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ASSESSMENT OF HEAVY METAL ACCUMULATION IN AGRICULTURAL SOILS AND PADDY RICE UNDER IRRIGATED FARMING SYSTEMS IN SELECTED COMMUNITIES OF ZAMFARA STATE, NIGERIA

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ABSTRACT

This study examines seasonal concentrations of selected heavy metals in paddy rice associated with irrigated farming systems in selected communities of Zamfara State, Nigeria, with particular reference to the Bakalori Irrigation Scheme. The assessment focuses on lead (Pb), cadmium (Cd), nickel (Ni) and chromium (Cr) in rice grains during wet and dry seasons. The available dataset recorded Pb concentrations of 1.196 and 2.109 mg/kg, Ni concentrations of 0.717 and 1.767 mg/kg, and Cr concentrations of 0.694 and 1.193 mg/kg, respectively. Cadmium was not detected in the wet season but measured 0.153 mg/kg in the dry season. Dry-season values were descriptively higher for Pb, Ni and Cr. No numerical result was available for arsenic. These values correspond to those published by Abdullahi et al. (2024) for rice from Kano State; their attribution to Zamfara samples therefore requires verification against original laboratory records. The findings highlight the importance of seasonal monitoring and reliable laboratory documentation for rice food-safety assessment.

1. INTRODUCTION AND BACKGROUND

Food safety is closely linked to the environmental quality of the places where food crops are produced. Agricultural soils, irrigation water, sediments and cropmanagement practices collectively influence the chemical environment in which plants grow. Potentially toxic elements may enter agricultural systems through natural weathering of parent materials and through human activities such as mining, mineral processing, industrial discharge, wastewater reuse, atmospheric deposition and the application of some fertilisers and

agrochemicals. Where an element is present in a chemical form accessible to plants, it may be taken up and transferred into edible crop tissues. (Aminu, 2022; Lwin et al., 2025; Mandal et al., 2022).

Unlike many organic contaminants, metals and metalloids cannot be destroyed through ordinary biological degradation. They may change chemical form, bind to soil constituents, dissolve, precipitate or move between environmental compartments, but the element itself persists. This persistence makes monitoring important where food crops are cultivated over repeated seasons. The presence of a metal in an agricultural environment does not automatically mean that the harvested crop is unsafe; concentration, chemical form, crop uptake and the applicable food standard all influence interpretation. (Lwin et al., 2025; World Health Organization, 2023).

Rice (Oryza sativa L.) is an important staple in Nigeria. Its consumption across different regions and household income groups makes rice quality relevant to nutrition, food security and public health. Rice is also cultivated under water-management systems that can include prolonged flooding, intermittent irrigation and drainage. These conditions influence soil oxidationreduction status and may affect the mobility of elements, especially arsenic and cadmium. The grain concentration of an element is consequently not a simple reflection of its total concentration in soil. (Abdullahi et al., 2024; Lwin et al., 2025).

Lead, cadmium, nickel and chromium are of interest in environmental and food monitoring. Their toxicological significance differs, and the risk associated with exposure depends on dose, duration, chemical species and individual susceptibility. The report focuses on Pb, Cd, Ni and Cr because these are the elements for which the agreed seasonal rice-grain dataset provides values. Arsenic remains important in rice safety research, but no value was supplied for either season. Its result is therefore described as not reported, not as zero or not detected. (Lwin et al., 2025; World Health Organization, 2023).

The route from environmental contamination to dietary exposure involves several processes. A metal may be present in irrigation water or soil, interact with dissolved organic matter and mineral surfaces, enter the root zone, be absorbed by the plant and then be retained in roots or transported to shoots and grain. Different elements use different transport pathways. Plant variety, root physiology, water regime, pH, redox potential and competing nutrients can influence uptake and translocation. Lwin et al. (2025) discuss these mechanisms for arsenic, cadmium and lead in soilrice systems.

Seasonal comparison is useful because growing conditions may differ between wet and dry production periods. Rainfall, irrigation supply, soil moisture, temperature, crop duration and

watermanagement practices can vary by season. Such differences may affect element availability and crop uptake. However, a difference between two reported seasonal means cannot by itself establish the mechanism responsible. Demonstrating a seasonal effect requires information about sample numbers, sampling design, rice variety, farm locations, analytical precision and variability within each season. (Abdullahi et al., 2024; Aminu, 2022; Lwin et al., 2025).

Zamfara State provides a relevant regional setting for this research. Previous studies have examined metals in Bakolori irrigation and drainage canal water and in rice and soils from mining-impacted agricultural land in Dareta. These studies establish that metals are an appropriate subject for local monitoring. They do not establish the concentrations in every farming community or the seasonal values in the dataset considered here. Local evidence must be interpreted according to the actual sampling locations and laboratory records. (Aminu, 2022; Mandal et al., 2022).

The present expanded report therefore uses a focused interpretation. It describes the agreed seasonal values for Pb, Cd, Ni and Cr in rice grain, records the absence of a reported As result, and discusses the implications and limitations of the observed seasonal pattern. It does not claim that the project measured irrigation water, agricultural soil or physicochemical properties, or completed a dietary exposure assessment. This scope discipline is necessary to keep the report scientifically defensible. (Scope and limitations are based on the project information supplied for this report.)

2. STATEMENT OF THE RESEARCH PROBLEM

Rice is consumed frequently, and longterm intake of food containing elevated concentrations of potentially toxic elements may contribute to exposure. Irrigated rice systems deserve attention because metals may be introduced through water, soil, sediments and agricultural inputs, and some elements may be taken up by the crop. The possibility of seasonal variation adds another dimension: the chemical environment and watermanagement practices during wet and dry production periods may not be identical. (Lwin et al., 2025; World Health Organization, 2023).

Research in Zamfara has already identified heavymetal concerns in specific settings. Aminu (2022) assessed the main irrigation and drainage canals of the Bakolori Irrigation Project and reported concerns involving cadmium, chromium and lead under the criteria used in that publication. Mandal et al. (2022) studied rice varieties and associated soils in mining-impacted Dareta and documented lead and arsenic. These studies are important contextual

evidence, but their findings cannot be transferred directly to other farms or treated as measurements of the rice dataset in this report.

The problem addressed in this revised report is the need to describe the seasonal concentrations of selected heavy metals in rice grain and assess how the reported wetand dryseason values differ. The available dataset includes Pb, Cd, Ni and Cr, but no reported As concentration. It also lacks paired soil and water results, physicochemical measurements, samplelevel replicates and dietary exposure parameters. Consequently, the report can describe seasonal concentration patterns but cannot establish contamination sources, soiltograin transfer, population intake or healthrisk indices. (Scope and limitations are based on the project summary dataset supplied for this report; see also Ihedioha et al., 2019, for the additional data required for dietaryrisk assessment.)

3. AIM AND SPECIFIC OBJECTIVES

The aim isto assess the seasonal concentrations of selected heavy metals in paddy rice produced under irrigated farming systems in selected communities of Zamfara State, Nigeria. (Study aim defined by the project team.)

Specific objectives:

1. Determine the concentrations of selected heavy metals, namely lead (Pb), cadmium (Cd), nickel (Ni) and chromium (Cr), in paddy rice samples during the wet and dry seasons. (Objective defined by the project team.)
2. Compare the measured seasonal concentrations of the selected heavy metals in paddy rice with applicable national and international foodsafety standards. (Codex Alimentarius Commission, 1995, 2025).
3. Examine seasonal variations in the concentrations of the selected heavy metals in paddy rice between the wet and dry seasons. (Objective defined by the project team.)

Arsenic is retained as a relevant contaminant in the literature review, but no arsenic result was reported in the agreed dataset. It is not treated as a completed concentration determination. (Project summary dataset supplied for this report.)

4. REVIEW OF RELEVANT LITERATURE

4.1 Heavy metals in agricultural environments

Metals enter agricultural environments through geogenic and anthropogenic pathways. Geogenic sources include weathering of rocks and minerals, while anthropogenic sources may include mining, smelting, industrial activities, wastewater discharge, atmospheric

deposition and agricultural inputs. In irrigated areas, water can transport dissolved metals or suspended particles into fields. Sediments may also be redistributed through canals, field channels and drainage systems. The relative importance of these pathways varies between locations and must be established through field evidence rather than assumed. (Aminu, 2022; Lwin et al., 2025; Mandal et al., 2022).

The environmental behaviour of metals is controlled by chemical speciation and interactions with soil constituents. A metal may be dissolved in soil solution, adsorbed onto clay or oxide surfaces, associated with organic matter, incorporated into mineral structures or precipitated as a relatively insoluble compound. Changes in pH, redox potential and ionic composition may alter the balance between these forms. Total concentration is useful for describing the overall burden, but it does not necessarily indicate the fraction immediately available for plant uptake. (Lwin et al., 2025).

4.2 Soil chemistry and crop availability

Soil pH can influence metal solubility and surface charge. Organic matter can bind metals and may either reduce or increase mobility depending on the metal and dissolved organic compounds. Clay minerals and iron or manganese oxides provide sorption surfaces. In flooded rice fields, oxygen depletion and changes in redox potential can affect iron and manganese phases and alter the behaviour of arsenic and other elements. These processes explain why total soil concentration and grain concentration may not be linearly related. (Lwin et al., 2025).

Although the present dataset contains no soil measurements, this literature is relevant for interpreting why seasonal grain concentrations may differ. It also explains why a ricegrain result cannot, on its own, identify whether an element originated from irrigation water, soil parent material, agricultural inputs or another source. (Lwin et al., 2025; Mandal et al., 2022).

4.3 Uptake and translocation in rice

Rice plants absorb elements through root surfaces and regulate their movement through biological transport systems. Some elements may be retained in roots, bound to cell walls or sequestered in intracellular compartments. Others may be transported to stems, leaves and grain through xylem and phloem pathways. The extent of translocation depends on elementspecific transporters, plant nutritional status, genotype and environmental conditions. Lwin et al. (2025) review uptake and transport mechanisms for arsenic, cadmium and lead in rice systems. (Lwin et al., 2025).

The distinction between root accumulation and grain accumulation is important for food-safety assessment. A high concentration in root tissue does not necessarily mean that the

same concentration will occur in the edible grain. Conversely, a low total concentration in soil does not guarantee that grain concentration will be negligible if the element is relatively available and efficiently transported. For this reason, the rice-grain matrix is the most directly relevant matrix for assessing the concentration in the food as consumed, provided the processing form and reporting basis are stated. (Ihedioha et al., 2019; Lwin et al., 2025; Mandal et al., 2022).

4.4 Seasonal influences

Wetand dryseason production may differ in water availability, irrigation frequency, soil moisture, temperature and crop development. Under flooded conditions, redox changes may alter metal mobility; during drainage, re-oxidation can change sorption and precipitation processes. Seasonal differences in concentration may also reflect changes in sampling locations, crop varieties, maturity, post-harvest handling or analytical batches. A seasonal comparison is therefore most reliable when the same sampling framework and analytical quality controls are applied in both seasons. (Abdullahi et al., 2024; Aminu, 2022; Lwin et al., 2025).

A two-season dataset can identify a descriptive pattern, but it cannot by itself identify the cause of the difference. For inferential testing, individual sample measurements and adequate replication are required. Without these, it is appropriate to report the numerical difference and describe it as an observed pattern rather than a statistically significant seasonal effect. (Abdullahi et al., 2024; Authors' interpretation of the available summary data).

4.5 Evidence from Zamfara State

Aminu (2022) investigated heavy metals in the main irrigation and drainage canals of the Bakolori Irrigation Project. The study analysed elements including Cd, Cr, Cu, Fe, Mn, Pb and Zn and reported partial pollution involving Cd, Cr and Pb according to the comparison criteria applied by the author. This work is directly relevant to the irrigation scheme but is limited to the canalwater matrix and its own sampling period. It cannot be used as a substitute for current ricegrain measurements. (Aminu, 2022).

Mandal et al. (2022) examined ten rice varieties grown in mining-impacted agricultural fields in Dareta village, Zamfara State. Their study analysed paired soil and rice-plant samples and reported variation in lead and arsenic concentrations and differences in transfer behaviour among rice varieties. The study is regionally important because it demonstrates that rice variety and site conditions may influence metal accumulation. Dareta, however, is a miningimpacted setting and should not be treated as representative of every irrigated farm in Zamfara. (Mandal et al., 2022).

4.6 Evidence from other Nigerian rice systems

Ihedioha et al. (2019) investigated heavymetal contamination in paddy soil and rice from Abakaliki, Nigeria. Their study combined concentration measurements with exposure and healthrisk calculations. It illustrates the value of evaluating the food matrix alongside the environment and of distinguishing concentration exceedance from calculated health risk. Those calculations depend on exposure assumptions, body weight, foodconsumption rate and toxicological reference values. (Ihedioha et al., 2019).

Abdullahi et al. (2024) examined seasonal variation and uptake patterns in rice grown at the Kano River Irrigation Project. The publication reports wet- and dry-season measurements and is especially relevant to the seasonal context. However, its geographic setting is Kano State. The numerical values supplied for the present report correspond exactly to the values in that publication, making verification of the Zamfara project's independent data provenance essential. (Abdullahi et al., 2024).

4.7 Foodsafety standards and interpretation

Food-safety standards specify maximum levels for particular contaminants in defined food commodities. Codex CXS 193-1995 is the international General Standard for Contaminants and Toxins in Food and Feed. Its limits must be read alongside the relevant commodity description and the form of the food. Codex CXS 198-1995 defines paddy rice, husked rice and milled rice as distinct forms. The measured material must therefore be identified before selecting a limit. (Codex Alimentarius Commission, 1995, 2025).

The European Union has separate maximum levels for inorganic arsenic in milled rice and in husked or parboiled rice. These examples show why the rice form and the chemical species matter. A limit for inorganic arsenic cannot be applied to a total arsenic result without speciation information. Similarly, an environmental soil guideline or drinking-water guideline must not be used to classify a ricegrain result. (European Commission, 2023; Codex Alimentarius Commission, 1995, 2025).

4.8 Research gap and justification

Previous studies provide evidence of metal concerns in selected Zamfara environmental settings and show that seasonal and varietal differences can occur in rice systems. The present report is limited to a seasonal comparison of selected metals in rice grain. This focus is useful because the grain is the edible commodity, but the lack of sample-level data, arsenic values, soil and water results, and exposure parameters limits the conclusions that can be drawn. (Aminu, 2022; Abdullahi et al., 2024; Mandal et al., 2022).

The report is justified as a descriptive record of the agreed seasonal concentrations and as a basis for identifying the information needed for a more complete food-safety assessment. It should not be interpreted as a complete environmental source investigation or a population health-risk study. (Ihedioha et al., 2019; World Health Organization, 2023).

5. DESCRIPTION OF THE STUDY AREA

The broader research project is associated with the Bakalori Irrigation Scheme area of Zamfara State, northwestern Nigeria. The scheme is associated with the SokotoRima River Basin Development Authority and has its project office in Talata Mafara. It supports irrigated agriculture in areas associated with Talata Mafara, Maradun and Bakura Local Government Areas. The scheme's infrastructure and watermanagement system make it an important agricultural setting for studies of rice production and environmental quality. (Transforming Irrigation Management in Nigeria, n.d.; Aminu, 2022).

The area experiences distinct wet and dry seasons. Wetseason crop production is influenced by rainfall and supplementary irrigation, while dryseason cultivation depends more directly on irrigation supply and management. Seasonal water conditions can affect field flooding, drainage and crop development. These factors provide a plausible context for examining seasonal patterns in ricegrain metal concentrations, although the supplied data do not identify the processes responsible for the observed differences. (Abdullahi et al., 2024; Aminu, 2022).

The map below is retained from the original report as a contextual illustration of the irrigation scheme and its canal system. It is not a map of verified project sampling points. The final report should not imply that the illustrated canal locations are the exact locations from which the reported rice samples were collected. (Aminu, 2022).

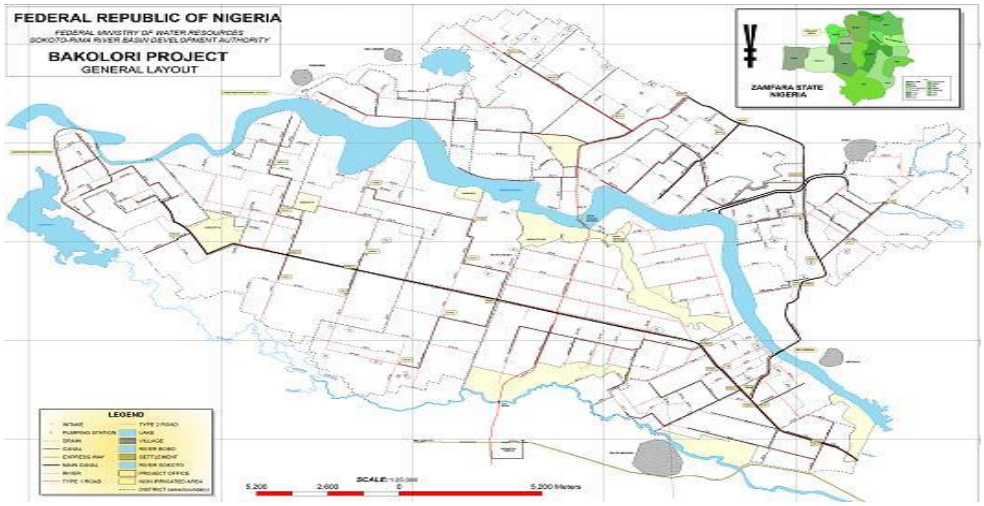

Figure 1. Bakolori Irrigation Project and main canal locations. Reproduced from Aminu (2022, p. 102); the original article acknowledges USAID (2010) as the map source. Contextual scheme map only.

6. RESEARCH METHODOLOGY

6.1 Research design and scope

The analysis presented in this report is a descriptive seasonal comparison of selected heavy-metal concentrations in rice grain. The available agreed dataset provides wet and dryseason concentrations for Pb, Cd, Ni and Cr. It also records no reported result for As. No irrigation-water or soil concentrations, physicochemical measurements or dietary exposure calculations were undertaken for the results represented here. The methodology is therefore restricted to describing the available grain dataset and the procedures required to interpret seasonal values responsibly. (Project scope and data inventory supplied for this report.)

6.2 Sample matrix and analytical variables

The matrix represented in the results is paddy rice grain. The target metals with numerical seasonal results are lead, cadmium, nickel and chromium. Arsenic is an important element in rice foodsafety research, but its result was not reported. The report does not infer that arsenic was absent, below detection or safe. The sample formpaddy, husked, milled or polished ricemust be confirmed from the original sample record because it affects the choice of foodsafety standard. (Codex Alimentarius Commission, 1995; project summary dataset supplied for this report).

6.3 Data source and completeness

The values were supplied as an agreed summary table. The summary does not include sample identifiers, collection dates, number of samples, farm coordinates, rice variety, sample preparation records, instrument details, calibration data, analytical wavelengths, detection limits, replicate measurements or qualitycontrol results. These omissions are recorded as limitations rather than filled with assumed procedures. The original field and laboratory records should be retained as the primary evidence supporting any final institutional report. (Project summary dataset supplied for this report; Abdullahi et al., 2024, contains the same seasonal numerical values and is therefore relevant to the provenance check.)

6.4 Data presentation and descriptive calculations

Concentrations are presented in milligrams per kilogram (mg/kg), following the units supplied. For Pb, Ni and Cr, the seasonal difference was calculated as the dryseason value minus the wet-season value. The percentage difference was calculated as [(dryseason concentration wetseason concentration) ÷ wetseason concentration] × 100. These calculations describe the difference between the two supplied seasonal values; they do not establish statistical significance. (Authors' calculations from the supplied project summary dataset.)

Cadmium was reported as not detected in the wet season and 0.153 mg/kg in the dry season. Since the wet-season detection limit and quantification limit are not available, the nondetect cannot be treated as zero and no percentage increase is calculated. Arsenic has no reported result, so no seasonal comparison is possible. (Project summary dataset supplied for this report; analytical reporting terminology should be confirmed against the original laboratory method and detection-limit records.)

6.5 Quality assurance and quality control

A complete analytical report should document the procedures used to prevent contamination during sampling and preparation and to verify instrument performance. Relevant records ordinarily include sample blanks, reagent blanks, duplicate or replicate analyses, calibration standards, continuing calibration checks, certified reference materials and method detection limits. The available summary does not provide these details. The report therefore does not claim that specific qualitycontrol procedures were performed. The research team should attach or archive the laboratory qualitycontrol records before final submission. (Recommended documentation items are consistent with the need for validated, traceable analytical results; see Ihedioha et al., 2019, for an example of a rice contamination and risk-assessment study.)

6.6 Statistical limitations

A mean value alone cannot describe the distribution of individual sample concentrations. To compare seasons statistically, the analysis would require sample-level results, sample numbers, a clear sampling structure and suitable tests based on distributional assumptions. Without these records, the report does not calculate standard deviations, confidence intervals, p-values or effect sizes. The observed seasonal differences are reported descriptively. (Authors' methodological limitation based on the absence of sample-level observations and replication in the supplied dataset; see Abdullahi et al., 2024, for an example of a study reporting seasonal sampling and statistical analysis.)

7. RESULTS AND ANALYSIS

The agreed seasonal rice-grain concentrations supplied for this revision are presented in Table 7.1. The units are mg/kg. The wet-season cadmium result is recorded as "not detected" exactly as supplied. Because the detection limit is unknown, it is not interpreted as zero. Arsenic is recorded as "not reported" for both seasons. (Project summary dataset supplied for this report; Abdullahi et al., 2024, reports identical numerical seasonal values, which must not be attributed to Zamfara without primary-record verification.)

Table 7.1. seasonal heavymetal concentrations in rice grain.

Metal	Wet season (mg/kg)	Dry season (mg/kg)	Reporting note
Lead (Pb)	1.196	2.109	Numerical result in both seasons
Cadmium (Cd)	Not detected	0.153	Wet-season detection limit unavailable
Nickel (Ni)	0.717	1.767	Numerical result in both seasons
Chromium (Cr)	0.694	1.193	Numerical result in both seasons
Arsenic (As)	Not reported	Not reported	No result supplied

7.1 Descriptive seasonal comparison

Metal	Wet season	Dry season	Absolute difference	Descriptive change
Pb	1.196	2.109	0.913 mg/kg	76.3% higher
Ni	0.717	1.767	1.050 mg/kg	146.4% higher
Cr	0.694	1.193	0.499 mg/kg	71.9% higher
Cd	Not detected	0.153	Not calculable	Wet-season detection limit needed

The highest reported concentration among the listed metals in each season was Pb. The dry-season values were higher than the wet-season values for Pb, Ni and Cr. These are comparisons of the supplied values and should not be interpreted as statistically significant differences. (Authors' descriptive analysis of the supplied project summary dataset.)

7.2 Visual comparison of seasonal values

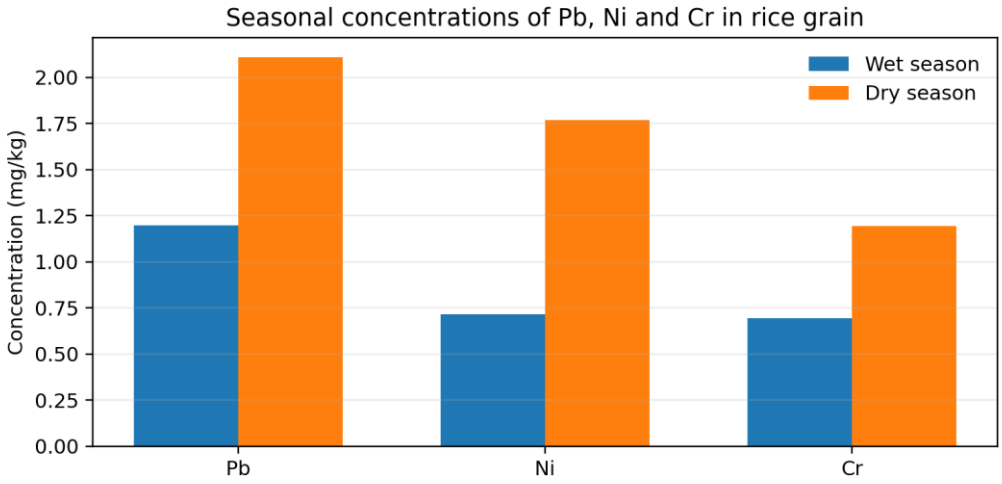

Figure 2. Wetand dryseason concentrations of Pb, Ni and Cr in rice grain. Cadmium is excluded from the bar chart because its wetseason result is a non-detect without a stated detection limit. Arsenic is excluded because no result was reported.

The chart makes the direction and magnitude of the supplied seasonal differences easier to compare. The dry-season bar is higher for all three metals displayed. Nickel shows the largest proportional seasonal difference, while lead has the highest absolute concentration in both seasons. The chart is descriptive and does not display uncertainty because standard deviations and replicate-level data were not supplied. (Authors' descriptive analysis of the supplied project summary dataset.)

7.3 Interpretation of nondetect and missing result

"Not detected" is an analytical reporting category. It means that the analyte signal was below the method's stated detection threshold, not necessarily that the analyte was completely absent. A method detection limit is therefore required to interpret the wetseason cadmium result quantitatively. "Not reported" has a different meaning: it indicates that no arsenic result is available in the supplied dataset. It cannot be treated as a nondetect. (Analytical interpretation; the method-specific detection limit and reporting convention must be confirmed from the laboratory record.)

These distinctions are important in environmental and foodsafety reports because coding non-detects as zero can bias seasonal means and ratios, while coding missing results as nondetects can incorrectly imply that an analytical test was performed and produced a belowdetection outcome. (Analytical interpretation based on the distinction between non-detect and missing data; project laboratory records are required for methodspecific confirmation.)

7.4 Achievement of the revised objectives

Objective	Evidence in this report	Achievement status
1. Determine seasonal concentrations of Pb, Cd, Ni and Cr in paddy rice.	Wet- and dry-season values for the four metals are presented in Table 7.1.	Addressed by the agreed summary dataset; verify provenance and laboratory records.
2. Compare concentrations with applicable food-safety standards.	The need for commodity-specific comparison is explained. The rice form and analytical reporting basis remain unverified.	Partially addressed; a definitive compliance classification is withheld pending confirmation.
3. Examine wet- and dry-season variation.	Descriptive differences are calculated for Pb, Ni and Cr; Cd is discussed qualitatively.	Addressed descriptively; no significance test is possible from summary values alone.

7.5 Foodsafety comparison: requirements

A valid comparison requires confirmation of whether the analysed material was paddy rice with husk, husked rice, milled rice or polished rice. Codex CXS 198-1995 defines these categories separately. The analyst must also confirm whether the values are expressed on a

wetweight or dryweight basis and whether any moisture correction was applied. For arsenic, total arsenic and inorganic arsenic are not interchangeable; a maximum level specifically defined for inorganic arsenic requires speciation data. (Codex Alimentarius Commission, 1995, 2025; European Commission, 2023).

The current Codex General Standard for Contaminants and Toxins in Food and Feed should be consulted for the applicable contaminantcommodity pairing. The report does not apply soil or drinking-water limits to grain. It also avoids declaring the rice safe or unsafe on the basis of a generic limit that may not match the commodity form or reporting basis. (Codex Alimentarius Commission, 2025).

8. DISCUSSION OF FINDINGS

The supplied results show higher dryseason concentrations than wetseason concentrations for Pb, Ni and Cr. Nickel displays the largest proportional difference, increasing descriptively from 0.717 mg/kg in the wet season to 1.767 mg/kg in the dry season. Lead increases from 1.196 to 2.109 mg/kg, while chromium increases from 0.694 to 1.193 mg/kg. These differences may justify further seasonal monitoring, but the data provided do not establish why the dry-season values are higher. (Authors' descriptive analysis of the supplied project summary dataset; Abdullahi et al., 2024, reports the same wet- and dry-season values.)

Potential explanations in rice systems include differences in water regime, soil moisture, redox conditions, irrigation frequency, crop variety, crop maturity and field management. However, none of these explanatory variables was measured in the dataset supplied for this report. They should therefore be treated as possible mechanisms discussed in the literature, not as demonstrated causes of the observed seasonal differences. (Abdullahi et al., 2024; Lwin et al., 2025).

The wetseason cadmium result was reported as not detected, while the dryseason result was 0.153 mg/kg. Without the method detection limit, the magnitude of the difference cannot be calculated. A non-detect is not zero, and the dryseason detection does not by itself establish the time or source of cadmium entry into the crop. Future reporting should include detection and quantification limits and, where possible, the actual instrument response for values below the quantification threshold. (Project summary dataset supplied for this report; Lwin et al., 2025).

No arsenic result was supplied. This is a notable gap because arsenic is a priority element in rice research. Its absence from the results table must not be interpreted as evidence of absence in the grain. Future analysis should identify whether total or inorganic arsenic is being

measured and use a validated method appropriate to the selected form. (Lwin et al., 2025; Mandal et al., 2022).

The seasonal pattern is consistent with the general observation that rice-grain concentrations can differ between wet and dry production periods. Abdullahi et al. (2024) reported higher accumulation in dry-season rice in their Kano River Irrigation Project study. That publication is useful for discussing seasonal behaviour in a comparable northern Nigerian irrigation context. However, the values supplied for this report match the published Kano values exactly. This creates a serious provenance question that must be resolved before these data can be represented as original Zamfara measurements. A published study from Kano cannot be relabelled as field results from Zamfara. (Abdullahi et al., 2024).

Regional literature also needs to be interpreted carefully. Aminu (2022) measured metals in Bakolori canal water, not the rice grain values shown here. Mandal et al. (2022) studied miningimpacted farms in Dareta, which is a different environmental setting. These studies help explain why monitoring is relevant in Zamfara, but neither can confirm the concentrations in the present rice dataset. (Aminu, 2022; Mandal et al., 2022).

The food-safety implications require caution. Concentration comparison with a maximum level is a regulatory screening step, while dietary exposure and health-risk assessment require additional information. A complete exposure model would need reliable concentrations in the edible rice form, consumption rate, body weight, exposure frequency and duration, and toxicological reference values. Those inputs were not measured or supplied. The report therefore does not calculate estimated daily intake, hazard quotient, hazard index or cancer risk. (Ihedioha et al., 2019; World Health Organization, 2023).

The key scientific interpretation is consequently limited: the agreed values show a higher dry-season concentration for Pb, Ni and Cr, and a dry-season Cd detection compared with a wet-season non-detect. The pattern is worthy of follow-up, but its statistical reliability, geographical representativeness, regulatory compliance and health significance cannot be established from the summary table alone. (Authors' interpretation of the supplied project summary dataset; Abdullahi et al., 2024, for the matching published values).

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This expanded report has revised the objectives to match the available seasonal rice-grain dataset. The agreed values indicate higher dry-season concentrations than wet-season concentrations for Pb, Ni and Cr. Cadmium was reported as not detected in the wet season

and 0.153 mg/kg in the dry season. No arsenic result was reported. The seasonal comparisons are descriptive because sample-level observations, replication and measures of variability were not provided. (Authors' conclusion based on the supplied project summary dataset.)

The objective of determining seasonal concentrations is addressed by the supplied values. Seasonal variation is described for the elements with numerical results in both seasons. The standardscomparison objective remains conditional on confirming the rice form, reporting basis and current applicable contaminant limits. No conclusions are drawn about soil or irrigation-water contamination, physicochemical properties, transfer factors, dietary exposure or health risk. (Project scope and summary dataset supplied for this report; Codex Alimentarius Commission, 1995, 2025).

The exact correspondence between the agreed numerical values and Abdullahi et al. (2024), a study conducted in Kano State, must be resolved against original Zamfara project records before the values can be certified as original IBR findings. (Abdullahi et al., 2024; verification against original Zamfara project records remains necessary).

9.2 Recommendations

1. Verify all agreed seasonal values against the original Zamfara sample register, laboratory worksheets, instrument outputs and quality-control records before submission. (Research-integrity recommendation arising from the unresolved data-provenance issue.)
2. Record sample numbers, collection dates, community or farm identifiers, rice variety, grain processing form and moisture basis for each season. (Codex Alimentarius Commission, 1995; project documentation requirements).
3. Report analytical detection and quantification limits, replicate precision, blanks, calibration checks and certified reference material recoveries. (Ihedioha et al., 2019; Lwin et al., 2025).
4. Obtain and report an arsenic result using a validated method; distinguish total arsenic from inorganic arsenic where food-safety standards require speciation. (Lwin et al., 2025; Mandal et al., 2022).
5. Compare the rice results with current Codex and applicable Nigerian standards using the correct rice category and reporting basis. (Codex Alimentarius Commission, 1995, 2025).
6. Plan future matched sampling of irrigation water, agricultural soil and rice grain if the project is extended to source attribution and environmental transfer assessment. (Aminu, 2022; Lwin et al., 2025; Mandal et al., 2022).

7. Undertake dietary exposure and healthrisk assessment only when validated grain concentrations and appropriate consumption and toxicological inputs are available. (Ihedioha et al., 2019; World Health Organization, 2023).

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