The seasonal distributions of heavy metals in water and cabbage samples were compared, and the results indicated that there was no statistically significant difference at $\rho > 0.05$, d = 0.32 during the rainy season and $\rho > 0.05$, d = 0.13 during the dry season. This suggests that heavy metals bioaccumulate in cabbage from water contaminated with heavy metals and there is the need to reclaim the pit to prevent further pollution.

KEYWORDS

Reclaim, Heavy metals, surface water, cabbage vegetation, Tilapia fish.

1. INTRODUCTION

Industrial scientists create several new chemicals annually which in return are toxic to the environment and usually cost huge sums of money to remove from the environment. A lot of these industrial inorganic pollutants which are usually of great concern to the environmentalist are heavy metals. Anthropogenic activities such as mining, processing of minerals manufacturing, and mechanized farming have the potentials to increase influx of some of these metals which are available in nature or increase their concentration to levels beyond permissible limits. A perfect example is the high concentration of metallic pollutants present in the wastewater discharged from various processing factories or food industries. A characteristic shared by all heavy metals is the ability to bioaccumulate in the bodies of their host in case of ingestion (Mason, 2003). Therefore, within the food chain, there is the chance that the concentrations of these metals will increase significantly. Certain algae in marine aquatic bodies have high heavy metal concentrations which may be over 100 times higher than the water bodies which they presently live in (Laws, 2000). Smaller fishes that consume such algae within the food chain develop higher heavy metal concentration on the flesh; same with larger fishes that feed on the smaller fishes.

Several human activities and other natural processes impacts on water which in turn affects the quality of water. Overview assessment of the natural qualities of water reveal that these qualities differ from each location arising from seasonal variation, climate change, soil type, surface on which the water flows and rock type. Diverse human activities such as commercial agriculture, industrial and urban growth, recreation, and mineral mining all significantly impair the quality of natural water which potentially alters the use of such water. Sustainable water resources can only be attained if available water quality remains suitable for the purpose it was intended for while making provision for it to be harnessed and utilized to a reasonable extent for some other purpose (Mandal and Kaur, 2019). Usually water resources qualities (physical and chemical) depletion because of human activities and interferences are fundamentally subtle or gradual rather than sudden. The aquatic ecosystem environment also gradually adjusts to the change, which might not be apparent until the aquatic ecosystem environment undergoes a significant change. Because of the slow enrichment of surface water by nutrients from plants, several shallow lakes in several European countries experienced severe pollution.

As a result, the ecosystem that was formerly dominated by aquatic plants with roots began to include algae suspended in the water column (Scheffer et al., 2001). According to Kalwale and Savale, water is considered polluted when human activity modifies its acceptable quality to the point where it becomes unfit for residential and commercial use (Kalwale and Savale, 2012). A certain amount of pollution can be naturally removed by rivers, lakes, streams, and oceans by dispersing it in an innocuous way (Kanu and Achi, 2011). According to recent studies, widespread human interference,

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steady industrial growth, and fast urbanization have all contributed to the contamination of water bodies and water resources. Accelerated rate of population growth, agriculture and commercial activities have led to the generation and mass accumulation of solid and liquid wastes that eventually end in water bodies, this eventually alters the water quality, distort biodiversity, and composition of species in several aquatic systems (Leslie, 2010).

Over the past few decades, the world's concern for environmental management to improve quality as it affects human well-being has increased due to the growth of urbanization and industrial processes, complex technologies, and their concomitant impacts on the environment (Carla, 2006). The Federal Environmental Protection Agency (FEPA) was established in Nigeria in 1988 because of the country's growing awareness of environmental quality. The agency's mandate includes the development and protection of the country's environment, as well as the formulation of policy regarding environmental research and technology (Stephen, 2007). However, while mining activities has been going on since the pre-colonial era, laws regarding mining and subsequent reclamation were not promulgated until 1949 by means of the 1949 Mineral Act (Currently Nigeria Mineral Act, 1999). The short coming of this law was the vagueness associated with the clause ‘‘reasonable restoration’’ which appeared not forceful enough to compel mineral investors to reclaim mined-out areas. These mined out areas represent some of the most heavily mined areas prior to 1946 and were incidentally also the most fertile areas for agriculture. For example, on the Jos Plateau, designated village areas of Kuru, Zawan, Vom, Shen, Du, Gyel and later Jos and Buruku which were some of the mined-out lands were also very good agricultural lands (Stephen, 2007).

Carla claims that in the various processes involved in turning a previously unusable or abandoned piece of land back into a good state, the term reclamation is frequently chosen over restoration or rehabilitation (Carla, 2006). This is because only reclamation adequately captures the goal of returning the land to the intended state when the dictionary definition of this term is applied to land that has been or is currently being mined using surface methods. As a result, this recognizes the two fundamental components of land reclamation: the need to define the desired condition from the outset and to modify it considering the circumstances at hand. According to Mason, it is impossible to restore the land to its original state in the strict sense of the word (Mason, 2003). This is a result of something being taken and not being replaced. For instance, the porosity of the soil and, consequently, its ability to hold and transfer water, would have changed if the swell of the replaced ground coincidentally compensates for the volume loss and allows the restoration of previous surface levels. However, in its new context, rehabilitation has much the same significance as reclamation, despite being inappropriate in its original meaning in the mining context (Li et al., 2021).

Between 1905 and 1994, the Jos Plateau's tin mining produced significant economic benefits for Nigeria (Alexander, 1985). Most Nigeria's tin came from the Plateau tin fields. During this time, the country's other sources of income and foreign exchange included timber from the former Mid-western region of Nigeria, cotton, groundnuts, palm oil, and palm kernels from Eastern Nigeria, cocoa from Western Nigeria, and hides and skins from Northern Nigeria. Tin helped the nation's economy grow significantly by providing a significant amount of foreign exchange and revenue (Stephen, 2007). Investigating the presence of heavy metals in water, tilapia fish, and cabbage vegetables from abandoned mining pits used for farming in Bukuru town, Jos South, Plateau State, is the aim of this study.

2. Materials and Methods

2.1 Study Area

This study was conducted in Bukuru, a mining and fishing town in the Jos South Local Government Area of the Plateau State. The project area can be reached by secondary, major, and minor roads, and it is situated as indicated in Figure 1 between latitude 90 54' N and 100 43' N and longitude 080 52' E to 080 52' E. It has two distinct seasons, like most of Nigeria (wet and dry). The wet season, which has the lowest duration, frequency, and intensity, runs from April through the middle of October and occasionally into early November. The south-west trade wind that blows across the nation from the Atlantic Ocean typically causes the rain. The dry season, which lasts from December to March, is marked by extreme heat waves and drought. The North-East trade wind that enters Nigeria from the Sahara Desert has an impact on the dry season. It is accompanied by harmattan, a dusty wind, a high midday temperature, severe dryness, and surface hardening. In the catchment, the average monthly temperature ranges from 200 to 280 degrees Celsius. The river Delimi, which empties into the Gongola River, which is situated northeast of the study area, eventually empties into the river Benue which drains the majority of the region.

The catchment has also been drained by smaller streams like Ankwe, Mada and Wase-Shemaker. In August and March, these streams experience peak and lowest flows respectively. Many of the streams resemble chains of water holes divided by silt and alluvium from December to March (during the dry season) (Alford et al., 1997). The ponds and streams provide water for use in residential, commercial, and industrial settings. Farmers and fishermen use the recharged and abandoned mining ponds for irrigation purposes.

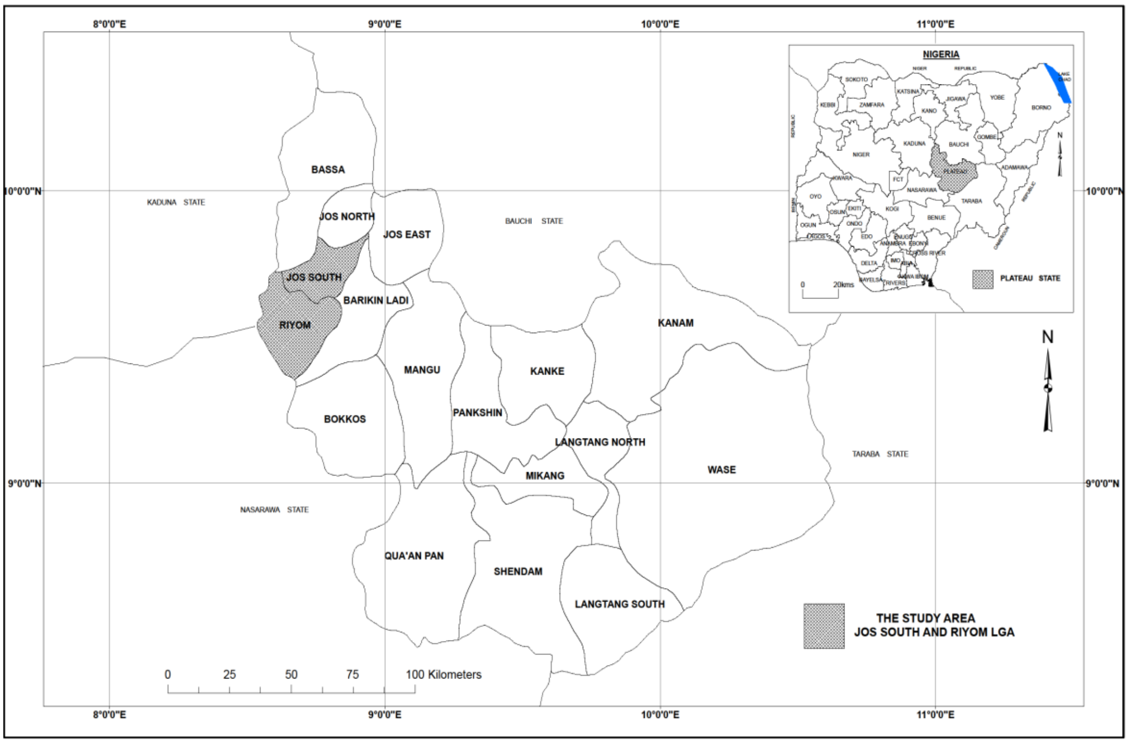

Figure 1: Study area in Riyom and Jos South Local Government Area

2.2 Data Collection

In Bukuru town, five sampling locations were purposefully chosen to act as representative samples of the unreclaimed ponds dispersed throughout the research region. In the Riyom Local Government Area, a control point was also set up in Riyom town. According to Stephen, this location has the fewest mining activities in the study area (Stephen, 2007). Samples of water, cabbage, and tilapia fish were gathered at each of the five carefully chosen sampling locations throughout the research region to investigate the possibility of heavy metal contamination. One of the main factors that affected the choice of the sampling point was accessibility. Furthermore, the study area's unclaimed mining ponds are dispersed geographically. Local farmers are also currently using the chosen pits for fish farming and irrigation. A Global Positioning System (GPS) was used to record the geographic coordinate of each location at each of the sampling points.

2.3 Water Collection technique

In 2019, July to September, water samples were collected as this was wet season while dry samples were collected within January to March of the same year. A total of thirty-two (32) water samples were collected for the study in the study area, fifteen (15) water samples were collected in each of the five sampling points during each season, along with a control sample. Eight (8) heavy metals, including zinc, cadmium, mercury, copper, lead, manganese, uranium, and nickel, were examined in the water samples. Elevated levels of toxicity associated with these parameters have been linked to several health issues, including damage to cells and tissues, liver and kidney failure, and others. The selection of water and cabbage for this study is due to their significance as heavy metal biomarkers in aquatic environments (Zaghloul et al., 2019; Li et al., 2021). The sampling bottles were first completely cleaned by rinsing them in clean water and methylated spirit. This was done in compliance with APHA to make sure that no contaminants entered the samples that were collected and transported to the laboratory (APHA, 1998). The 250 ml plastic bottle was dipped 30 cm below the water's surface using the grab sampling method (Li et al., 2021). After being appropriately labeled, the samples were transported to the Kaduna state Environmental Protection Agency (KEPA) laboratory for analysis and storage.

2.4 Cabbage Collection technique

Samples of cabbage were gathered between January to March, and July to September, which correspond to the dry and rainy seasons, respectively, during the time that sediment data was gathered. Eight (8) tomato samples were gathered, with three samples taken during each season and two (2) control samples taken during the rainy and dry seasons. Eight heavy metals, including cadmium, manganese, mercury, copper, nickel, lead, uranium, and zinc in the case of water, were examined in the samples. Given that vegetables are a good bio-assay indicator for aquatic pollution, tomato fruit was selected (Marzena et al., 2014; Mandal and Kaur, 2019). Furthermore, tomato fruit is a significant source of income for the people living in the study area and elsewhere. Samples of tomatoes were chosen by hand and kept in black polyethylene bags. The samples of polyethylene bags were labeled with the correct source and the date of collection, sun-dried, and then brought to the Kaduna State Environmental Protection Agency's (KEPA) laboratory for examination.

2.5 Collection of Tilapia Fish

Samples of tilapia fish were taken between January to March and July to September, respectively, to represent the dry and rainy seasons just as it was done with the water samples. Eight (8) fish samples, three (3) per season, plus two (2) control point samples, were gathered for the study. Eight heavy metals, including cadmium, manganese, mercury, copper, nickel, lead, uranium, and zinc in the case of water, were examined in the samples. *Tilapia nilotica* is a good bio-assay indicator for aquatic pollution, according to research, which is why tilapia fish was selected (Rashed, 2001). Furthermore, *Tilapia nilotica* is a significant source of protein and a means of subsistence in the research region and elsewhere. Fishhooks or nets were used to gather the fish samples, which were then stored in black polyethylene bags. The samples of polyethylene bags were labeled with the correct source and the date of collection, sun-dried, and then brought to the Kaduna State Environmental Protection Agency's (KEPA) laboratory for examination.

2.6 Sample Preparation

2.6.1 Water Sample Preparation

Before being sent to the lab for testing, the water was packaged and labeled. 50 ml, or one-third of the total weight, of the meticulously shaken water samples from each sampling location was accurately measured into a beaker. The samples were then digested for a few hours at 100 °C on a hot plate with 5 ml of concentrated HNO_3, until the solutions were less than 20 ml by volume. After that, the solutions were placed in 100 ml plastic containers, and an atomic absorption spectrometer (AAS) was used to find out if any heavy metals were present.

2.6.2 Preparation of Cabbage sample (Digestion)

To prevent microbial impacts, the plant samples were oven-dried. They were then pulverized, put through a 2mm filter, and submitted to conventional scientific examinations. A quantity of dried plants weighing around 2.0 g was digested in 15cm3 of a tri-acid combination (5:1:1 ratio of HNO3, HCI, and H2SO4) at 800C until a translucent solution was visible. After cooling down, the digested samples were filtered through White man No. 41 filter paper, and the filtrates were then stored in 50 cm3 of distilled water. Subsequently, the transparent solutions were placed inside sample vials for reading by the Atomic Absorption Spectrometer.

2.6.3 Preparation of Tilapia fish sample (Digestion)

To prevent microbiological impacts, the fish samples were oven-dried. They were then pulverized, put through a 2 mm filter, and submitted to normal laboratory tests. A chunk of dried fish weighing around 2.0 g was digested in 15 cm^3 of a tri-acid mixture (5:1:1 ratio of HNO3, HCI, and H2SO4) at 800C until a translucent solution was visible. After cooling, what man No. 41 filter paper was used to filter the digested samples, and the filtrates were then kept at 50 cm^3 distilled water. After that, the transparent solutions were put into sample vials so that the Atomic Absorption Spectrometer could read them.

2.7 Establishing the Standard Curve

The preparation of the heavy metal standard curves considered the fact that these elements only exist in minuscule amounts. From a stock solution of 1000 parts per million (ppm), standard solutions were created. Using distilled water as a filler, 1 ml of the 1000 ppm stock solution was pipetted into a 100 ml volumetric flask. The concentration of this solution was 10 ppm. Standard solutions of 0.2, 0.4, 0.6, 0.8, and 1 ppm were created from this solution by measuring out amounts of 0.2, 0.4, 0.6, 0.8, and 1 ml into 10 ml volumetric flasks. Standard curves for the individual elements were then generated by running them in the Air Acetylene flame.

2.8 Analytical Method

The Kaduna State Environmental Protection Agency (KEPA), located in Kaduna, used an Atomic Absorption Spectrometer (AAS) (Bulk Scientific Model 200H AAS) to analyze the chosen heavy metals following sample digestion. Both dissolved and total metals in soil and water can be treated with this technique. The digest, which was processed on an Atomic Absorption Spectrometer (AAS) that burns air acetylene, weighed 100 milliliters per sample. By using a known standard curve for each element and the appropriate wavelength for each, the absorbance of the chemical elements present in the samples was determined. Using the standard absorbance of each individual element, the absorbance from the various heavy metals present in the samples was converted to parts per million (ppm) or milligrams per liter (mg/l) values as their concentration levels.

2.9 Statistical Analysis

The laboratory analysis results are subjected to basic descriptive statistics, including standard deviation (SD) and mean. To compare sample distributions, the student t test was employed at 0.05 significant levels. Since the study used mean and compared the means of two sample sets with seasonal variability, the t-test was selected. Microsoft Excel and the statistical software SPSS (version 16.0) are used to perform statistical analysis.

3. Results

The findings of the rainy season heavy metal concentrations in surface water from abandoned mining pits used for irrigation in Bukuru, Jos south, are shown in Tables 2 and 3. Except for Cd, all the heavy metal parameters in Table 2 were within the ranges recorded at the control point and maximum allowable limits for water. However, in dry season Cd was slightly higher above levels across all the control points except BKKSI (ECWA farm, Bukuru). Mn was also observed to marginally exceeded levels observed at both control point and standard threshold for portable water at BKKSII (Behind ECWA farm 1, Bukuru), BKKSIV (Behind Yelwa club junction, Bukuru) and BKKSV (ECWA family church, Bukuru). Uranium was not detected in water samples for both rainy and dry season.

Table 2: Concentration of heavy metals during the rainy season in surface water from unreclaimed mining pits used for irrigation in Bukuru, Jos south.

		BKKS I	BKKS II	BKKS III	BKKS IV	BKKS V	Control	NESREA Standard
Cd (mg/l)	Mean Conc. Level (6 months)	0.0286	0.0377	0.0414	0.05	0.054	0.0099	0.003
Mn (mg/l)	Mean Conc. Level (6 months)	0.0333	0.0279	0.0401	0.0288	0.0316	0.0031	0.05
Hg (mg/l)	Mean Conc. Level (6 months)	0.0001	-	0.0002	0.0021	0.0021	-	0.006
Cu (mg/l)	Mean Conc. Level (6 months)	0.0178	0.0267	0.0638	0.0595	0.0465	0.0026	2.0
Ni (mg/l)	Mean Conc. Level (6 months)	0.006	0.0025	0.012	0.0253	0.0165	0.0013	0.07
Pb (mg/l)	Mean Conc. Level (6 months)	0.0016	0.0181	0.02	0.0251	0.011	0.0001	0.01
Ur (mg/l)	Mean Conc. Level (6 months)	-	-	-	-	-	-	0.0013
Zn (mg/l)	Mean Conc. Level (6 months)	0.2816	0.1222	0.076	0.0588	0.1604	0.0294	3.0

Table 3: Concentration of heavy metals during the dry season in surface water from unreclaimed mining pits used for irrigation in Bukuru, Jos south.

		BKKS I	BKKS II	BKKS III	BKKS IV	BKKS V	Control	NESREA Standard
Cd (mg/l)	Mean Conc. Level (6 months)	0.0001	0.0444	0.0578	0.0628	0.0388	0.0099	0.003
Mn (mg/l)	Mean Conc. Level (6 months)	0.0714	0.0412	0.0614	0.058	0.0644	0.0031	0.05
Hg (mg/l)	Mean Conc. Level (6 months)	<0.0001	0.001	0	0.0001	0.0001	0	0.006
Cu (mg/l)	Mean Conc. Level (6 months)	0.4761	0.028	0.0317	0.0416	0.0167	0.0026	2.0
Ni (mg/l)	Mean Conc. Level (6 months)	0.0001	0.0111	0.0216	0.0024	0.016	0.0013	0.07
Pb (mg/l)	Mean Conc. Level (6 months)	0.01	0.0026	0.0112	0.0056	0.0047	0.0001	0.01
Ur (mg/l)	Mean Conc. Level (6 months)	-	-	-	-	-	-	0.0013
Zn (mg/l)	Mean Conc. Level (6 months)	0.071	0.1446	1.047	0.4776	0.0482	0.0294	3.0

Table 4 displays a comparison of the mean concentration of heavy metals in water from various sampling locations. In the rainy and dry seasons, the average Cd concentration at each sampling location was 0.042 and 0.041, respectively. At $\rho > 0.05$, d = 0.43, no statistically significant difference was found in the concentration levels between the rainy and dry seasons across the sampling stations. There was a 1.2% difference in percentage between the two seasons. In the rainy and dry seasons, respectively, the mean concentration of Mn across the sampling points was 0.032 and 0.059. The mean during the dry season was higher than the level during the rainy season; however, a statistically significant difference was found between the two seasons at $\rho < 0.05$, d = 0.002. There was a 29.7% difference in percentage between the two seasons. In the rainy and dry seasons, the mean mercury levels across the sampling points were 0.001 and 0.0001, respectively, with an 81.8% percentage deviation. At $\rho > 0.05$ and d = 0.16, no statistically significant difference was found in the concentration levels across the sampling points.

In the rainy and dry seasons, the mean copper levels were, respectively, 0.043 and 0.119. The percentage deviation from the mean level was 46.9%, and at $\rho > 0.05$ and d = 0.24, there was no statistically significant difference found between the concentration levels across the sampling points. For the rainy and dry seasons, the mean Ni level at each sampling location was 0.012 and 0.010, respectively. At $\rho > 0.05$ and d = 0.36, statistical differences were not detected, and the percentage of deviation from the mean was 9.09%. For the rainy and dry seasons, the mean Pb levels at each sampling point were 0.015 and 0.007, respectively. At $\rho > 0.05$ and d = 0.08, differences in the concentration level between the sampling points were not statistically significant. The mean concentration differed by 36.4% between the two seasons. The mean Zn levels for the rainy and dry seasons were 0.14 and 0.358, respectively, across sampling points. At $\rho > 0.05$, d = 0.19, no statistically significant difference was found in the levels of zinc across sampling stations. 43.8% was the percentage of variation in the mean Zn levels throughout the sampling point.

Except for Mn, the concentration levels of the heavy metals under investigation in water samples at all sampled points did not significantly change between seasons overall. In addition, compared to levels observed during the rainy season, Cd, Ni, Pb, and Hg were marginally higher during the rainy season, whereas Mn, Cu, and Zn levels were higher during the dry season.

Table 4: Student T-test comparison of the average concentrations of heavy metals in water samples from unreclaimed mining pits used for irrigation across seasons in Bukuru, Jos south,

		BKKS I	BKKS II	BKKS III	BKKS IV	BKKS V	Mean±SD	P-value	% of Deviation
Cd (mg/l)	Rainy	0.0286	0.0377	0.0414	0.05	0.054	0.042±0.01	0.43	1.2
	Dry	0.0001	0.0444	0.0578	0.0628	0.0388	0.041±0.02		
Mn (mg/l)	Rainy	0.0333	0.0279	0.0401	0.0288	0.0316	0.032±0.005	0.002	29.7
	Dry	0.0714	0.0412	0.0614	0.058	0.0644	0.059±0.01		
Hg (mg/l)	Rainy	0.0001	0	0.0002	0.0021	0.0021	0.001±0.001	0.16	81.8
	Dry	0.0001	0.001	0	0.0001	0.0001	0.0001±0.004		

Table 4 (Cont.): Student T-test comparison of the average concentrations of heavy metals in water samples from unreclaimed mining pits used for irrigation across seasons in Bukuru, Jos south,

Cu (mg/l)	Rainy	0.0178	0.0267	0.0638	0.0595	0.0465	0.043±0.02	0.24	46.9
	Dry	0.4761	0.028	0.0317	0.0416	0.0167	0.119±0.19		
Ni (mg/l)	Rainy	0.006	0.0025	0.012	0.0253	0.0165	0.012±0.009	0.36	9.09
	Dry	0.0001	0.0111	0.0216	0.0024	0.016	0.010±0.009		
Pb (mg/l)	Rainy	0.0016	0.0181	0.02	0.0251	0.011	0.015±0.009	0.08	36.4
	Dry	0.01	0.0026	0.0112	0.0056	0.0047	0.007±0.004		
Ur (mg/l)	Rainy	-	-	-	-	-	-	-	-
	Dry	-	-	-	-	-	-		
Zn(mg/l)	Rainy	0.2816	0.1222	0.076	0.0588	0.1604	0.140±0.09	0.19	43.8
	Dry	0.071	0.1446	1.047	0.4776	0.0482	0.358±0.42		

Note: The difference is statistically significant at the 0.05 level of confidence (one-tail).

A statistical difference in concentration levels between mean concentration and trend observed at control point at $\rho < 0.05$, $d = 0.02$, as demonstrated in Table 5 comparison of mean seasonal levels of heavy metal levels in water samples with control, suggests that the presence of heavy metals in water samples was statistically higher than levels obtained at control point. However, during the dry season, there was no statistically significant difference between the distribution and the control group at $\rho > 0.05$ and $d = 0.06$. This implies that storm water and rainfall (a type of diffuse pollution) play a significant role in the heavy metal contamination of the research area.

Table 5: Comparison of mean seasonal levels of heavy metal in water samples from unreclaimed mining pits used for irrigation in Bukuru, Jos south, (Riyom) using the Student T-test

		Cd	Mn	Hg	Cu	Ni	Pb	Ur	Zn	P-value
Rainy Season	Mean conc.	0.042	0.032	0.001	0.043	0.012	0.015		0.140	0.02
	Control (Riyom)	0.0099	0.0031	0	0.0026	0.0013	0.0001	0	0.0294	
Dry season	Mean conc.	0.041	0.059	0.000	0.119	0.010	0.007		0.358	0.06
	Control (Riyom)	0.0099	0.0031	0	0.0026	0.0013	0.0001	-	0.0294	

Note: Difference is statistically significant at 0.05 level of confidence (one-tail)

Table 6 displays the mean seasonal distribution of heavy metals in the vegetable cabbage. Rainy season levels of Cd, Mn, Cu, Ni, Pb, and Zn exceeded both the maximum allowable limit for human consumption and the levels observed with the control sample. During the dry season, a comparable pattern was also noted. Table 7 shows that for both seasons, the maximum allowable limit for fish consumption was exceeded for all investigated heavy metals, except for Ur, which was not detected.

Table 6: Seasonal heavy metal distribution in cabbage vegetables (Brassica oleracea var. capitata) grown in Bukuru, Jos south, from unreclaimed mining pits used for irrigation.

	Rainy Season	Rainy season Control	Dry Season	Dry season Control	NESREA STANDARD
Cd	0.00145	0.0006	0.0213	0.00129	<01
Mn	0.01289	0.0025	0.1883	0.00146	<01
Hg	-	10^{-3}	$<10^{-3}$	10^{-3}	$<10^{-3}$
Cu	0.0894	0.0027	0.1083	1.243	<01
Ni	10^{-2}	10^{-3}	0.011	0.669	<0.59
Pb	10^{-3}	$<10^{-3}$	10^{-3}	10^{-2}	<01
Ur	-	-	-	-	<3
Zn	0.2459	0.0266	0.6557	0.245	3

Table 7: Tilapia fish (Oreochromis niloticus) seasonal concentrations of heavy metals from unreclaimed mining pits used as fishponds in Bukuru, Jos south.

	Rainy Season	Rainy season Control	Dry Season	Dry season Control	NESREA STANDARD
Cd	10^{-2}	10^{-3}	0.021	0.001	0.01
Mn	0.010	10^{-2}	0.188	0.070	0.03
Hg	-	10^{-3}	10^{-3}	10^{-3}	$<10^{-3}$
Cu	0.066	0.004	0.208	0.123	1
Ni	0.002	0.005	0.061	0.015	0.02
Pb	0.006	0.000	0.027	0.006	0.05
Ur	-	-	-	-	-
Zn	0.163	0.005	0.656	0.114	1.0

The seasonal distributions of heavy metals between the control sample (cabbage) and water sample, as well as between the vegetable and water sample, are shown in Figures 2–5. There was no statistically significant difference in the levels of heavy metals between the water and the cabbage sample in the rainy season ($\rho > 0.05$, $d = 0.32$), suggesting that the heavy metals in the water had bioaccumulated in the cabbage. A comparable pattern was noted at ρ > 0.05, d = 0.13 during the dry season. When cabbage from unreclaimed mining pits and a sample from a control point are compared for heavy metal levels, the results indicate that there is no statistically significant difference in concentration levels at ρ > 0.05, d = 0.09 and ρ > 0.05, d = 0.21 in the rainy and dry seasons, respectively. Although Riyom is a different local government area and is known to have recorded the least amount of mining activity in Jos South, the statistical similarity in concentration levels between cabbage samples from the unreclaimed mining pit and samples from the control point may indicate contamination at that location.

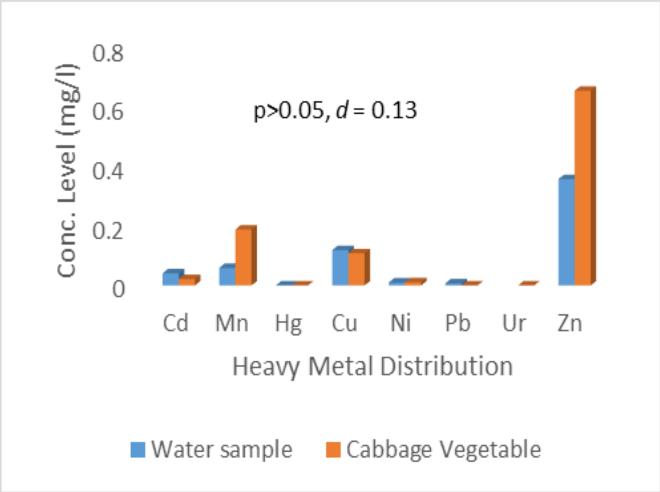

Figure 2: Comparison of rainy season level of heavy metal concentration in water and cabbage samples in Bukuru, Jos South.

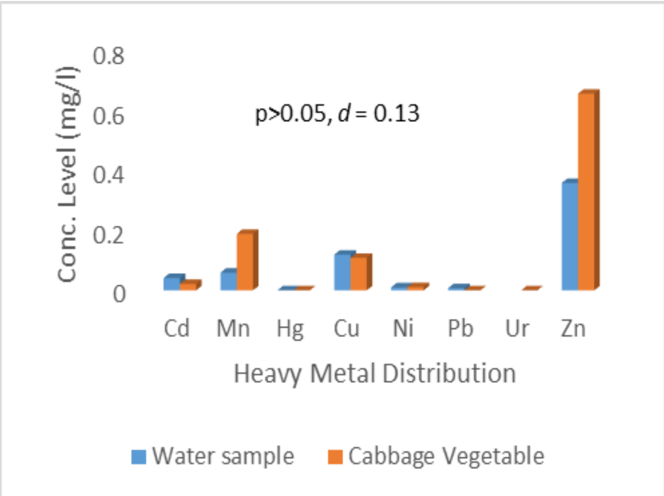

Figure 3: Comparison of dry season level of heavy metal concentration in water and cabbage samples in Bukuru, Jos South.

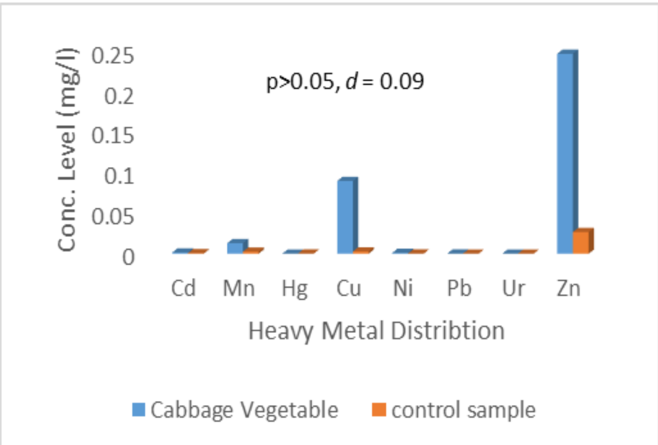

Figure 4: Comparison of rainy season level of heavy metal concentration in cabbage samples in Bukuru, Jos South.

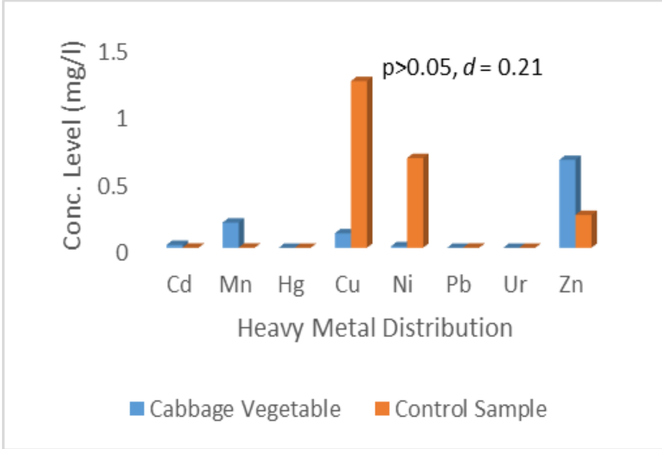

Figure 5: Comparison of dry season level of heavy metal concentration in cabbage samples in Bukuru, Jos South.

The seasonal distributions of heavy metals in fish and water samples, as well as in control samples (Tilapia fish), are compared and shown in Figures 6–9. Rainy found no statistically significant difference in the levels of heavy metals between the fish sample and the water at ρ > 0.05, with d = 0.28 indicating that tilapia had bioaccumulated heavy metals from the contaminated water. In the dry season, a similar pattern was seen at ρ > 0.05 and d = 0.05. When the levels of heavy metals in fish from unreclaimed mining pits and control point samples are compared, there is no statistically significant difference in concentration levels at ρ > 0.05, d = 0.28 and ρ > 0.05, d = 0.07 in the rainy and dry seasons, respectively.

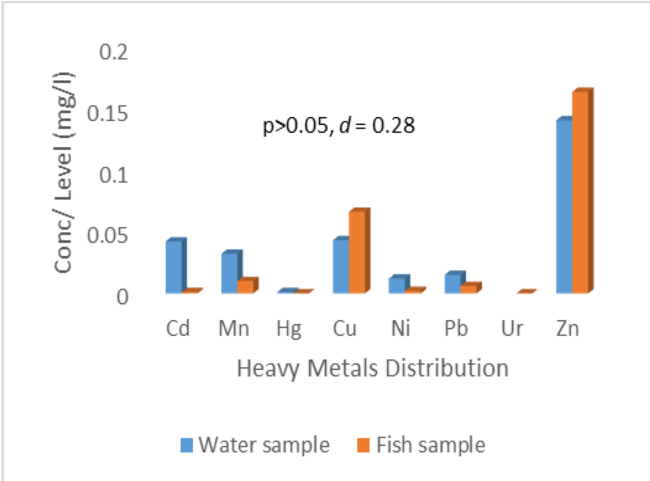

Figure 6: Comparison rainy seasonal levels of Heavy Metals between water and fish in Bukuru, Jos south.

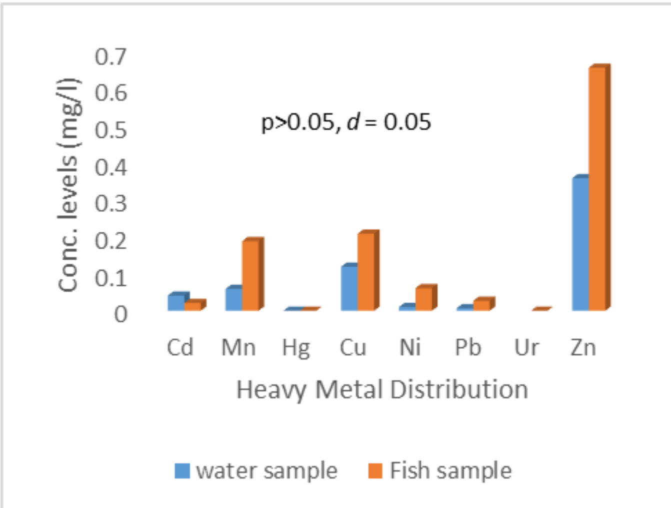

Figure 7: Comparison of dry seasonal levels of Heavy Metals between water and fish samples in Bukuru, Jos south.

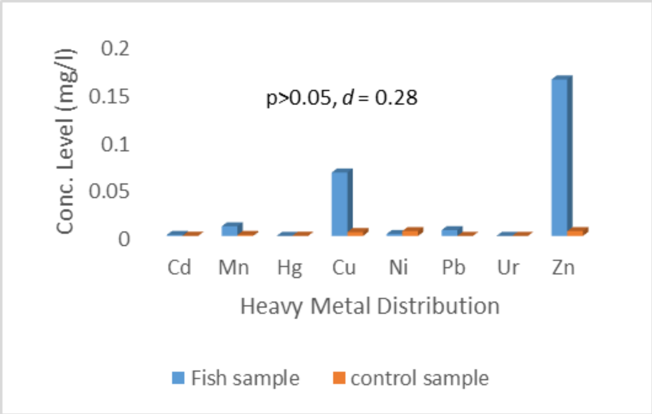

Figure 8: Compared Rainy seasonal levels of Heavy Metals between fish samples in Bukuru, Jos south and Control sample.

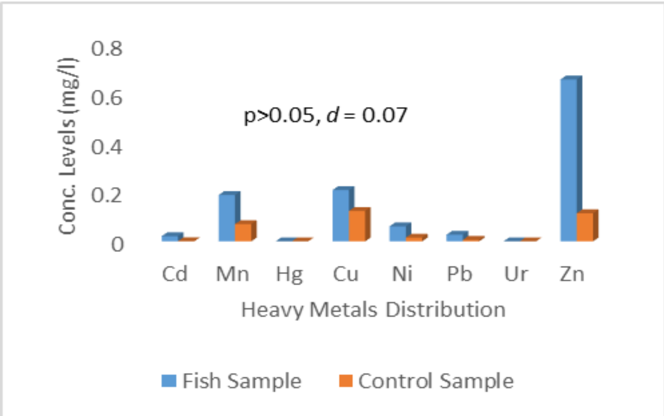

Figure 9: Compared Dry seasonal levels of Heavy Metals between fish in Bukuru, Jos south and Control sample.

4. CONCLUSION

The results of the analysis of heavy metal concentrations in water reveals that the concentration of the metals investigated were within the permissible limits and within the human consumption threshold with Cd being the exception. However, the heavy metal parameters investigated in cabbage and fish samples exceeded the threshold and human consumption limits. There is an urgent need for reclamation using professional procedure to prevent spread of diseases within the study area.

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