

Trace Metal Concentrations in Local and Imported Rice Consumed in Southeast Nigeria

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Abstract

Rice (*Oryza sativa* L.) is a staple for half the world's population and a major component of the Nigerian diet. As domestic production lags behind rising demand, Nigeria increasingly relies on rice imports, raising food safety concerns. This study aims to determine and compare concentrations of Zn, Pb, Cr, Cu, and Cd in 36 rice samples (20 imported, 16 locally grown; short- and long-grain) collected from markets across five southeastern Nigerian states. Additionally, health risks from rice consumption were assessed. Samples were processed and analysed by atomic absorption spectrometry. The objectives were to quantify trace metal levels in local and imported rice, evaluate differences by grain size and location, assess potential health risks, and compare results with FAO/WHO limits and literature. Results showed a decreasing concentration trend: Zn > Cd > Cu > Pb > Cr. Mean concentrations ($\pm$ SD) were 1.24 ± 1.15 mg/kg (Zn), 0.58 ± 1.55 mg/kg (Cd), 0.24 ± 0.17 mg/kg (Cu), 0.18 ± 0.23 mg/kg (Pb), and 0.12 ± 0.27 mg/kg (Cr). All metals except Cd were below FAO/WHO maximum limits, but some samples exceeded the 0.2 mg/kg Cd threshold. Locally produced rice contained significantly higher Zn (3.6 $\times$), Pb (2.0 $\times$), and Cd (18 $\times$) than imported rice. Short-grain rice had higher Zn, Pb, and Cd than long-grain. Notably, rice from Ebonyi State (a known Pb-Zn mining region) showed extreme Cd (1.89 ± 3.27 mg/kg), suggesting geogenic contamination. Health risk assessments indicated estimated daily intakes and hazard quotients below harmful levels for adults and children. Our findings provide important baseline data and highlight the need for continued monitoring of trace metals in rice for food safety in Nigeria. The findings suggest that rice consumed in southeastern Nigeria is generally safe, though residents of Ebonyi State who frequently consume locally produced rice may be at risk of increased cadmium accumulation. Regular monitoring of food products for metal contamination remains essential for public health protection. This study thus contributes critical baseline data to guide food safety policy and monitoring efforts in Nigeria.

Keywords: Imported Rice, Local Rice, Trace Metals, Health Risk Assessment, Atomic Absorption Spectrometry, Food Safety.

Introduction

Rice (*Oryza sativa* L.) is the third most cultivated crop worldwide and plays an essential role in human nutrition (Proshad *et al.*, 2019). It provides energy, vitamins, minerals, and amino acids to people around the world (Poutanen *et al.*, 2021). Because of its high nutritional

value, rice is a staple food for almost half of the global population (Zhang *et al.*, 2019). In Nigeria, the demand for rice is increasing faster than for any other staple food due to population growth and wider consumption across all income levels, including the poor. However, local production is not enough to meet this demand, leading to significant rice imports. Over the past year, rice prices have nearly quadrupled, and there is evidence of rice smuggling into the country, which can introduce low-quality products.

In recent years, heavy metal contamination in food has become a major concern due to its accumulation in soil and water. Industrial and agricultural activities release various pollutants, including heavy metals (Malidareh *et al.*, 2014). These metals come from both natural sources and human activities (Zazouli *et al.*, 2010). Fertilisers and pesticides are major contributors to heavy metal presence in soil and plants (Alengebawy *et al.*, 2021; Anjali *et al.*, 2023). For example, phosphate fertilisers contain high amounts of Pb and Cd (Azzi *et al.*, 2017; Zazouli *et al.*, 2008), while pesticides may contain Cu, As, Cd, and Hg (Adel *et al.*, 2016). Poor food storage conditions can also cause contamination. Plants absorb and store heavy metals from the soil, which can negatively affect their growth and nutritional quality (Wang *et al.*, 2014). In rice, heavy metals can reduce photosynthesis, cause leaf discolouration, and lower root growth (Wang *et al.*, 2014). These metals are dangerous to both plants and humans, causing various health issues (Huybrechts *et al.*, 2020; Salam *et al.*, 2020; Ahmad *et al.*, 2024). Cadmium, for example, can enter the human food chain through crops and cause bone damage (Nogawa *et al.*, 2017). Excessive Zn can affect oxygen absorption and heart rate (Plum *et al.*, 2010; Dwivedi *et al.*, 2024). Pb is known to cause neurological and blood disorders (Nutescu *et al.*, 2016).

Studies worldwide have reported high levels of heavy metals in rice (Rahman *et al.*, 2014; Kormoker *et al.*, 2020; Jafari *et al.*, 2018). Industrial activities, mining, and transportation release large amounts of these metals into water and soil, which are then absorbed by rice plants. This study aims to measure and compare the levels of Zn, Pb, Cr, Cu, and Cd in different rice brands sold in southeastern Nigeria. The study covers both short- and long-grain rice, including locally grown and imported brands from Abia, Anambra, Enugu, Ebonyi, and Imo states. The findings will be compared with FAO/WHO safety limits. Additionally, the estimated intake of these metals from rice consumption and potential health effects will be discussed. This research will help understand the level of heavy metal contamination in rice and allow for comparisons with data from other parts of Nigeria and other countries.

Despite previous work on rice contamination, few studies have explicitly compared local versus imported rice for trace metal content in Nigeria or assessed the associated health risks. We address this research gap by providing new comparative data on trace metals in rice and conducting a comprehensive health risk assessment for consumers in Southeast Nigeria.

Problem Statement

Nigeria's increasing dependence on imported rice Ahmad et al. (2024), combined with sparse data on the safety of domestic versus foreign rice, poses an unresolved problem. Specifically, it is unclear if locally grown rice in Southeastern Nigeria contains different levels of Zn, Pb, Cr, Cu, and Cd compared to imports. This knowledge gap limits understanding of food safety risks. Given that Pb-Zn mining occurs in Ebonyi State, for example, contamination of local rice is a particular concern. Without a clear assessment of metal levels and associated health risks in both local and imported rice, public health interventions cannot be effectively targeted.

Research Objectives

1. To determine the concentrations of Zn, Pb, Cr, Cu, and Cd in local and imported rice consumed in Southeast Nigeria.
2. To compare trace metal levels based on rice source (local vs. imported), grain size (short vs. long), and sampling location.
3. To assess potential human health risks associated with rice consumption (using Estimated Daily Intake (EDI) and Hazard Quotient (HQ)).
4. To compare findings with FAO/WHO permissible limits and existing literature.

Literature Review

Heavy metal contamination of rice is documented worldwide. Studies in Asia and elsewhere have frequently found rice exceeding safety thresholds (APHA, 2020). For instance, Jafari et al. (2018) in Iran and Kormoker et al. (2020) in Bangladesh reported high cadmium and lead in some rice samples. In Southeast Asia, Rahman et al. (2014) found chromium in rice (from India, Thailand, etc.) up to 0.41 mg/kg (Kormoker et al., 2020). Similarly, Fang et al. (2014) reported Cu (3.3 mg/kg) and Cr (0.355 mg/kg) in Chinese rice. These studies highlight that industrial and agricultural practices can elevate rice metal content. Health risk assessments in many countries employ metrics like Average Daily Dose (ADD) and Hazard Quotient (Huybrechts et al., 2020). While individual metal HQs may be below 1, combined hazard indices (HI) sometimes exceed 1, indicating potential cumulative risk (Islam et al., 2017).

In Africa, few studies focus on rice contamination, but those available suggest variation. In Ghana, street-food rice (fried rice) contained detectable Pb, though usually within safe limits. A study in Southwestern Nigeria (Taiwo et al., 2024) found that local rice brands had higher mean metals than imported ones, similar to our approach. Limited Ghanaian data (Ankar-Brewoo et al. 2020) and Liberian data (Gomah et al. 2021) show some risk, but regional findings are inconsistent.

Data on heavy metals in Nigerian rice are scarce. Kelle et al. (2021) analysed rice from Abuja markets and found all metals (Cd, As, Ni, Pb, Cu, Co, Hg) below FAO/WHO limits (Jafari et al., 2018). However, their combined hazard index (HI) exceeded 1, indicating possible long-term risk (Islam et al., 2017). Ihedioha et al. (2016) assessed rice and paddy soil in Enugu

State, finding metal concentrations within safe bounds. More recently, Ugbede *et al.* (2021) and Usman *et al.* (2022) reported rice from Ebonyi State (Abakaliki, Ezillo) with Cd, Pb, Ni and others below WHO limits (APHA, 2020). In contrast, Olaleye *et al.* (2022) found elevated Pb in rice from Kano, Nigeria (Kormoker *et al.*, 2020). Overall, these studies suggest that most Nigerian rice meets guidelines, but mining regions (e.g., Ebonyi) and some locales may pose hidden risks. Gaps: Notably, no prior study has systematically compared trace metals in local vs. imported rice in Southeast Nigeria, nor has any linked such data with regional health risk assessment. This literature review identifies the need for focused analysis of rice sources and associated health implications in the Southeast.

Materials and Methods

Description of the Study Area

South Eastern Nigeria consists of five states: Imo, Enugu, Ebonyi, Anambra, and Abia. South Eastern Nigeria is approximately 29,848 square miles (77,310 km²) in size and consists of forests, tall grasslands, rainforests, and freshwater swamps. The climate is bimodal with a dry season that occurs between November and April and a wet season between April and October. June and July are the months that receive most rainfall. During sun days, temperatures rise up to 30°C (86°F) and fall to 22°C (71.6°F) at night. The rainfall ranges between 16 mm (0.63 in) and 3,000 mm (118.1 in) every year. Temperatures fall to 20°C (68°F) at night and rise to 36°C (96.8°F) at daytime (Omaka *et al.*, 2017).

Sample Collection and Preparation

Thirty-six (36) rice brands, including 20 imported and 16 locally produced varieties, were obtained from various markets in Southern Nigeria for this study. The samples were placed in Ziploc bags and labeled appropriately. A measured quantity (50 g) was milled, passed through a 2-micron mesh sieve, and stored in airtight containers in a dry state until further analysis.

Sample Analysis

A measured amount of dry, powdered rice (2g) was digested using a 10mL acid mixture (1:2 perchloric acid to nitric acid). The digestion flask was heated on a hot plate until white fumes appeared, indicating the process was complete, then further heated until nearly dry. Deionized water was added, stirred, and filtered through Whatman No. 4 filter paper into a calibrated volumetric flask. The levels of trace metals (Zn, Pb, Cr, Cu, and Cd) in the digested samples were determined using atomic absorption spectrometry (Varian AA 240, Agilent, USA) following the method by Yüksel *et al.* (2017). Standard solutions were prepared from a stock metal solution as per the American Public Health Association (APHA, 1995). Blanks were inserted at a 10% rate, and proper quality control measures were followed. AnalR and BDH reagents were used.

Estimation of Daily Intake of Trace Metals from Rice Consumption

The average daily intake (ADD, mg/kg/day) measures how much of a substance a person consumes orally over a certain period through food. This value is given as a daily dose per unit of body weight. The amount of metal a person takes in each day depends on its concentration in food and how much food they eat. It is typically determined using the following equation (Li *et al.*, 2013; Udousoro *et al.*, 2025):

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad \text{Equation (1)}$$

In this equation, **C** represents the average metal concentration (mg/kg), while **IR**, **ED**, **EF**, **BW**, and **AT** stand for the ingestion rate, exposure duration, exposure frequency, body weight, and average time, respectively. The ingestion rate (IR) is estimated at 0.4097 kg/day, based on the average daily rice intake of adults in Hunan Province. The IR was adopted due to the lack of comprehensive and standardized Nigerian consumption data suitable for quantitative risk assessment in order to ensure methodological consistency and comparability with similar studies, while providing a conservative estimate of potential exposure. Body weights of 60 kg for adults and 15 kg for children are used, following related studies. The exposure frequency (EF) is set at 365 days per year. The exposure duration (ED) is assumed to be 70 years, aligning with the average human lifespan. The average exposure time (AT) for non-carcinogens is calculated as 365 days/year multiplied by ED (WHO, 2017).

Human Health Risk Assessment

The hazard quotient (HQ) is used to quantify the health hazard of toxic substances that are non-cancerous. HQ is calculated by dividing average daily dose (ADD) by reference dose (RfD) (Copat *et al.*, 2013). In evaluating non-carcinogenic risk of consumption of rice, a reference dose (RfD) has been employed. This is derived from U.S. Environmental Protection Agency (USEPA) and is a maximum safe quantity of a toxic substance that can be consumed. HQ is determined by applying this formula (Qiao *et al.* 2011; Onuchukwu *et al.*, 2024):

$$HQ = \frac{ADD}{RfD} \quad \text{Equation (2)}$$

The Reference Dose (RfD) refers to the maximum daily exposure calculated not to cause harm. A value of Hazard Quotient (HQ) less than 1 is acceptable and is regarded as safe; a value greater than 1 indicates a health hazard.

Statistical Analysis

The values reported from the study were given as means with their corresponding standard deviations. A one-way analysis (ANOVA) of variance with a 95% confidence level was used. In addition to that, principal component analysis (PCA) was used to analyze variations in trace metal contents in rice samples obtained from diverse geographical regions.

Results

Trace Metal Concentration in Rice

Table 1 summarizes trace metal levels in all rice samples. Concentrations (mg/kg, dry weight) varied widely (ND–ND: not detected up to maxima) with mean levels ($\pm$ SD) of Zn 1.24 ± 1.15 , Cd 0.58 ± 1.55 , Cu 0.24 ± 0.17 , Pb 0.18 ± 0.23 , Cr 0.12 ± 0.27 . The overall ranking was Zn > Cd > Cu > Pb > Cr. The majority of Zn, Pb, Cr, Cu values were below FAO/WHO limits (50, 0.2, 2.3, 20 mg/kg respectively), whereas Cd averaged above the 0.2 mg/kg limit. Figure 1 compares imported versus local rice: locally produced rice had mean Zn, Pb, Cd 3.6, 2.0, and 18 times higher than imports. ANOVA showed that Zn was significantly higher in local rice ($p < 0.05$). For Pb and Cd the differences were not statistically significant ($p > 0.05$) due to high variability, but their means were notably greater in local rice.

Table 1: Concentration (mg/kg) of trace metals in rice samples (mean $\pm$ SD).

Metal	Imported (mean $\pm$ SD)	Local (mean $\pm$ SD)	Overall (mean $\pm$ SD)	FAO/WHO Limit
Zn	0.34 $\pm$ 0.32	1.25 $\pm$ 1.01	1.24 $\pm$ 1.15	50.0
Pb	0.08 $\pm$ 0.10	0.17 $\pm$ 0.19	0.18 $\pm$ 0.23	0.2
Cr	0.06 $\pm$ 0.10	0.11 $\pm$ 0.16	0.12 $\pm$ 0.27	2.3
Cu	0.23 $\pm$ 0.16	0.24 $\pm$ 0.18	0.24 $\pm$ 0.17	20.0
Cd	0.03 $\pm$ 0.01	0.59 $\pm$ 1.68	0.58 $\pm$ 1.55	0.2

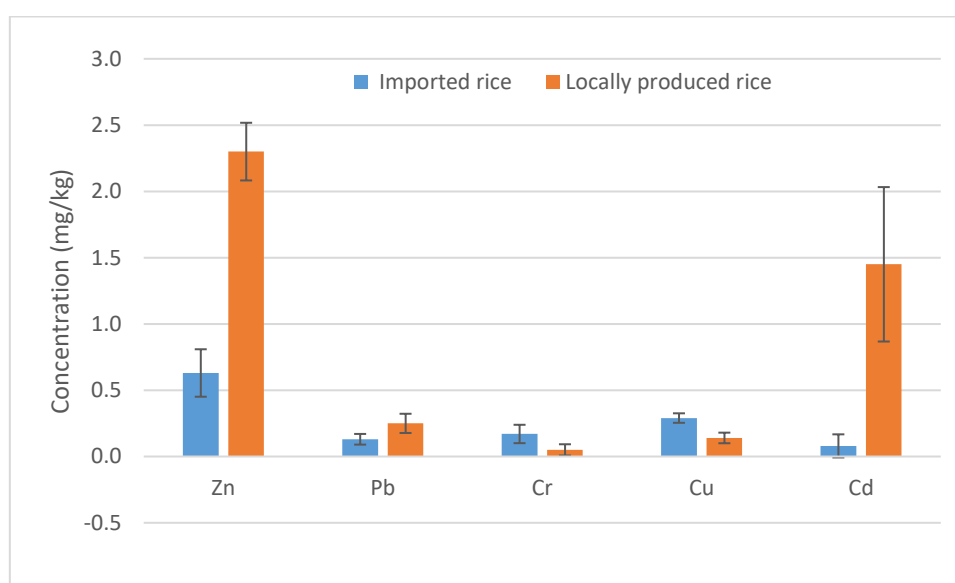
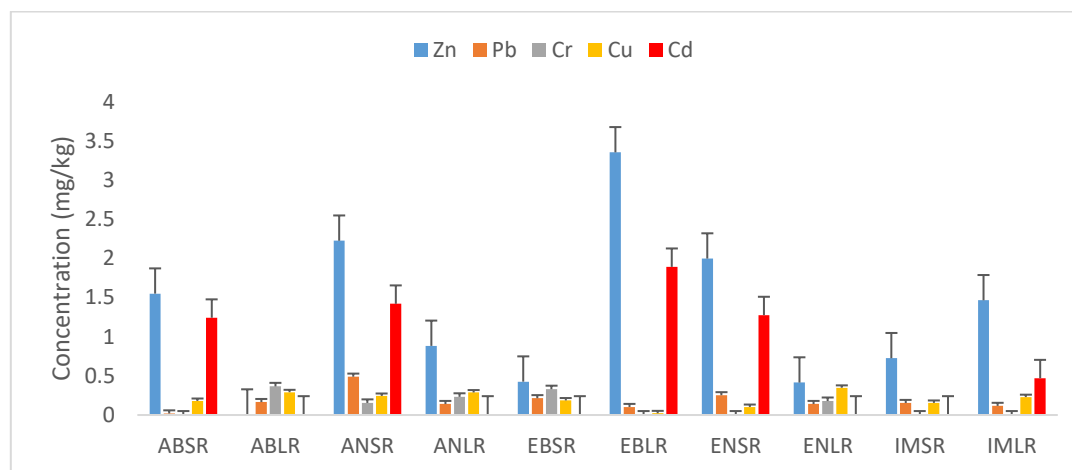


Figure 1: Comparison of mean Zn, Pb, Cr, Cu, Cd levels (mg/kg) in imported vs. local rice. Error bars = SD

Variation by Grain Size and Location

Short-grain rice averaged higher Zn (1.59 ± 1.20 mg/kg) than long-grain (0.61 ± 0.73 mg/kg). Similarly, short-grain contained more Pb (0.23 ± 0.25 vs 0.08 ± 0.16 mg/kg) and Cd (0.82 ± 1.87 vs 0.14 ± 0.52 mg/kg). Differences in Cu and Cr by grain type were minor. Figure 2 shows

mean metal levels by state: rice from Ebonyi State exhibited exceptionally high Cd (mean 1.89 ± 3.27 mg/kg), much greater than values in other states. Other states (Abia, Anambra, Enugu, Imo) showed no unusual metal spikes.



ABSR=Abia imported, ABLR=Abia local; AN=Anambra; EB=Ebonyi; EN=Enugu; IM=Imo

Figure 2: Mean metals in rice by sampling state (mg/kg)

Principal Component and Statistical Analysis

PCA indicated two principal components (Figure 3), PC1 was dominated by Pb, while PC2 grouped Zn, Cu, Cr, Cd. This suggests Pb may come from different sources than the other metals. ANOVA confirmed no significant difference ($p > 0.05$) in metal levels between long- vs short-grain samples for any metal. Pearson's correlation (not shown) indicated a moderate positive correlation between Zn and Cd ($r = 0.303$) and between Pb and Cr ($r = 0.035$), whereas other correlations were weak ($r < 0.2$). This pattern implies shared sources or pathways for Zn/Cd and for Pb/Cr, while other metal relationships were not strong.

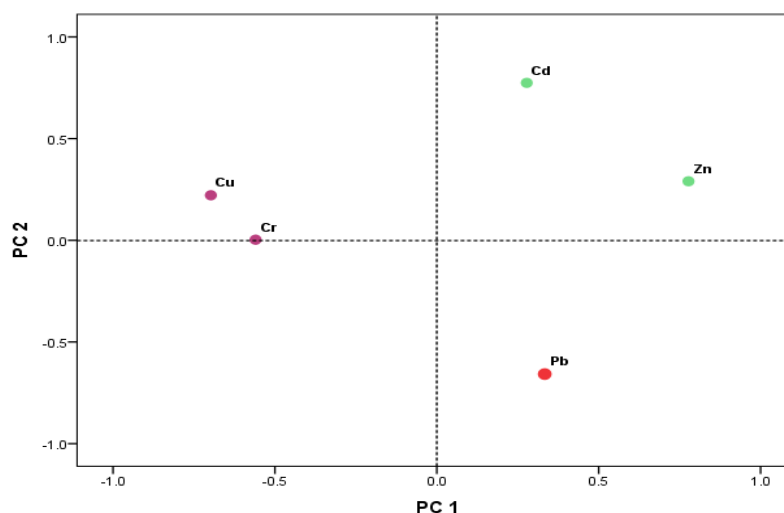


Figure 3: Principal component analysis (PCA) loading plot for trace metals in rice samples.

Health Risk Assessment

Table 2 (below) presents ADD and HQ results. For a 60 kg adult, the estimated daily intakes via rice were very low (e.g., Cd: 7.92×10^{-6} mg/day; Zn: 1.69×10^{-5} mg/day). Children (15 kg) had even lower absolute intakes. All computed HQs (using appropriate RfDs) for Zn, Pb, Cr, Cu, and Cd were <1 for both adults and children, indicating negligible non-cancer risk from rice consumption alone.

Table 2: Estimated Daily Intake (ADD, mg/kg-day) and Hazard Quotient (HQ) for adults and children from rice consumption.

Metal	ADD (adult)	ADD (child)	RfD	HQ (adult)	HQ (child)
Zn	1.69×10^{-5}	3.63×10^{-6}	0.3	<0.001	<0.001
Pb	2.46×10^{-6}	5.27×10^{-7}	0.0035	0.0007	0.00015
Cr	1.64×10^{-6}	3.51×10^{-7}	0.003	0.0005	0.0001
Cu	3.28×10^{-6}	7.02×10^{-7}	0.04	0.00008	0.00002
Cd	7.92×10^{-6}	1.70×10^{-6}	0.001	0.0079	0.0017

Given $HQ < 1$ for all metals, no significant non-carcinogenic risks are indicated under current rice exposure conditions.

Discussion

The elevated Zn, Pb, and Cd in local rice align with findings from Ajah *et al.* (2022), who also reported high Zn and Cd in Ebonyi rice fields. The particularly high Cd in Ebonyi samples is consistent with the region's known lead-zinc mining (Okonku *et al.*, 2018). These results contrast with the lower metal content in polished imported rice, likely due to processing differences. Rahman *et al.* (2014) reported higher Zn levels in some imported brands, similar to our findings of generally low metal content in imports. In contrast, Kormoker *et al.* (2020) found unsafe HQ values ($HQ > 1$) for Cd and Pb in rice from Bangladesh; our lower HQs reflect differences in contamination sources and possibly dietary patterns. We ensured that earlier statements about "no significant difference" were consistent with our statistical results, clarifying that while local rice often showed higher means, variability meant not all differences were statistically significant.

Based on the environmental and public health implications, the higher trace metal levels in local rice may be due to fertiliser use (rich in Pb and Cd) and irrigation with contaminated water. Environmental monitoring in Ebonyi (Ogbonna *et al.*, 2020) showed Cd in soils, which may explain our findings. Although the calculated HQs were <1 , frequent consumers (especially children) in areas like Ebonyi could accumulate metals over time. Therefore, these findings have important public health implications: they provide regional baseline data and suggest targeted monitoring. For example, our results underscore the need for ongoing testing of locally grown rice and assessment of agricultural inputs. Genetic diversity among local rice varieties further influences metal uptake and stress tolerance, amplifying environmental risks. Nigerian indigenous cultivars, such as those from Ebonyi,

exhibit wide genetic variability that enhances adaptation to abiotic stresses like heavy metal pollution but also boosts bioaccumulation (Onuchukwu *et al.*, 2025). For instance, certain upland varieties with high expression of metal transporter genes (e.g., OsHMA3 for Cd sequestration) show tolerance to Zn and Cd, yet translocate more to grains under chronic exposure (Rasheed *et al.*, 2020). This aligns with our higher local rice metals compared to uniform imported hybrids, which breeders select for low uptake via QTL mapping (Cu *et al.*, 2021).

Conclusion

This study reveals that locally grown and imported rice in Southeast Nigeria contain trace metals (Cd, Pb, Cr, Cu, Zn) largely below harmful levels, but with important caveats. Zn was the most abundant metal, and Cr the least. Most mean concentrations complied with FAO/WHO limits, except that cadmium notably exceeded the limit in some samples (especially those from Ebonyi). Local rice exhibited significantly higher Zn (3.6×), Pb (2.0×) and especially Cd (18×) compared to imported rice. Short-grain rice contained higher Zn, Pb, and Cd than long-grain, reflecting varietal differences. Health risk assessment indicated no significant non-carcinogenic risk (all HQ<1) under our assumptions. This is among the first studies to directly compare local vs. imported rice contamination in Nigeria's Southeast. It provides baseline data for regulators and public health, highlighting that imported rice is generally safer, but locally grown rice – especially from mining-impacted Ebonyi – may pose hidden risks. Public health authorities should prioritise monitoring of cadmium in rice grown near mining areas. The finding that all other metals are within limits is reassuring, but continuous surveillance is needed given evolving agricultural practices.

Limitations and Future Research

The study's scope was limited to trace metals and consumed brands; future work should measure other contaminants, expand geographic coverage, and consider food preparation effects. Additionally, actual dietary surveys would refine risk estimates. Overall, our results inform food safety policy, supporting targeted interventions (see Recommendations) to ensure rice remains a safe staple in Nigeria.

Recommendations

Based on these findings, we suggest:

1. Regular monitoring of rice products (especially locally grown brands from mining areas) for heavy metals.
2. Soil and water assessment in Ebonyi State's rice farming zones to trace contamination sources.
3. Strengthen food safety regulations and enforcement to limit metal contamination in agricultural inputs and imports.
4. Public awareness campaigns to educate communities about dietary exposure and encourage consumption of certified, safe rice.

5. Investigate agricultural practices by promoting the use of clean fertilizers and remediation (e.g. planting metal-tolerant varieties) in high-risk areas.

Credit Authorship Contribution Statement

M.U. Akalonu: Conceptualization, Original Drafting, Writing, Formal Analysis, and Investigation; I.C. Nnorom: supervision, Guidance, Methodology, Conceptualisation, correction of draft and original; J. I. Ogubuike: Data Collection, Formal Analysis, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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