Food Safety of Rice (*Oryza sativa* L.) in Agricultural Zones within Ebonyi State , Nigeria: A Mineral and Heavy Metal Health Risks Assessment

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Abstract

Rice is consumed heavily in Nigeria by both children and adults of the rich and the poor alike. Though available, studies often lack the indepth and critical approach that encourages policy formulations. We investigated the physicochemical properties, essential mineral content, and heavy metal concentrations in rice from three major producing centres in Ebonyi State, Nigeria, alongside associated human health risks. Physicochemical analysis showed correlateions among gelatinization temperature, electrical conductivity (EC), and viscosity, suggesting agrochemical influence, and a negative correlation between EC and pH. Essential mineral analysis revealed potassium, magnesium, and calcium levels generally below daily recommended intake, while sodium levels were commendably low. Heavy metal concentrations of chromium, lead, cobalt, copper, and zinc were largely within WHO/FAO limits. Cadmium and manganese consistently exceeded their thresholds across all locations. Iron in Abakaliki and Afikpo, and nickel in Afikpo, also surpassed permissible limits, likely due to localized soil, agricultural practices, and irrigation water quality. Estimated Daily Intake (EDI) for most metals was within safe limits for adults and children. Cadmium posed a significant carcinogenic risk, especially for children. Chromium, lead, and nickel also warrant monitoring due to their potential carcinogenic effects at high exposure. Therefore, while rice provides essential minerals, the persistent exceedances of cadmium, manganese, iron, and nickel necessitate continuous monitoring, sustainable farming, and farmer education to ensure long-term food safety for consumers of rice from Ebonyi State.

Keywords

Agriculture, Cancer, Carcinogenic, Dietary intake, Health, Toxcity

1. Introduction

Rice (*Oryza sativa* L.) is a cornerstone of global food security, providing sustenance for over half the world's population ,particularly across Asia and Africa [1,2,3]. Beyond its caloric value, rice delivers vital essential minerals critical for human physiological functions like growth, metabolism, and overall health [4]. However, the nutritional integrity of rice ,including its mineral profile, is profoundly influenced by complex interactions of geographical location, soil composition, agricultural practices, and environmental factors, notably heavy metal contamination [5,6]. The escalating pace of global industrialization and agricultural intensification has amplified concerns regarding the bioaccumulation of potentially toxic heavy metals in agricultural soils and, consequently, in food crops [7,8]. Heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), cobalt (Co), and zinc (Zn) can infiltrate the food chain through contaminated irrigation water, industrial effluents, and the indiscriminate use of agrochemicals, including certain fertilizers [5,9,10] While certain elements like Fe, Zn, and Cu are essential micronutrients, their accumulation beyond permissible limits poses severe health risks, ranging from neurological disorders and kidney damage to various forms of cancer, contingent on the specific metal and exposure level [11,12,13]. In Nigeria, rice is a rapidly growing staple [14,15], with Ebonyi State in southeastern Nigeria emerging as a significant rice-producing hub dominated by smallholder farmers [11,16]. Given rice's indispensable role in the local diet, a comprehensive assessment of its nutritional quality, particularly essential mineral content, and the potential risks from heavy metal contamination is imperative. Existing studies underscore the impact of soil degradation and agricultural practices on nutrient levels in staple crops [17,5]. Furthermore, while grains contribute to potassium intake, they typically do not fulfill the entire daily requirement for this mineral [18]. Similarly, rice is not usually considered a primary source for meeting daily calcium requirements [18]. These findings emphasize the need for dietary diversification.

The pervasive presence of heavy metals in food crops is a critical global health concern [19,20]. Cadmium, for Instance, even at low concentrations, presents a significant carcinogenic risk, especially for vulnerable populations like children, with some reported cancer risk values surpassing the acceptable threshold of 10-4 [11,21-27]. Lead also poses a carcinogenic threat when its levels in rice exceed safety standards, contributing to multifaceted health issues affecting multiple organ systems [21,28-30]. Conversely, the carcinogenic potential of elements like chromium and manganese in rice can vary, with some studies suggesting a low overall risk if levels are within safe limits, while others raise concerns about elevated exposure due to pollution [11,21,22,31-34]. Nickel, though an essential trace element in some contexts, presents a carcinogenic risk at elevated levels, particularly for children due to their heightened susceptibility to its adverse health effects compared to adults [11, 21].

Despite the growing body of literature on food safety and nutritional quality, comprehensive regional assessments focusing specifically on rice grown in Nigeria's key agricultural zones, such as Ebonyi State, remain crucial. Such studies are vital for elucidating regional variations in mineral content and heavy metal accumulation, which are often shaped by unique local environmental conditions, geological factors, and agricultural practices, including the use of fertilizers potentially laden with trace elements [33-39]. The excessive use of substandard fertilizers, for example, has been noted as a contributing factor to the accumulation of potentially toxic trace elements in rice grains [11,40]. Moreover, variations in post-harvest methods, such as milling and parboiling, can also significantly influence elemental concentrations [41-46].

Understanding the estimated daily intake (EDI) and associated human health risks (carcinogenic and non-carcinogenic) from consuming locally produced rice is paramount for evidence-based public health policies and dietary recommendations. Previous research indicates that, while overall heavy metal levels in food might be below global permissible limits, continuous consumption can still lead to long-term health implications, especially for susceptible populations [21,28,29,47-51]. Therefore, this study aims to provide a detailed analysis of the essential mineral and heavy metal composition of rice samples from different agricultural zones in Ebonyi State, Nigeria, and to assess the associated health risks for both adult and child populations. This research will contribute invaluable, region-specific data to the understanding of food safety and nutritional adequacy of a critical staple crop.

2. Methodology

2.1 Study Area and Sampling Sites

The study was conducted in Ebonyi State, a prominent agricultural region in southeastern Nigeria, characterized by significant smallholder crop farming. The state is geographically divided into three distinct agricultural zones: Ebonyi North, Ebonyi South, and Ebonyi Central, encompassing a total of thirteen local government areas (LGAs). These zones are vital for cultivating staple food crops such as rice, cassava, yam, potato, maize, plantain, and various vegetables. Specific sampling locations within these zones were selected to ensure a representative coverage of rice production areas across the state (Figure 1).

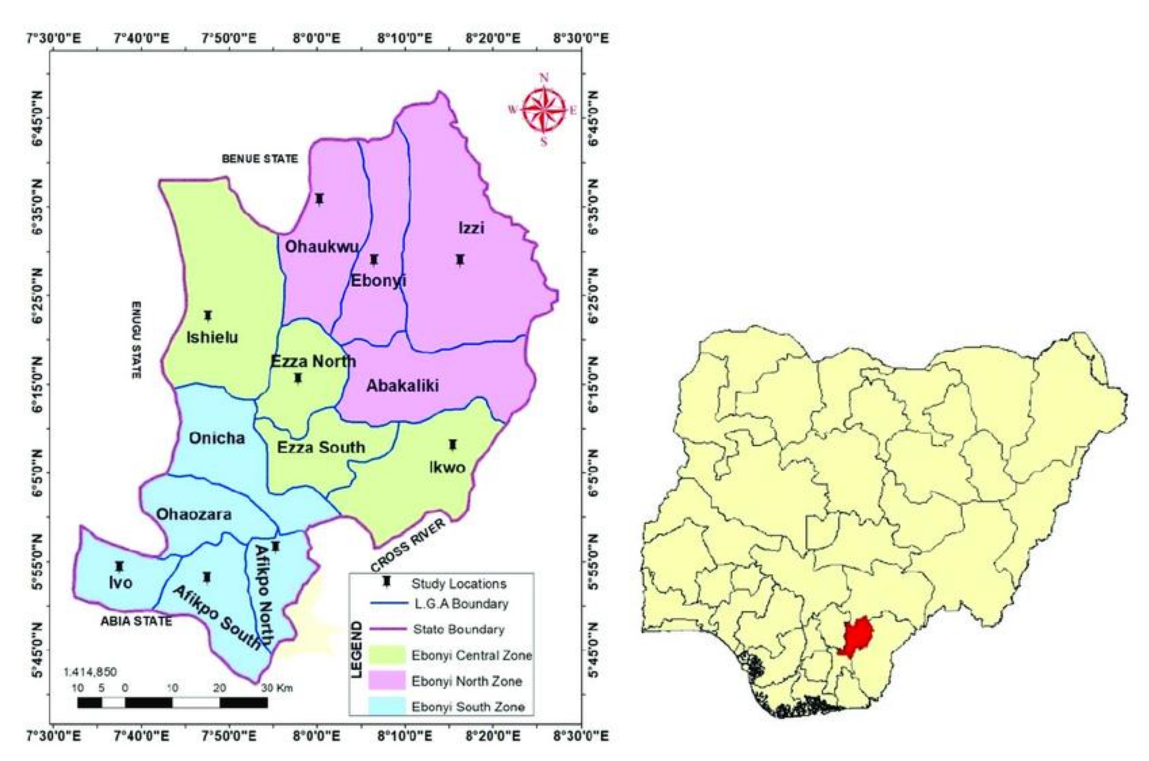

Figure 1. Map of Ebonyi state showing the three agricultural zones, the thirteen LGAs and the nine sampling locations

2.2 Sample Collection and Preparation

For this analytical study, rice samples were systematically collected from the three designated agricultural zones across the 13 LGAs of Ebonyi State. Samples were carefully placed in clean, sterile sampling bags and meticulously labeled with brand information and unique identification numbers to maintain traceability. Upon collection, 100 grams of each rice sample were accurately weighed and then ground into a fine powder using a **c**ommercial-grade electric grinder, FOSS Tecator Cyclotec 1093. To ensure homogeneity and remove larger particles, the resultant powdered rice was then sifted through a 2-micron mesh sieve. The processed samples were subsequently transferred to airtight, sterile containersand stored under controlled conditions of cool, dry place or refrigerated at 4°C, to prevent contamination and degradation prior to further physicochemical and elemental analyses.

2.3 Physicochemical Characterization of Rice Samples

A range of physicochemical properties crucial for understanding rice quality and processing characteristics were determined. These included pH, electrical conductivity (EC), viscosity, gelatinization properties, moisture content, ash content, and color.

pH and Electrical Conductivity (EC): These parameters were measured using a calibrated pH meter and EC meter, respectively, following standard procedures for aqueous extracts of rice flour (AOAC, 2012).Viscosity profiles of the rice flour slurries were determined using either a Rapid Visco Analyzer (RVA) Perten RVA 4500. This instruments provide insights into the pasting properties of rice starch, indicating its behavior during cooking.The color attributes of the powdered rice samples were quantified using a colorimeter, measuring reflectance values (L*, a*, b* values) to objectively describe the lightness, redness/greenness, and yellowness/blueness of the samples.The oven-drying method was employed to determine moisture content. A known weight of rice sample was dried in a convection oven at a specific temperature (105°C) until a constant weight was achieved, typically for 24 hours (AOAC, 2012).Ash content was determined by incinerating a precisely weighed sample in a muffle furnace at a high temperature (550°C) until all organic matter was combusted and a constant residue weight was obtained [4]. The residual inorganic matter represents the ash content.

2.4 Elemental and Heavy Metal Analysis

2.4.1 Sample Digestion for Heavy Metals

For heavy metal analysis, a slightly different digestion protocol was followed to ensure complete dissolution of various metal species. Three grams (3.0 g) of each powdered sample were weighed and dry-ashed in a silica dish using a muffle furnace at a temperature range of 400-500°C for one hour. After ashing, the furnace was allowed to cool with the door open for 30 minutes. The cooled ash was then quantitatively transferred and digested using 10 mL of aqua-regia (a concentrated 1:3 mixture of HNO_3:HCl, trace metal grade). This mixture was heated on a hot plate at 150°C for 2 hours to convert the metals into soluble salt forms suitable for analysis. After cooling, each digest was dissolved in 30 mL of de-ionized water in a conical flask, stirred thoroughly, and then filtered (e.g., using Whatman No. 42 filter paper) to obtain the filtrate. These filtrates were subsequently transported to Awka for the determination of metal elements via Atomic Absorption Spectrophotometry (AAS).

2.4.2 Atomic Absorption Spectrometry (AAS)

The concentrations of heavy metals (Cr, Pb, Cd, Mn, Fe, Co, Ni, Cu, Zn) in the prepared samples were determined using an Atomic Absorption Spectrophotometer(Varian AA240, Agilent, USA). The analysis adhered strictly to the validated methodology described by Okechukwu[11], ensuring accuracy and precision. Appropriate hollow cathode lamps for each element were used, and calibration curves were established using certified multi-element standard solutions (e.g., Merck, Germany). Quality control measures included the analysis of blanks, replicate samples, and certified reference materials (CRMs) to ensure data reliability and method validation.

2.4.3 Human Health Risk Assessment (HHRA)

A comprehensive Human Health Risk Assessment was conducted to evaluate the potential health risks associated with the consumption of heavy metals from rice for both adult and child populations.

Estimated Daily Intake (EDI) of Heavy Metals

The **estimated daily intake (EDI)** of heavy metals (in mg/kg/day) from rice consumption was calculated using the following formula, adapted from established guidelines (USEPA, 1989; OEHHA, 2015; WHO, 2011):

$$EDI=\frac{C\times IR\times CD\times EF}{BW\times AT} \quad (1)$$

Where:

EDI = Estimated Daily Intake (mg/kg/day), C = Concentration of the metal in rice (mg/kg)

IR = Ingestion rate of rice (0.4097 kg/day for adult Nigerians; 0.19 kg/day for children in Nigeria)3, EF = Exposure frequency (365 days/year), ED = Exposure duration (70 years for adults; 6 years for children, as per context in later tables), BW = Consumer's body weight (assumed average of 70 kg for adults; 16.7 kg for children), AT = Average exposure time (for carcinogens: 70×365=25550 days for both children and adults; for non-carcinogens: ED×365 days, specifically 6×365=2190 days for children and 70×365=25550 days for adults).

Carcinogenic Risk (CR)

The cancer risk (CR), representing the additional probability of developing cancer over a lifetime due to exposure to a specific chemical, was calculated using the following equation (USEPA, 1989):

$CR=CDI \times SF$

The chronic daily intake of chemical carcinogen (CDI)was determined as:

$$CDI=\frac{EDI \times IR \times ED \times EF}{BW \times AT} \quad (2)$$

Where:

CDI = Chronic daily intake of a chemical carcinogen (mg/kg body weight per day)

SF = Cancer slope factor (mg/kg per day), quantifying the risk associated with a substance.

Specific SF values used: Lead (Pb) = 0.085; Nickel (Ni) = 0.91; Zinc (Zn) = 0.0006; Chromium (Cr) = 0.5; Cadmium (Cd) = 0.38; Manganese (Mn) = 0.000437; Cobalt (Co) = 3.0. Copper (Cu) and Iron (Fe) are generally not considered significant carcinogens, with SF values often reported as "NA" or zero in this context.

The United States Environmental Protection Agency (USEPA) considers a cancer risk ranging from 10-4 to 10-6 to be acceptable, with 10-4 corresponding to a 1 in 10,000 likelihood and 10-6 to a 1 in 1,000,000 likelihood of developing cancer over a lifetime.

2.4.4 Data Analysis

All collected data were subjected to rigorous statistical analysis using appropriate software SPSS. Descriptive statistics (mean, standard deviation) were employed to summarize the physicochemical properties and elemental concentrations. Analysis of Variance (ANOVA) was performed to identify significant differences in mineral and heavy metal concentrations across the three sampling locations. Microsoft Excel was utilized for correlation analysis to investigate relationships between different physicochemical properties (e.g., size, pH, EC, viscosity, gelatinization temperature) and elemental concentrations. Data were visualized using tables, graphs, and charts to effectively present the findings.

3. Results and Discussion

3.1 Correlation: Size, pH, EC, Gelatinization Temperature and Viscosity

The correlation coefficient matrix reveals the extent of correlation among the logarithmic values of elemental concentrations. Table 1 displays the correlation matrix for physicochemical properties found in the rice samples. Notable positive correlations were identified between gelatinization temperature and electrical conductivity, as well as between gelatinization temperature and viscosity.

Table 1. Correlation: Size, pH, EC, Gelatinization Temperature and viscosity

Location: Ikwo	**Size**	**pH**	**EC**	**Viscosity**
pH	-0.359			
EC	0.988	-0.500		
Viscosity	0.830	0.223	0.733	
Gelatinization Temp	0.914	0.050	0.840	0.985
Location: Abakaliki	**Size**	**pH**	**EC**	**Viscosity**
pH	-0.962			
EC	-0.486	0.229		
Viscosity	0.939	-0.997	-0.155	
Gelatinization Temp	0.932	-0.996	-0.137	1.000
Location: Afikpo	**Size**	**pH**	**EC**	**Viscosity**
pH	0.786			
EC	-0.052	-0.577		
Viscosity	0.339	0.849	0.922	
Gelatinization Temp	0.557	0.951	0.800	0.970

These positive correlations imply that a shared source, likely agrochemicals such as phosphate, nitrate, and ferrous sulfate fertilizers utilized in rice farming, may be responsible for their presence. A negative correlation existed between EC and the numerical value of pH.

3.2 Essential Mineral Content

Across all three sites, potassium levels were generally below the recommended daily intake of 3800 mg/day, although they still offer a notable contribution to overall potassium intake. This finding aligns with studies indicating that while grains are a source of potassium, they often don't provide the full daily requirement on their own [18]. Specifically, the Ikwo site exhibited higher potassium levels compared to Abakaliki and Afikpo, suggesting regional differences in nutrient absorption or soil composition.

Table 2. Essential minerals of rice samples from different locations in Ebonyi State

Location	Element	Site 1	Site 2	Site 3	Mean	SD	WHO /FAO PL (mg/Kg) in foods	Dietary daily intake (mg)
Ikwo	Na	850	970	898	906.00	60.40	2000	2300
	K	3205	2544	3447	3065.33	467.42	NA	2600 - 3800
	Mg	6.7	6.2	7.05	6.65	0.43	NA	310 - 420
	Ca	321	548	521	463.33	124.00	NA	1000 - 1200
Abakaliki	Na	426	285	304	338.33	76.51	2000	2300
	K	1705	1772	2190	1889	262.82	NA	2600 - 3800
	Mg	3.4	3.2	5.7	4.10	1.39	NA	310 - 420
	Ca	236	338	468	347.33	116.28	NA	1000 - 1200
Afikpo	Na	822	659	637	706	101.06	2000	2300
	K	2991	2624	2944	2853	199.71	NA	2600 - 3800
	Mg	4.8	3.58	4.73	4.37	0.69	NA	310 - 420
	Ca	325	328	593	415.33	153.87	NA	1000 - 1200

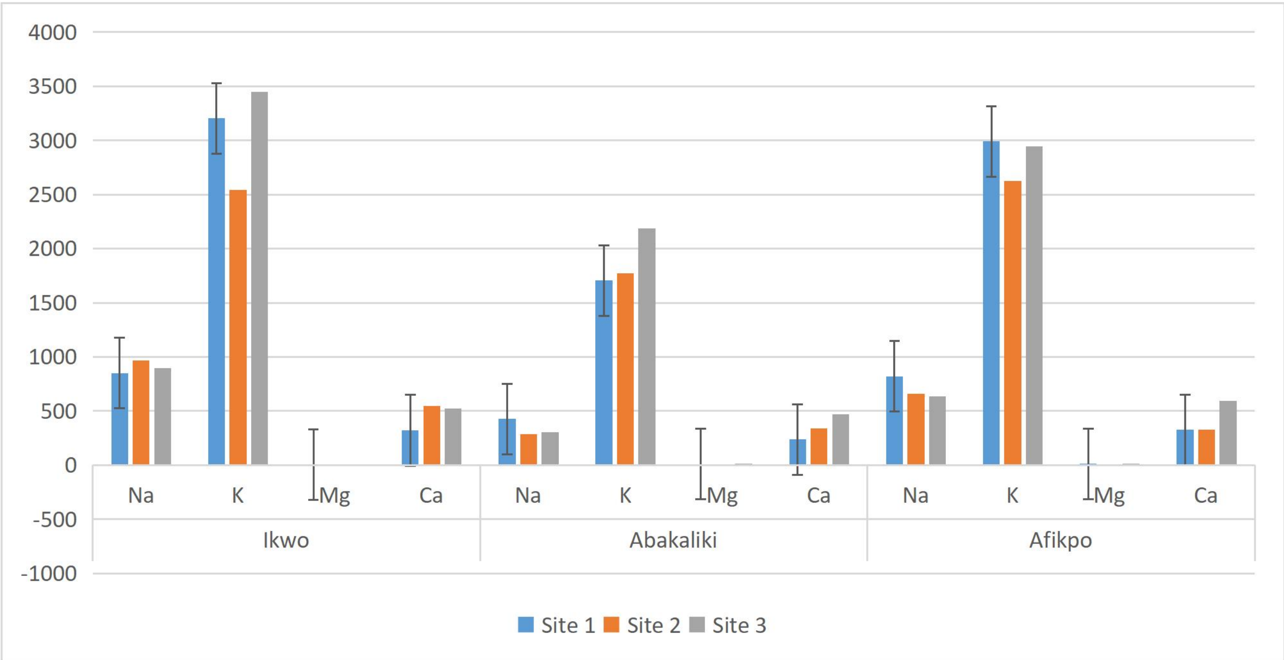

Figure 2. Essential minerals of rice samples from different locations in Ebonyi State

Similarly, the magnesium content in samples from all sites was lower than the recommended daily intake range of 310-420 mg/day. This is consistent with observations by Jones [5], who found that magnesium levels in staple crops can be influenced by soil degradation and agricultural practices. The Afikpo site, however, displayed higher magnesium levels when compared to Abakaliki and Ikwo, indicating potential variations in soil mineral availability or plant uptake efficiency in that region.

Calcium content, while varying across the sites, was also generally lower than the recommended daily intake of 1200 mg/day. The Afikpo site recorded the highest calcium content, followed by Abakaliki and then Ikwo. This trend of lower calcium in rice, as observed here, is broadly supported by research suggesting that rice is not typically a primary source for meeting daily calcium requirements [18].

In contrast to the other minerals, sodium levels in the rice samples were significantly lower than the WHO recommended limit of 2300 mg/day. This suggests that consuming rice from these regions is unlikely to contribute significantly to excessive sodium intake, a finding that is beneficial for public health given concerns about high sodium consumption [5].

3.3 Potential Dietary Implications

The mineral analysis suggests that while rice from Ikwo, Abakaliki, and Afikpo can contribute to daily mineral intake, it may not be sufficient to meet full daily requirements for potassium, magnesium, and calcium. This underscores the importance of a balanced diet that includes a variety of other mineral-rich foods to ensure adequate nutrient intake. These findings align with the broader understanding that no single food can provide all essential nutrients, and a diverse diet is crucial for optimal health [5,18].

3.4 Heavy Metal Concentration in Rice Samples

Table 4 summarizes these findings, juxtaposing them against WHO/FAO permissible limits (PL) for food. While overall heavy metal levels largely adhered to international safety thresholds, regional variations and specific exceedances warrant a detailed discussion and comparison with global literature.

Initially, it's pertinent to note that the majority of heavy metals analyzed, including chromium (Cr), lead (Pb), cobalt (Co), copper (Cu), and zinc (Zn), were found below the WHO/FAO permissible limits across all sampled locations. This overarching compliance with international standards aligns with observations from other agricultural regions globally that are not heavily industrialized or subjected to severe contamination [52,53]. The lower concentrations of these elements can be attributed to factors such as their low bioavailability in local soils, influenced by strong affinity for soil organic matter and acidic groups in root cell walls, leading to stable covalent bonds [54]. Additionally, the robust, deep, and extensively branched root systems characteristic of traditional rice varieties in Ebonyi State may enhance the selective uptake of essential nutrients over certain non-essential heavy metals, influencing their concentrations in the grains [55]. Post-harvest processing, such as milling and parboiling, can also influence the final metal concentrations in rice samples [41].

However, significant findings emerged for specific elements. The mean concentrations of cadmium (Cd) and manganese (Mn) consistently exceeded their respective WHO/FAO thresholds of 0.3 mg/kg and 3 mg/kg across all locations (Ikwo, Abakaliki, and Afikpo). This widespread exceedance for Cd is particularly concerning given its high toxicity, long biological half-life, and established carcinogenic potential, even at relatively low exposure levels [23]. This finding resonates with studies from other major rice-producing regions where cadmium contamination poses a significant public health challenge, often linked to contaminated irrigation water or the use of phosphate fertilizers containing Cd impurities [26,27]. The elevated Mn levels, while exceeding the WHO/FAO threshold, require careful interpretation. Manganese is an essential micronutrient, but excessive intake can lead to neurotoxicity [32]. Studies in other rice-growing areas have also reported high Mn accumulation in rice, which can be influenced by soil pH and redox conditions, especially under flooded conditions typical for rice cultivation [56].

Further analysis revealed that Iron (Fe)concentrations, specifically in Abakaliki and Afikpo, exceeded the WHO/FAO permissible limits (450 mg/kg), reaching means of 926.67 mg/kg and 1468 mg/kg, respectively. This contradicts the initial assertion that Fe levels were "significantly below the dietary intake limit" and instead suggests potentially concerningly high iron levels in rice from these two locations. While iron is vital, excessive intake, particularly through food, can lead to iron overload, which may contribute to oxidative stress and organ damage in susceptible individuals over time [57]. This finding contrasts with studies from areas experiencing widespread iron deficiency where staple crops often contain insufficient iron [58]. The high levels in Abakaliki and Afikpo may point to localized soil geochemistry, specific agricultural practices, or anthropogenic sources contributing to iron enrichment.

Regarding nickel (Ni), the mean value at Afikpo (1.65 mg/kg) was found to exceed the WHO/FAO permissible limit of 1.5 mg/kg. Similarly, Abakaliki also showed higher Ni levels (1.32 mg/kg) compared to Ikwo (0.907 mg/kg), although only Afikpo surpassed the limit. Nickel is a known allergen and a potential carcinogen at high exposures [59]. The elevated Ni concentrations, particularly in Afikpo, could be indicative of specific soil characteristics, pollution from industrial activities, or the application of certain agrochemicals or waste products [60]. This calls for closer scrutiny of soil and water quality in these areas.

While zinc (Zn) levels were within permissible limits (mean ranging from 28.64 to 45.52 mg/kg), they were noted as approaching or exceeding the dietary intake limit (50 mg/kg in the table provided), implying rice from these regions can be a significant source of zinc. This is a beneficial aspect, as zinc deficiency remains a public health issue in many developing countries [61]. However, studies in other cultivated areas sometimes report suboptimal zinc levels due to nutrient depletion, contrasting with our findings and highlighting the local variability [62].

The observed spatial differences in elemental concentrations, such as slightly higher **Cr** and **Pb** in Abakaliki and Afikpo compared to Ikwo, and significantly higher **Co** in Afikpo, underscore the role of localized environmental factors. Differences in soil composition, varying fertilization practices, and proximity to specific pollution sources or geological anomalies may contribute to these variations in heavy metal uptake by rice plants [33,34].

The excessive use of substandard fertilizers, specifically urea, triple superphosphate, and muriate of potash, applied at rates higher than recommended by local farmers, has been identified as a potential contributor to the accumulation of trace elements in rice grains[24]. Furthermore, irrigation water quality can significantly influence heavy metal accumulation in rice, serving as a direct pathway for contaminants from both natural and anthropogenic origins [30].

Table 3. Heavy metal contents of rice samples from different locations in Ebonyi State

Location	Heavy Metals	Site 1	Site 2	Site 3	Mean	SD	WHO/FAO PL (mg/Kg) in foods
Ikwo	Cr	0.97	1.24	1.08	1.097	0.136	10
	Pb	0.07	0.03	0.049	0.050	0.020	0.2
	Cd	0.85	0.7	0.88	0.810	0.096	0.3
	Mn	7.54	7.21	7.05	7.267	0.250	3
	Fe	152	88	97	112.333	34.646	450
	Co	0.005	0.006	0.007	0.006	0.001	NA
	Ni	0.52	1.23	0.97	0.907	0.359	1.5
	Cu	74	86	96	85.333	11.015	NA
	Zn	27.3	27.1	38.54	30.980	6.548	50
Abakaliki	Cr	1.52	1.05	1.257	1.28	0.24	10
	Pb	0.04	0.045	0.051	0.05	0.01	0.2
	Cd	0.58	0.92	0.874	0.79	0.18	0.3
	Mn	6.52	6.49	7.28	6.76	0.45	3
	Fe	359	335	386	926.67	63.91	450
	Co	0.002	0.027	0.007	0.01	0.01	NA
	Ni	0.491	1.68	1.79	1.32	0.72	1.5
	Cu	102	96	135	111.00	21.00	NA
	Zn	47.06	28.9	28.37	28.64	16.53	50
Afikpo	Cr	1.73	1.95	1.68	1.79	0.14	10
	Pb	0.004	0.063	0.078	0.05	0.04	0.2
	Cd	0.84	0.977	0.907	0.91	0.07	0.3
	Mn	6.06	6.26	7.89	10.40	5.82	3
	Fe	392	374	338	1468	326.12	450
	Co	0.047	0.062	0.081	0.06	0.02	NA
	Ni	1.08	1.95	1.92	1.65	0.49	1.5
	Cu	98	87	104	96.33	8.62	NA
	Zn	49.27	48.1	37.18	45.52	7.39	50

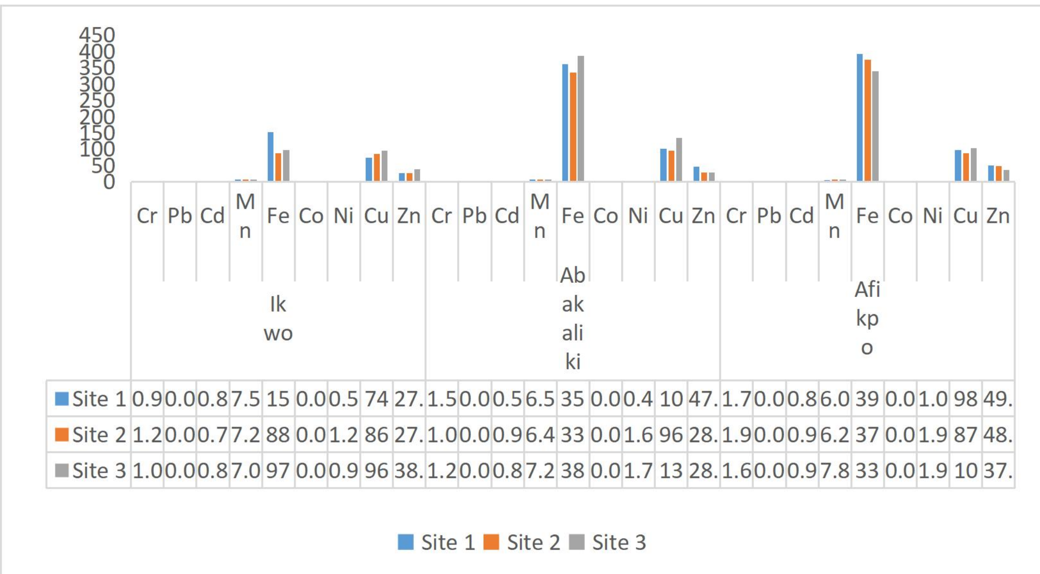

Figure 3. Heavy metal contents of rice samples from different locations in Ebonyi State

In Ebonyi State generally, heavy metal levels were found to be below critical health thresholds for several elements. However, the concerning exceedances for cadmium and manganese across all sites, and iron and nickel in specific locations, necessitate proactive measures. These findings highlight the importance of continuous monitoring of agricultural soils and produce, promoting sustainable farming practices, and educating local farmers on appropriate fertilizer use to mitigate the risks associated with heavy metal accumulation and ensure the long-term food safety of rice for consumers in Ebonyi State.

Table 4. Estimated dietary intake (EDI) (mg/kg/day) of Heavy metals for the adult population through consumption of rice in these locations (Carcinogenic)

EDI for adults in all Locations for Carcinogenic						
	CM of Ikwo	**CM of Abakaliki**	**CM of Afikpo**	**EDI for Ikwo**	**EDI for Abakaliki**	**EDI for Afikpo**
Cr	1.097	1.276	1.787	6.419E-03	7.466E-03	1.046E-02
Pb	0.050	0.045	0.048	2.907E-04	2.653E-04	2.829E-04
Cd	0.810	0.791	0.908	4.741E-03	4.632E-03	5.314E-03
Mn	7.267	6.763	6.737	4.253E-02	3.958E-02	3.943E-02
Fe	112.333	360.000	368.000	6.575E-01	2.107E+00	2.154E+00
Co	0.006	0.012	0.063	3.512E-05	7.023E-05	3.707E-04
Ni	0.907	1.320	1.650	5.307E-03	7.728E-03	9.657E-03
Cu	85.333	111.000	96.333	4.994E-01	6.497E-01	5.638E-01
Zn	30.980	34.777	44.850	1.813E-01	2.035E-01	2.625E-01

Table 4 shows the non-carcinogenic Estimated dietary intake (EDI) (mg/kg/day) of Heavy metals for the adult population through consumption of rice in these locations (non-carcinogenic) The estimated daily intake of the heavy metals for carcinogenicity for adult population through consumption of rice located in these locations are resented in Table 4. The EDI for chromium ranged between 1.04 $\times10^{-2}$ to 7.510^{-3}, with the highest EDI found in sample from Afikpo and the lowest in sample from Abakaliki. That lead ranged between 2.65×10^{-4} to 2.91×10^{-4}, with the highest EDI found in sample from Abakaliki and the lowest in sample from Ikwo. That of cadmium ranged between 4.63×10^{-3} to 5.31×10^{-3}, with the highest EDI found in sample from Abakaliki and the lowest in sample from Ikwo. Manganese ranged between 3.94×10^{-2} to 4.25×10^{-2}, with the highest EDI found in sample from Afikpo and the lowest in sample from Ikwo. That of iron ranged between 2.10 to 6.58×10^{-1}, with the highest EDI found in sample from Afikpo and the lowest in sample from Ikwo. Cobalt ranged between 3.7×10^{-4} to 7.0×10^{-5}, with the highest EDI found in sample from Ikwo and the lowest in sample from Abakaliki. That of nickel ranged between 5.31×10^{-3} to 9.66×10^{-3}, with the highest EDI found in sample from Ikwo and the lowest in sample from Afikpo. Copper ranged between 4.99×10^{-1} to 6.5×10^{-1}, with the highest EDI found in sample from Ikwo and the lowest in sample from Abakaliki. Copper, an essential trace element with numerous biological functions, serves as a prosthetic group in several important enzymes. However, excessive copper intake can lead to symptoms such as headaches, dizziness, nausea, diarrhea, and damage to the liver and kidneys. That of zinc ranged between 1.81×10^{-1} to 2.63×10^{-1}. with the highest EDI found in sample from Ikwo and the lowest in sample from Afikpo. The levels of EDI for heavy metals found in rice grains were within the permissible limit of 10^{-6} as set by the FAO/WHO for human consumption.

Table 5. Estimated dietary intake (EDI) (mg/kg/day) of Heavy metals for the children population through consumption of rice in these locations

EDI for adults in all Locations for Non-carcinogenic						
	CM of Ikwo	**CM of Abakaliki**	**CM of Afikpo**	**EDI for Ikwo**	**EDI for Abakaliki**	**EDI for Afikpo**
Cr	1.097	1.276	1.787	1.498E-02	1.742E-02	2.440E-02
Pb	0.050	0.045	0.048	6.783E-04	6.191E-04	6.601E-04
Cd	0.810	0.791	0.908	1.106E-02	1.081E-02	1.240E-02
Mn	7.267	6.763	6.737	9.924E-02	9.236E-02	9.200E-02
Fe	112.333	360.000	368.000	1.534E+00	4.916E+00	5.026E+00
Co	0.006	0.012	0.063	8.194E-05	1.639E-04	8.649E-04
Ni	0.907	1.320	1.650	1.238E-02	1.803E-02	2.253E-02
Cu	85.333	111.000	96.333	1.165E+00	1.516E+00	1.316E+00
Zn	30.980	34.777	44.850	4.231E-01	4.749E-01	6.125E-01

Table 5 shows the non-carcinogenic Estimated dietary intake (EDI) (mg/kg/day) of Heavy metals for the adult population through consumption of rice in these locations (carcinogenic) The estimated daily intake of the heavy metals for carcinogenicity for adult population through consumption of rice located in these locations are resented in Table 5.

3.5 Estimated Daily Intake (EDI) of Potentially Harmful Elements

Table 4 an 5 presents the EDI of heavy metals from various rice cultivars, alongside a comparison to the Maximum Tolerable Daily Intake (MTDI). The estimated daily intake for an adult and children has been calculated based on the consumption of these rice varieties. The findings indicate that the estimated intake of toxic elements varies significantly among the different rice cultivars.

The findings indicate that while the risk of adverse health effects may be minimal for adults, those with lower body weight and higher rice consumption may be at an increased risk from heavy metal exposure. All metals analyzed were found to be below the tolerable daily intake for an average adult weighing 70 kg who consumes 0.0679 kg of rice daily. Nonetheless, the ongoing consumption of heavy metals from rice and other dietary sources could present potential health risks

This indicates a no risk associated with Ni, Pb, and Cu in rice samples, highlighting the connection between lead and nickel exposure and various health issues impacting the nervous, respiratory, cardiovascular, hematopoietic, immune, endocrine, hepatic, renal, and reproductive systems. Nickel, which is not broken down in the body, changes its chemical form, and its metabolism is closely related to its ability to bind and form ligands for transport within the body. The toxicity of nickel-containing compounds is associated with the bioavailability of the metal ion (Ni^{2+}) at systemic or localized target sites.

According to the United States Environmental Protection Agency (USEPA), CR values exceeding 10^{-6} are typically regarded as a threshold for cancer risk in adults. In this study, CR values for all heavy metals analyzed were found to be below this threshold across all rice cultivars. These findings suggest that consuming various rice cultivars available in the different locations in Ebonyi State does not pose carcinogenic health risks to consumers. The SF values are as follows: chromium (Cr)= 0.5, lead (Pb) = 0.0085, nickel (Ni) = 0.84, cadmium (Cd)=0.38, manganese (Mn)= 0.000437, iron (Fe)=NA, cobalt=3.0, copper (Cu)= generally not considered to be a significant carcinogen and zinc (Zn) = 0.0006.

	Slope actor mg/kg-day)$^{-1}$ for adult	CDI for Ikwo	CDI for Abakaliki	CDI for Afikpo	CR for Ikwo	CR for Abakaliki	CR for Afikpo
Cr	0.16	0.01498	0.01742	0.02440	2.396E-03	2.787E-03	3.904E-03
Pb	0.0085	0.00068	0.00062	0.00066	5.765E-06	5.262E-06	5.611E-06
Cd	0.38	0.01106	0.01081	0.01240	4.204E-03	4.107E-03	4.712E-03
Co	3	0.00008	0.00016	0.00086	2.458E-04	4.916E-04	2.595E-03
Ni	0.84	0.01238	0.01803	0.02253	1.040E-02	1.515E-02	1.893E-02
Zn	0.3	0.42308	0.47493	0.61250	1.269E-01	1.425E-01	1.838E-01
CR for children in all Locations							
	Slope actor mg/kg-day)$^{-1}$	**CDI for Ikwo**	**CDI for Abakaliki**	**CDI for Afikpo**	**CR for Ikwo**	**CR for Abakaliki**	**CR for Afikpo**
Cr	0.5	0.01248	0.01451	0.02033	6.239E-03	7.257E-03	1.016E-02
Pb	0.0085	0.00057	0.00052	0.00055	4.803E-06	4.384E-06	4.674E-06
Cd	0.38	0.08267	0.07695	0.07664	3.142E-02	2.924E-02	2.912E-02
Co	3	0.00007	0.00014	0.00072	2.100E-04	4.200E-04	2.160E-03
Ni	0.84	0.01032	0.01502	0.01877	8.669E-03	1.262E-02	1.577E-02
Zn	0.3	0.97086	1.26287	1.09601	2.913E-01	3.789E-01	3.288E-01

Figure 4. CR (mg/kg/day) of Heavy metals for the adult and children population through consumption of rice in these locations (Carcinogenic)

Iron (Fe) is a vital nutrient found in rice, but there is no conclusive evidence linking iron in rice to cancer. Some research has explored the health implications of heavy metals, including iron, and raised concerns about the non-carcinogenic effects of iron, especially in contaminated rice. Cobalt (Co), another essential micronutrient, is generally regarded as having a low carcinogenic risk in rice. In contrast, cadmium (Cd) presents a significant carcinogenic risk in rice, particularly with high exposure levels, with studies indicating cancer risk values exceeding 10^{-4}, especially in children. The carcinogenic potential of chromium (Cr) in rice varies based on its concentration and environmental factors, with some areas showing Cr levels above acceptable limits due to pollution. While some research suggests a carcinogenic risk from Cr, particularly in children and adults with high exposure, other studies indicate that the overall risk remains low if Cr levels are within safe limits. Manganese (Mn) is present in rice, but its associated carcinogenic risk is generally considered minimal, with the cancer slope factor for manganese being effectively zero. Although high manganese exposure can lead to neurological and developmental issues, there is insufficient evidence to classify it as a direct carcinogen. Nonetheless, concerns about potential contamination with other heavy metals in rice persist, which could elevate cancer risks.

The presence of lead (Pb) in rice can present a carcinogenic threat, especially when its levels surpass established safety thresholds. Research shows that Pb concentrations in rice, particularly in certain areas, may exceed national standards, increasing the potential carcinogenic risk. While some studies report that specific rice varieties have carcinogenic risk values within safe limits, others suggest that consuming Pb-contaminated rice can elevate cancer risk, particularly in children and adults. Similarly, while copper (Cu) is a necessary trace element, excessive amounts in rice can lead to health hazards, including both carcinogenic and non-carcinogenic effects. Nickel (Ni) also poses a carcinogenic risk in rice, particularly at elevated levels, with a high-risk level defined when the incremental lifetime cancer risk (ILCR) for Ni surpasses 10^{-4}. Children are particularly susceptible to the adverse health effects of heavy metals like Ni compared to adults. Although zinc (Zn) is a vital nutrient, excessive zinc levels in rice, often due to contamination or over-fertilization, can pose health risks, albeit not necessarily carcinogenic like other heavy metals. Zinc toxicity may lead to non-carcinogenic health issues and could contribute to other health complications, but it is not directly associated with cancer development in the same manner as arsenic, cadmium, or lead.

4. Conclusion

This study reveals critical insights into the food safety of rice in Ebonyi State, Nigeria. While rice contributes some essential minerals, it generally falls short of meeting daily requirements for potassium, magnesium, and calcium, emphasizing the need for dietary diversification. More importantly, the analysis exposed concerning heavy metal contamination. Cadmium and manganese consistently exceeded WHO/FAO limits across all locations. Elevated iron and nickel levels were also found in specific zones, likely influenced by local soil, agricultural practices, and irrigation. Despite estimated daily intakes for most metals being within tolerable ranges, cadmium poses a significant carcinogenic risk, particularly for children. The potential for chromium, lead, and nickel to also pose health risks, especially with increased exposure, warrants attention. This necessitates immediate policy interventions. The government should implement stricter regulations on fertilizer composition and usage, alongside establishing robust monitoring programs for heavy metals in agricultural soils and produce. Such measures are crucial to mitigate contamination, safeguard public health, and ensure the long-term safety and nutritional adequacy of rice in Ebonyi State.

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