

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

*Sufiyanu SANI*

Department of Soil Science, Federal University Dutsin-Ma, Katsina state, Nigeria

*Mariya MUHAMMAD  
ABUBAKAR*

Department of Soil Science, Federal University Dutsin-Ma, Katsina state, Nigeria

*Aliyu ABDULKADIR*

Department of Soil Science, Federal University Dutsin-Ma, Katsina state, Nigeria

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; Tytla 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 (Tytla 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 fertility, 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<sub>3</sub> 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<sub>3</sub> 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).

#### **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 ( $\text{Cr}^{6+}$ ), 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.  $\text{Cr}^{6+}$  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.

## REFERENCES

Abdulkadir A., Manne I.Z., Sani S. (2025). Impact of distance from the water body on the point of zero charge of Dutsin-Ma Dam floodplain soils, Katsina State, Nigeria. *International Journal of Bonorowo Wetlands*, 15(1).

Abdulkadir A., Musa S., James D. (2024). A review of the role of cover crops in mitigating soil health degradation and other challenges associated with maize monoculture. *FUDMA Journal of Agriculture and Agricultural Technology*, 11: 115-128.

Abdulkadir A., Halilu Y., Sani S. (2022). Evaluation of Physical and Chemical Properties of Soils at Bichi Local Government Area, Kano State, Nigeria. *IRE Journal*, 5: 556-562.

Abdullahi M.B., Mosa A., Elnaggar A., El-Ghamry A., Trüby P., Omar M. (2024). Impact of Longterm Irrigation with Wastewater on Potentially Toxic Elements Accumulation in some Edible Plants: Northern Dakahlia Governorate As A Case Study. *Journal of Soil Sciences and Agricultural Engineering*, 15: 99-106.

Aliyu Abdulkadir, Sufiyanu Sani, Mansur Usman Dawaki, Sani Mahmud, Muazu Salisu, Yakubu Muhammad Abdullahi and, Firdausi Haruna Dalha (2024). Bioavailability of some selected heavy metals as affected by amendments under varying depth and growing stage of maize in Sudan savannah of Nigeria. *Earth Sciences: an International Journal*, 1: 37-45.

Alloway B.J. (2013). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability*. Springer Science & Business Media.

Amankwah E., Antwi-Agyei P., Nyantakyi E.K., Bryan I.M., Mensah N.J., Sebiawu G.E., Antwi-Akomeah S. (2023). Assessment of irrigation water quality for vegetable production in the Bono and Bono East regions. *Journal of the Ghana Institution of Engineering*, 23: 18-23.

Andleeb S., Ur Rehman K., Mahmood A., Elsadek M.F., Ul Safa N., Hussein D.S., Essam El-Din M.M. (2023). Human health risk hazards by heavy metals through consumption of vegetables cultivated by wastewater. *Journal of King Saud University - Science*, 35: 102467.

APHA (2005). *Standard methods for the examination of water and wastewater*, Washington DC: American Public Health Association.

Atamaleki A., Yazdanbakhsh A., Fakhri Y., Salem A., Ghorbanian M., Mousavi Khaneghah A. (2021). A systematic review and meta-analysis to investigate the correlation vegetable irrigation with wastewater and concentration of potentially toxic elements (PTES): A case study of spinach (*Spinacia oleracea*) and Radish (*Raphanus raphanistrum* subsp. *sativus*). *Biol. Trace Elem. Res.*, 199: 792-799.

Atamaleki A., Yazdanbakhsh A., Gholizadeh A., Naimi N., Karimi P., Thai V.N., Fakhri Y. (2022). Concentration of potentially harmful elements (PHEs) in eggplant vegetable (*Solanum melongena*) irrigated with wastewater: a systematic review and meta-analysis and probabilistic health risk assessment, *International Journal of Environmental Health Research*, 32: 1419-1431.

Atta M.I., Zehra S.S., Dai D.-Q., Ali H., Naveed K., Ali I., Sarwar M., Ali B., Iqbal R., Bawazeer S., Abdel-Hameed U.K. (2023). Amassing of heavy metals in soils, vegetables and crop plants irrigated with wastewater: Health risk assessment of heavy metals in Dera Ghazi Khan, Punjab, Pakistan. *Frontiers in Plant Science*, 13: 1080635.

Ayers R.S., Westcot D.W. (1985). *Water quality for agriculture* (Vol. 29, p. 174). Rome: Food and agriculture organization of the United Nations.

Boukich O., Ben-tahar R., Brahmi M., Alzain M.N., Noman O., Shahat A.A., Smiri Y. (2025). Assessment of groundwater quality for irrigation using a new customized irrigation water quality index. *Journal of Hydrology: Regional Studies*, 59: 102346.

Canipari R., De Santis L., Cecconi S. (2020). Female fertility and environmental pollution. *Int. J. Environ. Res. Public Health*, 17: 8802.

Çınar G., Doğan M., Dalgıç A.C. (2025). Heavy metal contamination and health risk assessment of green leafy vegetables irrigated with municipal wastewater in Gaziantep, Türkiye. *Polish Journal of Environmental Studies*, 20: 1-9.

Dawaki M.U., Haruna K.A., Samndi A.M. (2018). Geospatial distribution of some phosphorus and potassium forms as influenced by period of irrigation in the kano river and the hadejia valley irrigation schemes. *Nigerian Journal of soil science*, 28: 1-11.

Diagomanolin V. (2004). Heavy metals (Ni, Cr, Cu) in the Karoon waterway river, Iran. *Toxicology Letters*, 151: 63-67.

Essien J.P., Ikpe D.I., Inam E.D., Okon A.O., Ebong G.A., Benson N.U. (2022). Occurrence and spatial distribution of heavy metals in landfill leachates and impacted freshwater ecosystem: An environmental and human health threat. *PLoS ONE*, 17: e0263279.

Fatta-Kassinos D., Kalavrouziotis I.K., Koukoulakis P.H., Vasquez M.I. (2011). The risks associated with wastewater reuse and xenobiotics in the agroecological environment. *Sci. Total Environ.*, 409: 3555-3563.

FAO (2024). *Global status of salt-affected soils*.

Garba M., Logah V., Wildemeersch J., Mahaman S., Yadji G., Quansah C., Abaidoo R.C. (2016). Improvement in physical quality of a Sahelian Arenosol and implications on millet yield. *Archives of Agronomy and Soil Science*, 62: 947-962.

Geng H., Xu Y., Zheng L., Gong H., Dai L., Dai X. (2020). An overview of removing heavy metals from sewage sludge: Achievements and perspectives. *Environmental Pollution*, 266: 115375.

Gupta N., Yadav K.K., Kumar V., Prasad S., Cabral-Pinto M.M. S., Jeon B.-H., Kumar S., Abdellattif M.H., Alsukaibia A.K.D. (2022). Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption. *Frontiers in Environmental Science*, 10: 791052.

Islam M.M., Karim M.R., Zheng X., Li X. (2018). Heavy metal and metalloid pollution of soil, water and foods in Bangladesh: A Critical Review, *International Journal of Environmental Research and Public Health*, 15: 2825.



- Javid A., Nasiri A., Mahdizadeh H., Momtaz S.M., Azizian M., Javid N. (2021). Determination and risk assessment of heavy metals in air dust fall particles. *Environmental Health Engineering and Management Journal*, 8: 319-327.
- Kaur S., Roy A. (2020). Bioremediation of heavy metals from wastewater using nanomaterials. *Environment, Development and Sustainability*, 23: 9617-9640.
- Khan K., Lu Y., Khan H., Ishtiaq M., Khan S., Waqas M., Wang T. (2013). Heavy metals in agricultural soils and crops and their health risks in Swat District, northern Pakistan. *Food and Chemical Toxicology*, 58: 449-458.
- Lyu S., Wu L., Wen X., Wang J., Chen W. (2022). Effects of reclaimed wastewater irrigation on soil-crop systems in China: A review. *Science of the Total Environment*, 813: 152531.
- Magaji J.Y., Abimbola T.A. (2020). Comparative analysis of water quality from different sources in Masaka, Nasarawa State, Nigeria. *Australian Journal of Science and Technology*, 4: 303-311.
- Minhas P.S., Saha J.K., Dotaniya M.L., Sarkar A., Saha M. (2022). Wastewater irrigation in India: Current status, impacts and response options. *Science of the Total Environment*, 808: 152001.
- Muhammad Amin A., Sani M., Bello Ahmad U., Sufiyanu S., Bashir Shehu H., Wada Rabiou A., Afiya Kabir L. (2019). Geo-statistical mapping of some soil fertility constraints in sorghum- based cropping system of Sudano-Sahelian zone of Nigeria. *Azarian Journal of Agriculture*, 6: 146-152.
- Muhammad A., Musa M., Sani S., Ibrahim U.M. (2024). Environmental contamination by agrochemicals and its indiscriminate use by dry season farmers in Sudan Savannah of Katsina State. *Sahel Journal of Life Sciences FUDMA*, 2: 67-77.
- Mujahid S.N., Bala M.U., Isyaku A.M., Abba M., Sani S., Aliyu H., Umar M.Y. (2024). Evaluation of specific heavy metals in drinking water consumed in Yar'akwa Quarters, Na'ibawa, Tarauni LGA, Kano State, Nigeria. *FUDMA Journal of Sciences*, 8: 208-213.
- Mununga Katebe F., Raulier P., Colinet G., Ngoy Shutcha M., Mpundu Mubemba M., Jijakli M.H. (2023). Assessment of heavy metal pollution of agricultural soil, irrigation water, and vegetables in and nearby the cupriferous city of Lubumbashi (Democratic Republic of the Congo). *Agronomy*, 13: 357.
- Nagajyoti P.C., Lee K.D., Sreekanth T.V.M. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental chemistry letters*, 8: 199-216.
- Natasha Shahid M., Khalid S., Murtaza B., Anwar H., Shah A.H., Sardar A., Shabbir Z., Niazi N.K. (2023). A critical analysis of wastewater use in agriculture and associated health risks in Pakistan. *Environmental Geochemistry and Health*, 45: 5599-5618.
- Noma S.S., S. Sani (2008). Estimation of soil organic matter content in soils of sokoto area: Comparing Walkley- Black and a proposed unconventional method. *Techno Science Africana Journal*, 2: 71-76.
- Ohiagu F.O., Verla A.W., Enyoh C.E., Chikezie P.C., Lele K.C. (2020). Pollution profile and ecological risk assessment of heavy metals from dumpsites in Onne, Rivers State, Nigeria. *Chemistry Africa*, 4: 207-216. 5
- Ogunbileje J.O., Sadagoparamanujam V.M., Anetor J.I., Farombi E.O., Akinosun O.M., Okorodudu A.O. (2013). Lead, mercury, cadmium, chromium, nickel, copper, zinc, calcium, iron, manganese and chromium (VI) levels in Nigeria and United States of America cement dust. *Chemosphere*, 90:

2743-2749.

Poonia P., Parihar S., Pachak S.K., Gaur L. (2023). Assessing the quality of the municipal wastewater used for irrigation in Jodhpur, Rajasthan, India. *Water Supply*, 23: 4775–4790.

Qin G., Niu Z., Yu J., Li Z., Ma J., Xiang P. (2021). Soil heavy metal pollution and food safety in China: Effects, sources and removing technology, *Chemosphere*, 267: 129205.

Sani M., Alhassan I., Amin M.A., Sani S., Musa A.A. (2019). Trends of soil organic matter and cation exchange capacity in Nigerian Northern Guinea Savannah, in relation to the soil texture and depth. *Dutse Journal of Agriculture and Food Security*, 6: 100-108.

Sani S., Abdulkadir A., Abubakar B., Muazu S., Wakili Habib D., Sani M., Hamza H. (2025). Assessment of water quality for irrigation in Dutsin - Ma Dam, Katsina State, Nigeria. *African Journal of Agricultural Science and Food Research*, 20: 191 -210.

Sani S., Aliyu A., Muhammad M. (2025). Spatial variability and mapping of soil structural stability: the interplay of texture and organic matter at Jibia Irrigation Project, Semi - Arid Zone of Nigeria. *Sahel Journal of Life Sciences FUDMA*, 3: 55 -67.

Sani S., Abdulkadir A., Pantami S.A. (2022). Assessment of Water Quality for Irrigation Purposes in Jibi a Irrigation Project, Katsina State, Nigeria. *IOSR Journal of Agriculture and Veterinary Science*, 15: 54-58.

Sani S.A., Pantami S.A., M. Sani (2019). Evaluation of soil physical properties at Jibia Irrigation Project, Katsina State, Nigeria. *Fudma Journal of Agriculture and Agricultural Technology*. 5: 231-24.

Sani S., Sani M., Salihu A.P., Aliyu A., Yakubu M., Garba N.H., Basiru L.J. (2022). Spatial variability of soil hydraulic properties in jibia irrigation project, Katsina state, Nigeria. *Natural Resources and Sustainable Development*, 12: 245-254.

Sani S., Abdulkadir A., Hmad Pantami S.A., Sani M., Amin A.M., Abdullahi M.Y. (2023). Spatial variability and mapping of selected soil physical properties under continuous cultivation. *Turkish Journal of Agriculture - Food Science and Technology*, 11: 719-729.

Singh R., Singh P.K., Madheshiya P., Khare A.K., Tiwari S. (2024). Heavy metal contamination in the wastewater irrigated soil and bioaccumulation in cultivated vegetables: Assessment of human health risk. *Journal of Food Composition and Analysis*, 128: 106054.

Smith C. J. (2020). A Geochemical Investigation of the Monticchio Lakes, Monte Vulture, Basilicata, Italy.

Sufiyanu Sani, Aliyu Abdulkadir, Musa Muhammad, Musab Ibrahim, Abdulsalam Sani Nababa, Ahmad Ubaidullah, Aliyu Suleiman (2024). Assessment of soil salinity and sodicity status at Jibia Irrigation Project, Katsina State, Nigeria. *Life Sciences: an International Journal (LSIJ)*, 1: 2024.

Tytła M., Widziewicz-Rzońca K. (2023). Ecological and human health risk assessment of heavy metals in sewage sludge produced in Silesian Voivodeship, Poland: a case study. *Environmental Monitoring and Assessment*, 195: 1373.

Ubaidullah A., Idris M.M., Ango M.L., Abdullahi M.H., Mohammad I.A., Iwa S.J., Okara O.G. (2023). A study of the levels of nickel, iron, cadmium, and lead in some potable drinking water from well sources in Dutsin-ma, Katsina State, Nigeria. *Asian J. Res. Rev. Phys.*, 7: 10-16.

Ullah N., Ur Rehman M., Ahmad B., Ali I., Younas M., Aslam M.S., Rahman A.U., Taheri E.,

Fatehizadeh A., Rezakazemi M. (2022). Assessment of heavy metals accumulation in agricultural soil, vegetables and associated health risks. PLoS One, 17: e0267719.

Vareda J.P., Valente A.J.M., Durães L. (2019). Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. Journal of Environmental Management, 246: 101-118.

WHO (2004). Cadmium in Drinking-water.

Wang Y., Peng Y., Lin J., Wang L., Jia Z., Zhang R. (2023). Optimal nitrogen management to achieve high wheat grain yield, grain protein content, and water productivity: A meta-analysis. Agricultural Water Management, 290: 108587.

Zara Musa, Ango K.A., Sufiyanu Sani (2025). Ecological assessment of tree species composition and diversity in Federal University Dutsin-Ma Take-off campus, Katsina State, Nigeria. Agriculture, Food, and Natural Resources Journal, 4: 31-37.

## References