Assessment of some heavy metals from municipal wastewater used for irrigation in Nigeria

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Abstract

Heavy metal contamination in soil and accumulation in cultivated vegetables is currently a serious and disturbing ecological problem prevalent throughout the world most especially in areas with water scarcity. The study was carried out to assesses the presence of heavy metals from a municipal waste water source used for irrigation in Unguwar kudu, Dutsinma Katsina state Nigeria. This study assessed the quality of irrigation water in terms of pH, electrical conductivity (EC), total dissolved solids (TDS), and heavy metal concentrations (cadmium, lead, nickel, and chromium). The results showed that the water is slightly alkaline (mean pH 7.5) and has medium salinity (mean EC 1.17 dS/m), which may affect sensitive crops. TDS levels were within permissible limits (mean 845 mg/L). However, heavy metal analysis revealed significant contamination: cadmium (mean 0.0226 mg/L) and lead (mean 0.9008 mg/L) levels exceeded WHO/FAO limits by 2-18 times, posing risks to soil, crops, and human health. Chromium levels were also high (mean 1.626 mg/L), more than 16 times the permissible limit, while nickel levels were relatively low (mean 0.0278 mg/L). These findings suggest potential health and environmental risks associated with using this water for irrigation, emphasizing the need for regular monitoring and mitigation strategies.

Keywords: Heavy metals, irrigation water, contamination, savannah

INTRODUCTION

In many developing regions, particularly semi-urban areas facing water scarcity, the use of municipal wastewater for irrigation has become increasingly common. The practice offers benefits like improved water availability and nutrient enrichment for crops. However, it also poses significant risks due to the presence of heavy metals, which can accumulate in soils and crops, threatening environmental health and human safety (Poonia *et al*., 2023; Atta *et al*., 2023). Several Studies have shown that wastewater irrigation can lead to elevated levels of heavy metals like lead, cadmium, chromium, zinc, and copper in soils and crops, exceeding permissible limits and posing health risks to consumers (Atta *et al*., 2023; Tytła and Widziewicz-Rzońca, 2023). For example, research in Nigeria found high levels of heavy metals in soils and vegetables irrigated with urban wastewater, rendering them unsuitable for consumption (Dawaki *et al.,* 2018).

The stability and mobility of heavy metals from wastewater sludge or irrigation practices determine their environmental risk. Improper sludge management can lead to significant ecological and human health risks, depending on metal concentrations and their chemical forms (Tytła and Widziewicz-Rzońca, 2023).

Globally, similar patterns have emerged, with wastewater irrigation resulting in high concentrations of heavy metals in soils and vegetables. This underscores the importance of assessing heavy metal pollution in wastewater used for irrigation and developing strategies to minimize health hazards and promote sustainable agriculture.

Key heavy metals of concern include lead, cadmium, copper, and zinc, which can accumulate in crops and pose health risks. Recent investigations in Nigeria have revealed elevated concentrations of heavy metals in soils and vegetables irrigated with wastewater, exceeding WHO/FAO safety thresholds. These metals are non-biodegradable and can persistently accumulate in soils and crops, posing serious threats to environmental health and human safety (Atta *et al*., 2023).

In Nigeria's arid regions, such as Katsina State, water scarcity has made wastewater irrigation a vital resource for farming. In Dutsin-ma, an agrarian community within the state, rapid urbanization and agricultural activities have increased wastewater generation. Farmers often use untreated or partially treated wastewater to irrigate crops, leading to the buildup of heavy metals like lead, cadmium, chromium, zinc, and copper in the soil (Sani *et al.,* 2025). These contaminants persist in the environment and can enter the food chain, threatening soil health, crop productivity, and human well-being. Although wastewater provides essential nutrients, its heavy metal content presents a growing environmental and public health concern, especially in regions where freshwater resources are limited.

In semi-urban areas of semi-arid Nigeria, the increasing reliance on municipal wastewater for irrigation poses significant environmental and public health risks due to the accumulation of heavy metals like lead, cadmium, copper, and zinc in agricultural soils. Chronic water scarcity, resulting from erratic rainfall and climate change fluctuations, has driven this trend. These metals are persistent, non-degradable, and can disrupt soil fer-

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tility, impair crop growth, and enter the food chain, potentially causing serious health issues, including kidney damage, neurological disorders, and cancer (Abdullahi *et al*., 2024; Gupta *et al*., 2022; Singh *et al*., 2024).

The environmental contamination of heavy metals is a global concern due to their toxicity, persistence, and bioaccumulation nature (Javid *et al*., 2021; Cinar *et al.,* 2025). Despite these concerns, wastewater is heavily used for irrigation farming in the study area, partly due to erratic rainfall and limited groundwater sources. However, there is limited awareness among farmers and a lack of localized data on contamination levels, which exacerbates the issue.

This study aims to evaluate the concentration of heavy metals in wastewater-irrigated soils in Unguwar Kudu irrigation site in Dutsin-ma, Katsina State, Nigeria. The findings will provide essential data to inform safer irrigation practices and support sustainable agriculture and public health protection. By assessing the levels of heavy metal contamination, this study will help identify potential risks and develop strategies to mitigate them, ultimately contributing to a safer and more sustainable food system.

MATERIALS AND METHODS

Study Area and Site Selection

The study is conducted in Unguwar Kudu Irrigation site in Dutsin-ma, located in the semi-arid region of Katsina State, Nigeria. Dutsin-Ma is a Local Government Area (LGA) in Katsina State, located in the northwestern region of Nigeria. Geographically, it lies approximately between latitude 12.45°N and longitude 7.49°E. It is part of the Sudano-Sahelian ecological zone, characterized by semi-arid conditions. The region experiences a tropical wet and dry climate with two main seasons: Rainy Season: May to September (peak in August). Dry Season: October to April. Average annual rainfall ranges between 700–1000 mm, which is relatively low and erratic. High temperatures prevail year-round, with averages ranging from 28°C to 40°C, often peaking during the dry season (March to May (Abaje *et al.,* 2020; Musa *et al.,* 2025). The soils of the study area are Predominantly sandy to sandy loam soils, often low in organic matter and susceptible to erosion and desertification due to sparse vegetation cover and wind action (Abdulkadir *et al.,* 2024, 2025).The area has seasonal rivers and man-made reservoirs and dams used for domestic use and irrigation—critical for sustaining agriculture during dry months. Cereals: Millet, sorghum, maize, and rice. Legumes: Cowpea, groundnut, and soybeans. Vegetables: Tomatoes, onions, peppers—commonly grown under irrigation schemes. Tubers: Cassava and yam (to a lesser extent due to soil constraints).

Water sampling

Reconnaissance Survey

A reconnaissance survey was conducted in the study area to determine the location, extent, sampling points, boundaries and to establish Agricultural fields irrigated with waste water for the sampling activities.

Water Sampling

To identify the concentration of heavy metals at the source, wastewater samples were collected from irrigation sources. Composite samples are taken by collecting wastewater from multiple points at each irrigation site. 30 Samples were placed in acid-washed polyethylene containers, labeled, and transported to the laboratory for immediate processing. The Water samples were filtered before storing in labelled 1 L plastic bottles that had earlier been soaked in 10% HNO_3 for 24 h and afterwards washed with deionized water to remove free soap and contaminants. The water samples were stored on ice before transporting to the laboratory where they were preserved at 4 °C for further analyses (APHA, 2005).

Water Samples preparation

Wastewater samples were filtered to remove particulate matter, ensuring that only dissolved heavy metals are analyzed. Samples are acidified to pH 2 using nitric acid to prevent metal precipitation and maintain sample stability during storage. Wastewater samples (50 ml) were digested at 80 °C in a 10 ml conc. HNO_3 to obtain a clear solution (APHA, 2005), that was further filtered and the filtrate made up to 50 ml by adding distilled water.

Water analysis

The water samples were tested for pH, TDS, and EC using pH, TDS and EC meters, respectively. The concentrations of heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), and zinc (Zn) in the wastewater samples are determined using Atomic Absorption Spectroscopy (AAS), a reliable method for detecting trace metals.

Data Analysis

Descriptive Statistics: Mean, median, and range are calculated to summarize heavy metal concentrations in soils and wastewater.

RESULTS AND DISCUSSION

Water quality plays a pivotal role in sustainable agriculture. Parameters such as pH, electrical conductivity (EC), and total dissolved solids (TDS) influence soil chemistry, plant health, and nutrient availability. More critically, the presence of heavy metals like Cadmium (Cd), Lead (Pb), Nickel (Ni), and Chromium (Cr) in irrigation water poses significant environmental and public health risks due to their toxic, persistent, and bioaccumulative nature. These metals, even at trace levels, can enter the food chain through plant uptake, leading to chronic health conditions in humans and animals.

Descriptive Statistics of Irrigation Water Quality

Table 1 provides a summary of the descriptive statistics for the physicochemical parameters and heavy metals analyzed in the irrigation water samples. The parameters include pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and the concentrations of Cadmium (Cd), Lead (Pb), Nickel (Ni), and Chromium (Cr).

PH

The irrigation water's pH ranged from 7.1 to 7.8, with a mean of 7.5, indicating slightly alkaline conditions. Although this falls within the FAO recommended range of 6.5-8.4, prolonged irrigation with slightly alkaline water can potentially raise soil pH in semi-arid areas like Dutsin-ma. This could reduce the availability of essential micronutrients like iron, zinc, and manganese, which are crucial for plant growth. Statistical analysis of the pH data revealed a mean of 7.5, with a standard deviation of 0.2028. The skewness value of -0.386 indicates a slight negative skew, suggesting that most samples were on the higher side of the pH range. Furthermore, the kurtosis value of 0.907 shows a distribution that is slightly peaked compared to a normal distribution.

According to the WHO/FAO guidelines (Table 2), the observed mean pH is within the acceptable range for irrigation water for irrigation, as it allows for optimal nutrient uptake by crops and as such is favorable for most crops (Boukich *et al*., 2025). A neutral pH ensures good nutrient availability and promotes nitrification, an essential process for the absorption of nitrogen by plants (Wang *et al*., 2023).While slightly alkaline water may not directly harm crops, it can affect nutrient availability. Specifically, micronutrients like iron and manganese become less accessible to plants in alkaline soils, as noted by Ayers and Westcot (1985). Therefore, it is essential to monitor and manage soil pH levels to ensure optimal nutrient availability for plant growth. The result is consistent with findings in similar arid and semi-arid environments (Magaji *et al.,* 2020; Sani *et al.,* 2022; Garba *et al.*, 2016).

Electrical Conductivity (EC)

The electrical conductivity (EC) of irrigation water measures its salinity and is one of the most important parameters used to determine the quality of irrigation water, often defined as the capacity of water to transmit electric current, and can impact soil structure and crop productivity (Amankwa *et al*., 2023). EC values ranged from 1.07 to 1.27 dS/m, with a mean of 1.17 dS/m. The low standard deviation (0.06815) and variance (0.005) indicate little variability in EC across the samples. The skewness of 0.052 shows a near-symmetric distribution, while the negative kurtosis (-0.975) indicates a flatter distribution. EC values below 2 dS/m are generally considered safe for most crops. The range falls within the 0.7 – 3.0 dS/m: Medium salinity – suitable with some management. The EC value suggests medium salinity hazard. Sensitive crops (e.g., beans, strawberries) may be affected; salt-tolerant crops (e.g., barley, cotton) are more suitable. Long-term use may lead to soil salinization, reducing agricultural productivity FAO (2024).

Table 1: Descriptive statistics of water parameters

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
PH	7.1	7.8	7.5	0.20	0.041	-0.39	0.91
EC	1.07	1.27	1.17	0.07	0.005	0.05	-0.98
TDS	790	901	844	35.2	1242	0.22	-0.60
Cd (mg/L)	0.02	0.03	0.02	0.003	0.000	1.37	3.34
Pb (mg/L)	0.16	1.10	0.90	0.290	0.085	-2.53	6.86
Ni (mg/L)	0.002	0.072	0.028	0.027	0.001	1.080	-0.280
Cr (mg/L)	1.34	1.96	1.62	0.200	0.042	0.080	-0.75

Table 2: Comparison of Measured Values with FAO/WHO Standards for Irrigation Water

Parameter	Range (Min–Max)	Mean Value	FAO/WHO Permissible Limit	Status Compared to Limit	Risk Implication
pH	7.1 – 7.8	7.5	6.5 – 8.4	Within range	No immediate hazard; slightly alkaline, possible micronutrient lock-up over time
EC (dS/m)	1.07 – 1.27	1.17	< 3.0	Within range	Slight to moderate salinity hazard; may affect sensitive crops over long term
TDS (mg/L)	790 – 901	844.6	< 2000	Within range	Low salinity risk now; possible salt buildup in semi-arid soils
Cd (mg/L)	0.0193 – 0.0282	0.0226	0.01	Above limit	Toxic; accumulates in leafy vegetables, kidney and bone health risk
Pb (mg/L)	0.1590 – 1.0960	0.9008	0.005	Far above limit	Severe contamination; neurological damage risk, especially in children
Ni (mg/L)	0.0015 – 0.0725	0.0278	0.02	Above limit	Can cause plant toxicity; allergic and respiratory health risk
Cr (mg/L)	1.3403 – 1.9647	1.626	0.1	Far above limit	Highly toxic and potentially carcinogenic; persistent in soil and crops

Total Dissolved Solids (TDS)

The TDS of irrigation water measures the concentration of dissolved solids, which can impact soil health and crop productivity. The mean TDS value of 845 ppm in the study falls below the threshold of 2000 ppm, considered suitable for irrigation (Ayers and Westcot, 1985). TDS levels varied between 790 and 901 mg/L, averaging 845 mg/L. The standard deviation was 35.2, with a variance of 1242, indicating moderate variability. The skewness (0.216) and kurtosis (-0.601) suggest a slightly right-skewed and flat distribution. The average TDS value is within permissible limits for irrigation, although prolonged exposure may lead to salinity issues in some sensitive soils. The water samples falls within the permissible limit for irrigation (450–2000 mg/L: Permissible for irrigation. TDS is within the permissible range, but relatively high and can lead to soil compaction and reduced permeability, especially in poorly drained soils. Possible gradual buildup of salts in the soil affecting long-term productivity (FAO, 2024).

Cadmium (Cd)

Cd concentrations ranged from 0.0193 to 0.0282 mg/L, with a mean of 0.0226 mg/L. The skewness value of 1.366 and kurtosis of 3.339 indicate a highly right-skewed and leptokurtic distribution, meaning most values cluster at the lower end, with a few higher outliers. Cadmium is toxic even at low concentrations, and its presence raises concern about potential long-term impacts on soil and crop health. WHO/FAO Limit is 0.01 mg/L (Table 2). Cd levels in the study area are more than twice the recommended limit. Cadmium is a toxic heavy metal, non-essential to plants and harmful to human health. Even at low concentrations, Cd accumulates in soil and plant tissues, posing a risk to the food chain (especially in leafy vegetables and rice) WHO (2004). The result is in agreement with Ullah *et al.* (2022) who reported higher concentration of cadmium content in waste water irrigated in Mingora Pakistan.

Lead (Pb)

Pb values exhibited significant variation, ranging from 0.1590 to 1.0960 mg/L, with a high mean of 0.9008 mg/L. The negative skewness (-2.534) and high kurtosis (6.861) point to a left-skewed and sharply peaked distribution. This suggests the presence of a few very low values among generally high concentrations, which may imply contamination in some areas. The observed Pb levels exceed recommended irrigation standards and may pose risks to both plants and humans. The WHO/FAO Limit is 0.05 mg/L (Table 2). The Pb levels in the study are 18 times above the safe limit. The water may be Highly toxic, as Pb is non-degradable and accumulates in soils and crops. These levels can affects plant growth, enzymatic activity, and photosynthesis; and can cause severe damage in humans, it causes neurological and developmental damage. Indicates potential industrial pollution or use of contaminated wastewater (Alloway, 2013). The results also conforms with the finding of Ullah *et al.* (2022) who found lead concentration of (0.393 mg/L)

Nickel (Ni)

Ni levels ranged between 0.0015 and 0.0725 mg/L, with a mean of 0.0278 mg/L. The skewness (1.080) indicates a moderate positive skew, while kurtosis (-0.277) suggests a flatter distribution. These results reveal some potential for Ni contamination, although most values remain relatively low. The WHO/FAO Limit: 0.2 mg/L. Ni levels are well below the maximum limit. Though not immediately hazardous, Ni can accumulate in crops, especially in leafy greens. Chronic exposure to even low levels has been linked to dermatitis, lung and kidney problems in humans (FAO, 1985; WHO, 2004). The result is in line with a study by Smith *et al* (2020) on heavy metal contamination in irrigation water who found nickel levels ranging from 0.01 to 0.1 mg/L, highlighting the potential risks of nickel accumulation in crops. Similar studies in Nigeria have reported varying levels of nickel contamination. A study in Kano State by Mujahid *et al.* (2024) found nickel levels in drinking water ranging from 0.026 to 0.052 mg/L, which conforms to WHO standards. Similar Research in Dutsin-ma, Katsina State, reported nickel levels in well water samples ranging from 0.005 to 0.055 mg/kg, with a mean of 0.021 mg/kg, posing no harm to the populace (Ubaidullah, 2023).

Chromium (Cr)

Cr concentrations were between 1.3403 and 1.9647 mg/L, with a mean of 1.626 mg/L. The skewness (0.076) and kurtosis (-0.745) indicate a nearly symmetric but slightly flat distribution. The Cr levels are considerably high, raising environmental concerns, especially regarding the accumulation of heavy metals in irrigated soils. The WHO/FAO Limit (Total Cr): 0.1 mg/L (Table 2). This implies that the Cr levels in the study area are more than 16 times the permissible limit. This is particularly disturbing as Chromium, particularly in its hexavalent form (Cr^{6+}), is extremely toxic—linked to cancer, organ failure, and genetic mutations. High Cr levels in irrigation water can result in toxicity to plants (chlorosis, stunted growth) and soil degradation. EPA (1986) The values obtained in this study conforms with the findings of Ogunbileje *et al.* (2013) who reported cadmium levels above the acceptable limit of up to 10.7 Mg/L.

The statistical analysis of irrigation water quality reveals critical contamination levels of heavy metals, notably Pb (0.9008 mg/L) and Cr (1.626 mg/L), which far exceed the WHO/FAO permissible limits of 0.05 mg/L and 0.1 mg/L, respectively (Table 2). The presence of Cd (0.0226 mg/L), over twice the allowable limit, is also concerning these elevated levels pose serious risks: such as Environmental Hazards as Heavy metals like Pb and Cr are persistent in soils. Their accumulation leads to soil toxicity, negatively affecting microbial activity and plant nutrient uptake. Cd and Cr can alter soil pH and enzyme function, leading to long-term degradation of soil quality (Alloway, 2013).

Another risk associated with the elevated levels of these heavy metals has Agricultural Implications as High levels of Pb and Cd interfere with photosynthesis and enzymatic activities in plants, causing stunted growth, leaf chlorosis, and reduced yield (Nagajyoti *et al.*, 2010). Also, Crops grown with such water are likely to bioaccumulate toxic metals, making them unsafe for consumption.

Human Health Risks is another problem associated with the use of waste water for irrigation because most of the heavy metals such as Cd is Linked to kidney damage and skeletal disorders. While Pb Causes neurotoxicity, especially in children. Cr^{6+} is a known carcinogen, associated with liver and respiratory problems.

The correlation table provides insights into the relationships between soil properties (pH, EC, TDS) and heavy metal concentrations (Cd, Pb, Ni, Cr) (Table 3). Here's a breakdown of the correlations: pH and EC: Strong negative correlation (-0.780*), indicating that as pH decreases, EC increases. pH and TDS: Strong negative correlation (-0.839**), suggesting that as pH decreases, TDS increases. EC and TDS: Strong positive correlation (0.886**), indicating that as EC increases, TDS also increases. Cd and TDS: Strong positive correlation (0.715*), suggesting that as TDS increases, Cd concentration also increases. Cd and Pb: Strong negative correlation (-0.852**), indicating that as Cd concentration increases, Pb concentration decreases. The Implications is that as Soil pH affects EC and TDS: Changes in soil pH may impact EC and TDS levels. Cd and Pb relationship: The strong negative correlation between Cd and Pb suggests different sources or behaviors of these metals in the soil. pH and EC Relationship: A study on heavy metal pollution in agricultural soils also found a strong correlation between pH and EC, indicating that pH affects soil electrical conductivity.

Heavy Metal Interactions

Research on heavy metal contamination in wastewater-irrigated soils found correlations between Cd, Pb, and other metals, suggesting common sources or behaviors. Metal Mobility: Some studies suggest Pb is more mobile in acidic soils, contradicting the negative correlation between Pb and Cd in your table, which might be specific to your study area. A study in Lubumbashi, DR Congo, found high levels of Cu, Pb, and Zn in soils and vegetables, highlighting the impact of mining activities on environmental pollution.

CONCLUSION

This study assessed the quality of irrigation water in terms of pH, electrical conductivity (EC), total dissolved solids (TDS), and heavy metal concentrations (cadmium, lead, nickel, and chromium). The results showed that the water is slightly alkaline (mean pH 7.5) and has medium salinity (mean EC 1.17 dS/m), which may affect sensitive crops. TDS levels were within permissible limits (mean 845 mg/L). However, heavy metal analysis revealed significant contamination: cadmium (mean 0.0226 mg/L) and lead (mean 0.9008 mg/L) levels exceeded WHO/FAO limits by 2-18 times, posing risks to soil, crops, and human health. Chromium levels were also high (mean 1.626 mg/L), more than 16 times the permissible limit, while nickel levels were relatively low (mean 0.0278 mg/L). These findings suggest potential health and environmental risks associated with using this water for irrigation, emphasizing the need for monitoring and mitigation strategies.

The irrigation water quality is compromised due to high levels of heavy metals, particularly Pb and Cr, posing risks to soil health, plant growth, and human consumption. The findings highlight the need for proper management and treatment of irrigation water to mitigate these risks.

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Table 3: correlation between soil properties

pH	PH	EC	TDS	Cd(mg/L)	Pb(mg/L)	Ni(mg/L)	Cr(mg/L)
pH	1		*				
EC	-.780*	1	*				
TDS	-.839**	.886**	1	.			
Cd(mg/L)	-.575	.591	.715*	1			
Pb(mg/L)	.603	-.344	-.542	-.852**	1		
Ni(mg/L)	.282	-.190	-.012	.106	.089	1	
Cr(mg/L)	.282	-.231	-.336	-.627	.614	-.114	1

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