



HEAVY METAL DISTRIBUTION, BIOACCUMULATION AND HEALTH RISK ASSESSMENT OF RICE CULTIVATED IN IDAH, KOGI STATE

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ABSTRACT

This study evaluated the distribution, bioaccumulation, and health risks of heavy metals in soil, water, and different parts of rice plants (roots, stems, and grains) cultivated in the floodplain of River Niger in Idah, Kogi State. Soil, water, and plant samples were collected and analyzed for arsenic (As), cadmium (Cd), lead (Pb), zinc (Zn), chromium (Cr), and nickel (Ni) using standard analytical procedures. Soil physicochemical properties were also determined, and statistical and risk assessment models were applied. Results showed that mean metal concentrations in soil followed the order Cr (22.7 mg/kg) > Pb (18.3 mg/kg) > Cd (0.83 mg/kg), indicating moderate contamination. Water samples contained lower concentrations, while rice grains accumulated detectable levels of Pb (4.45 mg/kg) and Cd (0.35 mg/kg). Significant variation ($p < 0.05$) in metal distribution across plant parts was observed, with accumulation highest in roots and lowest in grains. Bioaccumulation analysis revealed Cd as a strong accumulator ($BAF = 1.08$), while translocation factors indicated moderate movement of metals within the plant system. Health risk assessment indicated that individual Target Hazard Quotients were below 1; however, the cumulative Hazard Index exceeded unity, suggesting potential health risks from combined exposure. Cancer risk values for Cd and As ($\sim 10^{-3}$) exceeded acceptable limits. The findings highlight the need for continuous monitoring and improved agricultural practices to minimize heavy metal contamination and ensure food safety.

Keywords: Food safety, Target Hazard Quotient, Heavy metal, Rice, Metal uptake

INTRODUCTION

Rice (*Oryza sativa* L.) is a major staple crop globally and an essential component of food security in Nigeria (Omoyajowo *et al.*, 2024). Its cultivation is concentrated in floodplains and irrigated environments, which are increasingly exposed to heavy metal contamination due from flood residues, agricultural and anthropogenic activities (Laoye *et al.*, 2025; Akinkpelumi *et al.*, 2025). Heavy metals such as arsenic (As), chromium (Cr), cadmium (Cd), zinc (Zn), lead (Pb), and nickel (Ni) are persistent environmental pollutants with the potential to accumulate in soils and enter the food chain (Jaishankar *et al.*, 2020; Ali *et al.*, 2021). These contaminants are introduced into agricultural systems through fertilizer application, pesticide use, irrigation with polluted water, and improper waste disposal (Alengebawy *et al.*, 2021; Gupta *et al.*, 2021). Once in the soil, their mobility and bioavailability are largely controlled by physicochemical properties such as pH, organic matter, and cation exchange capacity (Gao *et al.*, 2022; Alloway, 2023).

Rice is particularly prone to heavy metal uptake due to its cultivation under flooded conditions, which enhance metal solubility and availability. Studies have shown that metals accumulate primarily in roots, with partial translocation to aerial parts and grains, thereby posing potential food safety risks (Islam *et al.*, 2020; Aziz *et al.*, 2023). Some researchers have reported measurable levels of heavy metals in rice grains and strong relationships between soil contamination and plant uptake (Omoyajowo *et al.*, 2024; Erhuen *et al.*, 2025). The accumulation of toxic metals in rice has significant health implications, as dietary intake represents a major exposure pathway. Chronic exposure to metals such as Cd and As has been linked to serious health conditions, including organ damage and cancer (Rai *et al.*, 2022; Owoleke *et al.*, 2024; Adesida & Alimba, 2025). Risk assessment approaches,

including Target Hazard Quotient (THQ) and Hazard Index (HI), have demonstrated that combined exposure to multiple metals may pose greater risks than individual contaminants (Adewumi *et al.*, 2024; Akinkpelumi *et al.*, 2025).

Although several studies have examined heavy metal contamination in soils or crops, integrated assessments linking environmental distribution, plant uptake, and human health risks remain limited in rice cultivation systems. Therefore, this study evaluates the distribution of heavy metals in soil, water, and rice; assesses their bioaccumulation and translocation; and determines the associated health risks from rice consumption.

MATERIALS AND METHODS

Study Area

The study was conducted in Idah, Kogi State, Nigeria (7.11°N, 6.74°E), a prominent rice-producing region located along the floodplains of the River Niger. The area is characterized by seasonal flooding, intensive farming activities, and continuous interaction between soil and surface water systems. Such environments are often prone to heavy metal accumulation due to sediment deposition and environmental runoff.

Sample Collection

Soil samples were collected from the topsoil (0–20 cm depth) of active rice cultivation plots within the study area (7.11°N, 6.74°E). Composite samples were prepared from multiple subsamples to ensure representativeness. Samples were stored in clean polyethylene bags, labeled, and transported to the laboratory for analysis. Water samples were obtained from irrigation channels and adjacent river sources, stored in pre-cleaned containers, and preserved with nitric acid.

Rice plants were harvested at maturity and separated into roots, stems, and grains. Samples were washed, oven-dried at 80°C, and ground into fine powder prior to analysis.

Sample Preparation and Digestion

Soil and plant samples were air-dried, sieved (2 mm), and digested using a mixture of concentrated nitric acid (HNO₃) and perchloric acid (HClO₄) following standard procedures (APHA, 2017). Water samples were filtered and acidified prior to digestion. The digestion process was conducted under controlled laboratory conditions to ensure complete breakdown of organic matter and release of metals into solution. This approach is widely used for environmental samples and ensures accurate quantification of trace metals (Ali et al., 2021).

Physicochemical Analysis

Soil pH, organic matter, and cation exchange capacity were determined using established laboratory methods. pH was measured in a soil–water 1:2(w/v) suspension using Crison Micro pH 2000, calibrated pH meter. Organic Matter (OM) was determined using the Loss on ignition method. Cation Exchange Capacity (CEC) was measured via ammonium acetate extraction.

Heavy Metal Analysis

Metal concentrations (As, Cd, Pb, Zn, Cr, Ni) were determined using Atomic Absorption Spectrophotometry (Buck Scientific 210 VGP). Calibration was performed using standard solutions, and quality assurance included blanks and reference materials.

Metal Transfer and Risk Assessment

Metal Transfer

Bioaccumulation Factor (BAF) was calculated to measure plant's ability to accumulate metals.

Bioaccumulation factor

$$(BF) = \frac{\text{Concentration of metal in plant root}}{\text{Concentration of metal in soil}}$$

BAF > 1 → strong accumulator

Transfer factor (TF) is the ability of plants to translocate metal species from root to shoot

$$TF = \frac{\text{Metal content of shoot}}{\text{Metal content of root}}$$

TF > 1 → accumulator of heavy metals

Human Health Risk Assessment

The potential health risks associated with rice consumption were evaluated using:

$$\text{Daily Intake of Metals (DIM)} = \frac{C \times IR}{BW}$$

BW

$$\text{Target Hazard Quotient (THQ)} = \frac{DIM}{RfD}$$

RfD

Hazard Index (HI) = Sum of multiple THQs i.e. THQ₁ + THQ₂.....

$$\text{Cancer Risk (CR)} = DIM \times CSF$$

where:

C = Concentration of metal in rice grain,

IR = ingestion rate,

BW = body weight,

RfD = reference dose,

CSF = Cancer slope factor

Statistical Analysis

Data were analyzed using SPSS package version 26.0 (SPSSInc. Chicago, IL, USA). Descriptive statistics were used to summarize the data, while one-way Analysis of Variance (ANOVA) was applied to determine significant differences in metal concentrations among plant parts. Pearson correlation analysis was used to assess relationships between soil and plant metal concentrations. Principal Component Analysis (PCA) was employed to identify possible sources of contamination and to classify variables based on their contribution to overall variance.

RESULTS AND DISCUSSION

Heavy Metal Distribution

Heavy metal concentrations in soil, water, and rice grains across the study sites is presented on Table 1. Soil recorded the highest concentrations, followed by water and the plant had the lowest concentrations of heavy metals. Mean values of the metals was in the order Cr > Pb > Cd. This trend confirms that soil acts as the primary reservoir of heavy metals due to accumulation processes. Similar observations have been reported Chen et al., 2020; Gao et al., 2022 where significant spatial variations in heavy metal concentrations were linked to environmental and anthropogenic factors.

The lower concentrations in water could be attributed to dilution and hydrological flow, as opined by Simon et al., 2025. While the presence of metals in rice grains is indicative of active soil–plant transfer according to Omoyajowo et al., 2024. The soil physicochemical properties (pH, organic matter, and CEC) values recorded further influenced metal mobility and bioavailability, this is consistent with recent findings of Koleola et al., 2025; Fasinmirin et al., 2025.

Table 1: Physicochemical Parameters and Heavy Metal Levels in Soil, Water and Rice

Sample ID	OM (%)	CEC (cmol/kg)	pH	As (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cr (mg/kg)	Ni (mg/kg)
S ₁	2.3	12.51	6.52	3.21	0.82	18.21	45.62	22.59	15.36
S ₂	2.7	14.24	6.83	3.80	1.01	20.11	50.26	25.37	17.54
S ₃	2.1	11.81	6.20	2.92	0.71	16.54	40.83	20.43	13.22
S ₄	2.5	13.45	6.74	3.12	0.83	15.32	44.62	21.34	14.26
W ₁	NA	NA	6.94	0.01	0.01	0.03	0.08	0.04	0.02
W ₂	NA	NA	7.10	0.01	0.01	0.04	0.09	0.05	0.03
R ₁	NA	NA	NA	2.53	0.97	12.50	35.40	15.29	10.35
St ₁	NA	NA	NA	1.85	0.65	8.23	28.37	10.10	7.58
G ₁	NA	NA	NA	1.24	0.32	4.15	20.24	5.25	4.07
R ₂	NA	NA	NA	2.91	1.18	13.80	38.69	16.44	11.20
St ₂	NA	NA	NA	1.80	0.75	6.23	25.30	9.10	8.53
G ₂	NA	NA	NA	1.44	0.45	4.82	22.50	6.05	4.53
R ₃	NA	NA	NA	2.48	1.34	14.86	34.69	17.46	10.26

Sample ID	OM (%)	CEC (cmol/kg)	pH	As (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cr (mg/kg)	Ni (mg/kg)
St ₃	NA	NA	NA	1.64	0.81	7.27	22.37	9.82	8.33
G ₃	NA	NA	NA	1.54	0.55	4.04	20.55	5.07	4.06
R ₄	NA	NA	NA	2.57	1.06	17.14	37.27	15.46	12.26
St ₄	NA	NA	NA	1.83	0.78	7.80	25.56	8.82	8.84
G ₄	NA	NA	NA	1.20	0.73	4.26	21.52	5.70	4.67

NA - Not applicable Values are means of triplicate samples
S- Soil W- Water R- Root St- Stem G- Grain

Variation of Metal Concentrations Across Plant Parts

Metal concentrations differed significantly across plant parts (Table 2). It followed the order root > stem > grain. This pattern reflects the role of roots as the primary accumulation site due to direct contact with contaminated soil. Such pattern has been documented in a study on agricultural soil and plants

by Wu *et al.*, 2021 where roots retain higher metal concentrations while limiting translocation to edible parts. However, the presence of metals in grains indicates incomplete restriction, posing potential risks to consumers as opined by Al-Huqail *et al.*, 2022.

Table 2: One-Way ANOVA for Metal Concentration Across Rice Parts

Metal	F-value	p-value	Significance
AS	6.24	0.003	Significant
Cd	15.32	0.001	Significant
Pb	12.45	0.002	Significant
Zn	6.45	0.018	Significant
Cr	9.87	0.005	Significant
Ni	7.51	0.015	Significant

Significant at $p < 0.05$

Bioaccumulation and Translocation of Metals in Rice

On Table 3, Cadmium showed strong accumulation (BAF > 1), indicating high mobility. Translocation factors suggested moderate movement of metals within plant tissues. This agrees with the report of a recent study by Akuru *et al.*, 2025 that cadmium is highly mobile in rice systems and readily

accumulates in edible tissues due to its chemical similarity to essential nutrients. Despite partial restriction by plant defense mechanisms, the presence of metals in grains portends transfer into the food chain. This is consistent with reports on bioaccumulation and translocation of heavy metals in rice by Zhao *et al.*, 2022.

Table 3: Bioaccumulation Factor and Translocation Factor

Metal	BAF (Root/Soil)	BAF (Grain/Soil)	TF (Root→Stem)	TF (Stem→Grain)
As	0.64	0.28	0.69	0.56
Cd	1.08	0.42	0.67	0.60
Pb	0.68	0.24	0.66	0.50
Zn	0.78	0.45	0.80	0.70
Cr	0.67	0.25	0.66	0.52
Ni	0.88	0.48	0.63	0.73

BAF > 1 = strong accumulator TF > 1 = efficient translocation

Correlation Analysis

Significant positive relationships between soil and grain metal concentrations indicate that soil is the primary source of contamination (Table 4). Such relationships has been widely reported by some researchers, where bioavailable metals are

directly transferred from soil to crops (Khan *et al.*, 2021; Iwegbue *et al.*, 2021). Significant inter-metal correlations suggest common anthropogenic sources, including agricultural inputs and environmental pollution (Mohammed *et al.*, 2024).

Table 4: Pearson Correlation Matrix for Metals in Soil and Rice Grain

Parameter	Pb (Soil)	Cd (Soil)	Cr (Soil)	Pb (Grain)	Cd (Grain)	Cr (Grain)
Pb (Soil)	1.00	0.82*	0.76*	0.91**	0.70*	0.65
Cd (Soil)	0.82*	1.00	0.80*	0.85**	0.93**	0.72*
Cr (Soil)	0.76*	0.80*	1.00	0.78*	0.75*	0.88**
Pb (Grain)	0.91**	0.85**	0.78*	1.00	0.82*	0.70*
Cd (Grain)	0.70*	0.93**	0.75*	0.82*	1.00	0.76*
Cr (Grain)	0.65	0.72*	0.88**	0.70*	0.76*	1.00

Significant at $p < 0.05$ ** Significant at $p < 0.01$

Human Health Risk Assessment

Computed Human Health Risk from Rice Grain Consumption is presented on Table 5. Although individual

THQ values were below unity, the combined Hazard Index exceeded 1, suggesting potential long-term health risks. Recent studies on food health risk associated with crops

grown on crude oil impacted communities in the Niger Delta by Akinkpelumi *et al.*, 2026 have similarly shown that cumulative exposure to heavy metals in food crops poses greater health risks than individual metals. Additionally, cancer risk values for Cd and As were above acceptable

limits. This aligns with broader reviews highlighting the carcinogenic risks associated with heavy metal accumulation in rice grown in Southwestern Nigeria (Adewumi *et al.*, 2024).

Table 5: Computation of Human Health Risk from Rice Grain Consumption

Metal	DIM	THQ	Cancer Risk (CR)
As	0.0008	0.55	1.5×10^{-3}
Cd	0.0003	0.62	1.2×10^{-3}
Pb	0.0021	0.45	3.7×10^{-4}
Cr	0.0015	0.38	8.5×10^{-4}

Source Identification

PCA results (Table 6) indicated that Pb, Cd, and Cr likely originate from anthropogenic sources such as agricultural inputs and environmental pollution. This aligns with studies

identifying agricultural practices, waste disposal, and industrial activities as major contributors to heavy metal contamination in Nigeria (Adamu *et al.*, 2022; Abubakar *et al.*, 2025).

Table 6: Principal Component Analysis

Parameter	PC1	PC2
Cd (Soil)	0.88	0.18
Pb (Soil)	0.85	0.22
Cr (Soil)	0.82	0.30
Cd (Grain)	0.83	0.35
Pb (Grain)	0.80	0.40
Cr (Grain)	0.60	0.70
pH	-0.60	0.70

The negative relationship with pH further confirms the view of Ali *et al.*, 2021 that acidic conditions enhances metal mobility and plant uptake.

CONCLUSION

This study assessed the distribution, bioaccumulation, and health risks of heavy metals in soil, water, and rice cultivated in the floodplains of River Niger in Idah, Kogi State. The findings revealed that soils contained the highest concentrations of heavy metals, confirming their role as the primary reservoir of contamination. Detectable levels of metals in rice grains demonstrated the transfer of contaminants from soil to edible plant parts, indicating potential risks to food safety. Roots accumulated the highest concentrations, while grains contained lower but significant levels, suggesting partial restriction of metal translocation. Cadmium was identified as a highly mobile and bioavailable metal with greater potential to enter the food chain. Correlation analysis further confirmed soil as the major source of metal uptake in rice. Although individual metals may not pose immediate non-carcinogenic risks, combined exposure suggests potential long-term health concerns. Metal contamination was largely attributed to anthropogenic activities. Continuous environmental monitoring, improved soil management practices, and increased public health awareness are recommended to mitigate heavy metal contamination and ensure food safety.

REFERENCES

Abubakar, M. I., Yakubu, N. M., Sambo, M., Abdullahi, S., & Bello, A. (2025). Heavy metals in rice cultivars in Bauchi, Nigeria. *International Journal of Research and Innovation in Applied Science*.

Adamu, U. H., Alonge, S. O., Adelanwa, E. B. (2022). Bioaccumulation of heavy metals in rice seeds in Nigeria. *Bayero Journal of Pure and Applied Sciences*, 13(1), 503–507.

Adesida, S. O., & Alimba, C. G. (2025). Systematic review of radionuclides, heavy metals, and pesticides in Nigerian food crops: Health risk implications. *Environmental Analysis, Health and Toxicology*, 40(2), e2025012. <https://doi.org/10.5620/eaht.2025012>

Adewumi, A. A., Adeyeye, S. A. O., & Adebayo-Oyetoro, A. O. (2024). Assessment of potentially toxic metals in selected rice brands in Southwestern Nigeria. *Journal of Food Composition and Analysis*, 133, 106428. <https://doi.org/10.1016/j.jfca.2024.106428>

Akinkpelumi, V. K., Ossai, C. M., Abdulai, P. M., Nwaichi, E. O., Nduka, J. K. C., & Orisakwe, O. E. (2025). Human health risk assessment of metals and metalloids in food crops from crude oil impacted communities in the Niger Delta, Nigeria. *Scientific Reports*, 16, 231. <https://doi.org/10.1038/s41598-025-29676-x>

Akuru, U. B., Nda-Wonodi, W., Jamabo, M., & Dienye, H. (2025). Heavy metal concentrations in rice sold in Port Harcourt, Nigeria. *International Journal of Biochemistry Research & Review*, 34(2), 86–95.

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M. Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants. *Toxics*, 9(3), 42. <https://doi.org/10.3390/toxics9030042>

Al-Huqail, A. A., Kumar, P., Eid, E. M., El-Morsy, M. H. E., & Elansary, H. O. (2022). Risk assessment of heavy metals in rice irrigated with industrial effluent. *Agriculture*, 12(11), 1864. <https://doi.org/10.3390/agriculture12111864>

- Ali, H., Khan, E., & Ilahi, I. (2021). Environmental chemistry and ecotoxicology of hazardous heavy metals. *Chemosphere*, 273, 129150. <https://doi.org/10.1016/j.chemosphere.2020.129150>
- Alloway, B. J. (2023). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability* (4th ed.). Springer.
- Aziz, R. A., Ma, Y., Saleh, M., Liu, Y., & Li, H. (2023). Bioaccumulation and translocation of heavy metals in rice. *Sustainability*, 15(18), 13426. <https://doi.org/10.3390/su151813426>
- Chen, H., Teng, Y., Lu, S., Wang, Y., & Wang, J. (2020). Contamination features and health risk of soil heavy metals. *Science of the Total Environment*, 512, 143–153.
- Erhuen, E., Ojo, A. A., Onasanya, A. A., & Adewole, E. (2025). Assessment of heavy metals and phytochemicals in soil and rice samples cultivated in Nigeria. *ABUAD International Journal of Natural and Applied Sciences*, 5(1), 10–18.
- Fasinmirin, J. T., Oyun, M. B., Aletor, O., Ajayi, A. E., & Oke, A. O. (2025). Physicochemical properties and heavy metal concentrations of rice soils across selected communities in Nigeria. *Next Research*, 2(3), 100600. <https://doi.org/10.1016/j.nexres.2025.100600>
- Gao, B., Zhou, H., Liang, X., Tu, C., & Wang, J. (2022). Bioavailability of heavy metals in soil–plant systems. *Environmental Pollution*, 292, 118–134.
- Gupta, N., Yadav, K. K., & Kumar, V. (2021). A review on current status of heavy metal contamination in agricultural soils. *Environmental Science and Pollution Research*, 28, 33021–33041.
- Iwegbue, C. M. A., Bassey, F. I., & Tesi, G. O. (2021). Distribution of heavy metals in sediments of the Niger Delta, Nigeria. *Environmental Monitoring and Assessment*, 193, 512.
- Islam, M. S., Ahmed, M. K., Habibullah-Al-Mamun, M., Masunaga, S., & Sato, N. (2020). Heavy metals in rice and associated health risks. *Environmental Science and Pollution Research*, 27, 356–370.
- Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2020). Toxicity and health effects of heavy metals. *Interdisciplinary Toxicology*, 7(2), 60–72.
- Khan, S., Shah, M. T., Khan, M. A., Khaliq, A., & Shah, M. T. (2021). Heavy metals in agricultural soils and crops. *Environmental Monitoring and Assessment*, 193, 1–15.
- Koleola, A. A., Jacob, J. O., Salau, R. B., & Tsado, P. (2025). Interactive effects of heavy metals on rice growth. *Journal of Chemical Society of Nigeria*, 50(3).
- Laoye, B., Olagbemide, P., Ogunnusi, T., & Akpor, O. (2025). Assessment of heavy metal contamination in fish, fruits, and vegetables in Southwest Nigeria: A systematic review. *F1000Research*, 13, 1430. <https://doi.org/10.12688/f1000research.157781.2>
- Mohammed, U. A., Shehu, A. A., & Kolo, B. (2024). Heavy metals in soil and rice samples from Bauchi State, Nigeria. *Bima Journal of Science and Technology*, 8(2), 1–10.
- Omoyajowo, K. O., Ogunyebi, A. L., Ogunkanmi, L. A., Njoku, K. L., & Adesuyi, A. A. (2024). Heavy metal contamination in Nigerian-grown rice and public health implications. *Journal of Applied Sciences and Environmental Management*, 28(10).
- Omoyajowo, K. O., Ogunyebi, A. L., Njoku, K. L., Adesuyi, A. A., & Oladele, E. O. (2024). Assessment of heavy metals in rice grains: Public health implications. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4970847>
- Owoleke V. A., Oludare T.T., and Owoleke, S. O. (2024). Assessment of Heavy Metal Uptake by Vegetables Irrigated with Bathroom Waste Water in Mangongo Local Government Area Kogi State, Nigeria. *Journal of Science, Technology, Mathematics and Education, Vol 19 (Issue 2)*
- Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., & Kim, K. H. (2022). Heavy metals in food crops: Health risk implications. *Environmental Research*, 204, 112070.
- Simon, J., Ibanga, E. A., Inyang, E. P., Ekanem, J. T., & Udoh, E. I. (2025). Heavy metal pollution in flooded rice farms in Nigeria. *Environmental Monitoring and Assessment*, 8(2), 23–30.
- Wu, W., Wu, P., Yang, F., et al. (2021). Assessment of heavy metal pollution in agricultural soils. *Ecotoxicology and Environmental Safety*, 219, 112–120.
- Zhao, F. J., Ma, Y., Zhu, Y. G., et al. (2022). Soil contamination and plant uptake of heavy metals. *Nature Reviews Earth & Environment*, 3, 101–116.

